URBAN CLIMATE ADAPTATION AND MITIGATION

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AMIR REZA KHAVARIAN-GARMSIR

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Contents

13. Automated object extraction of satellite imagery to estimate the loss of vegetative land cover and inform climate adaptation actions in San Antonio, Texas

Azza Kamal

14. Smart transformation in Iran, a step toward adaptation and reduction of climate change

Amin Faraji, Amin Gharibi, and Azadeh Azimi

15. Technological solutions for adaptation with Iran's water resources crisis

Behzad Doosti Sabzi, Najmoddin Yazdi, and Ali Maleki

16. The way forward for data-driven and climate-resilient cities

Amir Reza Khavarian-Garmsir and Ayyoob Sharifi

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Preface

The convergence of climate change and urbanization has caused significant unprecedented challenges for cities globally. As the frequency and intensity of climate-induced stressors and disasters are expected to significantly increase in the future, a top priority for cities and communities is to build up on their resilience, and they need scientific support toward this goal. Therefore, it is essential to develop evidence-based scientific solutions to improve the capacities to prepare for, absorb, recover from, and adapt to disastrous events. This requires not only a better understanding of urban complexities but also enhanced predictive abilities to reduce uncertainties and to avoid being overwhelmed by extreme events. To deal with these challenges, scientists cannot only rely on conventional methods and need to develop disruptive and transformative approaches. Accordingly, the rapid advances in ICT-enabled smart cities that rely on big data analytics provide manifold new possibilities for scientists to better understand the complexities of urban systems and subsystems, to provide decision makers with better and more regularly updated information on human activities that may relate to climate change adaptation and mitigation, to facilitate online monitoring of risks, to inform different stakeholders on how to enhance their preparation and predicative abilities, and to develop methods that enable real-time response to disasters.

There is now reasonable evidence showing the utility of smart city solutions for resilience and climate change adaptation/mitigation. However, the literature is sector based and fragmented. It is essential to synthesize the existing evidence in a more integrated manner to make it easier for interested target audience groups to understand the potential benefits of smart city projects. Also, there is still a lack of toolkits and assessment frameworks for assessing contribution of smart solutions to climate resilience. In view of the aforementioned issues, the main research question that this book addresses is this: “Do smart city projects contribute to climate change adaptation and mitigation in cities?” Other noteworthy questions are as follows: “What are the indicators of smart city resilience?” “What procedures should be taken to improve efficacy of smart city solutions?” “What are the opportunities and challenges for promoting smart city resilience and for integrating resilience thinking into smart city planning?”

In addition to providing theoretical insights and synthesizing the state of the art, through detailed analyses of selected smart city initiatives around the world, this book provides insights on how to harness smart technologies for urban climate resilience and sustainability planning. Furthermore, the book introduces an assessment framework for evaluating the actual and potential contributions of smart city projects. The framework can function as a decision support tool to inform communities of global change and climate-related risks and to enable them to develop better preparation, recovery, and adaptation strategies. Finally, the book includes several case studies that showcase real-world contributions of smart solutions and technologies to climate change adaptation and mitigation in cities. We hope that the proposed book will support urban researchers, planners, and decision makers in their efforts toward developing climate-resilient, smart, and sustainable cities.

Ayyoob Sharifi and
Amir Reza Khavarian-Garmsir

CHAPTER

1

Urbanization in the context of global environmental change

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1.1 Global environmental change

Climate change represents a challenge to guarantee the subsistence of humanity, which has been raised since previous meetings of the world summit of 2021, 25 sessions celebrated since 1995 in addition to international agreements that have been focused on formulating global strategies for reduction of carbon emissions, aligned with documents such as the Kyoto Protocol in 1997 and the Paris Agreement in 2015. The Kyoto Protocol (2005) enters into force and puts into operation the United Nations Framework Convention on Climate Change, which commits industrialized countries to limit and reduce greenhouse gas (GHG) emissions by adopting public policies and mitigating environmental impacts. During the first period, 37 industrialized countries were committed (2005–12), in a second period with the approval of the Doha Amendment (2013–20), new responsibilities and a series of indicators on GHG were proposed that had to be adapted to each country and report on its monitoring to assess the impacts generated (United Nations Climate Change, 2021). The Paris Agreement, an international treaty adopted by 196 countries in 2015 (COP21), entered into force in 2016, where the objective of limiting global warming to 1.5 °C was raised. For this, the countries set out to achieve the maximum of GHG emissions whose objective entailed an economic and social transformation. These climate action plans were presented in 2020, through Nationally Determined Contributions (NDC); however, the expected objectives were not achieved.

The international cooperation proposed to get the objectives implies the management of financial, technical, and capacity-building support, especially toward developing countries, whose advances have resulted in low-carbon solutions and opening to new markets focused on carbon neutrality and solutions of zero emissions impacting the industrial and economic sphere, although there is still much to advance. It is estimated that by 2030, these solutions could be highly competitive in sectors that account for more than 70% of global emissions

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(United Nations, 2021a, 2021b). Given this, it is important to establish a historical framework on the repercussions of anthropogenic activities, which refers to proposing those scenarios of an industrialized era that have marked inadequate practises that transcend today regarding the use and abuse of natural resources.

CO_2 is the main anthropogenic GHG that has skyrocketed since 1995 with 360 ppm (parts per million) to 420 ppm in 2020. This monitoring has been carried out by the World Health Organization regarding emissions to the amount of gas that is released into the atmosphere. Carbon dioxide is the main long-lived greenhouse gas in the atmosphere related to human activities, and methane (CH_4) is the second most important long-lived greenhouse gas and contributes approximately 17% to radiative forcing. And finally, nitrous oxide (N_2O) emissions come from natural sources (around 60%) and anthropogenic sources (40%), such as oceans, soils, biomass burning, fertilizers, and various industrial processes (Organización Meteorológica Mundial, 2019).

According to UN data, it is estimated that the world population by 2050 will be concentrated in urban areas by 68% compared to 55% today, where cities represent 70% of the world economy with energy consumption proportional, as well as in its carbon emissions (ONU, 2020). On the other hand, according to World Bank data, cities will generate 3.4 billion tons of solid waste by 2050, compared to 2 billion in 2016 (Mundial, 2021). In this way, the United Nations (UN) World Conference on Climate Change (COP26) held in 2021 in Glasgow, United Kingdom, brings together world leaders to address the critical aspects of global warming (United Nations, 2021a, 2021b), where a call for attention has been raised to take urgent measures to recent extreme climatic situations such as heat waves, floods, super storms, among others, through the substantial reduction of carbon emissions by 2030 and zero net emissions by 2050. In this sense, the SDG11 of resilient and sustainable communities and cities started to increase actions focused on affordable and sustainable housing and transportation, which involves mitigation processes of extreme meteorological phenomena, reduction of environmental impacts in addition to promoting urban resilience environments (ONU, 2020). Thus, it is identified that only 8.6% of the world economy is circular, which indicates that only 8.6% of waste is reused, so it is important to adopt circular economy strategies as a good practice to reduce global emissions. By 39% and the material footprint by 28% by 2030 (Circularity-Gap. World, 2021).

Faced with a devastating scenario, at the Paris Climate Conference in 2015, local governments have also committed to take local measures that under climate emergency conditions are necessary to achieve zero emissions and reduce the loss of biodiversity, coupled with the fact that we are currently in a PostCovid recovery process in line with meeting the Sustainable Development Goals by 2030 (Wright, 2021). In this sense, what was learned by COVID-19 and what was agreed at COP26 show that the pandemic could be taken as a catalyst to rethink how cities and buildings will be adapted to face current and future health crises, so they should look for smarter and more adequate alternatives, since deficiencies in the operation of the systems that make up the city have been highlighted (Candido, Bentley, & Marzban, 2021).

It is important to mention that the climate crisis must rationally mark appropriate actions and strategies that have not been effective so far, although it has implications for international incidence, it has not been possible to understand the dimensions of the impacts at the local level, much less the solutions in the process of establishing an emergency framework as a response regarding the already tangible impacts in various latitudes and with human and economic capital costs. For this reason, various positions and approaches are exposed that highlight certain tendencies toward somewhat encouraging practises, which surpass what has been done until now, and which represent promising areas of development toward a better future.

1.2 The environmental footprint of cities: A historical perspective

To establish a historical framework regarding the ecological footprint, whose concept arose in 1996 proposed by Willians Rees and Mathis Wackernagel, the concept refers to an indicator of sustainability that tries to measure the impact of our way of life, which is directly related to the environment with respect to the decisions we make on a daily basis and that impact the planet and its capacity for natural renewal (CENEAM, 2021). The scale is measured from 0 to 11, with the highest value being the one that represents the greatest impact from the integration of various productive human activities, which can be measured from a continental, regional, national, zonal, family, or individual scale, and it can be categorized from a direct, indirect or collective impact, with direct, indirect, and community impact implications respectively. The regions with an ecological footprint between 8 and 10 are industrialized countries (high demand regions), there are others with a footprint between 7 and 4 (medium demand regions) that are those regions not yet integrated into the industrial world and that survive on the sale of raw material, and finally the regions of low demand (between 4 and 0), which are poor or sparsely inhabited regions (CEPAL, 2007). According to the 2012 report by the Global Footprint Network, the current demand for activities on a global scale is 2.7 ha per person (ha), while the planet can only supply around 2 ha per capita, which has variances with respect to certain regions of the planet such as the USA with an ecological footprint of 8.2 ha per capita, Spain with 3.8 and Angola with 0.9 ha per person, which denotes a strong imbalance with respect to developed and developing countries, reducing the possibilities of ecological regeneration in the near future (Global Footprint Network, 2021).

This has implications in the approach to actions focused on mitigating the effects of climate change, since in a globalized world, inequity scenarios and partial approaches are palpable. In this line, there are notable differences between the scientific, political, and world leaders regarding the approach to climate change, whose concern has been evident since the late 1980s (García Galindo, 2021). Thus, by having a higher emission of pollutants from cities and of course from the construction sector, aspects such as the increase in construction density, the sealing of the soil of large areas are identified, which prevents the permeability of the soil and the lack of aeration, which intensifies the environmental load, especially on days with extreme temperatures, taking into account that there are conditions of drastic effects on the populations in the cities, for which an adequate planning adjusted to the climate is urgently required (Henninger & Rumberg, 2021).

Industrial processes and constructions, from the use of materials and the processes of extraction of raw materials, processing, and manufacturing, as their use, have been the object of study in the process of having more sustainable environments. From this perspective, the sustainable materials of the future have characteristics such as being completely circular where their processing implies a low or no carbon emission, a desired functionality, ecological materials do not imply adverse effects and refer to a low cost so that they are accessible to the community, among others (Ramakrishna & Jose, 2021). The problems of the existing infrastructure are also associated with obsolete practices according to current needs, where solutions to issues of water supply, pollution control, risk situations, rainwater, etc., are developed in isolation, for what is necessary to propose a scenario of resilience of the infrastructure necessary to manage and mitigate the impacts of climate change, together with population growth, economic, and social movements, which implies dequate planning in the medium and long term (Wallis-Lage & Kisoglu Erdal, 2022).

The progressive growth of materiality as the basis for the livelihood of societies shows an extreme dependence on fossil materials and energies that seriously deteriorate the environment, which would represent an expectation of a growing endowment of finite planetary resources. A criticism has been established of these practices that in an abstract way determine economic growth, so work should be done to redirect the commitment to combat the environmental crisis from scenarios that integrate particular circumstances of each region, including cultural, human, and social contexts (García Galindo, 2021).

Among these effects, we find urban ecosystems that significantly alter surface temperatures, promoting extreme microclimates due to the massive replacement of natural vegetation by hand-made constructions, which is why the sustainable management of urban vegetation driven by data is important (Khalaim, 2021).

In front of the climate change, two types of strategies have been identified, on the one hand, mitigation or attenuation, which aims to prevent or slow down the effects of climate change through lower emissions of carbon dioxide; and adaptation, which is a strategy that seeks to face the already existing consequences of climate change, such as meteorological phenomena. Given this, it is important to mention that both strategies must involve collective choices, which results in integrating cultural aspects of community awareness (Rishi & Schleyer-Lindenmann, 2021). For this reason, it is important to understand that people are a fundamental part of the actions undertaken in the face of climate change, since their actions imply important changes in the way of building environments focused on the conformation of sustainable cultures of life (Roge-Wiśniewska, 2021).

Strengthening climate action from the SDGs, not only from SDG11 but also related to the environment, offers profitable opportunities from a multisectoral approach to link health security with climate action that enables human, animal, and environmental health in a sustainable way (Machalaba et al., 2021). Carbon emissions are increasing, and the lives of human beings are drastically changing, and in this regard, information technology can contribute to having a proper understanding of the value proposition and processes of human beings toward more respectful behaviors with the environment, where digitization has broad possibilities of contributing to better practices and processes with a lower environmental impact, highlighting the role of governmental and nongovernmental institutions as well as research centers, whose focus should be on the redefinition of the human processes, in virtual experiences, ethics, and transformation in education about information systems (Trkman & Černe, 2021).

Some of the technologies and innovations associated with aspects of climate change include new materials and technologies such as photocatalysis, self-cleaning materials, coatings, and paints; new renewable energies, food production technologies, among others, to focus on minimizing greenhouse gases. The actions that have focused on aspects of climate change and mitigation of risk situations from COVID-19 are measures based on restrictions, and rules for the use and planning of cities, measures based on digital media and smart cities, measures based on research, technology and innovation, such as the use of big data that help improve the efficiency, awareness, and flexibility of urban ecosystems in real time. Technology alone will not solve climate change, it will be necessary to combine technology and innovation to achieve zero carbon emissions, and some examples could be energy storage, prioritizing the use of renewable energy, the transition to electric vehicles and transport, more efficient construction technologies, nature-based solutions and regeneration of green spaces, urban agriculture, among others (Kakderi, Komninos, Panori, & Oikonomaki, 2021).

International law and policies have recently focused on adaptation to the adverse effects of climate change, which integrate aspects of biological diversity, which has been based on international treaties as mentioned previously, and where countries have begun to develop their own instruments aligned to the adaptation of human beings to nature (Peña Neira, 2021). The Paris agreement indicates that for adaptation financing processes, priorities should be considered above all of developing countries, taking into account that they are the most vulnerable to the impacts of climate change and understanding that each country has its own mechanism in depending on the available resources, for which some international cooperation actions are focused on a financing mechanism to achieve these objectives, raising priority needs (Perea Blazquez, 2021).

The transition toward a sustainable energy system is a long-term process that depends on the integration of renewable energies in urban areas, which will be reflected in the pertinent adoption of new technologies, which also allow the systematic evaluation of the desired impacts, such as the case of solar technologies in Mexico, which is also a very attractive market according to the availability of solar resources in the place (Báez Fumero & Molar-Cruz, 2021). On the other hand, urban expansion is an important and aggressive form of land transformation related to the increase in population and availability of resources and services, which is why areas of opportunity are identified in remote sensing technologies to inform and evaluate the development and urban transitions, which allow elements for a more adequate future growth (Ennouri, Smaoui, & Triki, 2021). Faced with the challenges of population growth, more forceful actions should be generated regarding urban mobility with low emissions, where a high potential is identified in initiatives not only to reduce traffic emissions but also in those actions that involve infrastructure, routines daily, daily practices of the population, whose information will be of vital importance for decision-making in terms of planning and urban development. The “functional” approach in this case would be focused on testing and evaluating initiatives of multidisciplinary origin, where it is possible to quantify the behavior and preferences of people, the traffic that they detonate and the resulting atmospheric emissions (Hulkkonen & Prisle, 2021).

1.3 The urban planet and its implications for resource use and environmental quality

1.3.1 Impacts of formal and informal urbanization on the environment: Notions of density and urban sprawl toward a better understanding of sustainability

Since 2007, the urban world population has increased over the rural. According to the London School of Economics (LSE) by 2050, it is expected that the population concentrated in cities will become 66%. While Latin America and the Caribbean (LAC) region faced intensive urbanization processes during the second half of the 20th century, these processes currently are taking place with much more intensity in Asia, Africa, and the Indian subcontinent.

The overwhelming fact is that today's cities have not stopped attracting citizens, and this condition in the light of data makes great sense. Cities such as London and Paris, just to mention two examples, along with the improvement of their infrastructures, have increased the life expectancy in comparison with data from 70 years ago, shifting cities into places for a long life, therefore more attractive to people as they concentrate greater opportunities for employability and wealth.

This demographic fact, for instance, is well explained if we have a look at the period from 2010 to 2015. During that time the urban world gained 77 million new city dwellers, the equivalent of Germany's population for the same period. While this demographic phenomenon occurs, the urban land in the planet only covers 3% of its surface (UN, 2020). This indicates that we are increasingly concentrating on smaller spaces. However, this contrasting situation of higher density should be seen differentially from two scopes within the same urban context: the formal and informal. In the first, density would allow geographic proximity relationships, positive in social, economic, and environmental terms; but these relations might become more complex to be managed from a public health dimension due to, for example, the viral management of a pandemic. In the informal scope, however, density takes another shape associated with inequality, lack of opportunities, overcrowding, and social vulnerability.

In the region known as global south, "it is only through informal settling that squatters and slum dwellers, mostly rural migrants, can access urban land housing markets and establish a foothold in the city" (Baumgart & Kreibich, 2011). Under those circumstances, informality may be considered as one of the biggest urban challenges stated by different research institutes and relevant organizations like The Rockefeller Foundation, The Ove Arup Foundation, UN-Habitat and the World Health Organization (WHO). It is a critical challenge that paralyzes the effective functioning of urban areas (UN, 2015b).

In the context of developed countries also known as Global North, the urban informality shaped by slums is limited and focused on some specific places with vulnerable foreign migrants population and in other cases in urban or suburban spots along the city or metropolitan areas with local recognized criminal activities as the case of Desio, a town close to Milan in northern Italy (Chiodelli, 2019).

From an environmental framework, formal and informal cities should be understood by having in mind two different approaches about the concept of urban density. By one hand, in the case of urban informality, the density has a negative notion as a result of spontaneous agglomeration without any institutional control. Some of their consequent and more relevant impacts in terms of sustainable resources management and environmental and life quality are related to air pollution, water contamination, flooding risk, reduction of open public space, the loss of environmentally sensitive areas—wetlands, fauna, etc.—and connection breakdown between natural areas, which reduces the ecosystem balance (Moliní & Salgado, 2011).

On the other hand, regarding the formal city the notion of density tends to be seen as a positive pattern of compact city concept. There are numerous authors who coincide in highlighting aspects in favor of this city model. One of these refers to the opportunity of keeping unbuilt land to preserve the territory naturally and increase the freedom of action of future generations. It means to recognize the land feature as a nonrenewable resource. Consequently, the low-density urban development setup a problem on the land that is sustained by the high degree of consumption thereof, through the transformation of natural land into urban land, the change of land use produced in agricultural areas and the effects that this generates on air and water quality, landscape modifications, and the loss of biodiversity (Moreno, 2007). In addition, there is recognized scientific evidence and several studies and comparisons to prove the relation between low-dense housing developments and high-energy consumption in comparison with high-density developments (Gauzin-Muller, 2003). Generally, a more compact city demands less resource therefore less environmental pressure occurs. Similar studies have been conducted showing lower water consumption in dense urban developments in comparison with low-density housing typologies (Domene & Sauri, 2006). Other positive impacts of adequate density in cities are connected with the reduction of resources demands mobility; the longer a city is, horizontally speaking, the more CO_2 is emitted because of fossil fuel consumption. A dense city reduces not only fuel consumption, and consequently its ecological footprint, but also the time wasted inside a vehicle. Currently, this aspect is also considered as a valuable welfare and competitiveness indicator in cities.

1.3.2 Urban informality in the Global South

It is important to consider that the physical or geographical reflection of urban informality in human settlements is globally known with the term "slum," which has been widely and recently spread in academic literature, related to urbanism. In some cases or scopes, the term may be also used related to shantytown as synonym. The United Nations Human Settlements Program has introduced a definition of slums: "A slum household is defined as a group of individuals living under the same roof lacking one or more of the following conditions: access to improved water; access to improved sanitation facilities; sufficient living area (not more than three people sharing one room); structural quality and durability of dwellings; and security of tenure" (UN, 2008).

Having in mind this definition, and according to data of Inter American Development Bank (IADB-BID, 2019), we can notice that LAC region (LAC) congregate approximately the 25% of its urban population in "slums" (in portuguese: favela, in spanish: tugurio, chabola, or barriada). These data mean that over a quarter of the region's citizens live in informal neighborhoods and almost half of all households lack adequate housing (i.e., lack access to water, sanitation, legal title, in overcrowded homes and few access to public spaces and lack of quality in mobility services). LAC also have some of the most unequal cities in the world (i.e., with high GINI coefficients) that reflect very evidently the paradox of globalization in terms of unbalanced economic growth.

In the case of Africa, which has the fastest growing urban population in the world, the phenomenon results in a deep change of social and economic dynamics for people; but, simultaneously, it emerges new challenges and opportunities for stakeholders committed in all aspects of urban life (Selhausen, 2016). In this order, the most important challenge related to the lack of balanced economic growth has resulted in a particular situation where developing cities emerge accompanied with slums and informal economy; the both dimensions: the spatial and economic are reflections of informality where the poorest urban dwellers become outside of the formal market and financial system making increase vulnerable settlements as irregular urban belts.

While in Latin America, the 25% of urban population lives in informal settlements (IADB-BID, 2019) in Africa the percentage is about 62% (UN, 2008). Accordingly, we may say that 6 in 10 African urban residents are slum dwellers. This phenomenon is very contrasting in comparison with other developing regions such as Latin American and even Southern Asia. However, as it was mentioned before, the absence of a balanced and inclusive economic growth because of the lack of opportunities for the new urban residents, most of them rural migrants, have pushed them to find employment in the informal sector or even being unemployed (Meier, 2016). This situation has a parallel impact, exacerbated because of high densities: the increase of slums residents provokes simultaneously a rising insecurity in those areas. We can easily notice this correlation through some indicators related to high criminal rates, drug abuse, gender violence, and health problems regarding infections and viruses such as HIV/AISD and most recently COVID-19 pandemic.

In the Asia context, as recently in Africa, the internal migration is the main factor behind urban growth, as it becomes a strategy adopted by rural populations to improve household livelihoods and benefit from better services in urban areas. Currently, as a general data, almost half of the population in the Asia region is living in urban areas. But Asia is a vast continent with different rates of urbanization depending on its subregions; for instance, in South East Asia, the percentage of urban population is estimated at 48.5%, while in South and South-West Asia only 34% of the population lives in urban areas. By contrast, the north of Asia, with important industrialized urban hubs, concentrates more than 60% of its population in urban areas (UN-DESA, 2012).

According to the UN Urbanization Prospects (UN-DESA, 2012), Africa has been the least urbanized continent in the world over the past 60 years, but now it also has the highest urban growth rate of 3.69% and 37.3% of urban population followed by the subregion of South East Asia with 2.83% and 48.5%, respectively. In order to illustrate the situation, in 1950, just 11% of Africans and 15.4% of people from Southeast Asia were living in urban areas, while 41% of the people in Latin America and 51% of Europeans lived in towns. In 2010, about a half of Southeast Asian population and a third of Africans lived in urban areas, while in North, Latin America, and Europe, the proportion surpassed 70%. Moreover, the UN Urbanization Prospects report shows the future projections of people living in urban areas by 2050 in different regions of the world where we can put in evidence the highest and progressive rate of urbanization in Asia and Africa since the 1950. Both regions will be urbanizing almost at the same rate exceeding the 50% of people living in urban agglomerations by 2050.

In terms of urban informality, Asia gathers over half of the world's slum population, and some cities in the region have reached worrying levels of inequality as it happens in Latin America and Africa. At the same time, the percentage of urban population living in slums, many in hazard-prone locations, has grown highly since 1990, coming to 30.6% in 2010, which represents about 500 million people (UN-ESCAP, 2010). Currently, one in eight people live in slums[a]; in total, around 1 billion people live in slum conditions today (UN, 2015a, 2015b).

[a] Totally, 881,080,000 slum dwellers are estimated to be living in developing countries or global south region. These data have been calculated by taking into consideration only four out of the five slum household's deprivations included in UN-Habitat's definition, as security of tenure cannot be accurately calculated yet. In some countries with limited information, only one of the five components has been measured. Therefore, the 881 million can indeed be considered a global minimum (UN, 2015a, 2015b).

What is particular now is that poverty grows up faster in urban areas than in rural areas as opposed to before when the most of poverty was located in rural areas. Even though the percentage of people living in slums along the world has decreased from 39% to 30%, between 2000 and 2014 (UN, 2015a, 2015b), in absolute numbers the amount of slum dwellers have increased becoming a critical challenge in order to face the poverty in the world, the climate change and consequently to reach the Sustainable Development Objectives (mainly the number 11: Sustainable cities and communities).

Essentially, from the perspective of urban informality, the challenges of sustainable growth in developing regions known as global south are basically the same. The main environmental issues are connected to the poor quality of air, clean water supply, management of waste, lack of sanitation, and natural hazards (such as flooding and landslides). For instance, the World Health Organization (WHO) estimates outdoor air pollution as the 13th greatest source of disease and death in the world. It causes around 519,000 premature deaths every year, mostly located in urban areas. At the same time, Asian cities are among the most vulnerable to natural hazards, with many informal settlements located in fragile environmental areas on coastlines and major river basins (UN-ESCAP, 2013).

1.4 Challenges of urbanization in the Anthropocene

It is important to specify that one thing is to build buildings and quite another to build a city to be sustainable. The need to face the current climate crisis demands urban development based not only on energy efficiency through carbon neutral development but also on a paradigm shift based in a new relation most respectful with nature and environment, circularity production and consumption and inequality reduction by promoting inclusion in economic and social terms. The abovementioned implies different views and approaches that in the midst of the current debate on sustainability, encouraged by climate resilience and decarbonization, may be gathered through the following statements: (Arias-Bustamante & Innes, 2021) the multidimensional nature of housing and public space (Han & Xia, 2021), universal access to sanitation and public health (Zharova & Khlobystov, 2021), the need for a more circular and inclusive economic model, and (Ababneh, 2021) a dignified and efficient public transport, while the use of private transport is reduced by promoting urban planning based in proximity centered on people. These foregoing demands have a common horizon: the well-being of the communities and the conservation of ecosystems and environment for sustainable urban metabolism (Castán Broto, Allen, & Rapoport, 2012). Each statement in terms of needs and challenges is described as follows:

1. Housing and public space from a multidimensional approach: The programs and projects for regularization and progressive self-construction of habitat, also known as Slum upgrading programs, should be at the center of the governments' agenda due to an insufficient supply of affordable housing for poor people. According to architects Alejandro Aravena (2016 Pritzker Prize) and Joe Noreo (Taller House), the idealistic purpose is that citizens stop being mere users and actively and consciously participate in the design of their city from their closest built environment. With regard to public space, there is enough technical evidence that correlates better public health indicators in cities with a greater supply of public space per inhabitant, quantitative and qualitative (UN, 2015a, 2015b).

2. Sanitation and public health. Two crucial demands collected through the Sustainable Development Goals no. 3 and no. 6. Guarantee a healthy life and promote well-being for all at all ages and guarantee the availability of water, its sustainable management, and sanitation for all. These objectives are especially important today, given the impacts of the COVID-19 pandemic and the need for an adaptable and resilient habitat to health emergency conditions as lockdowns and social distance. This need becomes even more demanding in contexts of urban informality as these areas have accounted for a higher mortality rate due to the pandemic, which has evidenced a direct relationship between inequality, informality, and vulnerability.
3. Circular and inclusive economy. The Anthropocene, as the current geological era, is characterized by the significant global impact of human activities on ecosystems. This era is based on a development and production model around the growth of human well-being and, although it has achieved greater prosperity and poverty reduction in general terms, it is also the cause of an unsustainable extractive growth model for conservation and balance of the planet's ecosystems. This linear production model, fueled by extractivism, which consists in the exploitation of limited resources, must migrate to circular production processes. An approach that recognizes the finite condition of natural resources as well as the importance to have responsibility in production and consumption in order to guarantee an ecosystem balance and greater climate resilience. This development paradigm based on the substantive reduction of the ecological footprint through the reuse of materials and products is also an opportunity to promote greater social and economic inclusion and reducing inequality, something reflected very notoriously through informal human settlements.
4. Mobility infrastructure that promotes proximity relations and decarbonized cities for climatic adaptation and improving public health conditions and people's well-being. In this sense, the compact and dense urban growth models, while promoting certain sustainability criteria by reducing hard surfaces and occupancy, require greater public space and green infrastructure per inhabitant to promote social interaction among different communities and more climatic adaptation. This demands a more equitable balance between the market and public investment through innovative and long-term urban policies that stimulate more democratic densities with a mix of uses and ecosystem linkage between the environment and different urban scales. These positions coincide with experts such as Joan Clos, former mayor of Barcelona and former director of UN Habitat, and the landscaper Enric Battle, architect of several ecological recovery projects in the same city, Barcelona.

As exhorted by the New Urban Agenda in order for these demands to be managed, within a framework of sustainability, resilience, and prosperity, it is imperative the recognition and participation of various stakeholders. To satisfy this demand is needed consensual decision-making based on the need for climatic adaptation, the rethinking of current models of production and consumption and the need to reduce inequality. This cross-cutting axis of citizen participation also makes it possible to promote more precise political decisions and regulatory frameworks to face new urban challenges while not only recognizing the vision, data, and information as technical evidence but also the local needs and realities of the people.

In this context, and according to data collected by the Department of Cities and Urban Age of the LSE, it is urgent to take actions that draw a more livable world in the next century where politicians are capable to equalize public and private interests focused on promoting well-being, people's health and more circular production and consumption models. That is in favor of greater economic inclusion and a balance of ecosystems and the natural and built environment. As Ricky Burdet, Director of LSE Cities and Urban Age, argues, the mix of public and private money is what generates solvent cities, citing the case of different London neighborhoods, including Kings Cross in London, whose transformation took 30 years and leads to prioritizing long-term urban planning and management. This sort of urban operations become less immediate, speculative, and trading oriented, which means more awareness of local realities. For this reason, it is important to act under the integral scope of sustainability in two directions, one in terms of energy and zero carbon growth (mediated by density, traffic, and housing production) and the other in social terms (characterized by health, inclusion, social security, and coexistence because of mixture and diversity, both economic and cultural) (Burdett & Sudjic, 2011).

1.5 Global policy frameworks: An instrument for mainstreaming sustainable urbanism (challenges)

1.5.1 The 2030 agenda for sustainable urbanism

The General Assembly of the United Nations, formed by 191 States, established the 2030 Agenda for sustainable development in 2015. This body designed 17 Sustainable Development Objectives (SDG) with 169 targets as a new roadmap to promote human rights and which come to succeed the previous Millennium Development Goals. Each of the 17 SDG also is strongly related and inspired by International Human Rights Law since they encourage the respect, protection, and basically the promotion of human rights and fundamental freedoms for all, without any distinction as race, origin, sex, language, religion, political opinions, disability, or other status.

From a global urban scenario the SDGs and the expectation to achieve them by 2030 strongly depend on nationals and local articulation of policies, legislations and actions focused on cities. In the light of this, SDG number 11 titled "sustainable cities and communities" is officially missioned to "Make cities inclusive, safe, resilient and sustainable" (UN-CEPAL, 2017). In this sense, there are remarkable data that help us to understand the relevance and pertinence of this objective according to United Nations (United Nations, 2021a, 2021b):

- Half of the human population (3.5 billion people) lives in cities today, and this number is projected to increase up to 5 billion by 2030.
- 95% of urban land expansion in the coming decades will take place in the developing world.
- Currently, 883 million people live in slums and the most of them are located in East and Southeast Asia.
- The world's cities occupy only 3% of the earth, but report between 60% and 80% of energy consumption and 75% of carbon emissions.

- The rapid urbanization is diminishing the freshwater supplies, wastewater, the living environment, and public health.
- More than half of the world's urban population is exposed to air pollution levels at least 2.5 times higher than the safety standard.[b]

To take into consideration the relevance of this goal is also significant first to get a comprehensive notion about the general patterns that define sustainable urbanism. In this sense, it is meaningful to bring on the table the Freiburg Chapter[c] that summarize accurately this approach through 12 principles gathered into 3 different categories as follows:

Spatial:

1. Diversity, safety, and tolerance.
2. City of neighborhoods, including decentralized governance and the protection of a city's identity.
3. City of short distances with accessibility to all infrastructure networks available on foot or by bicycle.
4. Public transport and density: land users with civic function and high frequency of use shall be located near to public transport nodes.

Content:

5. Education, science, and culture as pillars of the city.
6. Innovative industry and future-oriented jobs provision.
7. Respect for the nature and environment, with all planning proposals evaluated for their environmental impact.
8. Design quality, especially for public spaces.

Process:

9. Long-term visión and planning.
10. Communication and participation of all levels and sectors of society.
11. Reliability, obligation, and fairness, to build trust and consensus.
12. Cooperation, financial support, incentives, and partnership for projects.

What is significant about these principles is the pertinence in the frame of current climatic and public health crisis because of COVID-19 pandemic. It might be inferred that they are the theoretical framework of the SDG no 11. According to its content, this objective faces a demanding challenge: inequality, given that more than a billion people live in slums and this number continues to grow. Urban energy consumption levels and pollution are also worrisome.

[b] According to the World Health Organization (WHO) since 2016, 90% of city dwellers have been breathing air with unacceptable safety standards. It corresponds to 4.2 million deaths due to air pollution (UN, 2020).

[c] The Freiburg Charter was developed in partnership with the City of Freiburg in recognition of winning the Academy's European City of the Year Award 2010. The city is an outstanding example of sustainable urbanism of which this publication aims to distill through 12 principles. https://www.academyofurbanism.org.uk/freiburg-charter/.

In terms of implementation, to accomplish this objective, an articulation of national and local governments through policies and programs designed according to its targets is needed. But this is achieved with the commitment of various actors and a determined and coordinated attitude of the different levels of government, promoting dialogues based on technical evidence. Another determining aspect for the achievement of the objectives has to do with the construction of capacities in different actors (Franco & Tracey, 2019). This facilitates the design of indicators for monitoring and evaluating targets. In addition to the above, it is also crucial to promote inclusive and proactive governance by local communities and other key stakeholders in order to put pressure on the political decisions necessary to move forward strategic actions and projects now even more because of the higher impact of the pandemic on the most vulnerable populations. However, this global public health crisis produced by COVID-19 has revealed the importance of prioritizing actions around transportation, open spaces, and, in general, city planning based on public health as a transversal axis (UN-ESCAP, 2010).

1.5.2 The New Urban Agenda as accelerator of SDG number 11 "Sustainable cities and communities"

The New Urban Agenda (NUA), adopted in 2016 in Quito and promoted by UN-Habitat each 20 years, provides member States a way to localize the SDGs. In the case of the number 11, it offers approaches on planning, design, management, governance, and financing of cities; nevertheless, most of the 234 SDG indicators have a direct connection to urban policies and an evident impact on cities and human settlements. It is also important to take into account that action in one area of any other objective that will affect the outcomes in other areas of other objectives as well. For instance, the goal on poverty is linked to access to land, slums, and inadequate housing; health is often affected by "place"; and gender equality can benefit from access to public spaces, basic infrastructure, and participation in local governance and decision-making. In terms of governance and institutional public relations, nearly one-third of indicators are also being measured at the local level, which highlight the importance of articulating governments between different scales or levels (UN, 2020).

The understanding of the NAU as SDG no 11 accelerator may also offer an opportunity for the global community to address collaboratively by cooperation of several urban challenges associated to growing inequalities, social exclusion, extreme poverty, high unemployment, particularly among women and youth, and the importance of approaches based on climatic resilience and risk management in urban contexts.

The interrelation among different goals makes it possible to prioritize the urban components of the SDGs related to the sprawl of cities, the increase of slums, the vulnerability of populations, and the poor conditions of the urban environment. For example, inclusive and productive cities are important for entrepreneurship and job creation. Similarly, resilient infrastructure and industrialization are essential for the prosperity of cities. The goals related to cities offer many opportunities to develop coherent mitigation and adaptation strategies to address climate change especially through environmentally sustainable and resilient urban development (UN, 2020). These opportunities are reflected for instance in the correlation between the waste generated by cities and the pollution of oceans that diminish natural habitats and accelerate the loss of biodiversity. In this case, it is very noticeable that degradation of oceans largely depends on the way cities are managed. Other examples may be related with the promotion of peaceful and inclusive societies that require cities free of violence and with strong institutions and law. Therefore, a comprehensive approach to the urban dimension of the different sustainable development goals is a key strategy to take advantage of their full potential by promoting articulated actions based on alliances and partnerships.

The New Urban Agenda articulated with SDG 11 might be summarized through the following demands: need of affordable housing, better transport, good air quality, efficient waste management, adequate public spaces, enhanced participation, resilience of cities, and disaster risk reduction, among others (ONU HABITAT, 2021). To fulfill these demands, comprehensive planning and strategies are required that promote resilience supported by national urban policies and local actions and programs. Some of them are related and dependent on indicator monitoring, for instance, through urban observatories linked to local governments that enhance information and knowledge management and data governance. According to the last report of United Nations regarding the progress of SDGs to have a proper indicator monitoring that is required to address numerous challenges such as the need to have consensus about the global definition of cities. According to last report of United Nations regarding the progress of SDG's to have a proper indicator monitoring, it is required to address numerous challenges such as the need to have consensus about the global definition of cities. Others are related to enhance local data collection systems, advance on methods to disaggregate information, particularly gender and youth data, support countries to handle the new demand of monitoring large numbers of cities or adopt the national sample of cities approach, strengthen capacities of Institutions and reinforce functional linkages among various levels of government. In this sense, an instrument developed for UN-Habitat's to enhance indicator monitoring is the City Prosperity Initiative (CPI). This instrument is built by over 450 cities with 72 urban indicators data points available, and this has been complimented by other global data from 200 cities from a Global Sample of Cities. Therefore, CPI becomes a complementary and valuable datasets to support global and local policy work as well as decision-making based in evidence, technical information, and real-time data (UN, 2020).

1.6 The need for disruptive solutions

The aspects of innovation and technology continue to be an incentive from which to generate alternatives to achieve the pre-established goals associated with mitigating climate change. Agencies and institutions concerned with adaptation to climate change tend to focus on the role of science with the intention of "educating" communities; however, they overlook the risk of marginalization by not taking into account aspects of cultural traditions, including faith, which in some cases represents high chances of success in actions. For this reason, it is important to consider that the cultural tradition represents a strong local wisdom that contributes in a transcendent way to the management of climate change in how the well-being of these same communities is maintained and improved (Morrison, 2021).

Some of the recommendations raised at COP26 associated with climate change and health mention committing to a healthy recovery, especially in the face of the impacts of global crises such as the pandemic; trying to understand that our health is not negotiable, that the health benefits derived from climate action must be taken advantage of as well as resilience to climate risks, the creation of energy systems that improve the climate and consequently health, must be fostered, which also implies re-imagining urban environments including transport and mobility, protecting and restoring nature as the basis for an adequate framework for health, promoting food systems, healthy environments, sustainability and resilience, financing for a healthier and fairer future and involve the community to join efforts toward urgent climate action. The above is the result of a consultation with more than 150 organizations and 400 health professional experts with the intention of highlighting areas of opportunity in the near future (WHO, 2021).

Other authors have mentioned the concept of "sufficiency" as a set of daily political and practical measures that avoid an excessive demand for energy, materials, water, land, and natural resources to provide well-being, at the same time that it promotes the minimization of inequality gaps (Saheb, 2021). For its part, the "ecological overshoot" occurs when humanity consumes the natural resources available to it faster than ecosystems can regenerate, based on waste that exceeds nature's assimilation capacity (Rees, 2021).

The transition to zero emissions requires significant changes from the social and industrial realm where governments and corporations must resort to technological innovations, which is reinforced in the WEF report, which identifies how digital technologies can help improve the efficiency of industrial processes such as systems based on Artificial Intelligence (AI) (Miller, 2020) (World Economic Forum, 2021). It is important to mention that other impacts of technologies such as the Internet of Things (IoT) that could have a shorter useful life are beginning to be seen, which also generates waste to the environment, which denotes the concern of waste management of the ICT, energy management, and long-term emissions (Dwivedi et al., 2022). Thus, it is seen that there is an urgent need to integrate initiatives and strategies that articulate the climate, health, equity in knowledge, practice, and public policies that allow proposing joint solutions to interrelated problems, not only within the framework of the objectives of COP26 (mitigation, adaptation, financing, and collaboration) but rather promote integrative actions toward a better future from the perspective of climate change and human health. Planning and policy mechanisms and instruments should be proposed that involve climate mitigation and adaptation processes based on cooperation, which encourages stakeholders to work in a more integrated manner focused on obtaining collateral benefits to ensure that public support for the climate action integrates responsible behaviors of citizens toward a more effective net zero transition. For this, appropriate local and global indicators must be created that allow the evaluation and monitoring of the actions carried out (EUPHA, 2021). Some of the technology-related areas that could be considered for a better understanding of environmental impact should include predictors of technology use, technological impacts, implementation problems and the knowledge gap, the useful life of the system, and the implications to the long term (Papagiannidis & Marikyan, 2021).

The UK government has been among the first to establish a legally linked goal of zero emissions by 2050; however, of the 92 policy recommendations established by 2021, only 11 have been met, which leads to rethinking actions toward 2030 and 2050. Thus, current government policies worldwide for rapid decarbonization by 2050 will have to integrate behavioral changes among populations and their role regarding technological innovation, which also impacts on changes in the environment, sustainable mobility practices, and healthy eating, among others (Marteau, Chater, & Garnett, 2021).

The foregoing not only serves urban environments but also has implications for the territory, including rural environments and the peripheries. The preservation of rural environments, such as the case of Portugal, implies a rebirth with a perspective of multifunctional landscapes and climate-adaptation strategies that allow restoring ecosystems from local actions that involve participatory action on site (Vizinho, Cabral, Nogueira, Pires, & Bilotta, 2021).

Public policy makers and stakeholders have begun to explore a series of short-term measures such as the case of the management of solar radiation in the protection of highly vulnerable regions; however, as they are not comprehensive solutions, neither neutrality is addressed of carbon nor the need to eliminate residual GHG emissions, which is why the argument that rapid decarbonization is the most attractive thing to do to manage the challenges of rising temperatures, not to mention that the most effective actions must integrate an environmentally and socially sustainable dynamism (Radunsky & Cadman, 2021). In this way, micro-level practices, as part of governance and sustainability management actions, include organizational actions and commitment to public policies in the construction of virtuous circles in favor of climate change (Hoyer, 2021). The relationship that exists between rural areas and climate change, in cases such as depopulated areas in areas of Europe, Australia, and America, attends to sectorial aspects such as agriculture, fishing, livestock, forestry, biodiversity, recreation, and a particular focus on the processes of adaptation of rural populations, where there are also phenomena such as migration and changes in land use, which may have a direct relationship with the impacts of climate change (Paniagua, 2021). The same can be seen in rural areas of Africa where women live in communities governed by a regime of customary law associated with customs, and in most cases, to a greater exposure to risks (Gachenga, 2021).

Climate change forecasts transcend territoriality scenarios from the local scale, where there must be processes of integration of the characteristics of territorial development, climate change, and the potentiality of the dynamics of human beings, taking into account the characteristics and purposes of each territory and prospective activities and agroclimatic conditions and infrastructure for development (Zharova & Khlobystov, 2021). The need to protect entire ecological systems and restore degraded or destroyed ecosystems represents a way to counteract the continuous consumption of stored carbon by allowing nature to carry out its own ecosystem regeneration process. These environmental protection actions are necessary to guarantee that the services and complex interactions between ecosystems can guarantee their permanence. Thus, the “Rights of Nature” (RoN) represent an approach where ecosystems are guaranteed a right to life according to national and international laws (Cooper Beeks, 2021).

The challenges through improved approaches to the so-called climate governance implies emerging international and national actions oriented to the territory, where in the case of local governments of developing countries such as South America, mechanisms of alienation and participation should be established among the national bodies and existing international resources (Rabbia & Zopatti, 2021). Some other challenges identified from local governments include insufficient personnel, lack of knowledge regarding the appropriate formats to bring together strategic actors to build a solid base for the creation of knowledge, cooperation scenarios, and coordination of agreements between stakeholders (Lange, Ebert, & Vetter, 2021).

Climate adaptation platforms may contain decision support tools that facilitate and include capacity building, collaborative networking, outreach resources to aid planning, and implementation of proven adaptation concepts, such as nature-based solutions (SbN), which has been implemented to mitigate impacts of floods, droughts, and heat stress (Boogaard, 2021). As mentioned, there are relevant contributions of Artificial Intelligence (AI) to climate change not only to climate sciences and interdisciplinary branches but also it represents an essential tool for scientific advancement and transdisciplinary collaboration, while recognizing the existing technological gap between developed countries and developing countries (Ababneh, 2021). It is evident that for developing countries the challenges of climate change are relatively new, so it is important to develop research from local settings, with actors from the government, academia, citizens, institutions with a certain degree of roots, and, of course, cooperative actions of international brought to the local (Akinbusoye & Ayotomiwa, 2021).

Policies for mitigation and adaptation to climate change are currently focused on aspects of technology, communication, sustainability, and vulnerability, where it is also important to incorporate historical and cultural aspects related to traditional knowledge, world views, territoriality, access to land, and practices of indigenous peoples, since local and cultural knowledge implies technology that must be reevaluated for current adaptation responses to climate change (Sánchez-Cortés, Terrón-Amigón, & Cruz-Montejo, 2021). The spiritual disconnection between people and nature also implies considerable loss of sacred spaces that have been destroyed, determining very important protection scenarios, so that spirituality, as in the case of the Mapuche peoples, represents processes of land recovery, spaces sacred that imply forest ecosystems, and therefore positive impacts toward mitigation aspects of climate change (Arias-Bustamante & Innes, 2021). In this way, it is important to encourage the efforts of local and national administrations in permanent collaboration with the communities, as was the case in reducing the impact of the pandemic on the conditions of habitability and community well-being, since the impacts on the use and adaptation of housing and public space allowed the evaluation of habitability conditions at the architectural and urban design scales (BuroDap International, 2020).

Thus, innovation scenarios from behavioral perception, climate change management, and the leadership of public institutions can be strengthened more effectively from the perspective of behavioral science, where new perspectives can be raised not only from the population but also from public servants and their institutions (Castro de Hallgren, 2021). As mentioned before, the absence of integration of different levels of government and multiple sectors represents one of the main barriers to comprehensively addressing the challenges of climate change, as it is confirmed by several authors that local governments are the ideal scenarios to address these integration mechanisms (Cid et al., 2021). Therefore, we must assume that the strategies and plans to be implemented must integrate transversally practices in a comprehensive approach to actions with a common goal.

1.7 Summary

Once some ideas and intentions have been raised regarding the approach to mitigation actions and adaptation to impacts of climate change, we can propose that processes are required that involve aspects of awareness and education focused on practices that make visible impacts to people and communities and above all in the environment, which also integrate responsible innovation and digitization aspects, where data and governance models represent a strategic agent in cities. Governance and the SDGs, sustainable development, climate change, and digitalization are aspects that will have to be jointly articulated and potentiated to prevent or mitigate impacts of future global ecological crises, which generates stimuli for the digitalization of the economy, society, and the health (Kirton & Warren, 2021).

Ways must be found to grow economically while providing protection to the environment, as well as actions to mitigate the impacts of climate change (Leal-Arcas, 2022). Climate change requires deep and collaborative transformation processes, where research on the transition to sustainability increasingly integrated governance aspects, such as the project called "Municipalities in transition," which establish a systemic and operational framework proven through action research participatory, which fosters synergies between local governments and civil society. These pilot projects were implemented in communities in Brazil, Hungary, Portugal, and Spain, with positive high impact results, which put into context the profusion of various governance frameworks for the transformation and management processes of climate change at the local level, in a framework of a comprehensive system for regenerative governance (Macedo, 2021). Thus, climate adaptation is not transmitted in isolation, but must be an integral component of holistic planning, from a regional to a local level (Hemberger, 2021).

It is impossible to determine the amount of coping strategies either from mitigation or adaptation mechanisms, when they depend to a great extent on the socioeconomic and cultural context of the vulnerable communities that represent a priority sector, since they are mostly exposed to extreme events; therefore, it is vitally important to evaluate the actions from their context (Md Atiqul Haq, Jafor Ahmed, Nazrul Islam, Hussain, & Islam, 2021). In addition to the above, there is a lack of environmental awareness of the growing population where strategies must also be proposed from the educational sector not only for the student population but also for the community in general (Coghi, 2021).

Climate change management and disaster risk reduction in LAC is a work in progress that involves various institutional efforts with a wide diversity of local and national responses during the past 3 decades, made up of more than 30 frameworks of national climate change and disaster risk systems within the region, a large number of institutions and mechanisms for regional and international cooperation, which has been recognized worldwide, especially due to the impacts in terms of vulnerability reduction, capacity building, access to information, institutional strengthening, levels of preparedness, and response to climate change impacts, which should also be strengthened from a more comprehensive perspective (Lucatello, 2021). In this way, synergies must be established between a transformative leadership and the ecologies of transdisciplinary research, it implies the use of research with pro-social and pro-environmental actions (Wolfgramm & Francis Tuazon, 2021). This means that until now research has focused only on communicating mitigation measures, while research aimed at climate change adaptation is still limited (Graulich, Schärling, Kuthe, Fiene, & Siegmund, 2021).

Truly effective actions against the impacts of climate change must find forms of scientific and practice-based knowledge, such as climate governance, where policy makers, environmental scientists, professionals, and the community contribute in "co-production" scenarios in the development of climate action products, which also involve permanent monitoring processes (Howarth, Lane, Morse-Jones, Brooks, & Viner, 2022). As human beings have entered the Anthropocene, the negative impact on the environment has been evidenced, where sustainable development represents the only way for human permanence, for which they will have to consider alternatives that involve natural processes such as agriculture after a fully industrialized society (Han & Xia, 2021).

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CHAPTER

2

Climate change adaptation and mitigation in cities

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2.1 Climate change and climate change scenarios

Climate refers to the record of changes in surface variables including temperature, precipitation, and wind over a long time, generally 30 years. Climate change has emerged as one of the most pressing global concerns, bringing with it a slew of widespread negative consequences. Change in climate can be caused by natural processes for instance, changes in the solar cycle, volcanic eruptions, as well as continued human activities with impacts on the atmospheric composition and land use. For instance, the emission of greenhouse gases (GHG) around the world has roughly more than doubled since the early 1970s, reaching about 55.6 gigatons CO_2 equivalent (Gt CO_2 eq.) in 2018 (Olivier & Peters, 2019). Present GHG emissions are about 57% higher than in 1990 and 43% higher than in 2000 (Olivier & Peters, 2019).

To measure climate change, certain indicators are used. A rise in surface temperature, vaporization, atmospheric humidity, precipitation, droughts, a rise in sea levels, and melting of glaciers and surface ice to name a few (Table 2.1). Some of these indicators can impact each other as well (Mimura, 2013).

2.1.1 A surge in average temperature of air and ocean

The mean global temperature climbed by 0.74 °C between the years 1906 and 2005. Eleven of these 12 years (1995–2006) were among the top 12 warmest years in record since 1980. The global mean temperature has risen twice as fast in the past 50 years as it has in the previous 100 years. This has caused surface water temperature to rise as well as rise of temperature to the depths of at least 3000 m. By the year 2100, Northern Canada, Greenland, and Northern

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TABLE 2.1 Indicators of climate change.

Atmosphere	Ocean	Land	Ice
Changes in Stratospheric temperature	Warming of the oceans	Higher number of warm days and nights; fewer cold days and nights	Decreasing the annual average ice extent in the Arctic Sea
Strength of the winter polar vortex	Growing rate of Global mean sea-level rise	Decreasing number of frost days	Widespread retreat of the glacier
Troposphere receives heat mostly from the surface	Changes in ocean salinity	Lessening snow cover in a number of regions	Ice sheet changes in Greenland and Antarctica
Changes in the large-scale atmospheric circulation	Acidification of the oceans	Degrading permafrost in areal extent and thickness	
Increasing GHG concentration		Large-scale precipitation changes	
Changes in cloud cover		Increase in heavy precipitation events	
Increasing tropospheric water vapor			
Changes in aerosol burden and ozone concentrations			
Rise in the global average of near-surface temperature			
Increasing surface humidity			
Warming of sea surface			

Asia will see an increase in winter temperature 40% more that the world average. Climate models (IPCC, 2018) predict that failure to implement widespread mitigation strategies will result in a global warming of about 1.8–4 °C between 1990 and to put this into perspective, even a 1.4 °C rise is more than the rise seen in any century over the past 10,000 years (IPCC, 2007).

Globally averaged concentrations of CO_2 reached 410.5 ± 0.2 ppm in 2019, up from 403.3 ppm in 2016. Concentrations of CO_2 are now 148% of pre-industrial (before 1750) levels, according to the Greenhouse Gas Bulletin, 2020 (WMO, 2009). The majority of the CO_2 is already in the atmospheric condition and will persist for more decades, perpetuating to warm our planet. Further to this, due to the oceans' ability to buffer an unprecedented temperature rise, the planet's climate cycle has witnessed a seasonal lag of several years. So, the earlier humankind lower emissions, the less is the probability of exceeding the Paris Agreement's temperature threshold, said the report.

The average daily concentrations of carbon dioxide in the atmosphere dipped by up to 17% at the beginning of, 2020 throughout the intensive time of lockdown due to the COVID-19 pandemic in comparison with the average daily carbon dioxide concentration in 2019, according to the World Meteorological Organisation's Greenhouse Gas Bulletin, 2020. Initial approximations suggest a total yearly reduction of carbon dioxide emission in, 2020 between 4.2% and 7.5% relative to 2019 levels. Unfortunately, a reduction in emissions of such magnitude will only slow the increase in yearly CO_2 concentration to 0.08–0.23 ppm lower than in the absence of the pandemic (IEA, 2020).

2.1.2 Temperature surge in the air and oceans

Between 1906 and 2005, the global mean temperature climbed by 0.74 °C. Eleven of the past 12 years (1995–2006) were among the top 12 warmest years in the global surface temperature record since 1980. The global mean temperature has risen twice as fast in the past 50 years as it has in the previous 100 years. Although surface water temperatures have risen the most, fresh scientific evidence reveals that global average ocean temperatures have risen to depths of at least 3000 m. Another concern is by the year 2100, the winter temperatures in northern Canada, Greenland, and northern Asia are may climb by 40% higher than the worldwide average. In the absence of implementation of climate change policies by different countries, climate change models forecast a worldwide warming of 1.8–4 °C between 1990 and 2100 if emissions are reduced. Perhaps a 1.4 °C increase would be larger than any period in the preceding 10,000 years (IPCC, 2007).

2.1.3 A rise in the average global sea level and widespread melting of glacier

Glaciers melt as warm surface water of the ocean seeps beneath them, increasing sea level. The 5th IPCC report described the rise of the global mean sea level higher than the past 2 millennia just between 1901 and 2010 when the world saw a rise in sea level of 0.19 (0.17–0.21) m. If this degree of global warming continues, over a millennium or more, it would result in the disappearance of the Greenland ice sheet. Consequently, the global mean sea level would rise by around 5 m by 2150 under the, high GHG emissions scenarios (SSP5–8.5). The specific threshold of temperature above the preindustrial era to cause this crisis has been variable across study methods. Studies using fixed ice-sheet topography indicate that the threshold is greater than 2 °C but less than 4 °C (medium confidence). However, another study based on dynamical ice sheet suggests the threshold is greater than about 1 °C (low confidence) (IPCC Synthesis Report, 2014).

2.1.4 Increase in frequency of extreme weather

The global warming of up to 1.5 °C from the preindustrial levels is predicted to bring on extremes of weather with heavy precipitation in some regions while causing intense and frequent draughts to others. The high-altitude regions of Northern Europe, Northern Asia, Alaska/Western Canada, Greenland, Iceland, and the Tibetan Plateau have all experienced heavy precipitation and will do more because of the 1.5–2 °C global warmings. If the global warming can be limited to 1.5 °C compared to that of 2 °C global warmings, the likelihood of higher numbers of heavy precipitation events on a worldwide scale and in particular locations can be reduced. This goal could reduce the global average heavy precipitation, tropical cyclones, and heavy precipitation related to those cyclones (Masson-Delmotte et al., 2018).

2.1.5 Climate change scenarios

Climate change scenarios, also known as socioeconomic scenarios, are a useful tool to analyze climate change, plan responses, and formulate climate policies. Analysts use these to assess future climate change vulnerability by developing predictions of future GHG emissions to forecast its effects and thus map out the best path to reach specific goals. The essential processes to create the climate change scenarios to analyze the effects of climate change are discussed in Fig. 2.1.

Emission scenarios are rational and coherent approximations of anthropogenic GHG emission based on certain driving variables including population and socioeconomic development. Quantities and loads of various gases and compounds that result from the above emission scenarios are calculated using carbon cycle and atmospheric chemistry models. Using input from such concentration scenarios, majority of the climate models can accurately depict the main aspects of present climate and can reproduce documented large-scale climate changes in the recent past (Fig. 2.1). These scenarios can be used in climate models to measure the effect of current and future anthropogenic activities as well. A Regional Climate Model is a

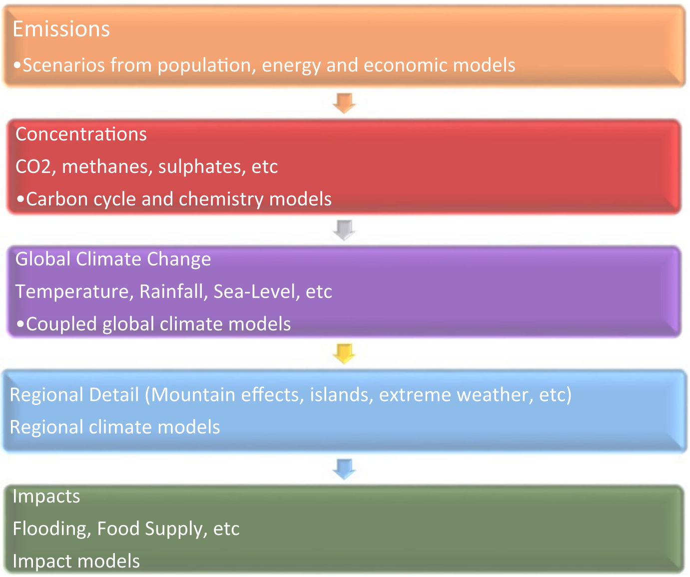

FIG. 2.1 Primary steps in constructing climate change scenarios. To assess the impacts of climate change five major areas are identified and the first factor leads to the second and so on (Prasad et al., 2009).

technique for incorporating information on changes in variability in climate extremes to perform a full assessment of imminent climate change (Jones et al., 2003).

Reviews of climate scenarios are used to develop worldwide targets to design climate change mitigation policies through involvement of the international bodies, i.e., the Intergovernmental Panel on Climate Change (IPCC), the Paris Agreement, and the Sustainable Development Goals. Scenarios are typically used in groups of two or more to compare alternative futures and options. For instance, climate policy analysis driven by such scenarios compares a prediction without policy action (sometimes referred to as the baseline scenario) with a path toward the desired objective (such as the 2 °C targets). As a result, understanding a single situation necessitates knowledge of the larger collection of scenarios in which it is contained.

Climate change scenarios can be of seven different types that are enumerated in Table 2.2.

To cite an example of the "emissions scenario," the emissions gap for 2030 is calculated utilizing the difference between projected global GHG emissions from least-cost scenarios (based on the pre-COVID-19 current policies scenario) that maintain global warming to below 2 °C, 1.8 °C, or 1.5 °C with varying levels of likelihood, and estimated global GHG emissions assuming that complete implementation of Nationally Determined Contributions would be achieved. By using the 2010 policies scenario and the current policies scenario as standard, the drop in emission by 2030 could then be determined. Such emission scenarios can predict the likelihood of the global warming. For example, the 1.5 °C global warming level is very likely to be exceeded under the very high GHG emissions scenario (SSP5–8.5). Under the intermediate and high GHG emissions scenarios (SSP2–4.5 and SSP3–7.0), it is likely to exceed the 1.5 °C global warming level. The low GHG emissions scenario (SSP1–2.6) on the other hand would predict this to be more likely than not to be exceeded. Under the low GHG emissions scenario (SSP1–1.9), the 1.5 °C global warming level is more likely than not to be reached. These are the four illustrative scenarios out of five in the near term (IPCC, 2021).

Climate change is occurring simultaneously with other ecological, societal, technological, financial, and cultural shifts. Climate change scenarios have helped climate change to be

TABLE 2.2 Climate change scenarios.

	Projections	Path	Both
Socioeconomic scenarios deal with social aspects of human interference with climate and climate change			Yes
Emissions, high GHG concentration, and climate forcing scenarios that emerge from these interactions and interferences	Yes		
Climate change scenarios resulting from human forcing of the climate	Yes		
Climate impact scenarios that are the results of the climate changes	Yes		
Mitigation scenarios describe ways to reduce the impact of human activities on climate change		Yes	
Adaptation scenarios describe societal impact of climate change		Yes	
Integrated scenarios associates several of the above components of future climate change			Both

Source: *https://climatescenarios.org/primer/*.

interpreted in a larger framework of change. The concept of adaptation approaches emphasizes forthcoming development patterns that force societies to become more climate resilient. Various processes, natural or manmade, produce chemical substances in the atmosphere which then disrupt the energy balance of the earth and lead to climate change. GHGs such as methane, carbon dioxide, and nitrous oxide are major contributors to climate change. The rising atmospheric concentration of GHGs causes climate change. Although GHGs are the primary contributors to climate change, nature only emits a small quantity of GHGs; the major contributor is anthropogenic GHGs. Many of the changes that have been witnessed since the 1950s are unexpected and as per the AR5 Synthesis Report, IPCC is 95% certain that the main reason behind the warming at the global scale is anthropogenic constituents and such contribution is on the rise across all continents. The following pie chart presents the world human produced GHG by different sectors (Environmental Protection Agency, 2020).

Climate change will continue as GHG atmospheric concentration remains high for a prolonged time, and the response of the climatic system is slow enough leading to an almost certain rise in temperature even if future emissions are reduced. In near future, the temperature will most likely rise even more (IPCC Synthesis Report, 2014). Overall GHG emissions in 2025 are expected to be 8.6% greater than that of 2000 (12.93 Gt CO_2 eq.) and 0.5% more than that of 2017 (13.97 Gt CO_2 eq.) (UNFCCC, 2021).

GHGs are emitted primarily from the use of fossil fuel and deforestation (Fig. 2.2). Methane (CH_4) is predominantly emitted through landfills, agriculture, and rice farming, accounting for nearly 80% of total anthropogenic GHG emissions. Chemical fertilizers, industrial operations, and fossil fuel combustion are sources of nitrous oxide (N_2O). The greenhouse effect is a natural process that governs the planet's temperature while heat is retained in atomosphere in the form of solar energy essentially keeping the planet warmer than without such effect. Although the atmospheric concentration of GHGs is less than 1% still it keeps the planet warm. Ozone, water vapor, carbon dioxide, methane, and nitrogen dioxide are some of the natural GHGs. The average temperature on Earth is at present 18 °C which would be 15 °C if the greenhouse effect did not exist.

Solar radiation fuels the climate (Fig. 2.3) and the visible portion of the electromagnetic radiation contains approximately 50% of the energy from the sun. The surface of the Earth absorbs about 50% of the incoming SWR. Clouds, gases, and aerosol together reflect 30%

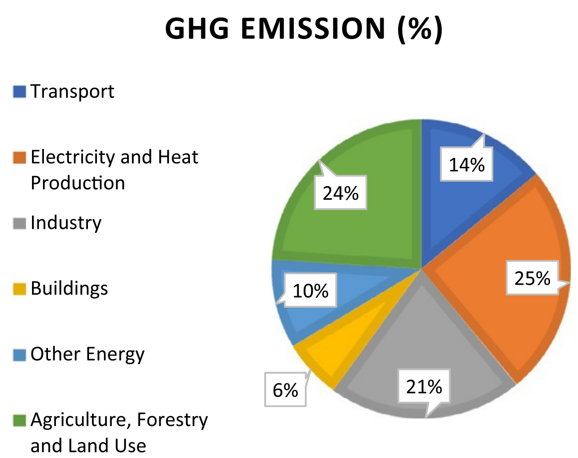

FIG. 2.2 Human produced GHG by sectors. Power generation, agriculture, and land use and industries are the major sources of GHG production. *Source: IPCC (2014). Climate change 2014: Synthesis report.*

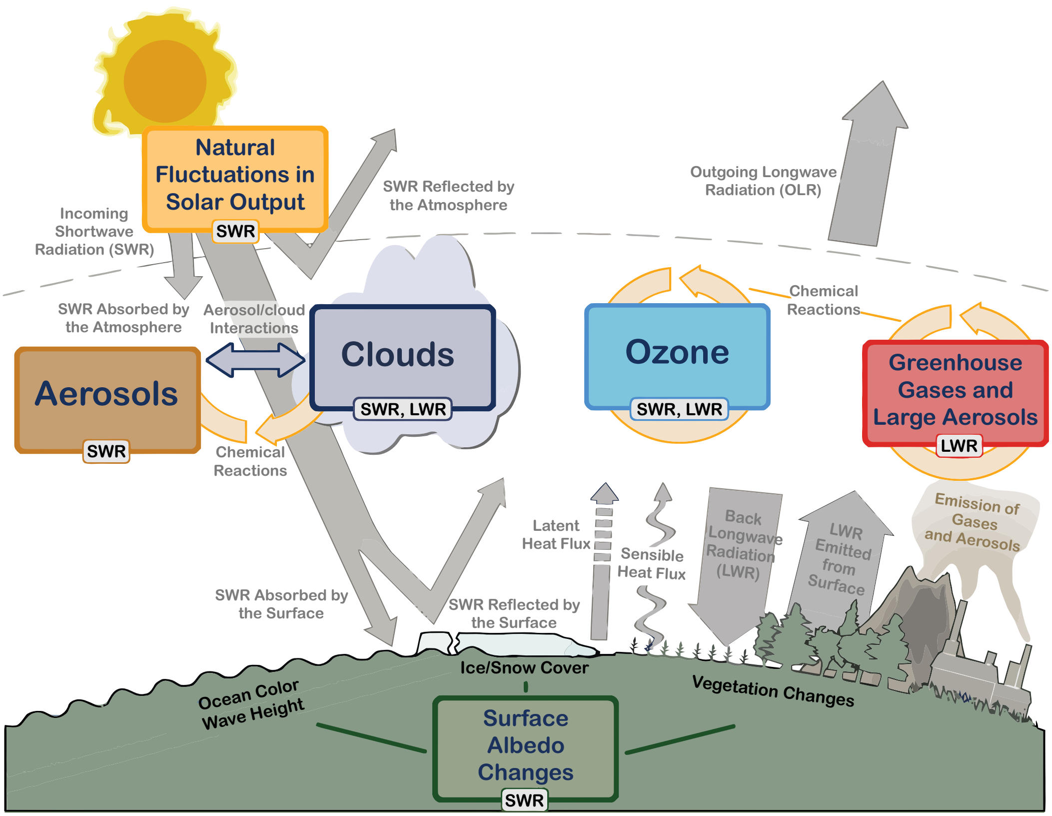

FIG. 2.3 Main drivers of climate change. The radiative balance between incoming solar shortwave radiation (SWR) and outgoing longwave radiation (OLR) is influenced by global climate "drivers." Natural fluctuations in solar output (solar cycles) can cause changes in the energy balance (through fluctuations in the amount of incoming SWR). Human activity changes the emissions of gases and aerosols, which are involved in atmospheric chemical reactions, resulting in modified O_3 and aerosol amounts. O_3 and aerosol particles absorb, scatter, and reflect SWR, changing the energy balance. Some aerosols act as cloud condensation nuclei modifying the properties of cloud droplets and possibly affecting precipitation. Because cloud interactions with SWR and LWR are large, small changes in the properties of clouds have important implications for the radiative budget. Anthropogenic changes in GHGs (e.g., CO_2, CH_4, N_2O, O_3, CFCs) and large aerosols (>2.5 μm in size) modify the amount of outgoing LWR by absorbing outgoing LWR and re-emitting less energy at a lower temperature. Surface albedo is changed by changes in vegetation or land surface properties, snow or ice cover and ocean colour. These changes are driven by natural seasonal and diurnal changes (e.g., snow cover), as well as human influence (e.g., changes in vegetation types) (Forster et al., 2007). *Adapted from P-126, Fig. 1.1 https://data.globalchange.gov/report/ipcc-ar5-wg1/chapter/wg1-ar5-chapter01-final Cubasch, U., Wuebbles, D., Chen, D., Facchini, M.C., Frame, D., Mahowald, N., & Winther, J.-G. (2013) Introduction. In* T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P.M. Midgley (Eds.), Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change *(pp. 119–158). Cambridge, UK and New York, NY: Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.007.*

of the remainder and lastly only 20% is absorbed in the atmosphere outgoing energy flow from the Earth is, however, mostly in the infrared spectrum that is dependent on the surface temperature of the planet. Water vapor and GHGs such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and clouds are the atmospheric constituents that absorb the LWR. This downward component of the LWR delivers heat to the lower layers of the atmosphere and the Earth's surface (greenhouse effect). Much of the energy lost from the Earth's infrared energy comes from the troposphere. The Sun primarily provides energy to the Earth in the tropics and subtropics, where it is largely transferred via atmospheric and oceanic transport mechanisms to the middle and high latitudes.

The atmosphere, terrestrial biosphere, fossil fuel, oceans, and sediments are the major carbon reservoirs of the planet. The exchange of carbon between these reservoirs, essential for life on earth, is called Carbon cycle. Land and ocean hold half of the projected total carbon dioxide resulting from anthropogenic emissions including fossil fuel combustion and deforestation acting as "sinks." Any decrease in sinking capacity will increase the total atmospheric concentration of GHGs and worsen global warming further. Vegetations also play a vital role in the natural sinking process as tree saplings can capture carbon dioxide for many years, thus afforestation can improve sinking capacity.

2.2 Climate change and cities

Based upon records of climatic events of the planet, variations in the current record, emergence of new trends in temperature extremes, and climate models at a global scale, it is evident that anthropogenic emissions are making cities more vulnerable to climate change. Comprehending these changes will help cities plan for a more sustainable economy. Sustainability will involve making cities more resilient to climate-induced calamities by enhancing capacity to reduce greenhouse gas emissions as well as addressing long-term climate concerns in ways that both safeguard people and promote development. Most of the climate change estimates are made on a global scale; however, the impact of such changes will vary on regional localization. For instance, sea level rise will have an impact on the huge, urbanized zones concentrated along the tidal shorelines, particularly those cities in regions where the land is already sinking. Therefore, it is vital to evaluate how cities will be affected by the changing environment. More than 50% of the world's population are in the cities. To address the vast range of climate change impacts that cities must confront, city leaders are collaborating with a variety of groups, such as city networks and climatologists. They are examining circumstances in their cities to implement scientific changes that will boost resilience and curb greenhouse gas emissions and will enable mitigation of climate change and the intensities of its effects. To this end, The United Nations has adopted the new Sustainable Development Goal (SDG) 11 titled "Make cities and human settlements inclusive, safe, resilient, and sustainable," in September 2015. Understanding climate change in the perspective of sustainability and specifically identifying climate change as a key component of SDG are critical. Cities have dynamic systems that make them prone to unique climate impacts; therefore, adaptations must be site-specific and adjusted to local conditions. Understanding the vulnerability and sensitivity to a particular set of climate change effects is the first step toward risk management and fostering long-term resilience. A city prepared for future climatic effects, by reducing the amount and intensity of such consequences, and adapting swiftly and efficiently, in an integrated and seamless manner once an impact has occurred, is a resilient city. Developing resilience would require sound decision making and building a network of social and institutional support system for people vulnerable to climate change. Collecting data on climate change pertaining to the loco-regional and population setting would be the first step in this. Identifying the social and local implications of climate change by integrating the community and their needs would be of utmost importance. Cities can then increase their adaptive capacity adequately to future climatic impacts through both formal and informal planning efforts, as well as exploring and investing in policy and planning.

Table 2.3 presents the summary of the potential effects of climate change on cities on a global scale according to IPCC estimation for the mid-to-late 21st century (World Bank Group, 2011).

Cities have unique climate change impacts like "Urban Heat Island Effect (UHI)," worsening of already extremes of climate and air pollution (IPCC Synthesis Report, 2014; Rosenzweig et al., 2018). Cities suffer from relatively limited cooling by vegetations, which in addition to higher heat absorption often makes them warmer. High temperatures worsen

TABLE 2.3 Possible impacts of climate change on cities of the world as per IPCC Synthesis Report (2014).

Key risk	Key climate change risk	Climatic drivers	Geographic location	Adaptation issues and prospects
Urban risks associated with housing (high confidence)	Urban heat island effect with increased risk of heat, leading to increased risk of heat-related mortality and morbidity Increased energy consumption for temperature control Increased consumption of water and declining quality of air and water Increased incidence of vector borne illness	Extreme temperature and precipitation	Inland zones/cities, and cities	Inferior quality housing located in an inconvenient location is frequently the most vulnerable to climate extreme events High-value infrastructure and housing assets damage causes economic loss Adaptation options: Enforcement of building codes and regulations Use adaptive housing to rebuild after disaster or in rapidly growing cities
Urban risks associated with water supply systems (high confidence)	Flooding, strong winds, and landslides Damage to water supply and degradation of surface and ground water Infrastructure damage Increase in water borne illnesses Interruption of transportation and communication systems In the short term, water stress may be relieved	Drying trend, flooding	Coastal cities, cities on flood plains and mountainous regions	Adaptation options: Maintain water supply and quality Flood risk reduction
Urban risks associated with energy systems	Increased water demand and degradation of quality Decreased water supply for	Warming trend, extreme	All particularly	Employ adaptative energy systems Nonadaptive centralized

Continued

TABLE 2.3 Possible impacts of climate change on cities of the world as per IPCC Synthesis Report (2014)—cont'd

Key risk	Key climate change risk	Climatic drivers	Geographic location	Adaptation issues and prospects
(high confidence)	hydroelectricity Loss of lands with decreased crop production leading to food shortage Rural to urban population migration because of all of the above	precipitation, damaging cyclone	cities close to arid regions	energy systems may have more widespread impact from a localized event
Water scarcity and increased competition (high confidence)	Erosion and submersion of lands Economic burden of coastal protection and relocation Increased salinity of ground water Tropical cyclones and coastal flooding	Extreme warming and drying	Coastal cities	Many people are already lacking adequate access to safe water Discrimination hindering access to safe water Large-scale water consumption by industries, agriculture, and power generation increases competition

the concentration of pollutants in the air (World Bank Group, 2011). Cities, informal settlements, and the urban poor are all affected by climate change. The correlation between land surface temperature (LST), urban heat island, and temperature can be established from changes in land use patterns because of fast urbanization, which is linked to rising LST and heat island expansion. Rapidly changing LULC due to uncontrolled urban expansion causes a loss of plant cover, which promotes the formation of heat islands by raising surface temperature (Akter, 2020). One study revealed that anthropogenic climate changes has increased the risk of 2018-like extreme heatwave events by four times. As climate system warms, the intensity, duration, and frequency of some weather events have been changing as found in some other studies. For example, intense marine heatwaves of Tasman Australia in 2017 and the consecutive year would have been nearly impossible without the impact of climate change (Eckstein, Künzel, & Schäfer, 2021).

2.2.1 Challenges of climate change: Evidence from Bangladesh

The already densely populated cities of the developing countries are facing a particularly difficult set of challenges with climate change with rapid and continued urbanization. In Bangladesh, the constant urbanization changes open landscapes such as agriculture and forest into high-rise buildings and pavement. Increased human activities, discarded heat, and

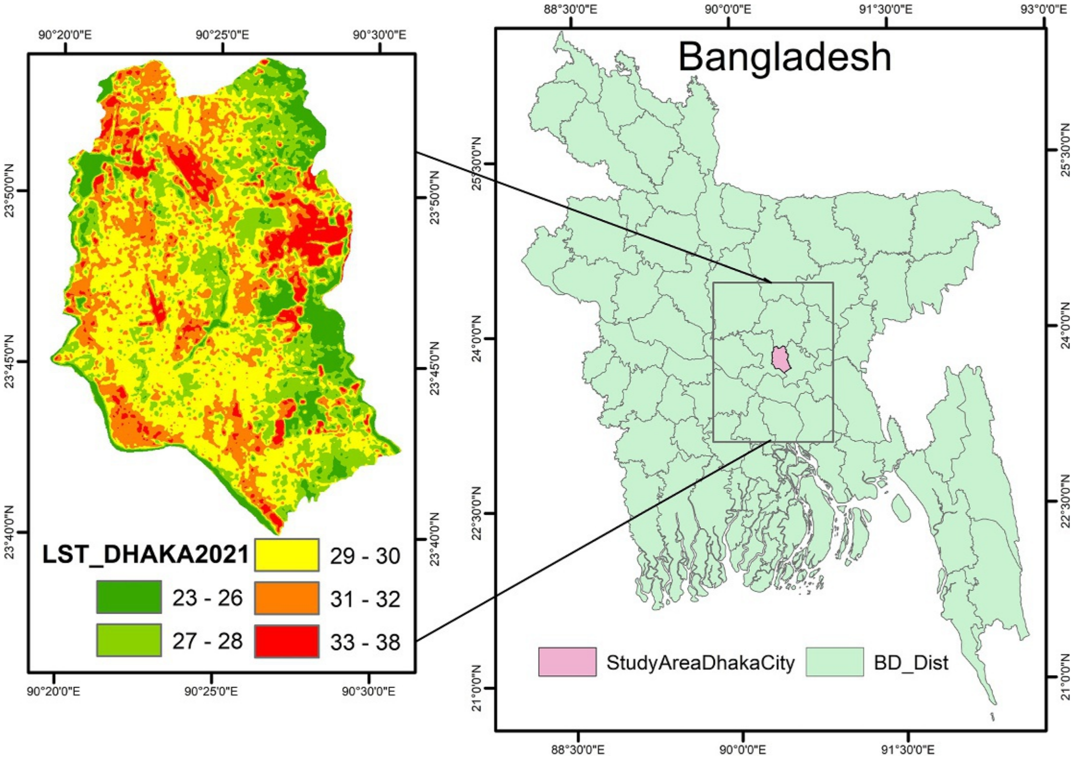

FIG. 2.4 Land surface temperature Dhaka city 2021. *Red* (dark gray in the print version) reflects the highest land surface temperature (LST) producing areas, while the *dark green* (dark gray in the print version) indicates the lowest land surface temperature producing areas of Dhaka city. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) *Source: Authors analysis using GIS and remote sensing technology, https://glovis.usgs.gov/app.*

increasing impermeable surfaces all contribute to change in local climate of the capital, Dhaka, like many other cities in the developing countries that share similar characteristic limitation of resources, land area and poor infrastructure development. It is impossible to restore the city's damaged urban forest and vegetation, but it might play a significant part in the city's urban ecosystem and environment.

In 2021, the highest land surface temperature was 38.44 °C (Fig. 2.4), and the low land surface temperature was 23.40 °C (Fig. 2.4). The number of urban heat islands was 74 (Fig. 2.7) in the said year, which was only 26 in 2011 (Fig. 2.8) and 29 in 1999 (Fig. 2.9). It can be inferred that during this time, higher LST zones and UHI have spread throughout the city (Akter, Gazi, & Mia, 2020). The majority of LST values fell within the range of 33–38.44 °C and covered an area of 1878.3 ha (Fig. 2.5).

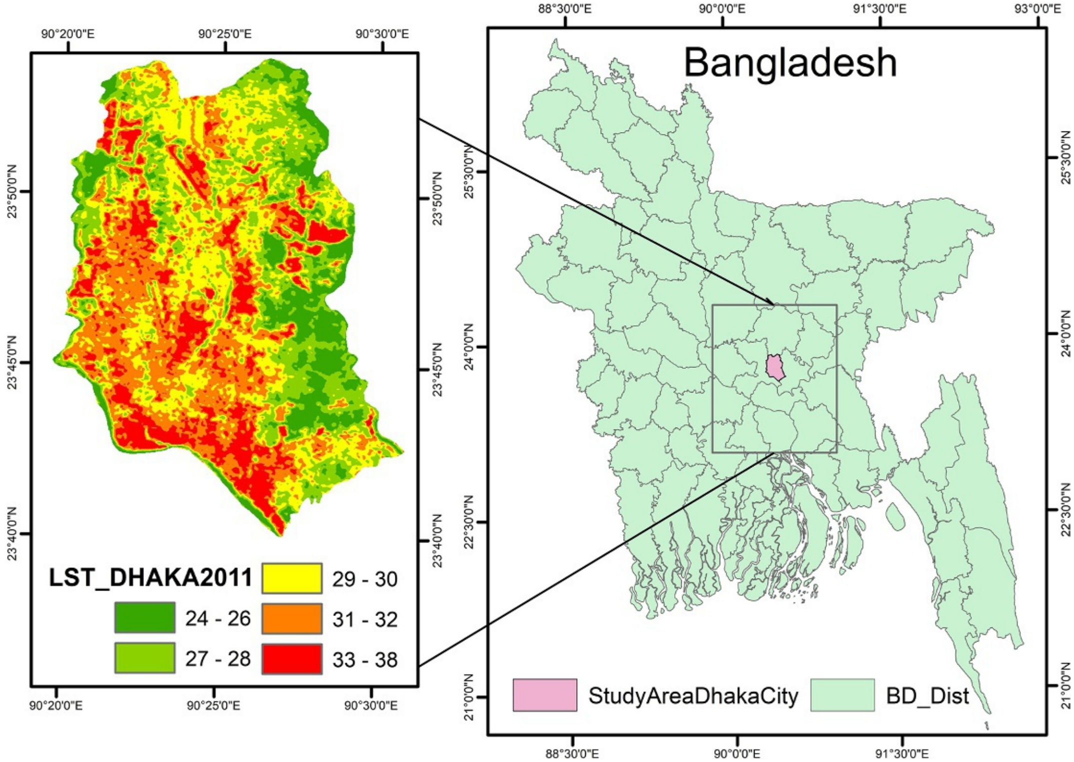

FIG. 2.5 Land surface temperature Dhaka city in 2011. *Red* (dark green in the print version) indicates the highest land surface temperature (LST) producing areas while the *dark green* (dark green in the print version) indicates the lowest land surface temperature producing areas of Dhaka city. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) *Source: Authors analysis using GIS and remote sensing technology, https://glovis.usgs.gov/app.*

In 2011, the highest land surface temperature was 37.61 °C (Fig. 2.6), and the low land surface temperature was 24.11 °C (Fig. 2.6). The majority of LST values fell within the range of 33–38 °C and covered an area of 94.14 ha.

In 1999, the highest land surface temperature was 35.25 °C (Fig. 2.7), and the low land surface temperature was 21.50 °C (Fig. 2.7). The majority of LST values fell within the range of 30–35 °C and covered an area of 31.95 ha.

Figs. 2.7–2.9 illustrate the urban heat island effect (UHI) considered in Dhaka city in 2021, 2011, and 1999, respectively. From the images analysis, it is evident that during the years 1999 and 2011, LST hotspots were mainly concentrated at the northern side of the city and UHI also followed the same pattern. However, in 2021, both LST and UHI are found to have spread all over the city.

Fig. 2.10 illustrates a correlation between average LST and average NDVI values considered in Dhaka city. The result represents a negative association between the LST and NDVI values, which means an increase in vegetation cover generally results in low land surface temperature and vice versa.

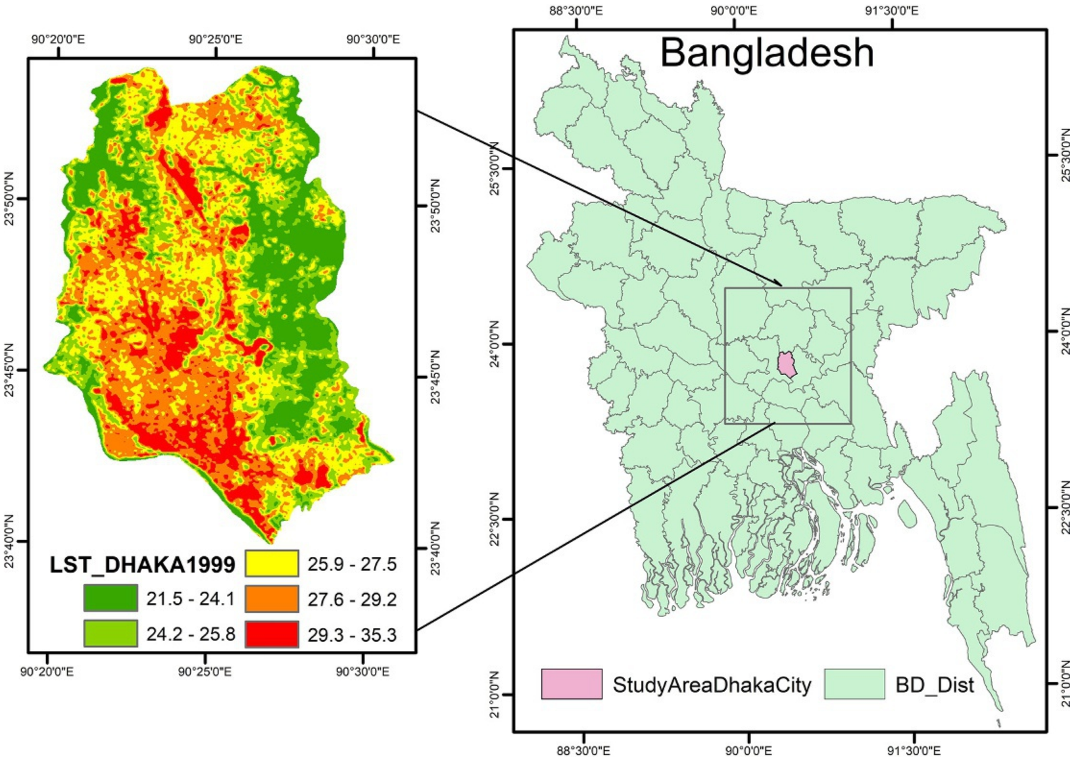

FIG. 2.6 Land surface temperature Dhaka city in 1999. The *red color* (dark gray in the print version) depicts the highest land surface temperature (LST) producing areas while the *dark green color* (dark green in the print version) depicts the lowest land surface temperature producing areas of Dhaka city. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) *Source: Authors analysis using GIS and remote sensing technology, https://glovis.usgs.gov/app.*

The basic pattern of UHI is attributed to LST measurements, while LST is related to land surface features and LULC classes (Guha, 2021). An inverse association between LST and NDVI is found throughout the city (Fig. 2.10). This implies that by increasing vegetation cover, a reduction in urban temperature can be effectively achieved (Garouani, Amyay, Lahrach, & Oulidi, 2021). Variance in reflectance of various land covers results in different land surface temperature (LST) for different parts of each land cover (Imran et al., 2021). The indication of low reflectance near red and high reflectance in near-infrared represents the high yield of NDVI which contribute to lower LST value and vice versa (Low NDVI value -Higher LST values) (Shamsudeen et al., 2022). Built-up surfaces gain heat slowly than bare soil but bare soil releases more heat quickly than built-up surfaces which could be established from the above figure (Imran et al., 2021).

The mean of maximum LST value of "fallow land" is the lowest since the said land use class has lowest reflectance and could be used as occasional river or pond or agricultural land (Abir & Saha, 2021). The mean of maximum LST value of "water bodies" is also lower since water's surface temperature rises slowly (Fig. 2.11). This finding implies that, unlike other

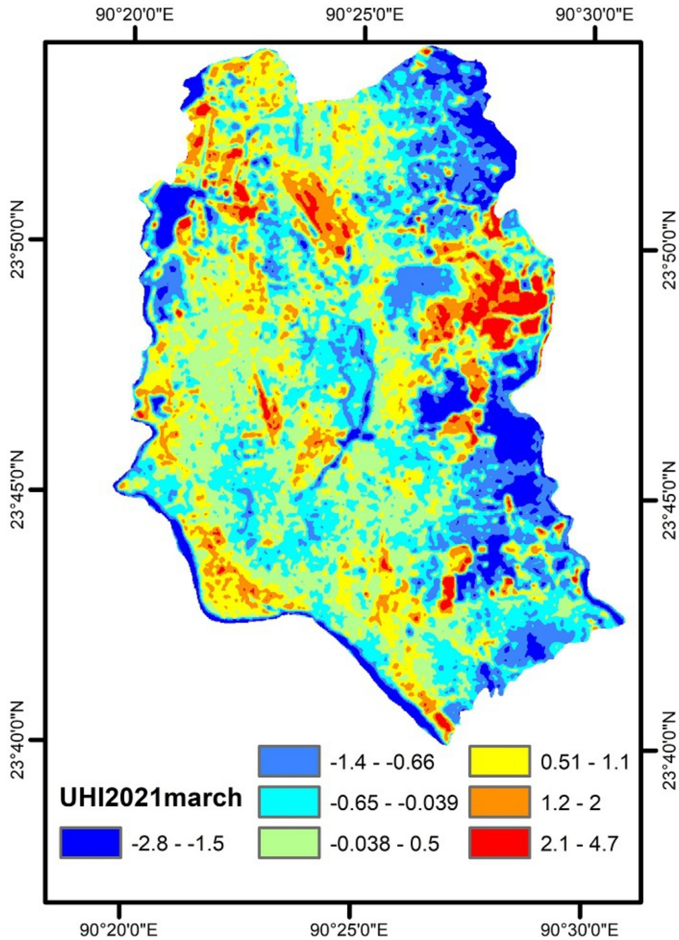

FIG. 2.7 Urban Heat Island (UHI) Effect in Dhaka City 2021. The UHI intensity in Dhaka is found to be more in temperature ranges from 2.1 °C to 4.7 °C indicated by *red color* (dark gray in the print version). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) *Source: Authors analysis using GIS and remote sensing technology, https://glovis.usgs.gov/app.*

land cover categories, aquatic bodies do not exhibit an inverse association between LST and NDVI (Ishtiaque, Tasin, & Akter, 2017).

Tools like probabilistic event attribution (PEA), climate model experiments are used to simulate and compare the probability of an extreme weather changes taking into account the anthropogenic GHGs emissions, to a world without such changes impacting the climate. Furthermore, more understanding has been developed about how global warming influences the underlying variables that contribute to extreme weather. Higher temperatures can aggravate the water cycle, resulting in more droughts and floods due to drier soil along with augmented humidity. Climate Risk Index 2021 data have clearly demonstrated the destructive effect of extreme precipitation resulting in floods and landslides in many areas in South Asia,

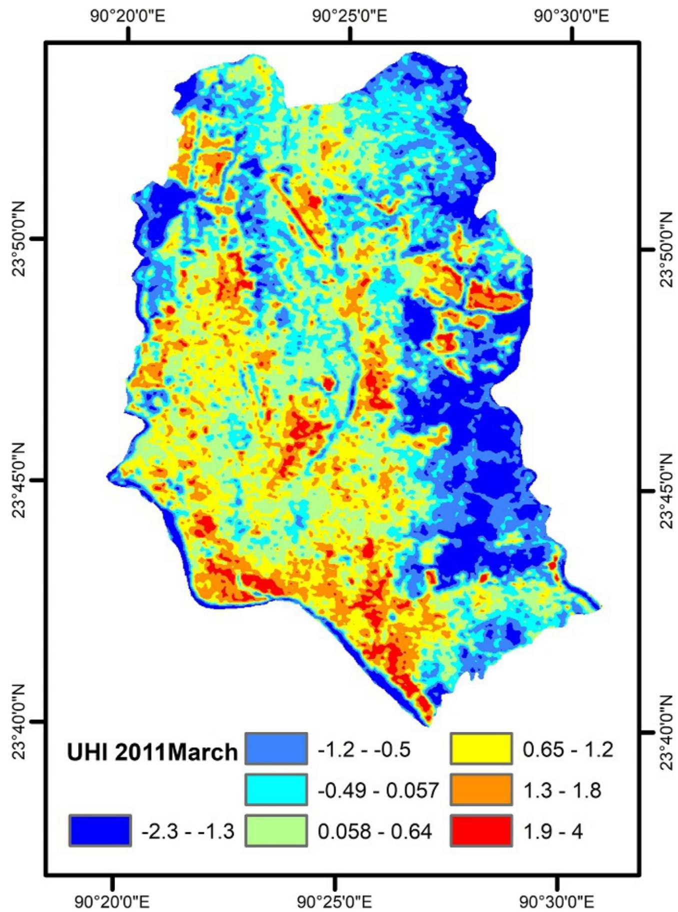

FIG. 2.8 Urban Heat Island (UHI) Effect in Dhaka City 2011. The UHI intensity in Dhaka is found to be more in temperature ranges from 1.9 to 4 °C indicated by *red color* (dark gray in the print version). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) *Source: Authors analysis using GIS and remote sensing technology, https://glovis.usgs.gov/app.*

Southeast Asia and Africa. As global warming alters the global hydrological cycle, extreme precipitation is expected to increase. Thereby, single precipitation events are expected to increase in intensity more than global mean changes in total precipitation. Extreme rainfall event likelihood caused by climate change reached 26% in 2010 indicating relationship between record breaking rainfall with rising temperatures.[a] Moreover, climate change has influenced the timing of floods as has been observed in many countries in Europe. Each year

[a] https://germanwatch.org/sites/default/files/Global%20Climate%20Risk%20Index%202021_2.pdf

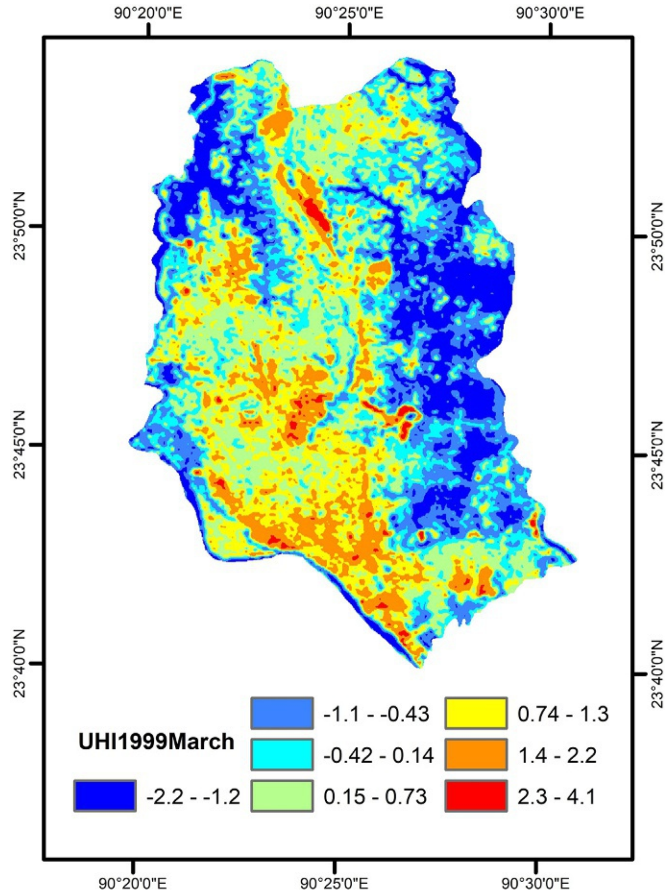

FIG. 2.9 Urban Heat Island (UHI) Effect in Dhaka City 1999. The UHI intensity in Dhaka is found to be more in temperature ranges from 2.3 °C to 4.1 °C indicated by *red color* (dark gray in the print version). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) *Source: Authors analysis using GIS and remote sensing technology, https://glovis.usgs.gov/app.*

river flooding across the world affects more people than any other natural disaster causing damages in the order of billions of dollars.

Anthropogenic climate change has influenced sea surface temperature increasing storm events, wind speeds, and precipitation, for example, Hurricane Harvey in 2017 brought an enormous amount of rain by absorbing the abnormal amounts of tropical moisture. Analysis of heatwaves in India in 2016 indicated how sea surface temperature could increase the likelihood of record-breaking heat. Furthermore, Non-climate related factors such as decline in soil permeability along with land subsidence are also influencing environmental disasters like flooding (Jha, Bloch, & Lamond, 2012). Regional localization will have different effects of climate change on cities. Cities in low-elevation coastal zones, for instance, may be affected by sea-level rise and severe storms due to land subsidence. Prolonged and even more severe heat waves may affect cities in the hot climatic region (Prasad et al., 2009).

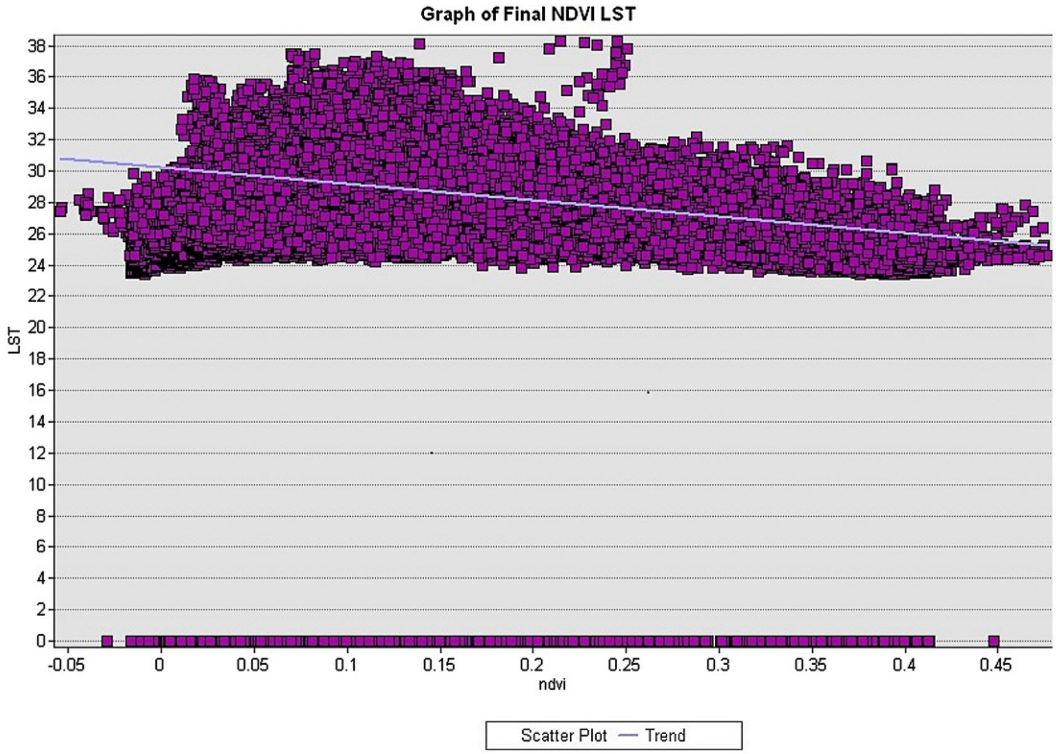

FIG. 2.10 LST and NDVI relationship in Dhaka city in 2021 The inverse relationship between LST and NDVI could be established for Dhaka city which means more vegetation cover can contribute to lower LST. *Source: Authors analysis using GIS and remote sensing technology, https://glovis.usgs.gov/app.*

Cities can also witness indirect effects of climate change including a decline in water quality and availability, increased stress on energy transmission, increased tendency of rural to urban migration, and eventually a threat to the well-being (World Bank Group, 2011). Climate extremes like drought can also cause increased frequency and duration of summer heatwaves leading to greater energy demand for cooling and therefore energy transmission and distribution may be heavily burdened.

Climate change is increasingly being addressed as an emergent global risk to the well-being of people all around the globe. The health hazards from climate change can be directly from heat and flood related mortality and morbidity as well as indirectly form its effects on water, ecological system, food and vector and waterborne illnesses (Table 2.3). The degree of such impact of climate on human health and well-being will differ depending on the type of exposure, their sensitivity, and their adaptive capacity to the climate-induced threat. Throughout their lives, people may be exposed to manifold of dangers simultaneously or at different time points which will increase their risks. However, individual lifestyle choices, living environment, and accessibility of healthcare are among the other factors that will ultimately influence their health risks and outcome (www.epa.gov, 2020). Cities will be faced with a wide variety of short- and long-term impacts on human health, economic activities,

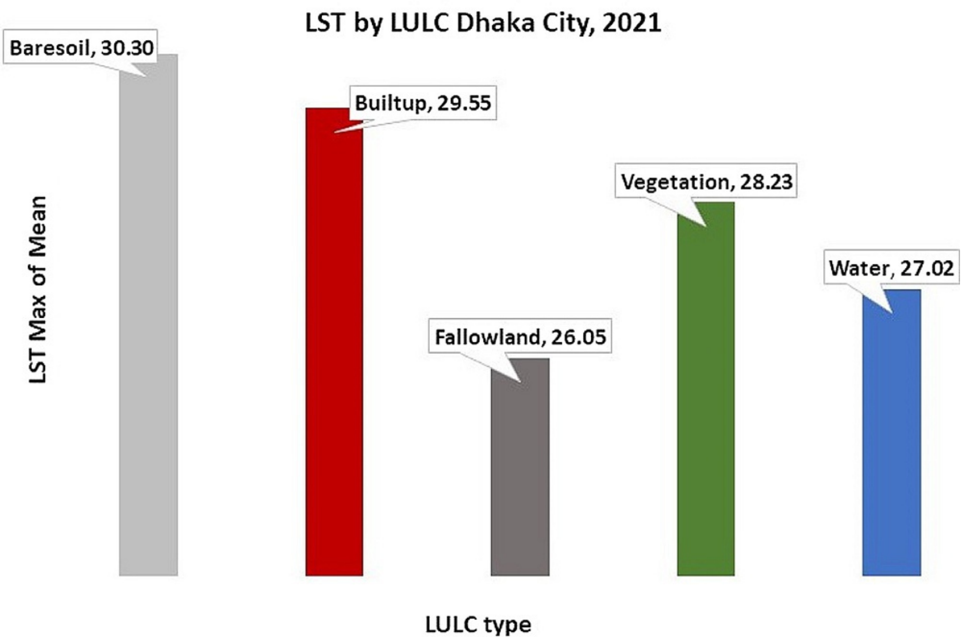

FIG. 2.11 Mean values of maximum LST with LULC type relationship in Dhaka city in 2021. The fallow land exhibit lowest LST as compared to other Land Use Classes. *(Source: Authors analysis using GIS and remote sensing technology, https://glovis.usgs.gov/app).*

and social systems. Mitigation strategies, adaptability, and preparedness will be critical to decrease the impact of extreme climate events.

Without enough preparation to face hazards, the cities would have to expense significantly higher cost associated to diasterous events. Puerto Rico, Myanmar, and Haiti are among the worst victims of extreme weather events over a 20-year period from 2000 to 2019. The Philippines, Mozambique, The Bahamas, and Bangladesh are some of the other worse victims. During the same period, more than 11,000 extreme weather events cost the lives of 475,000 people and US$ 2.56 trillion across the world. Common causes behind the damage and losses in 2019 were precipitation, floods, and landslides, and tropical cyclones that hit 6 of the 10 worst-affected countries in that year. What is of increasing concern is that the incidence of major tropical cyclones will increase with every 10th of a degree increase in global mean temperature. Single extraordinarily intense extreme weather events with profound impacts move the affected territories up on the Global Risk Index ranking. Climate change has an especially negative influence on developing countries and as they are more prone to the harmful impacts of a hazard and lack enough resources to adapt to them. In 2019, low- to lower middle-income nations account for 8 of the 10 countries most affected by the quantitative impacts of climate change events, while least developed countries (LDC) account for half of them. The global pandemic of COVID-19 has highlighted the reality that both hazards and vulnerabilities are systemic and interrelated. Therefore, building strong resilience of the most vulnerable regions against a variety of risks including climate, geophysical, economic, or associated to health is the first requisite. The process must produce the following outcomes: (a) a decision on supporting vulnerable countries depending on loss and damage; (b) the required actions for generating and making funds available to meet these requirements; and (c) a stronger execution of climate change adaptation measures. The COVID-19 pandemic has negatively influenced the expected progress to achieve long-term financial objective and assistance for adaptations in 2021 and 2022.

2.3 Resilience and climate change adaptation/mitigation

Understanding vulnerability goes hand in hand with comprehending resilience. The ability of a community or civilization to adjust when faced with a hazard is known as resilience that requires resistance and adjustments to achieve and maintain a satisfactory degree of functioning and structure. A resilient civilization or city can survive shocks and, if required, rebuild itself, can maintain itself through its systems in the face of threats, harm, or attempts to destroy it. In human-ecological systems, three characteristics define resilience: (a) the amount of disruption a society can tolerate while remaining within the sphere of attraction; (b) the capacity of the society to adjust and re-organize; and (c) the extent to which society can develop and expand its learning and adapting capabilities. Even within a single community, resilience varies widely from one household to the next. The assets that people own (a) and (b) the services rendered by exterior infrastructure and institutions are two factors of build resilience; the usage will depend on local requirements and capacities, aiming particularly at the disadvantaged communities. The degree of knowledge and labor accessible to the household, their physical and financial wealth, social relationships, and access to natural resources are all examples of assets owned by people. On the other hand, emergency relief systems, credit and financial assistance programs are examples of external services that can be offered by local authorities or other bodies for aid. Transportation, communication, infrastructure development for flood control, and coastal protection are also included in external services. The extent of external services has a significant impact on resilience.

Infrastructure development can be geared toward building risk-specific resilience such as cyclonic event and tsunami shelters. Identification and determination of severity and demonstration of benefits of such specific measures of adaptation is required prior to embarking on this. Most city centers of East Asia undertook effective resilience as investments aiming at lowering the specific natural adversities. Water resource management, coastal zone management, mountain area management, and land use planning are also critical in adaptation strategies. Resilience can also refer to the ability to overcome adversity in general that disrupts people's lives and livelihoods. Climate, land use, nutrient reserves, humanism, and policies are all underlying, slowly changing variables that influence the resilience of urban communities. The resilience of urban societies can be negatively influenced by increased pollution that leads to worsening of air, water, and food quality. Other limiting factors could be institutions that are rigid and not adaptable enough to respond to society's requirements and subsidies that promote unsustainable resource usage or resource concentration among a limited section of society. Emphasis on manufacturing and enhancing efficiencies without internalizing environmental costs can also limit resilience measures.

TABLE 2.4 Program and adaptation policy of UNFCCC and UNDP.

UNFCCC program for adaptation	UNDP adaptation policy
Methods and tools	Identify the scope and design an adaptation project
Data and observations	Assessment of current vulnerability
Climate change scenarios and models	Assessment of future risks
Climate-related risks and extreme events	Formulation of strategies for adaptation
Socioeconomic information	Maintain the adaptation process
Adaptation planning and practices	Assessment and enhancement of adaptive capacity
Research	Stakeholders' engagement
Technologies for adaptation	
Economic diversification	

2.3.1 Regional responses to climate change: A review of the evidence

Greater opportunities for resilience strategies integration in urban settings can be identified with a deeper understanding of mitigation, adaptation, resilience, and low-emissions development synergies. Reduced UHI, improved air quality, increased resource efficiency in the built environment and energy systems, and increased carbon storage connected to land use and urban forestry, for example, are expected to contribute to GHG emissions reductions while strengthening the resilience of a city. Specific adaptation and mitigation actions should be chosen in the context of other SDGs and considering the existing resources and technological capabilities, requirements of the local population of the specific city.

Agriculture, forestry, and fisheries, as well as industries, transportation, health, energy, tourism, finance, and insurances, are all involved in adaptation. United Nations Framework Convention on Climate Change (UNFCCC) program for adaptation consists of nine components and the United Nations Development Program (UNDP) adaptation policy framework consists of seven components (Table 2.4). Region-specific adaptation actions are different (Table 2.5).

2.4 Climate change adaptation in cities

Adaptation can be defined as a set of processes and behaviors that assist a system in absorbing changes that have already happened or that are expected to happen in future. Socioeconomic progress is inextricably related to adaptive capacity (IPCC, 2007). It aims to improve the coping capacity and lessen the vulnerability of society and the environment to reasonably abrupt change, thereby mitigating the effects of global warming. Adapting to climate change involves making the necessary modifications and changes to reduce the negative effects of climate change. There are numerous adaptation possibilities and opportunities including behavioral changes at the individual level, such as limiting water use during droughts and utilizing insecticide-sprayed mosquito nets, and large-scale population-directed technological

TABLE 2.5 Adaptation actions taken in regions of the world.

Region	Adaptation actions
Africa	To reduce vulnerability • Governance systems for adaptation • Risk management • Infrastructure and technology adjustments • Ecosystem-based approaches • Implement basic public health measures • Diversification of livelihood
Europe	• Coastal and water management • Environmental protection • Planned land use
Asia	• Integration of adaptation strategies to local development plans • Establishment of early warning systems • Integrated water resources management • Agroforestry • Coastal reforestation of mangroves
Australasia	• Diverse approaches to curb sea-level rise
North America	• Municipal level adaptation planning • Investment in energy and public infrastructure
Central and South America	• Ecosystem-based adaptation including protected areas • Conservation agreements • Involvement of communities in managing natural areas • Introduction of resilient crop varieties • Establishment of climate forecast systems • Agricultural water resource management
Arctic	Adaptive comanagement combining traditional and scientific knowledge
Small islands	Community-based adaptation (CBA)
Ocean	International cooperation and marine spatial planning

measures such as enhanced sea fortifications or flood-proof dwellings on a platform, early warning systems, better water management, enhanced risk management, a variety of insurance choices, and biodiversity conservation.

Community-based adaptation (CBA) efforts is an example of the disaster risk reduction and preparedness that has helped to improve flood protection and to deal with tropical cyclones (Table 2.5). Planting mangrove plants to avoid coastal erosion is an example of such a project; a solution that is now being implemented in Puerto Rico (Table 2.5). The government of Bangladesh has been mobilizing resources to execute adaptation initiatives since the 1970s, with the help of development partners. Flood management plans have been created to safeguard low-lying rural regions from catastrophic flooding. During the monsoon season, flood protection and drainage facilities have been put in place to safeguard metropolitan areas from rainwater and river flooding during monsoon. In coastal areas, over 6000 km of embankments and polder systems have been built to protect and increase agricultural production by limiting tidal floods and intrusion of saline water. By building an extensive network of about 4000 small cyclone shelters installing early warning systems and evacuation strategies with enhanced communication, Bangladesh has been able to reduce cyclone-related mortality by more than 100-fold over the past 40 years by reducing fatalities from 500,000 in 1970 to 4234 in 2007 (David Ecstein, Künzel, & Schäfer, 2021). Bangladesh has also adopted adaptive agricultural techniques like cultivation of crops on rafts to mitigate flood damage and crop loss. Irrigation schemes have been introduced to allow farmers to plant dry season rice produces in places prone to significant monsoon flooding as well as other sections of the country, including drought-prone areas. Rice and other crops have been developed using agricultural research programs that are adaptable to saline, drought, and flood conditions. To reduce exposure to high winds and minimize the threats by the tropical cyclones, Australia has successfully implemented building regulations. Large-scale engineering projects like floodgates and dams can also help to mitigate damage at times at the expense of large economic burden and negative environmental impacts. Due to the rapid pace of climate change impacts, it is critical that adaptation measures should be adopted as part of national and global efforts to achieve sustainable development with allocation positing funds, tools, and techniques to succeed.

2.5 Climate change mitigation in cities

Mitigation, in addition to adaptation, is a vital strategy to survive the effects of change in climate. Mitigation entails human initiatives to reduce emission and/or to accelerate the removal of GHG from the environment by creating “sinks.” Actions taken to slow or stop the long-term change in climate are known as mitigation. Reductions in anthropogenic emissions are typically used to combat climate change (GHGs). Increased capacity of carbon sinks, such as reforestation, can also help with mitigation. Mitigation programs can significantly minimize the dangers of human-caused global warming. IPCC 2014 assessment report has concluded that mitigation and climate change can be described using the theory of public good where mitigation can be thought of as public good and climate change can be identified as the tragedy of the commons. Collective efforts are required for achieving sustainable mitigation as focus on individual interest only will make such goal unachievable. Mitigation strategies include transitioning from fossil fuels in favor of low-carbon energy sources such as renewable and nuclear energy, as well as growing forests and other carbon sinks to absorb more CO_2 from the atmosphere. Improved building insulation, for example, might play a significant role in increasing energy efficiency. For example, Bangladesh has prioritized the development of renewable energy, solar home systems, and biogas plants to reduce emissions. A countrywide social forestry program with community participation has planted coastal greenbelts as a vital mitigation strategy. Methane from landfills, flooded rice fields, and urban waste is a key source of greenhouse gas emissions in Bangladesh. Improved agronomic techniques and efficient waste management will likely reduce methane emissions from those sources. The country is also dedicated to forestry resource development and is looking at all possibilities, including the REDD+ procedures (Reducing Emission from Deforestation and Forest Degradation). Climate engineering is another method of reducing global warming directed toward reducing the carbon dioxide burden and to counterbalance greenhouse gas effects by causing the planet to receive less solar radiation.

City planners and policymakers must put efforts into integrating mitigation (reasons of climate change) and adaptation (climatic variation) as win-win actions aiming at the global transition to a low-emissions economy and a resilient world (Grafakos, 2018). Adaptation efforts also aid the mitigation of climate impacts. Climate change has already caused irreversible loss and harm, and it will continue to do so in the future. To deal with the residual loss and damage can be financially demanding. In 2020, the projected cost of residual loss and damage for developing countries was between USD 290 billion to USD 580 billion. Financial assistance is especially important for the poor and vulnerable countries depending on humanitarian assistance for the immediate relief and recovery aftermath of a calamity. The available quantity of financial assistance, however, is insufficient (Eckstein et al., 2021). Preventing and minimizing potential losses and damages through effective mitigation, adaptation, and risk reduction strategies thus should be the top priority for the countries.

2.6 Summary

Climate change has been occurring at an unprecedented rate due to anthropogenic activities with a minor component of natural changes. Global average temperature has risen twice as fast in the past 50 years as it did in the previous 100 years, hence widespread effects of global warming on climate will likely to perpetuate in the future. Cities have distinct climate change implications such as the "Urban Heat Island Effect (UHI)," as evidenced by a Landsat image analysis of Dhaka, which concluded that increasing vegetation could aid in climate change mitigation and adaptation. The long-term consequences of change in climate on our health, agriculture, forests, water supplies, coastal cities, species, and nature reserves are undeniable. The main cause of climate change is greenhouse gas emissions. Some of the LDCs, SIDS, and developing countries such as Myanmar, Haiti, the Philippines, Mozambique, Puerto Rico, The Bahamas, and Bangladesh are among the worst victims of climate change over the past 20 years. The losses constitute a large percentage of the GDPs of these countries. The world community has begun implementing strategies to adapt to change in climate change and mitigate-associated negative effects. The initiatives that have been implemented in places around the globe are various; however, they seem to be focused on adaptation rather than mitigation, and on eco-modern approaches that have both financial and environmental returns. Though city-level engagement is increasing, evidence of the effectiveness of interventions of these initiatives yet to be perceptible.

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CHAPTER

3

Smart cities: Key definitions and new directions

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3.1 Introduction

The smart city is one of the manifestations of the world's most recent revolution, the technological revolution, which has changed many societies' facets (Allam, 2020). The trend line illustrated in Fig. 3.1 shows that the literature on this topic began with the digital city in 1990 when ICT and modern technological infrastructures were emphasized (see Fig. 3.2: 1st wave). During this time, some nations, including the USA and Singapore, recognized the importance of IT and telecommunications and attempted to make their citied digital (Albino, Berardi, & Dangelico, 2015; Mahizhnan, 1999). In 1992, the National Computer Board of Singapore published a strategic vision that depicted Singapore's IT development and defined Singapore's future as an Intelligent Island (Choo, 1997). However, despite some of the initial efforts, smart city and its related concepts did not receive much attention from scholars until 2000s and it remained as an "urban labeling."

With the widespread of the Internet all over the world in the second millennium, the digital city came to the attention of researchers, and the number of published papers gradually increased. Simultaneously, the Tokyo Protocol was entered into force, and many digital city projects appeared around the world (Ahvenniemi, Huovila, Pinto-Seppä, & Airaksinen, 2017). However, the digital city was criticized for being too technical, and the necessity of a shift toward a people-oriented approach that put much emphasis on social and human capital, knowledge, inclusion, participation, social innovation, and equity was felt (Albino et al., 2015; Angelidou, 2014; Colding & Barthel, 2017). Therefore, smart city, an umbrella term

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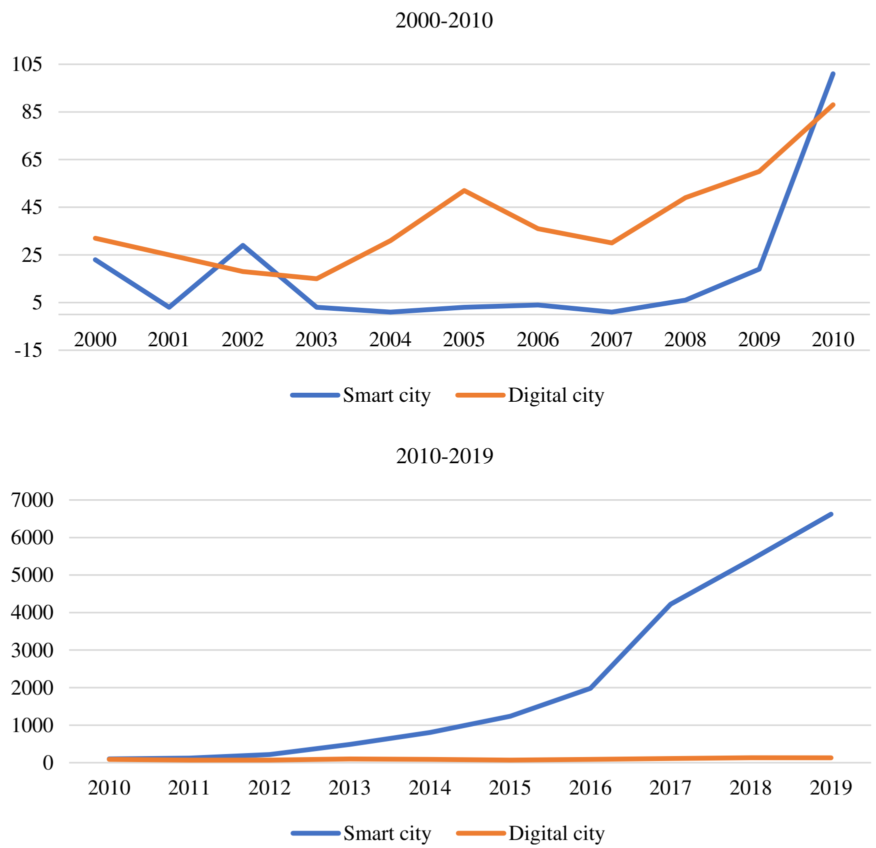

FIG. 3.1 Number of papers published about the smart city and digital city concepts in two time periods: 1990 to 2010 and 2010 to 2019.

FIG. 3.2 A word cloud created based on the definitions of "smart city" collected in Table 3.1. Each word's relative size is determined by the extent to which it appears in definitions.

covering soft and hard infrastructures, took the place of the digital city in the 2010s gradually. In the 2010s, many initiatives were launched. The smart city became a global agenda to address challenges that cities face regarding the quality of life, economic development, time cost, resource utilization, and sustainable future (Zheng, Yuan, Zhu, Zhang, & Shao, 2020). According to Fig. 3.1, while the number of papers published about the smart city was about 101 papers in 2010, this number reached 6622 in 2019.

3.2 Key definitions of the smart city concept

Combining some terms such as "smart," "sustainable," "livable," "green," and "resilient" with urban represents a part of human attempts to solve everyday problems and needs. Defining a built environment as a smart place suggests the necessity of being smart in coping with challenges such as climate change deprivation and social inequality. However, it leaves a question about what planners and policymakers mean by "smart." Merriam Webster describes the term "smart" as having or showing a high level of skill in the mind. The Cambridge Dictionary also defines it as having the intellectual ability or a high degree of intelligence. It implies that smartness is a desirable ability to promote a system to act intelligently in a challenging situation. However, what cities are smart? Various definitions are presented for smart cities. Table 3.1 demonstrates the definitions proposed for the smart city concept.

The table shows that the primary purpose of the smart city is undergone many changes during recent years. For instance, the primary definition provided by Hall et al. (2000) much emphasizes urban infrastructures and services provision, and less attention is paid to the environmental, economic, and social benefits that smart city solutions may provide for citizens. Giffinger (2007) reflects a similar perspective and notes that the smart city's primary goal is to enhance the quality of the services provided to citizens. However, due to the Great Recession of 2008–09 and the rising concerns about climate change, scholars attempted to present a more comprehensive and multidimensional definition for the concept. For example, Eger (2009) believes that moving toward a smart community is far from the deployment of smart infrastructures, but it also is a way to reinvent cities for a new economy and society.

Since 2010, scholars have attempted to provide a more detailed definition and identify the main domains of smart city operation. They pointed to several overlapping goals as the primary purpose of a smart city, including improving the quality of life (Caragliu et al., 2011; Chen, 2010; Piro et al., 2014; Thite, 2011), capacity building for learning and innovation (Komninos, 2011), sustainable development (Thuzar, 2011), economic development (Caragliu et al., 2011), and effective use of resources (Nam & Pardo, 2011; Neirotti et al., 2014).

Based on the collected definitions, we create a word cloud to show the most common characteristics of the smart city definitions (see Fig. 3.2). Fig. 3.2 shows that "quality of life," "ICT," "communications technology," "smart community," "information technology," "sustainable economic development," "social capital," "urban environment," and "natural resources" are the most frequently presented terms in the definitions. One can categorize the terms into two groups of goals and tools. Accordingly, the most prominent goal defined for smart cities is to improve the quality of life. The cloud map shows that terms such as sustainable economic development, urban environment, smart community, and natural resources have been

TABLE 3.1 Definitions of the smart city concept.

Definition	Source
"A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens." (p. 1)	Hall, Bowerman, Braverman, Taylor, and Todosow (2000)
"Smart city generally refers to the search and identification of intelligent solutions which allow modern cities to enhance the quality of the services provided to citizens." (p. 11)	Giffinger (2007)
"Smart community—a community which makes a conscious decision to aggressively deploy technology as a catalyst to solving its social and business needs—will undoubtedly focus on building its high-speed broadband infrastructures, but the real opportunity is in rebuilding and renewing a sense of place, and in the process a sense of civic pride. […] Smart communities are not, at their core, exercises in the deployment and use of technology, but in the promotion of economic development, job growth, and an increased quality of life. In other words, technological propagation of smart communities isn't an end in itself, but only a means to reinventing cities for a new economy and society with clear and compelling community benefit." (p. 48)	Eger (2009)
"The use of smart computing technologies to make the critical infrastructure components and services of a city—which include city administration, education, healthcare, public safety, real estate, transportation, and utilities—more intelligent, interconnected, and efficient." (p. 2)	Washburn et al. (2010)
"Smart cities will take advantage of communications and sensor capabilities sewn into the cities' infrastructures to optimize electrical, transportation, and other logistical operations supporting daily life, thereby improving the quality of life for everyone." (p. 3)	Chen (2010)
"(Smart) cities as territories with high capacity for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management." (p. 182)	Komninos (2011)
"A smart city infuses information into its physical infrastructure to improve conveniences, facilitate mobility, add efficiencies, conserve energy, improve the quality of air and water, identify problems and fix them quickly, recover rapidly from disasters, collect data to make better decisions, deploy resources effectively, and share data to enable collaboration across entities and domains." (p. 284)	Nam and Pardo (2011)

TABLE 3.1 Definitions of the smart city concept—cont'd

Definition	Source
"Creative or smart city experiments [....] aimed at nurturing a creative economy through investment in quality of life which in turn attracts knowledge workers to live and work in smart cities. The nexus of competitive advantage has [...] shifted to those regions that can generate, retain, and attract the best talent." (p. 623)	Thite (2011)
"Smart cities of the future will need sustainable urban development policies where all residents, including the poor, can live well and the attraction of the towns and cities is preserved. [...] Smart cities are cities that have a high quality of life; those that pursue sustainable economic development through investments in human and social capital, and traditional and modern communications infrastructure (transport and information communication technology); and manage natural resources through participatory policies. Smart cities should also be sustainable, converging economic, social, and environmental goals." (p. 96)	Thuzar (2011)
"When investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and high quality of life, with a wise management of natural resources, through participatory governance." (p. 50)	Caragliu, Del Bo, and Nijkamp (2011)
"Smart cities have high productivity as they have a relatively high share of highly educated people, knowledge-intensive jobs, output-oriented planning systems, creative activities, and sustainability-oriented initiatives." (p. 94)	Kourtit and Nijkamp (2012)
"A community of average technology size, interconnected and sustainable, comfortable, attractive and secure." (p. 326)	Lazaroiu and Roscia (2012)
The application of information and communications technology (ICT) with their effects on human capital/education, social and relational capital, and environmental issues is often indicated by the notion of smart city. (p. 137)	Lombardi, Giordano, Farouh, and Yousef (2012)
"Places where information technology is combined with infrastructure, architecture, everyday objects, and even our own bodies to address social, economic and environmental problems. (p. 50)	Townsend (2013)
"A smart city is understood as a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green" referring to urban infrastructure for environment protection and reduction of CO2 emission, "interconnected" related to revolution of broadband economy, "intelligent" declaring the capacity to produce	Zygiaris (2013)

Continued

TABLE 3.1 Definitions of the smart city concept—cont'd

Definition	Source
added value information from the processing of city's real-time data from sensors and activators, whereas the terms "innovating", "knowledge" cities interchangeably refer to the city's ability to raise innovation based on knowledgeable and creative human capital." (p. 218)	
"Making a city smart essentially means installing cameras and sensors that monitor the use and conditions of urban environments, and then sending streams of data to central control rooms, thus feeding real-time analytics and powering automated management." (p. 4)	Kitchin (2014)
"Are characterized by a pervasive use of Information and Communication Technologies (ICT), which, in various urban domains, help cities make better use of their resources." (p. 25)	Neirotti, De Marco, Cagliano, Mangano, and Scorrano (2014)
"A 'Smart City' is intended as an urban environment which, supported by pervasive ICT systems, is able to offer advanced and innovative services to citizens in order to improve the overall quality of their life." (p. 2)	Piro, Cianci, Grieco, Boggia, and Camarda (2014)

frequently used in smart city definitions. This is indicative of expectations that smart city solutions should enhance conditions related to these issues. In connection with smart city tools, ICT, information technology, and communication technology refer to technologies widely used to move toward a smart community. It might be concluded that a main part of scholars seeks to achieve sustainable development and improve life quality through ICT and novel smart solutions within cities.

3.3 The genealogy of the concept

Fig. 3.3 demonstrates the smart city concept evaluation after the technological revolution. At first glance, one can point to four waves during which the smart city concept was redefined in its general meaning. The first wave returns to the Technology Revolution, in which some of the smart city concept's core pillars, such as the Internet and computing technologies, were invented. The technology-oriented city idea arose as a result of the changes before 2000. Then, the digital city came to be popularized in the 2000s. Combining Web 2 and novel computing technologies created a revolution, and smart technologies helped local governments deal with urban challenges. However, the lack of commitment to climate change and sustainability has made reevaluating the digital city model necessary. The smart city was therefore adopted in the 2010s as an alternative concept with a broader definition. The smart city concept's prevalence was connected to smart technologies' accelerating speed, including 5G, AI, and Big Data. However, there were some obstacles to the entire deployment of smart city solutions that COVID-19 seemed to solve. Hence, in the 2020s, the post-COVID smart city tended to be different from its predecessor.

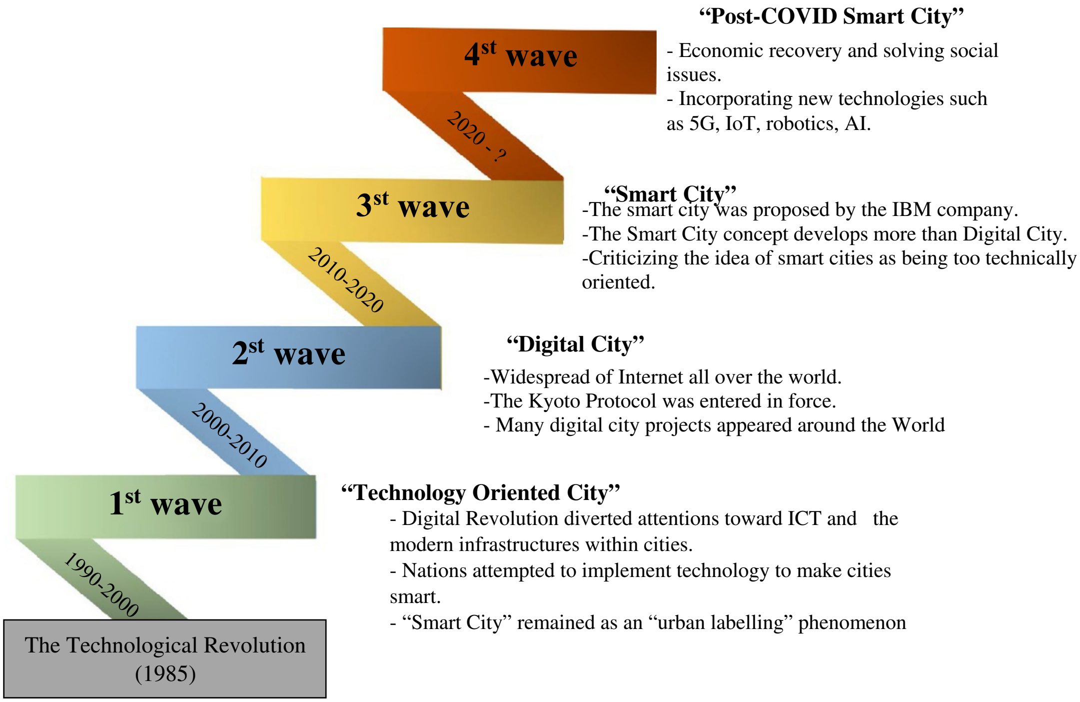

FIG. 3.3 Waves of smart city development through the technological revolution and into the future. *Source: Authors.*

3.3.1 Technology oriented city

The intersection of technology and society has attracted the attention of many researchers. Technological advances have given rise to this hope for communities to solve their problems. With the growth of the world's population, computing technology has been introduced to many fields, including censuses and related matters. It, particularly in the second half of the 20th century, helped governments accelerate the census process. At the time, several corporations invested in communication technology for research and development, and the most famous of which was IBM in the United States.

The first use of emerging technology to cope with urban issues took place in the 1960s and 1970s. Using computer databases, cluster analysis, and infrared aerial imagery, the Community Analysis Bureau in Los Angeles collected information on neighborhood status, housing efficiency, and poverty-fighting efforts. It was one of the first steps ICT technologies took to collect the resources needed to solve urban problems. The next step in developing the smart city can be traced to the efforts of the National Computer Association of Singapore in 1980, which tried to use IT to improve economic development and quality of life in the city.

In the past 1990s, cities' sprawling growth and the various urban problems led some US cities to explore technological solutions to these problems. The focus was on ICT infrastructure within cities. The California Institute for Smart Communities was one of the first institutions that explored the potential of information technology in urban design and development (Alawadhi et al., 2012). Some cities in India, the United States, Canada, the United Kingdom, and Australia started using ICT. In the second half of the 20th century, the two advances in the Internet and computer technology went hand in hand. Their convergence in the past 1990s laid the groundwork for the digital city, sparking hope for many that urban problems could be solved the novel innovations (Albino et al., 2015).

3.3.2 Digital city

Internet technology was first invented in the 1960s. The growth of internet technology followed the advent of Web 2, which contributed to the creation of "the digital city." Blogging became popular with web 2, and it became possible for people to publish their views to the general public independently. Subsequently, many social networking platforms emerged and became popular, such as Facebook and MySpace. Wi-Fi technology and the third-generation (3G) wireless mobile communication technology were developed at this time, paving the way for further expanding social networks. In response to these technological developments, cities embraced these new forms of communication and established a connected society that served the needs of government, companies, employees, and citizens (Zheng et al., 2020).

Cell phone use proliferated, and the number of subscribers far exceeded the number of landline subscribers. More citizens connected to the Internet and Internet use proliferation opened a window to the Internet of Things (Townsend, 2013). Simultaneously, the first mobile web-based applications were developed by companies such as Facebook, which led to the growing popularity of social networks. These social networks allowed people to connect and exchange ideas and build virtual communities to solve urban problems. The participatory planning approach and social networks formed a fertile ground for ideas and solutions to societal issues.

In the past 2000s, the rural population was outpaced by the world's urban population, and technological progress continued. IBM's central role in computing technology growth during the 20th century was completed by their investment in 2008, and the company launched a project called "Smarter Planet." The company launched the Smarter Cities Challenge in 2009, focusing on improving cities, saving money, and ultimately improving its citizens' lives. Many believe that this was the beginning of the use of the term "smart city." This conceptual transformation was a reaction to the increasingly technology-driven criticism of the "digital city." At this time, the need for a more governance-oriented perspective that emphasizes the role of social capital in urban growth has been explained. The idea of "digital city" was then replaced by a "smart city" in the next decade (Albino et al., 2015).

Moreover, the past years of the 2000s were accompanied by technology companies' efforts to adopt new technologies such as automation systems, business data analytics, and sensor networks in smart cities. Since then, the smart city has become an emerging market that IBM and other tech companies such as General Electric and Cisco have begun to compete (Höjer & Wangel, 2014).

3.3.3 Smart city

In the 2010s, technology continued to develop, and various countries saw substantial progress in digitalization. What led scholars to embrace the idea of the "smart city" instead of the "digital city" was the need to pay more attention to the social and environmental aspects. Indeed, in the digital city, the focus was on deploying information and communications technology infrastructures to help sustainability, particularly its ecological part. For example, the emphasis was on reducing greenhouse gas emissions by implementing technical advances (Ahvenniemi et al., 2017).

In this decade, the accelerating rate of innovation has changed not only technology but also society. Many smart city initiatives were developed at the national or EU level in the early part of this decade. Smartphones evolved a lot and replaced the old feature phones in both developed and developing countries. Samsung overtook Nokia, the most considerable cell phone manufacturer in the 2000s, and Apple and Google have revolutionized mobile operating systems by developing new platforms such as IOS and Android. Besides, smartphones were introduced in the early 2010s, and laptops and tablets replaced PCs.

Technology for communication was also continued to expand. The fourth generation of communication technology (4G), which emerged in the late 2000s, became widespread in the 2010s. If 3G opened a window of opportunity for calling, texting, and Internet communication for mobile phones, 4G offered tenfold speeds and more Internet access capability. In the past 2020s, the fifth generation of communication technology (5G) was also invented. Many cities began to develop the infrastructure required in South Korea, China, Thailand, and the United States.

Social networks also became more widespread in the 2010s, reaching 3.8 billion users in 2020. The growth of mobile technology led to various social networking applications such as WhatsApp, Instagram, and Tik Tok. Facebook and Twitter, which were the top social media platforms of the 2000s, persisted as top social media platforms of the 2010s. The role of social networks in economic and social change was very prominent in the late 2010s, and many people received political news from social networks and played an important role in the results of the elections. The central part of social activists shifted their social network activities, and a significant portion of companies' communication with customers was done through cyberspace.

Emerging developments in this decade have also revolutionized the conventional labor market. Many individuals shifted from traditional jobs and worked on a platform as independent contractors. This new labor market, called the Gig Economy, became popular, and an increasing number of workers became digital platform workers. Ridesourcing companies are an example of the geek economy that, with the advent of digital networks, transformed the taxi industry market and carried out a large part of urban transportation in the late 2010s.

The value of data in the effective use of resources and information-based decisions has been increasingly recognized in the 2010s. The prevalence of the Internet and the deployment of digital infrastructures created a large volume of data. The IDC study predicts that in 2020 the amount of data projected to be processed will reach 35 trillion gigabytes. Since none of the conventional data management systems could store and process the large volume of data generated in smart cities, new technical developments arose. The introduction and advancement of artificial intelligence, Big Data, IoT, and machine learning were responses to the management and analysis of Big Data (Allam & Dhunny, 2019). Through analyzing Big Data with novel computing tools, officials gained useful perspectives for city planning issues.

3.3.4 Post-COVID smart city

An unprecedented event marked the late 2010s. In December 2019, the first case of COVID-19 was detected in Wuhan's Chinese city, marking the beginning of an unprecedented pandemic crisis whose deaths and financial losses were comparable to those of the Second World War. Reducing face-to-face contact and social distancing were among the first steps to stop the virus's spread in all societies, disrupting the functioning of many economies. The distinction between this outbreak and prior experiences, such as the Spanish flu, was that it was for the first time that there were alternatives to physical contact. Smart city technologies have helped local governments tackle, recover, and adapt to the disease.

The advancement of smart city technologies during the 2010s led to the development of various smart city solutions, such as social networks and video conferencing applications, making it possible for many to continue living, working, shopping in the quarantine. As a result, the education system shifted from the classroom to e-learning or digital classrooms. Many employees became teleworkers, meetings were held with video conferencing tools such as Zoom and Skype, online shopping experienced exponential growth, and social networks were faced with an unprecedented increase in users' number. With the aid of smart city solutions developed in the past, some cities effectively managed the epidemic. For example, some cities in Thailand and China used 5G to maintain their function, monitor, and control the pandemic. Data mining methods at this time analyzed large volumes of COVID-19-related data collected by IoT sensors, networks, and applications and provided the information needed to cope with the epidemic (Sharifi, Khavarian-Garmsir, & Kummitha, 2021).

Overall, governments' efforts to address this epidemic were divided into prevention, detection, tracking, quarantine, and social distancing (Sharifi, 2021). Smart city strategies were a crucial component in the four policy-making areas. The technologies identified high fever people in public spaces in the prevention efforts, alerting close face-to-face encounters. Urban dashboards also informed people about outbreak hotspots using real-time data collected. Social networks played a crucial role in educating the public and raising awareness about the disease (Sharifi et al., 2021).

Hospitals were also disrupted due to the lack of diagnostic capabilities and a large number of patients. Technological solutions led to enhancing health system capabilities. They made it simpler, for example, to detect body metrics like temperature. Many smart cities also tracked infected people using data from noncash transactions and geographic information systems installed on smartphones, smartwatches, and biometric bracelets. Smart city technologies, such as smartphones, smart delivery networks, and video conferencing, were utilized by government agencies to track, manage, and implement quarantine and social distancing.

The COVID-19 pandemic, along with the extensive damages, seems to be a turning point for smart cities' development, creating new normals, and breaking many of traditional human habits that hindered the development of smart technologies. This outbreak revealed some of the unseen and undiscovered advantages of smart technology. This epidemic taught many people new ways of living based on technological tools. It showed that economic, health, hygiene, and education systems could function in a different environment without face-to-face relationships. While some of the improvements were temporary in response to this outbreak, others appeared to remain.

In the 2020s, factories tended to be more digitized and automated. In the post-COVID era, factories are expected to give robots and automated devices more complex and higher level tasks. More people are expected to use telecommunication technologies, and the education system continues to take advantage of distance education. Hospitals are anticipated to shift toward telemedicine increasingly, and smart technologies will perform more hospital tasks. Eventually, the pandemic opened the way for the further expansion of new communication technologies. It challenged the frequently criticized 5G technology, highlighting its benefits, and encouraged more cities to embrace 5G and even 6G in the future.

3.4 The underlying principles of smart city concept

Cities can customize a definition of smart cities in response to their needs and challenges. Although the paths toward smartness are different depending on cities' forms, sizes, finances, and infrastructure, they need to focus on similar basic principles. Dhaliwal (2019) points to 8 basic principles of smart cities, including livable, sustainable, efficient, secure, resilient, productive, inclusive, and transparent.

Dhaliwal (2019) believes that smart technologies should enhance cities' livability. This means that given the uneven distribution of amenities and services in many cities and, as a result, the deprivation of some citizens, smart urban solutions should facilitate citizens' access to everyday needs, such as food, health services, and education. There have been some technological solutions that have raised hopes of reducing urban deprivation. For instance, ridesourcing companies have expanded public transportation coverage within cities, enabling citizens to move around in regions where public transportation is insufficient (Khavarian-Garmsir, Sharifi, & Hajian Hossein Abadi, 2021). Telemedicine and new generations of communication technologies, such as 5G and 6G, have also delivered health services to residents in remote areas. Smart city solutions have also attempted to bridge the technological divide. As of this point, some population groups, such as the elderly, the illiterate, the poor, and others, have not yet embraced this technological revolution. Reducing this gap can help these groups to improve their quality of life (Van Dijk, 2006).

Sustainability is another fundamental principle of smart cities. The principle suggests that smart city initiatives must address economic, social, and environmental issues, targeting multidimensional and balanced growth. There is much focus on sustainable smart cities, and as a result, sectors such as manufacturing, energy, transportation, and waste treatment are being transformed to create a cleaner and healthier environment. For example, the scarcity of resources such as water and energy has necessitated an optimal use of these resources in recent years. Simultaneously, the significant effect of high traffic and vehicle volumes on air pollution, greenhouse gas emissions, and, eventually, climate change has necessitated a transformation for the transportation sector. Smart irrigation systems, zero-waste, zero-emission public transit, smart traffic management systems, and smart mobility are examples of smart city solutions to these sustainability problems.

Efficiency is the third fundamental principle of smart cities. It seeks to increase the efficiency of services and infrastructure provided to citizens through smart city solutions. In other words, technologies in a city accommodate different sectors such as transportation, health, energy, and production to operate more efficiently. For example, smart transportation initiatives have sought to broaden transportation options for individuals and increase mobility by introducing alternative transportation modes for private cars. They seek to connect more people to the public transportation system while reducing fuel consumption and greenhouse gas emissions produced by vehicles. One can also mention smart technologies' role in increasing health systems' efficiency during the COVID-19 pandemic. With the onset of the epidemic, hospital visits increased, so there were not enough beds and staff. Some cities used communication technologies such as social platforms to connect with patients and suspected people, helping hospitals keep their function while reducing physical connections. Besides, the AI technology allowed some hospitals to scan chest CT images much faster and respond to the increasing daily tests. Overall, smart technologies can open windows of opportunity for cities to optimize resources and significantly save time, energy, and money.

Another fundamental concept of smart cities suggested by Dhaliwal (2019) is developing a safe and secure environment. Cities are increasingly introducing novel technologies such as IoT, UAVs, sensors, and CCTV cameras to provide people with an additional layer of emergency support and protection. Furthermore, innovative innovations have assisted communities in achieving zero road mortality vision, resulting in a significant decrease in fatalities and severe injuries. However, there is evidence that smart cities are still vulnerable to certain risks, and city security cannot be restricted to the physical environment. Smart cities must also be ready to protect themselves against hacking, cyber-attacks, and data theft. Throughout the day, sensors and other smart technology collect a large amount of data. The protection of this data to protect citizens' privacy has become a major concern and is regarded as an important smart city task.

Since cities have always been grappling with human and natural disasters, such as war, terror, social unrest, earthquake, and pandemics, and resilience is vital for smart cities. Innovative solutions help cities to become more prepared in the four resilience phases of planning and preparation, absorption, recovery, and adaption. They assist municipalities in planning and preparation to increase their absorption capacity to unwanted shocks. For instance, during the COVID-19 pandemic, some cities repurposed the technologies developed in the past to reduce this pandemic's effects significantly. Furthermore, innovative city technologies can aid societies to absorb a considerable part of the sudden shock that occurs in the early days of a crisis. For instance, cities with extensive investment in communication technologies, like 5G, were better able to adapt responses to the COVID-19 pandemic promptly. Finally, smart city solutions help cities adapt their transportation, energy, water, and communications infrastructure facing emerging crises, capable of functionally returning to the normal and then moving to a more favorable situation.

Smart cities, it has been argued, should be productive and set economic targets based on triple-bottom-line outcomes. Innovative city policies have resulted in the creation of a multifaceted and robust human resource development system. The emphasis is on skill development and the efficiency of citizens' employment. Furthermore, cutting-edge city technology can assist in determining the most cost-effective and easiest investment routes. This case has the potential to create new employment opportunities and boost economic competitiveness. Finally, cities can use smart technology to promote public–private partnerships (PPPs) to help the economy develop and diversify.

Dhaliwal (2019) identifies social inclusion as a central tenet of smart cities. This objective aims to create an equitable society in which all citizens can live in dignity. In this regard, smart cities transition from a technology-centric to a citizen-centric orientation. They embrace smart city solutions that make communities more livable and make service delivery to residents more convenient, regardless of age, gender, or ethnicity. A community, in this context, is a place where people of different ethnicities, races, economic classes, and institutions can live comfortably and escape homelessness. For example, in some Indian cities, creative methods are being used to provide slum residents with postal codes, allowing them to use government facilities and open bank accounts. The community also has an equitable and inclusive economy that offers well-paying employment and opportunities to live in dignity and security. As a result, increasing the wages of low-income workers is seen as the most important target in eliminating wage gaps.

Finally, cities use smart technology to achieve socioeconomic and environmental goals, and the technologies help governance structures govern more transparently and collaboratively. These smart tools improve cross-departmental collaboration and data exchange, resulting in more effective decision-making. Furthermore, improved transparency is achieved due to increased public access to data generated by smart technology about a city's work. Consequently, cutting-edge and disruptive technologies can significantly reduce citizens' physical interactions with the government and enable creating a cashless and paperless government.

3.5 Smart cities and climate resilience

Climate change has impacted cities in various ways based on their climatic conditions. It has disrupted rainfall patterns, resulting in flooding and drought in urban areas, rising sea levels, and coastal erosion in port cities. However, climate change's effects are not limited to direct effects and indirectly affect the urban residents' lives through changing social and economic factors (Khavarian-Garmsir, Pourahmad, Hataminejad, & Farhoodi, 2019). As a result, it poses a significant threat to people's quality of life, necessitating appropriate responses by planners.

The contribution of smart cities to climate change adaptation efforts can be classified into six distinct areas of action. The first two fields are concerned with smart people and governance, both of which involve the public adapting to and making decisions about climate change (Rajmis, Barkmann, & Marggraf, 2009). This case may include a series of initiatives and a bottom-up assessment of the impact. Climate change adaptation strategies emerge from a participatory approach in which stakeholders are identified and involved at all stages (Turhan, 2016). Another component of smart people and governance efforts is capacity building, institutional capacity development, public awareness raising through continuous learning, and learning through active participation. These efforts may result in public awareness campaigns and education programs about climate change (Cartwright et al., 2013; Paz, Negev, Clermont, & Green, 2016). However, it should be noted that a mutual relationship between smart people and smart governance is required. Regular meetings and summits are essential to make this goal a reality, and cross-department cooperation must be formed (Gauthier, Bernier, Kuuluvainen, Shvidenko, & Schepaschenko, 2015).

The smart environment is the focus of the third field of activity. It is concerned with protecting the environment and the sustainable management of natural resources such as water and energy. The transition to renewable energy sources for electricity generation is critical for increasing energy security and efficiency while reducing carbon emissions and pollution. This measure should be considered in both residential and commercial areas (Cartwright et al., 2013; Hallegatte, Henriet, & Corfee-Morlot, 2011). LED lighting, solar photovoltaic panels, energy star certification, and the smart grid are all examples of renewable energy-related measures that can contribute to climate change adaptation and mitigation. Water-energy nexus is the other aspect of the smart environment action field (Farzaneh, Suwa, Dolla, & de Oliveira, 2014; Maryam & Büyükgüngör, 2019). These sectors are highly interrelated. Water resources are used to generate energy, and energy is used to transfer water in cities. Societies that can transfer water using renewable energy sources can significantly alleviate the water stress caused by climate change. They can also generate their electricity using renewable sources. Finally, because climate change contributes to water scarcity in some contexts, efficient water resource management is viewed as a component of climate adaptation measures (Koop & van Leeuwen, 2017; Nadal et al., 2017).

Smart mobility and smart living are smart city action fields attracting a considerable part of cities' measures to increase their resilience to climate change. The main goal of smart mobility is to achieve reduced congestion and emissions and improved air quality through a group of actions such as emission tax, congestion fee, and replacement of fossil-fueled vehicles with hybrid and electric cars (Deng et al., 2013; Dulal, 2017; Hallegatte et al., 2011). Smart living deals with issues such as housing quality, sanitation conditions, and social cohesion. A more robust housing against all wind classifications is an intelligent living strategy that needs regulations to avoid vulnerable homes. It also requires creating urban structures that separate sewage water from rainwater (Chen, Doherty, Coffee, Wong, & Hellmann, 2016; Stewart, 2015). Those residential areas located in flooded plains should be relocated to more safe places.

Moreover, housing design can be done based on low carbon housing or neutral housing, sustainable design, and smart energy system approaches (Brudermann & Sangkakool, 2017; Ma, Goldstein, Pitman, Haghdadi, & MacGill, 2017). Besides, health conditions should be managed to result in residents' well-being while addressing climatic conditions like severe temperature. Smart city tools can provide planners and policymakers with possibilities to model health impacts in extreme temperature scenarios. They can present models considering people, health, and weather in their analyses and provide strategies for increasing vegetation and albedo. Finally, smart cities can promote slum settlements and create a healthy and green society through the evolution of roads, sanitation, lighting, and social services (Martins et al., 2016).

The latest action field that is central to climate change-related measures is smart technologies. Frontier technologies, such as artificial intelligence (AI), the Internet of Things (IoT), 5G, digital twins, robotics, and Big Data, are playing a vital role in states' efforts to cope with climate change's impacts. These technologies' contribution in mitigation and adaption to climate change is as follows.

AI is one of the growing smart technologies that has addressed uncertainties about climate change prediction during the past decade. This technology has made it possible to automatically predict emissions, climate disasters, and renewable energy potentials (Coeckelbergh, 2021). It has also helped some researchers assess and model climatic hazards risks and determine climate events' role in migrations trends, war, and geopolitical transformations. Using the risk assessment models enabled by AI, insurance companies have identified the degree to which their business could be affected and adjusted their business models to coordinate climate change. AI has also supported climate change-related decisions by predicting and presenting scenarios about climatic parameters such as temperature and rain.

Moreover, the technology has increased energy efficiency in buildings, farming, and oil and gas reservoirs. It has also been practiced in learning and public education about climate change. It can calculate individuals' carbon footprint and alarm about their activities' impact on climate change. Another contribution of AI in climate change-related solutions concentrates on quality control. It has provided a mechanism by which one can recognize fake news and data and prevent hackers and people from disseminating fake information about climate change (Fathi & Srinivasan, 2019; Fathi, Srinivasan, Kibert, Steiner, & Demirezen, 2020).

IoT is applied in traffic, building, and energy savings sectors, contributing to carbon dioxide reduction plans. In transportation, IoT-based applications are being developed to assist drivers in finding parking spaces and avoiding congested roads, resulting in reduced VMT and VTT in cities. This smart technology has culminated in the traffic flow through synchronized traffic lights. IoT-enabled devices can intelligently control energy storage systems, ensuring that they run efficiently and use energy only when necessary. They are capable of coordinating energy supply and demand to avoid energy waste. For instance, lamps, thermostats, and cooling and heating systems can adjust their operation using IoT systems (Gharaibeh et al., 2017; Uzairue, Ighalo, Matthews, Nwukor, & Popoola, 2018).

5G is a smart city tool that enables cities to mitigate and respond to climate change by providing high-speed broadband and increased coverage (Masson-Delmotte et al., 2006). It can accelerate the adoption of automated vehicles by increasing communication speeds between sensors that track traffic and assisting in the real-time collection of large amounts of data (Akhunzada, Ul Islam, & Zeadally, 2020).

Massive amounts of climatic data are collected every day through remote sensing observations, in-situ observations, and climate model simulations (Zhang & Li, 2020). The large dataset will provide detailed, accurate, and current information for developing climate change mitigation and adaptation strategies. It also is a critical component of vulnerability assessment studies (Hassani, Huang, & Silva, 2019). These studies often lack longitudinal evidence, and climate change is dynamic, multidimensional, and constantly changing. Big Data analytics has solved the problems through automatic and real-time data collection. For example, real-time data collected about people's daily mobility could allow researchers to investigate the impact of mobility on climate change (Soomro, Bhutta, Khan, & Tahir, 2019). Additionally, Big Data may be used to build a geo-referenced dataset containing information about vulnerability factors. Furthermore, big climate data can help cities improve their climate risk monitoring capabilities and provide real-time information to decision-makers (Dattana, Gupta, & Kush, 2019).

Digital twins, another smart city technology, provide ways to deal with the uncertainty in forecasting climate events caused by climate change (Abigail, Neda, & Taylor, 2020). The technology replica or represents a physical object, product, service, process, system, or geographic location, building a bridge between the virtual and physical worlds (Schrotter & Hürzeler, 2020). The depiction of the real world can provide a window of opportunity for proper city management in the face of climate change. For example, digital twins may aid planners in developing resilient infrastructures against natural disasters such as flooding (Ruohomäki et al., 2018).

3.6 Summary

The smart city, which began as a labeling concept, has evolved into one of the most fundamental urban planning ideas. At the start of the new century, the concept was a technology-centric approach that moved toward a human-centered approach emphasizing social and human capital, education, inclusion, participation, and equation. The history of technology shows that the rapid technological advancements of the 2010s provided opportunities to address the growing challenges of urbanization intelligently. The COVID-19 pandemic seems to have accelerated the intelligent city boom and eliminated several obstacles to smart city initiatives. While there is no universal definition of a smart city, it assumes that urban planners and policymakers want to use information and communication technologies to achieve sustainable development and improve quality of life.

As a result, smart cities have emerged to resolve major urbanization challenges in the 21st century. It aspires to create a livable city where all citizens and socioeconomic groups have equitable access to urban services and facilities. Smart cities can assist societies in increasing urban services and facilities provision efficiency, pursue multidimensional economic, social, and environmental goals simultaneously, and achieve sustainable development. Smart city initiatives can help communities improve their safety and security and resilience to unexpected shocks caused by human and natural disasters. It may provide a window of opportunity for governments to function more transparently and make more effective decisions based on the encouraged involvement of stakeholders.

The smart city's contribution to climate change management is also discussed in this chapter. It is recognized that smart cities will contribute to climate change mitigation efforts in six action areas: citizens, government, environment, mobility, and living. Cutting-edge technology such as AI, IoT, 5G, digital twins, and Big Data are now at the heart of climate change adaptation and mitigation efforts. They have created opportunities to increase climate-related public awareness, encourage energy system efficiency, develop precise risk assessment tools, minimize uncertainty in climate-hazard prediction, and investigate cause and effect. Smart technical devices can help reduce traffic congestion and greenhouse gas emissions.

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CHAPTER

4

Smart city solutions and climate change adaptation: An overview

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4.1 Introduction

Climate change impacts are now felt in many parts of the world. These include, but are not limited to, flooding, extreme weather, sea-level rise, and increased and more intense storms. It is now becoming more common to see headlines such as the "hottest year on record," "record heat swells," or "record floods" on a regular basis. In the summer of 2021, the issue of climate change impacts once again gained traction with millions of people being affected with the unprecedented extreme heat that hit many parts of the world, particularly North America. In fact, this even led to the death of hundreds of people (Taylor & Cecco, 2021). As humans continue to emit greenhouse gases (GHGs) into Earth's atmosphere, these impacts are expected to further increase and intensify in the coming decades (IPCC, 2014). Also, due to historical emissions, we are locked into certain levels of climate change impacts even if the ambitious climate stabilization targets are met.

Cities are particularly vulnerable to climate change impacts as they are home to the majority of global population and also host significant shares of economic activities. Currently, about 56% of world population lives in cities and this share is projected to increase to about 68% by 2050 (UNDESA, 2018). Most of this urban population growth will occur in developing countries of Africa and Asia that have limited capacity to regulate urban growth and develop and implement climate action plans (Creutzig et al., 2016). Overall, cites are key foci for climate action plans to deal with the impacts of climate change.

Actions aimed at addressing climate change impacts are divided into two major categories, namely, adaptation and mitigation (Sharifi, 2020a, 2021a). Adaptation aims to reduce

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vulnerabilities and improve coping capacity and according to the Intergovernmental Panel on Climate Change (IPCC) is “the process of adjustment to actual or expected climate and its effects” in human and/or natural systems (IPCC, 2014). Mitigation, on the other hand, refers to any actions that contribute to reducing GHG emissions and enhancing the state of emission sinks (e.g., forests, oceans, and soil) (Sharifi, 2020a, 2021a). For a long time, mitigation has been at the center of climate change plans and negotiations and is often highlighted in agreements such as the Kyoto Protocol and the Paris Climate Agreement. However, the increased awareness of climate change impacts has also resulted in better recognition of the significance of adaptation. This paradigm shift toward focusing on both adaptation and mitigation has particularly started since the publication of the fourth assessment report of the IPCC (AR4) (IPCC, 2014). The need for adaptation has also been highlighted in other international policy frameworks such as the New Urban Agenda (Habitat, 2017), the United Nations Sustainable Development Goals (particularly SDG 11 and SDG 13) (UNSDG, 2015), and the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015).

Adaptation to climate change requires efforts across different scales and sectors. Multiple adaptation measures related to urban planning and land use, transport, building, waste, energy, green and blue infrastructure, urban policy and governance, and water have been introduced in the literature (Sharifi, 2020a, 2021a). Technological advances, specially those based on Information and Communication Technologies (ICTs), can also contribute to climate change adaptation. In the context of cities, such technological advances are often deployed under the banner of smart cities. In fact, since about 3 decades ago a lot of initiative have been taken in different parts of the world to utilize smart and digital technologies for improving efficiency and effectiveness of urban operations (Sharifi, Allam, Feizizadeh, & Ghamari, 2021). These efforts and initiatives have also been supported and facilitated by major ICT corporations such as Cisco and IBM (Allam & Newman, 2018; IBM, 2010; Swabey, 2012). The initial major investments by these corporations demonstrated the benefits of smart initiatives to different stakeholders, leading to their increased adoption in many parts of the world (Gascó-Hernandez, 2018; IBM, 2010).

While only focusing on technology-based solutions is not sufficient for effective climate change adaptation, the widespread adoption of smart technologies could be considered as an opportunity to leverage adaptation efforts and improve their efficiency and effectiveness. In this chapter, we provide an overview of the applications of smart solutions in different sectors, including urban planning and policy making, transportation, building, water, energy, infrastructure, economy, and governance. For this purpose, we rely on the text mining abilities of VOSviewer, which is a software tool for bibliometric analysis (Van Eck & Waltman, 2009). It is hoped that this overview will raise awareness about potential contributions of smart solutions and technologies to climate change adaptation and will lead to their further uptake to deal with climate change impacts.

The materials and methods are presented in the next section. Section 4.3 presents the findings and provides some interpretations. Finally, Section 4.4 concludes the study by summarizing the results and making recommendations for future research.

4.2 Materials and methods

Systematic review has traditionally been the main method for reviewing academic literature. It allows gaining detailed knowledge about the structure of a field and addressing specific review questions. However, systematic literature review becomes challenging when dealing with a large number of documents and when the field of interest is rapidly evolving (e.g., climate change, on which a large number of papers is published annually). Bibliometric analysis techniques can be used to, partially, overcome this issue. In the past 2 decades, several bibliometric analysis software tools have been developed for this purpose (Sharifi, 2020b, 2021b; Van Eck & Waltman, 2009). These tools use text mining algorithms that allow them to understand overall structure and trends of literature by analyzing bibliometric data that are archived in academic databases (Van Eck & Waltman, 2009).

The input data for bibliometric analysis can be obtained from different academic databases such as the *Web of Science* (WoS), Scopus, Semantic Scholar, and Dimensions. For the purpose of this chapter, we retrieve the necessary bibliometric data from the WoS that is widely recognized for indexing quality peer-reviewed literature. Broad-based search strings were developed to include as many relevant papers as possible in the study (see Table 4.1). It can

TABLE 4.1 The search strings used for retrieving literature related to linkages between smart solutions and climate change adaptation from the *Web of Science* (WoS).

Topic	Search string	No. articles
Smart city search string (A)	(“digitali*ation” OR “digital technolog*” OR “Information and communication technolog*” OR “ict” OR “information technolog*” OR “internet of things” OR “iot” OR “artificial intelligence” or “AI” or “machine learning” OR “blockchain” OR “virtual reality” OR “VR” OR “augmented reality” OR “AR” OR “3D print*” OR “three-dimensional printing” OR “cloud computing” OR “big data” OR “5G” OR “6G” OR “Smart technolog*” OR “smart home*” OR “smart house*” OR “smart cit*” OR “home energy management system*” OR “industry 4*” OR “society 5*” OR “robotic*” OR “automation” OR “unmanned aerial vehicle*” OR “UAV*” OR “smart meter*” OR “smart grid” OR “vehicle-to-vehicle communication” OR “machine-to-machine communication”)	NA
General urban issues	TS=((“urban” OR “city” OR “cities”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	219
Integrated urban planning and policy making	TS=((“urban planning” OR “spatial planning” OR “city planning” OR “urban policy making” OR “urban management”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	27
Transportation systems	TS=((“transport*” OR “mobility” OR “transit”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	66
Building systems	TS=((“building*” OR “housing”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	162
Urban waste management	TS=((“waste”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	21
Water	TS=((“*water*”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	331

Continued

TABLE 4.1 The search strings used for retrieving literature related to linkages between smart solutions and climate change adaptation from the *Web of Science* (WoS)—cont'd

Topic	Search string	No. articles
Energy	TS=((“energ*”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	235
Urban infrastructure (other)	TS=((“green infrastructure” OR “blue infrastructure” OR “critical infrastructure”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	24
Economy	TS=((“economy” OR “economic”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	196
Urban governance	TS=((“governance*”) AND (“urban” OR “city” OR “cities”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A))	38

be seen from Table 4.1 that a common smart city search string (indicated as “A”) has been used to retrieve literature related to different urban sectors and issues. This search string includes different terms related to smart solutions and technologies such as digitalization, digital technologies, ICT, Internet of Things (IoT), artificial intelligence (AI), machine learning, blockchain, virtual reality, augmented reality, 3D printing, cloud computing, Big Data analytics, 5G, 6G, smart home, smart city, home energy management systems, industry 4, industry 5, robotic, automation, unmanned aerial vehicle, smart meter, smart grid, vehicle to vehicle communication, and machine to machine communication.

To explore linkages between smart solutions and different urban sectors and issues, the core search string (i.e., “A”) was combined with search terms related to that specific urban sector. For instance, in the case of energy sector the following search string was used: TS=((“energ*”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“adapt*” OR “resilien*”) AND (A)). In each case, we searched in the Titles, Abstracts, and Keywords of literature indexed in the WoS to retrieve relevant literature. Also, there were no time restrictions, meaning that all papers indexed until July 1, 2020 (the date of literature search) were included in the analysis.

As mentioned earlier, VOSviewer was used for bibliometric analysis (Van Eck & Waltman, 2009). The software allows conducing different analyses such as co-citation and bibliographic coupling that can be used to understand interlinkages between different authors, publications, journals, institutions, and countries. Based on these interlinkages, it is also possible to identify the most influential authors, publications, journals, institutions, and countries. Term co-occurrence analysis is another analysis that can be used using VOSviewer. It provides useful insights regarding major focus of a research field and key research clusters. As shown in Fig. 4.1, the output of term co-occurrence analysis is a network of nodes and links. Each node represents a key term, and node size is proportional to its frequency of co-occurrence with other terms. Also, links indicate that two terms are connected (have co-occurred) and thickness of links is proportional to the strength of connections between

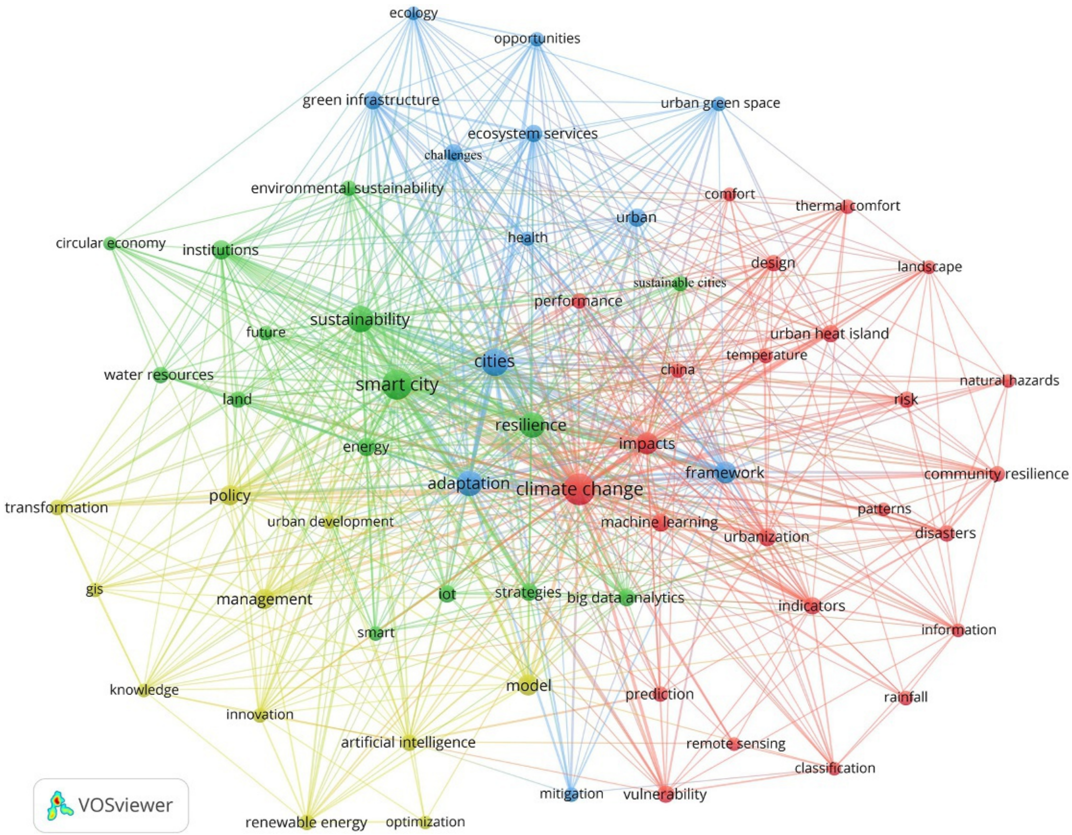

FIG. 4.1 General overview of existing literature on the linkages between smart solutions and technologies and urban climate change adaptation.

two nodes. Terms that have co-occurred frequently form thematic clusters that are shown in different colors. Results related to each analysis are presented and discussed in the next section.

4.3 Results and discussions

Results of term co-occurrence analysis for the general linkages between smart city technologies and urban climate change adaptation are presented in Section 4.3.1. Following that, results related to linkages and contributions to urban planning, transportation systems, building systems, waste management, water sector, energy sector, urban infrastructure, urban economy, and urban governance are presented in Sections 4.3.2 through 4.3.10, respectively.

4.3.1 General overview

As can be seen from Fig. 4.1, existing literature on the interlinkages between smart solutions and climate change adaptation deals with various issues ranging from disaster risk management to performance improvement, sustainable resource management, health, and ecosystem services. Four major thematic clusters can be identified from Fig. 4.1. The largest cluster (in red color) is mainly related to resilience against natural hazards and extreme heat, indicating that a lot of research has been published on these issues. Connections and proximity between terms such as machine learning, Big Data analytics, and remote sensing and terms related to hazards and vulnerability (e.g., rainfall and disasters) indicate their utility for disaster risk management and community resilience. There is, for example, a lot of research showing how machine learning techniques can be used to predict rainfall patterns, the hourly amounts of rainfall runoff discharges, and rainfall-induced landslides (Kuradusenge, Kumaran, & Zennaro, 2020; Refonaa, Lakshmi, Dhamodaran, Teja, & Pradeep, 2019; Young, Liu, & Wu, 2017). Such prediction abilities can significantly improve the capacity of meteorological agencies and disaster management departments to plan and prepare for and respond to adverse events. Machine learning approaches have also been widely used for monitoring and management of urban heat island effects (Liu et al., 2021; Yao, Chang, Ndayisaba, & Wang, 2020). Machine learning models and analysis of Big Data obtained from different sources such as satellite images and sensors can provide useful information on the urban heat island patterns and urban characteristics that contribute to the formation and/or mitigation of heat island effects (Erdem, Cubukcu, & Sharifi, 2020; Yoo, 2018).

Two major subthemes can be identified from the yellow cluster. The first one is focused on policy and management and is linked to terms such as GIS, knowledge, and innovation. This can be interpreted as the utility of Geographic Information Systems (GIS) for enhancing urban management and urban policy making processes. Indeed, by facilitating spatiotemporal analysis of large volumes of data, GIS systems enable planners and decision makers to make better informed decisions that contribute to disaster resilience (Feizizadeh et al., 2021; Omarzadeh et al., 2021). The second major sub-heme is focused on performance optimization. The utilities of artificial intelligence (AI) solutions for optimized integration of renewable energy sources are increasingly recognized in the literature (Boza & Evgeniou, 2021; Kanase-Patil et al., 2020). Optimized integration of renewable energy sources can contribute to enhanced energy resilience, thereby improving the capacity to adapt to climate change impacts (Sharifi & Yamagata, 2016). Furthermore, optimized integration can reduce the overall management and maintenance costs, thereby improving economic resilience (Boza & Evgeniou, 2021).

The green cluster is focused on the generic contributions of smart cities to sustainability and is also linked to other important terms such as land, energy, and water resources. The use of IoT and other smart technologies such as smart grid and smart water meter systems can lead to efficient resource management, thereby improving urban resilience (Gupta, Pandey, Feijóo, Yaseen, & Bokde, 2020; Zahraee, Khalaji Assadi, & Saidur, 2016). Enhanced water efficiency, for instance, can improve resilience against water scarcity that is expected to be a major climate change impact.

The blue cluster is dominated by terms related to ecology and green infrastructure. Green infrastructures are widely promoted by urban planners since they can provide multiple ecosystem services (provisioning, regulating, cultural, and supporting). Such services are essential for improving adaptation to climate change impacts. For instance, regulating microclimatic conditions enhances adaptation to extreme weather events. Or, supporting natural habitats and preventing environmental degradation can mitigate potential adverse impacts of floods. Despite the multiple benefits of green infrastructure systems, they have not been effectively integrated into urban planning and management and also different green infrastructure systems have often been implemented in a fragmented manner. It is argued that utilizing smart solutions and technologies can facilitate establishing more integrated green infrastructure systems that could provide multiple cobenefits for health, sustainability, and resilience (Muvuna et al., 2020; Nitoslawski, Galle, Van Den Bosch, & Steenberg, 2019).

4.3.2 Integrated urban planning and policy making for climate change adaptation

Fig. 4.2 shows that, overall, limited research exists on how application of smart solutions and technologies can facilitate integrated urban planning, thereby contributing to climate change adaptation in cities. The term "smart city," however, has a central position in the

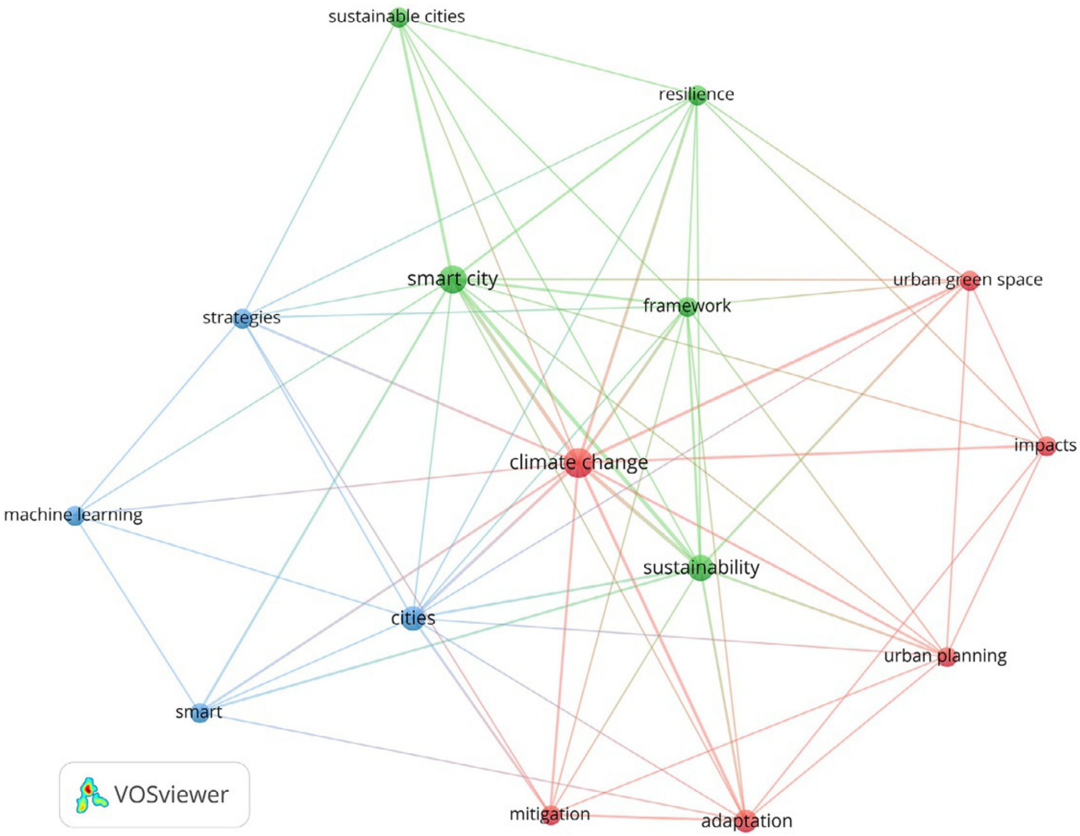

FIG. 4.2 Thematic focus of existing literature on the linkages between smart solutions and technologies, urban planning, and urban climate change adaptation.

figure and is closely linked to other key terms such as "climate change," "sustainable cities," "urban planning," and "resilience." This indicates that smart city initiatives have the potential to facilitate integrated planning approaches that can lead to synergistic benefits. This would be a paradigm shift from conventional planning approaches that are often practiced in a silo-based manner. Appropriate adaptation to climate change impacts requires integrated approaches to avoid cascading and compounding risks. Otherwise, failure to appropriately dealing with some risks may cause other serious problems. For instance, integration between water and energy sector is essential to ensure that impacts on water resources would not affect functionality of energy systems. In addition, integrated approaches could be used to obtain other synergistic benefits and avoid trade-offs. For instance, in the absence of integrated approaches, measures aimed at enhancing climate change adaptation may lead to mitigation trade-offs (Sharifi, 2020a).

Combining multiple smart solutions and technologies such as IoT sensors, machine learning algorithms, and Big Data analytics allow developing integrated systems that can be used to understand and deal with dynamic urban interactions in a systemic manner. For instance, Urban Observatories that have been developed and implemented in cities such as Newcastle, UK, have proved effective in collecting, processing, and analyzing large volumes of real-time data on various measures related to air quality, travel patterns, and climatic conditions. Such observatories function as integrated platforms that allow planners and decision makers better understand how to quickly respond to changing circumstances. For instance, in case of route closures due to storm surges, they can rapidly inform citizens and transit service providers of necessary changes that need to be made and the alternative routes that are available to minimize functionality loss. The utility of such observatories was also demonstrated during the COVID-19 pandemic as they enabled authorities to take evidence-based decisions in response to the pandemic (James, Das, Jalosinska, & Smith, 2020; Sharifi & Khavarian-Garmsir, 2020). Overall, advances in smart technologies have provided unprecedented opportunities for promoting integrated urban planning, and it is essential to take effective measures to tap into these opportunities.

4.3.3 Transportation systems

A large volume of research has been published on the application of smart city initiatives in the transportation sector (Sharifi et al., 2021). Advances in Information and Communication Technologies and Internet of Things have particularly contributed to developing smart transportation systems (Saarika, Sandhya, & Sudha, 2017). ICT- and IoT-enabled smart technologies have, for instance, facilitated better management of parking lots, better communication of transit timetables, more efficient control of traffic signals, improved traffic monitoring and control through enhanced prediction abilities, and new forms of information exchange between vehicles through vehicle-to-vehicle communication systems that can provide benefits such as reducing congestion and improving traffic safety (Lee & Chiu, 2020; Lin, Hsieh, & Li, 2018; Saarika et al., 2017).

Based on Fig. 4.3, it can be argued that research on contributions of smart technologies to better adaptation to climate change impacts in the transportation sector is still limited. Connections between terms such as "transport," "machine learning," "prediction," and

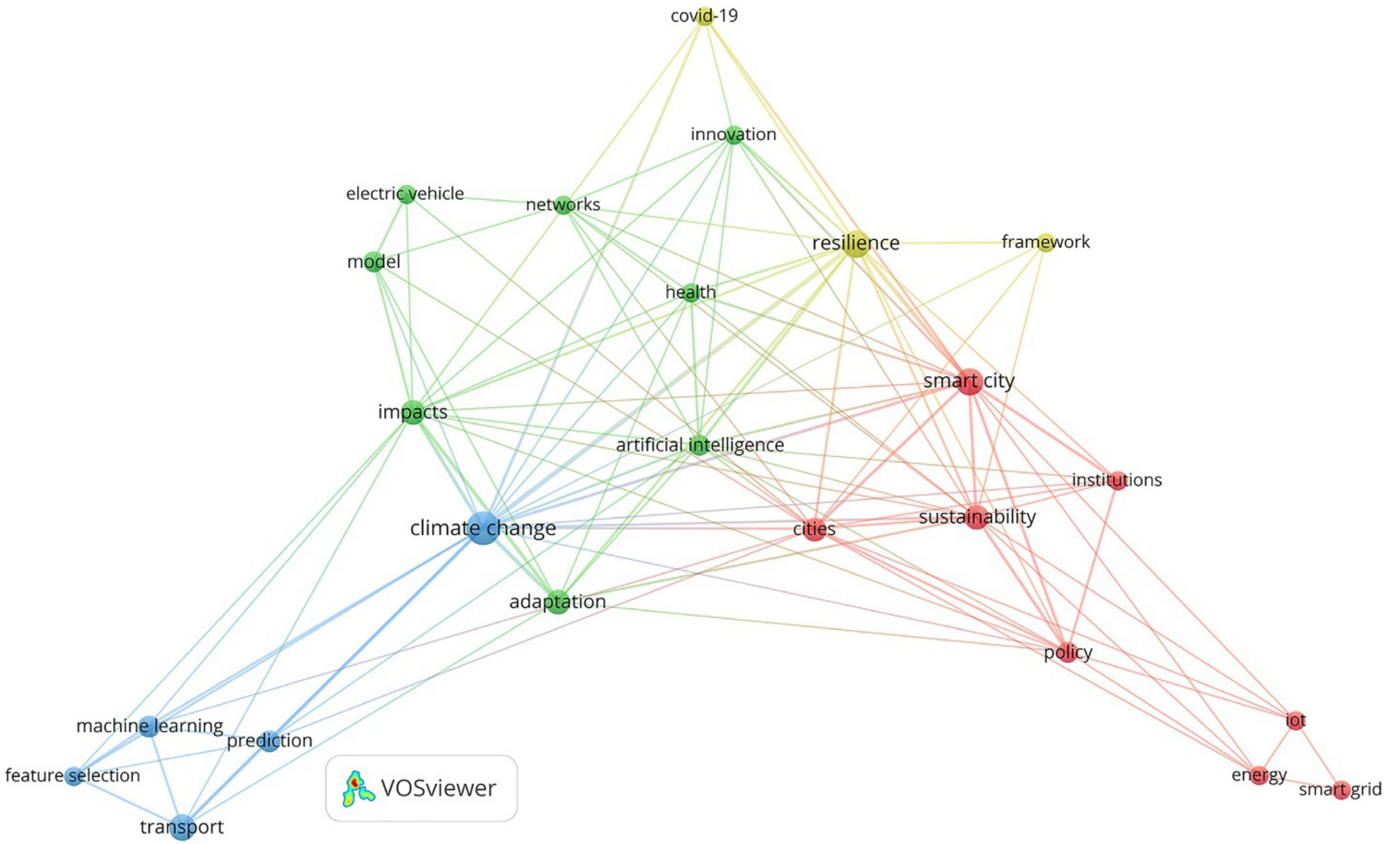

FIG. 4.3 Thematic focus of existing literature on the linkages between smart solutions and technologies, transportation, and urban climate change adaptation.

"adaptation," however, indicate that enhancing prediction capacity of transit service providers and enabling them to quickly respond to disruptive events could be a major contribution. For instance, Ha et al. (2021) demonstrate how machine learning models can be utilized to predict and map susceptibility of urban road networks to flash floods (the frequency and intensity of which may increase due to climate change). Similar benefits of such prediction abilities could also be extended to adaptation to other climate-induced stressors such as storms and extreme weather events.

Through reducing emissions and contributing to climate change mitigation (e.g., by facilitating better management of electric vehicle charging systems), smart technologies can also provide health cobenefits that, indirectly, contribute to climate change adaptation (Cao, Ahmad, Kaiwartya, Puturs, & Khalid, 2018; Sharifi, 2021a). Indeed, it is argued that healthy population has more capacities to cope with and adapt to climate change impacts (Sharifi, 2021a). Overall, results of this analysis indicate that contributions of smart cities to climate change adaptation in the transportation sector are still underexplored and further research is needed in this regard.

4.3.4 Building systems

There is also a large body of research on the applications of smart city technologies in the building sector. This covers various issues and technologies such as smart home management systems, building information modeling, real-time task scheduling, and smart meters and other smart devices for efficient water and energy management (Guerriero, Kubicki, Berroir, & Lemaire, 2017; Hui, Sherratt, & Sánchez, 2017; Lee & Bahn, 2013).

Fig. 4.4 shows that integrating smart solutions into buildings can provide at least three, interconnected, benefits: enhanced thermal comfort, improved prediction capacity, and optimized resource consumption. Terms related to thermal comfort and thermal performance are dominant, indicating that IoT-based smart devices can be used to model and regulate thermal performance of buildings and ensure thermal comfort of residents in an efficient manner (Hu, Wen, Guan, Jin, & Tseng, 2018; Park & Rhee, 2018). This is essential for resilience against extreme weather events (i.e., extreme cold and heat). In the absence of smart solutions to maintain thermal comfort in an energy-efficient manner, the increased energy demand may result in power outages and cause major problems.

Machine learning models and IoT-based devices can also enhance the capacity of residents and utility providers to predict future resource demands and make necessary preparations (Luo et al., 2019). Communicating results of such predictions with the stakeholders may lead to improved resource management and provide saving benefits. Further resource savings can be achieved through smart devices and allow optimizing energy/water demand and improving resource efficiency. For instance, through allowing continuous and real-time communication with residents, smart meters can contribute to reducing resource demand and facilitating efficient resource management (Hopf, Sodenkamp, & Staake, 2018). It should be noted that building and transportation systems should not be considered as isolated. As will be discussed later, smart technologies could also be used to facilitate better integration of these two sectors (e.g., through optimizing performance of solar panel systems that facilitate vehicle to grid connectivity) (Monteiro, Pinto, & Afonso, 2019).

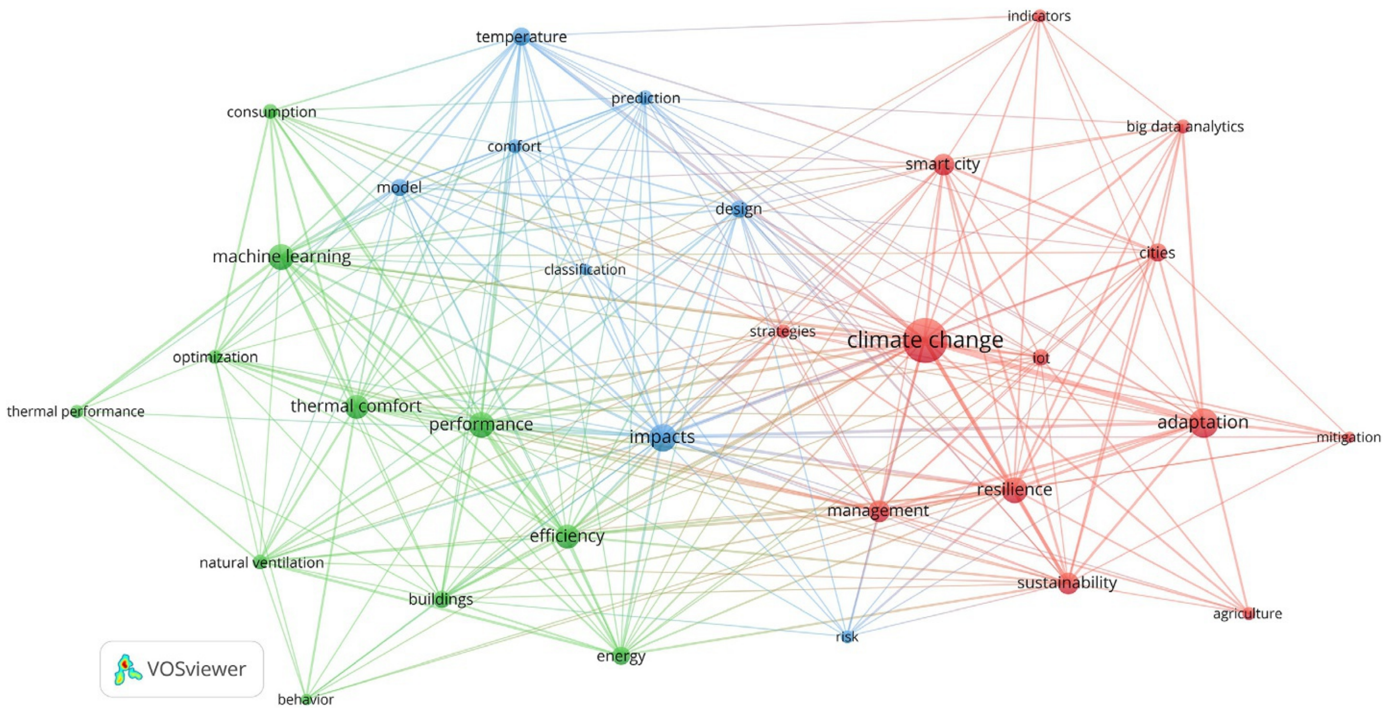

FIG. 4.4 Thematic focus of existing literature on the linkages between smart solutions and technologies, buildings, and urban climate change adaptation.

4.3.5 Urban waste management

Different smart solutions have been developed for improving municipal and household waste management. For instance through integration of radio frequency identification (RFID) tags with sensors and cloud-based software tools, it is possible to develop web-based platforms and dashboards to facilitate better waste management (Catarinucci et al., 2019). Several IoT- and sensor-based algorithms have been proposed for more effective and efficient waste collection and their benefits compared to conventional collection methods have also been demonstrated (Pardini, Rodrigues, Hassan, Kumar, & Furtado, 2018; Shyam, Manvi, & Bharti, 2017). Recent advances in IoT and machine learning also enable better waste sorting and recycling, thereby improving waste management practices (Dubey, Singh, Yadav, & Singh, 2020). A key feature of these smart solution is that not only was collection agencies but also citizens can be engaged in the waste collection processes. For instance, IoT-based methods can inform citizens of the filling level of waste bins and allow them to make adjustments to improve efficiency of waste management processes (Pardini et al., 2020).

Fig. 4.5 shows that terms such as "water resources," "food," and "energy" have co-occurred frequently with the term "smart city." Obviously, through enhancing efficiency and effectiveness of waste management processes, reducing waste generation, and promoting waste recycling, smart solutions are expected to contribute to better resource management and facilitate transition toward circular economy. These could directly or indirectly

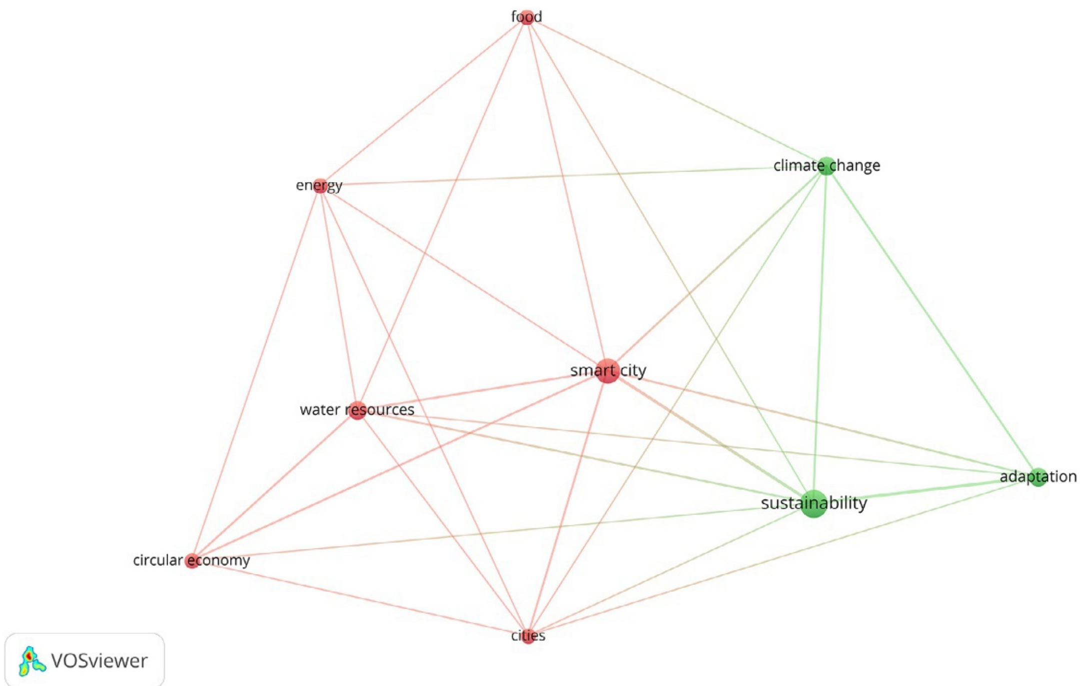

FIG. 4.5 Thematic focus of existing literature on the linkages between smart solutions and technologies, waste management, and urban climate change adaptation.

contribute to climate change adaptation. In fact, climate-induced stressors such as drought may increase pressure on the already stressed water resources in some parts of the world and this may, in turn, lead to pressure on energy and food resources due to water-energy-food nexus. Therefore, more efficient waste management processes are essential to ensure efficient resource management and facilitate better adaptation to climatic impacts (Gondhalekar & Ramsauer, 2017).

4.3.6 Water

Fig. 4.6 shows that contributions of smart solutions and technologies to better water and wastewater management are well studied in the literature. This is not surprising as some major climate-induced stressors such as floods and droughts are directly related to the water sector. Several major thematic focus areas can be identified from the figure. The red and yellow clusters are mainly related to prediction abilities facilitated by smart solutions and technologies such as artificial intelligence and machine learning. In fact, machine learning models have been used frequently to predict rainfall patterns and associated levels of urban flood inundation (Hou, Zhou, Chen, Huang, & Bai, 2021; Wu, Zhou, Wang, & Jiang, 2020). Results of such models could be used by planners and urban authorities to facilitate better urban flood mitigation and stormwater management.

In addition to flood mitigation and stormwater management, machine learning models and Big Data analytics can also facilitate more efficient water use at different urban sectors, ranging from individual households to commercial and administrative buildings and urban agriculture. Smart systems allow real-time monitoring of water quality, pressure, and use. They can be used to detect potential water leakage and inform authorities in a timely manner to avoid losses (Fikejz & Roleček, 2018). Additionally, smart technologies can be used to develop web-based dashboards that can inform customers and other stakeholders of consumption and production patterns (Gupta et al., 2020; Nadipalli, Akhil, Kumar, & Ganesh, 2021). Furthermore, IoT-based methods can also be used to optimize irrigation scheduling, thereby contributing to saving water (and energy) resources (Wu et al., 2020). These water conservation benefits of smart solutions are critical for enhanced adaptation to the increasing pressure on the already scarce water resources.

4.3.7 Energy

Contributions of smart solutions and technologies to better energy management are well recognized in the literature (Sharifi et al., 2021). Fig. 4.7 shows that linkages between energy-related smart technologies and climate change adaptation is also well studied in the literature. The term co-occurrence map shows that two major utilities of smart technologies have received relatively more attention in the literature: prediction and optimization.

Machine learning and artificial intelligence models could be utilized to forecast future energy demand of households based on their historical consumption patterns (Chou & Tran, 2018). Based on results of such prediction models, decision makers can implement strategies for enhancing efficiency of energy generation and distribution networks. Artificial intelligence models could also be used to predict household energy consumption patterns under

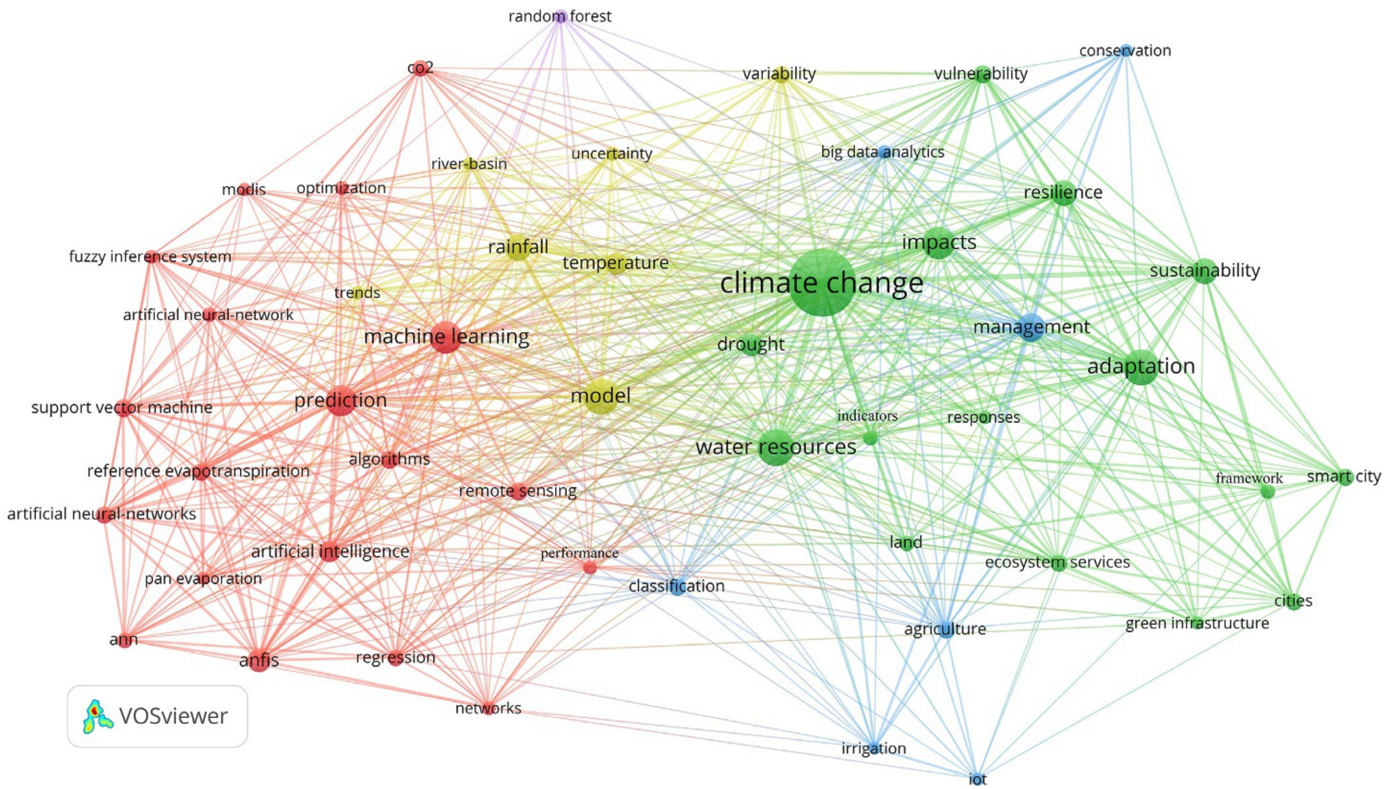

FIG. 4.6 Thematic focus of existing literature on the linkages between smart solutions and technologies, water management, and urban climate change adaptation.

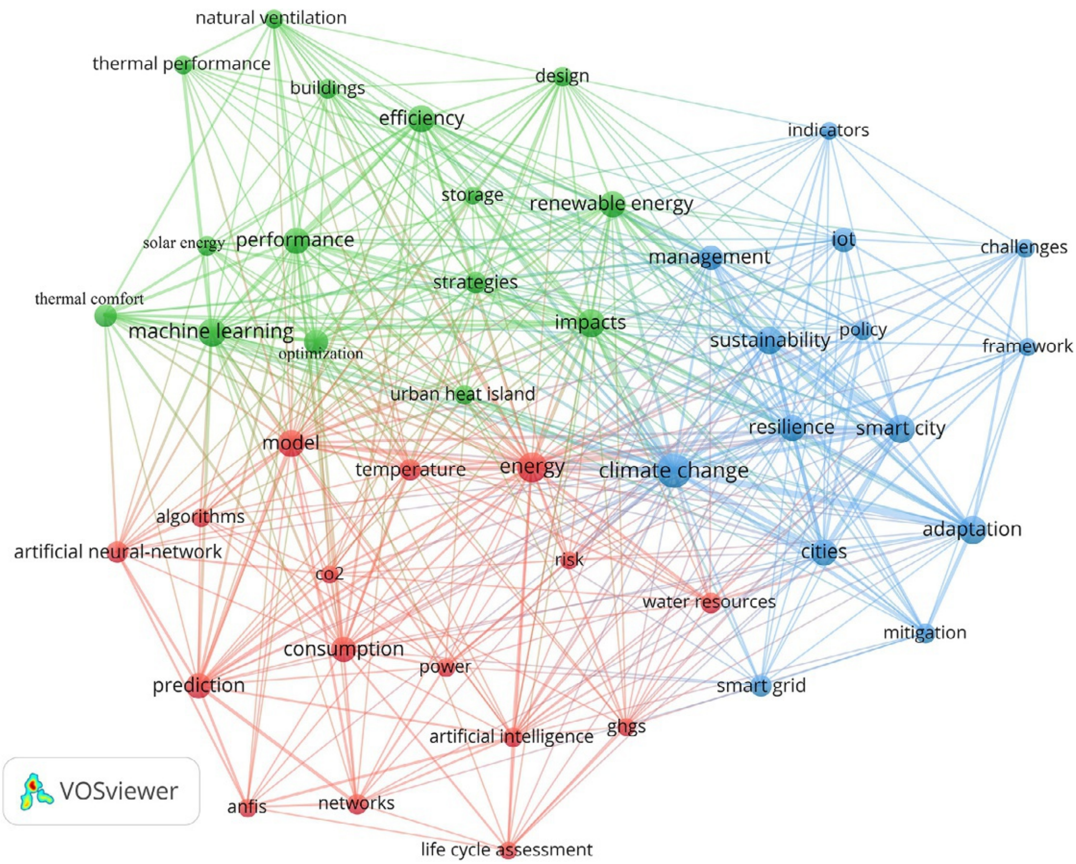

FIG. 4.7 Thematic focus of existing literature on the linkages between smart solutions and technologies, energy management, and urban climate change adaptation.

different climate change scenarios (Chakraborty et al., 2021). Based on such projections, authorities, and decision makers can develop appropriate plans to minimize energy disruption due to climate change impacts (Sharifi & Yamagata, 2016).

Smart solutions based on IoT, machine learning, and artificial intelligence also contribute to optimization of building energy performance and also for optimized integration of renewable energy technologies into buildings (Carli & Dotoli, 2017). For instance, smart solutions can facilitate optimized operation of vehicle to grid and vehicle to community systems that are important for improving energy efficiency and also ensuring continuity of energy supply under disruptive events that may affect centralized grid systems (Mehrjerdi & Hemmati, 2020; Sharifi & Yamagata, 2016). Using smart technologies, it would also be possible to develop microgrids that are more resilient that centralized grid systems (Amirioun, Aminifar, Lesani, & Shahidehpour, 2019; Masrur, Sharifi, Islam, Hossain, & Senjyu, 2021). Further, recent advances in blockchain technology applications have provided opportunities to further promote microgrid systems through peer-to-peer energy trading (Thukral, 2021).

While it is not highlighted in the figure, smart solutions and IoT-based devices can also provide other benefits for climate change adaptation and energy resilience. They allow real-time interactive communication with residents through smart metering systems and web-based dashboards, thereby providing opportunities for efficient energy consumption and behavior change toward more sustainable consumption patterns. Additionally, smart devices can facilitate continuous and real-time communication of energy system performance to utility managers, allowing them to respond to potential disruptions in a timely manner to ensure continuity of energy supply (Al-Ali, Zualkernan, Rashid, Gupta, & Alikarar, 2017). Utility managers and service providers can also use smart technologies to share information among themselves to ensure effective and efficient urban energy management. Overall, smart technologies provide multiple benefits for climate change adaptation. In addition, their application can provide mitigation cobenefits. Therefore, further integration of smart technologies in the energy sector is needed.

4.3.8 Urban infrastructure

Smart solutions and technologies are widely integrated in urban infrastructure systems. However, as Fig. 4.8 shows, actual and/or potential contributions of such integration to

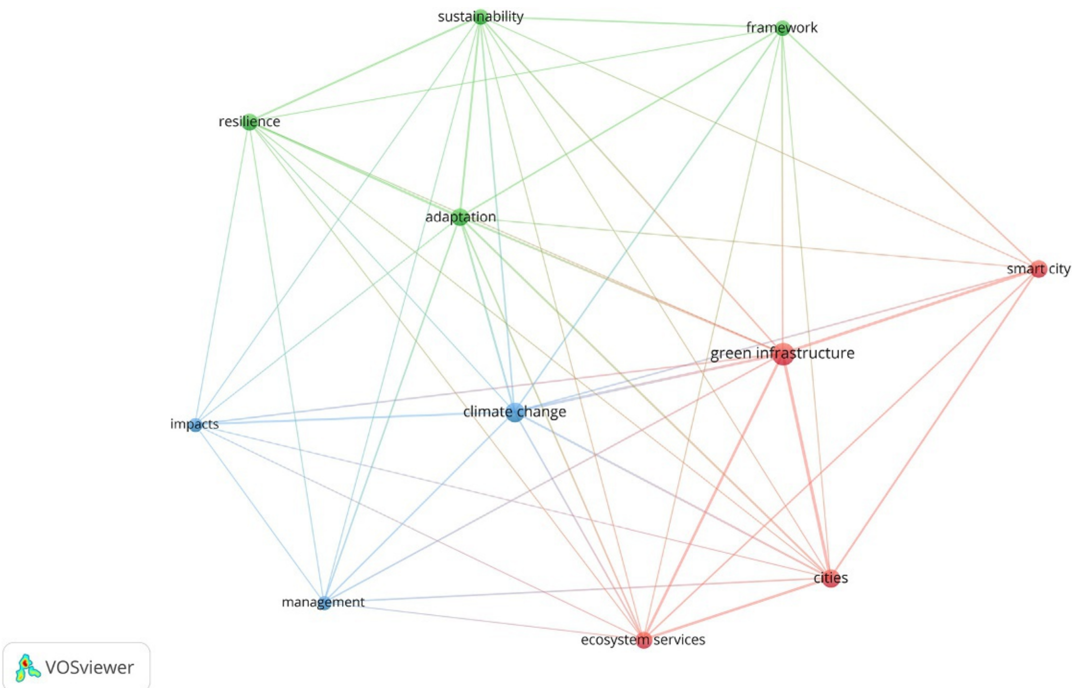

FIG. 4.8 Thematic focus of existing literature on the linkages between smart solutions and technologies, urban infrastructure, and urban climate change adaptation.

climate change adaptation are not well explored in the literature. The term "green infrastructure" has a central position in the figure, indicating that it has received relatively more attention. Green infrastructure refers to a wide range of measures taken to increase the fraction of natural and semi-natural areas in cities. Various types of green infrastructure such as green roofs and walls, urban forestry, and sustainable stormwater management systems have been proposed that contribute to climate change adaptation by providing flood mitigation and cooling cobenefits (Sharifi, 2021a). It is, therefore, no surprise that green infrastructure has been highlighted in the figure.

Several studies have demonstrated the utility of smart solutions based on IoT, artificial intelligence, and machine learning for enhanced design and implementation of green infrastructure systems (Harfouche et al., 2019; Labib, 2019). For instance, Labib (2019) examined how "artificial neural network (ANN) and adaptive, network-based fuzzy inference system (ANFIS) algorithms in conjunction with statistical modelling" can be used to "predict green or gray transformation likelihoods for derelict sites and vacant sites along waterway corridors in Manchester based on ecological, environmental, and social criteria." Another study suggests that artificial intelligence allows "accelerating climate resilient plant breeding" that is critical for climate change adaptation and food security (Harfouche et al., 2019).

Considering the potential adverse impacts of climatic impacts (e.g., major floods or storms), security of critical infrastructure systems should be prioritized. In this regard, machine learning methods have the capacity to facilitate real-time monitoring and automated risk detection, thereby contributing to critical infrastructure resilience (Dick, Russell, Dosso, Kwamena, & Green, 2019). Further advances in automation may also provide opportunities for automated repair of damaged sections. Overall, smart solutions and technologies have a high potential to enhance resilience against climate change impacts and should be appropriately integrated into critical infrastructure systems.

4.3.9 Economy

The term co-occurrence map presented in Fig. 4.9 indicates that integrating urban solutions and technologies into urban planning and development can provide economic co-benefits across different sectors. It can be argued that such economic benefits can be gained by either improving operational efficiency of urban infrastructure systems or reducing potential damage from adverse events. In either case, the overall costs on cities can be minimized that is critical for enhancing their adaptive capacity.

As discussed earlier, smart city applications can contribute to waste management and recycling, which is essential for transition toward circular economy. Furthermore, innovative smart solutions can enhance operational efficiency across different sectors such as agriculture, energy, food, and water, thereby allowing different stakeholders (households, farmers, companies, etc.) to reduce the overall operational and maintenance costs. Such savings can, in the long run, improve their economic resilience.

Prediction capacities provided by smart solutions and technologies are also important as they can function as early warning systems and allow planners and decision makers to take necessary planning and preparation actions in a timely manner. Such actions are likely to

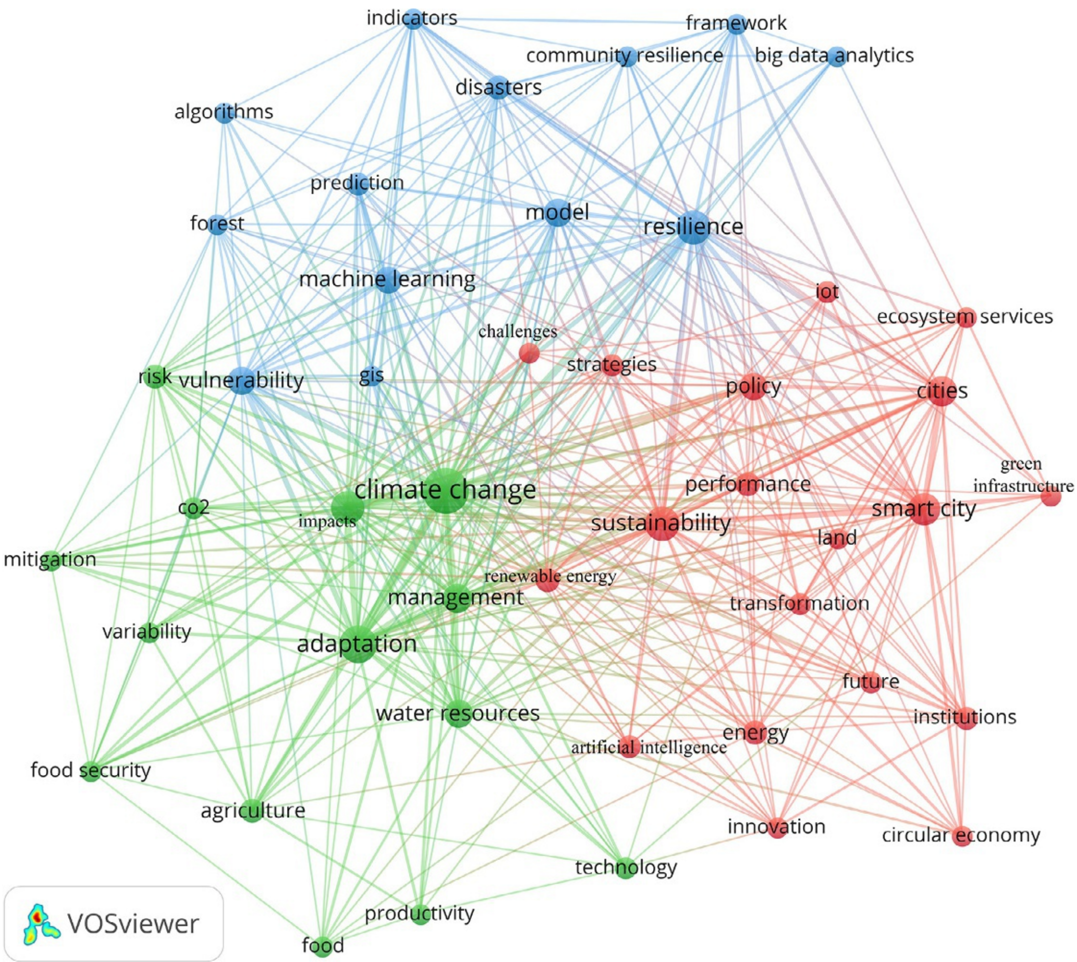

FIG. 4.9 Thematic focus of existing literature on the linkages between smart solutions and technologies, economy, and urban climate change adaptation.

facilitate better absorption of shocks when disasters occur, thereby minimizing the overall functionality loss and adverse impacts. In turn, better absorption means less budget will be needed for rapid recovery to normal conditions. A report by World Bank estimates that annual direct loss from natural disasters in cities will be several hundred billion US dollars in the coming decades unless cities take necessary actions to enhance their resilience (Sharifi, 2019; World Bank (WB), 2015). It is, therefore, essential to tap into the opportunity provided by smart solutions and technologies and maximize and optimize their integration into urban infrastructure and urban planning and design processes in order to minimize economic impacts of disasters.

4.3.10 Urban governance

Smart city solutions have revolutionized urban governance systems, providing opportunities for more effective, efficient, and inclusive urban governance. The ability to analyze Big Data has allowed urban decision makers to take nimbler and more evidence-based decisions. As discussed earlier, there are now platforms such as urban observatories that facilitate real-time and evidence-based decision making. Fig. 4.10 shows that terms such as "future," and "transformation" have central positions and are closely linked to sustainability and climate change. It can be argued that integrating smart solutions into urban governance contributes to accelerating transformation toward sustainability and addressing climate change challenges (García Fernández & Peek, 2020).

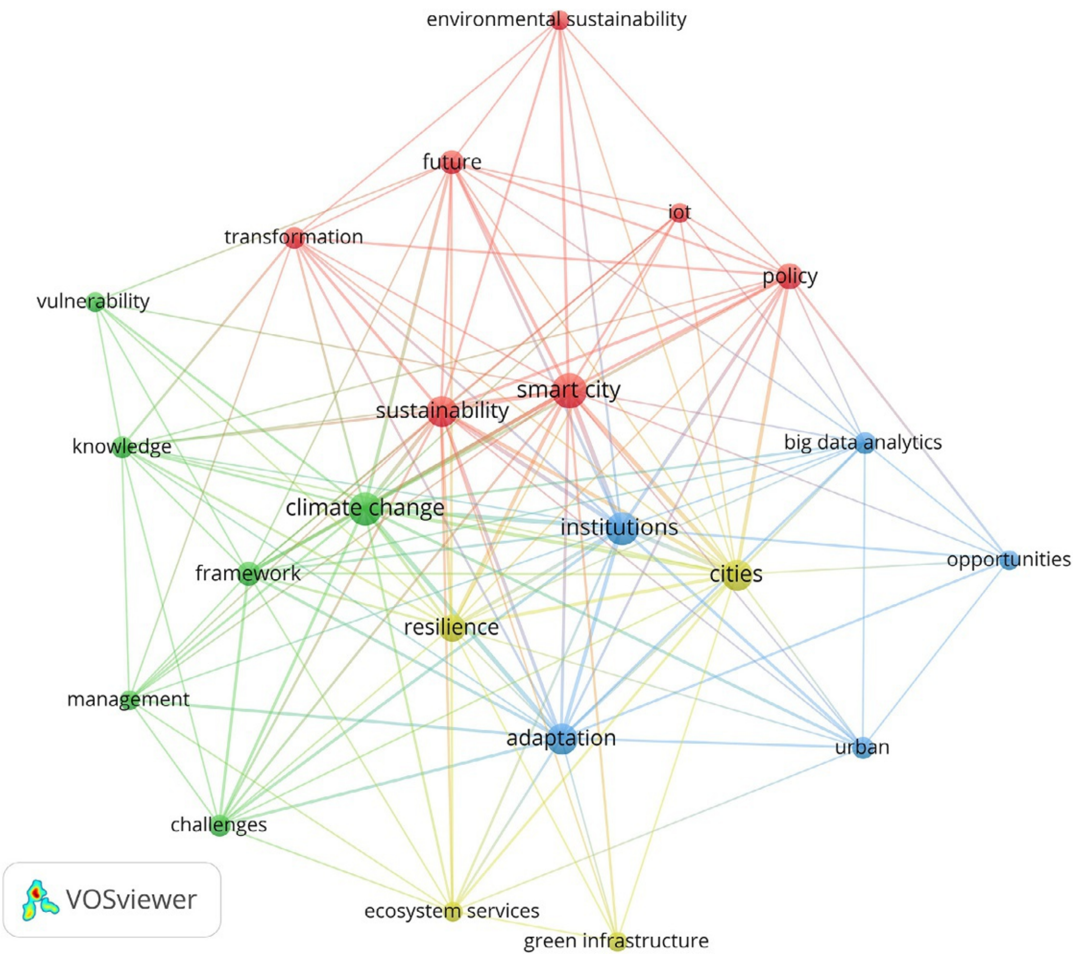

FIG. 4.10 Thematic focus of existing literature on the linkages between smart solutions and technologies, urban governance, and urban climate change adaptation.

To better facilitate transition toward sustainable development and understand the needs and priorities under future climatic conditions, scenario making is of great importance. Machine learning and artificial intelligence techniques can assist urban managers and decision makers in their efforts to develop more accurate and evidence-based scenarios. Furthermore, smart solutions could enable regular updating of future climate scenarios to reflect the ever-evolving climate dynamics and minimize projection uncertainties.

Citizen awareness and engagement is arguably essential for sustainable urban governance. Enhancing awareness and engaging people in planning practices could also contribute to better climate adaptation. It has, however, always been challenging to engage various stakeholders in urban planning and decision-making processes due to capacity limitations. Smart city solutions, however, have provided unprecedented opportunities to overcome such challenges. For instance, different platforms and applications have been developed that can ease communication between citizens and authorities. Such platforms could also be used to disseminate information necessary for better planning, response, recovery, and adaptation to adverse climatic impacts.

4.4 Conclusions

Due to the increasing trends of anthropogenic GHG emissions and the historical emissions, climate change impacts are inevitable, and it is essential to develop effective plans and strategies to deal with them. Recognizing this, climate change adaptation has increasingly become a priority across different research and policy circles. Indeed, given the magnitude of the challenge, concerted efforts across different sectors and stakeholders are needed for effective adaptation to climate change impacts. In this regards, smart city solutions and technologies, enabled by rapid advances in ICTs, are also important and efforts are needed to maximize their contributions to climate change adaptation.

In this chapter, we used VOSviewer to obtain an overall understanding of the state of knowledge on the actual and/or potential contributions of smart city solutions and technologies to climate change adaptation in cities. Term co-occurrence maps related to integrated urban planning, transportation, buildings, waste management, water, energy, urban infrastructure, economy, and urban governance were generated using VOSviewer and based on data obtained from the *Web of Science*.

Results showed that smart solutions and technologies have the potential to enhance adaptive capacity across all sectors. Enhancing prediction capacity to better plan and prepare for future risks, improving operational efficiency for better resource management, enhanced awareness and improved environmental behavior, and integrated urban management are noteworthy benefits that smart solutions and technologies can provide across these different sectors. It was discussed that these benefits are essential for improved adaptation to climate change impacts.

The information and discussions presented in this chapter can be used to further promote integration of smart city technologies into urban planning, design, and management, thereby, contributing to better climate resilience. It is worth noting, however, that in most cases the information provided on the linkages between smart solutions and climate adaptation are not discussed explicitly in the literature. This is, particularly, the case for some sectors such as waste and economy. Therefore, further research is needed to better understand the nature of interactions and contributions between smart solutions and climate change adaptation in cities.

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CHAPTER

5

Smart city solutions and climate change mitigation: An overview

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5.1 Introduction

Cities account for over 70% of global CO_2 emissions, and this share is expected to further increase in the coming decades as about 68% of world population is projected to live in cities by 2050, up from about 57% in 2022 (UNDESA, 2018). Projections by United Nations indicate that almost all future population growth will occur in cities. Obviously, cities need to build large amounts of new infrastructure to accommodate this population increase. This is in addition to the need to retrofit the old and inefficient urban infrastructure in the existing cities. The new construction and retrofitting activities are likely to be energy intensive. Furthermore, increasing urbanization could also increase demand for energy and other resources due to lifestyle changes. These all will have major implications for addressing climate change and that is why cites are key foci for climate action plans.

Actions aimed at addressing climate change impacts are divided into two major categories, namely, adaptation and mitigation (Sharifi, 2020a, 2021a). Adaptation aims to reduce vulnerabilities and improve coping capacity and according to the Intergovernmental Panel on Climate Change (IPCC) is "the process of adjustment to actual or expected climate and its effects" in human and/or natural systems (IPCC, 2014). Mitigation, on the other hand, refers to any actions that contribute to reducing greenhouse gas emissions (GHG emissions) and enhancing the state of emission sinks (e.g., forests, oceans, and soil) (Sharifi, 2020a, 2021a). Mitigation has, for a long time, been at the center of climate change plans and negotiations and is often highlighted in agreements such as the Kyoto Protocol and the Paris Climate

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Agreement. While, traditionally, the focus has been on mitigation efforts at the global scale, due to reasons mentioned above, the urban scale has received increasing attention in the past several years. This is evidenced by the increasing emphasis on reducing urban emissions in international policy frameworks such as the New Urban Agenda (Habitat, 2017), and the United Nations Sustainable Development Goals (particularly SDG 11) (UNSDG, 2015). Also, since the Fifth Assessment Cycle (AR5) of the Intergovernmental Panel on Climate Change (IPCC) a separate chapter has been allocated to cities under the Working Group III that is focused on mitigation.

Climate change mitigation requires efforts across different scales and sectors. Multiple mitigation measures related to urban planning and land use, transport, building, waste, energy, green and blue infrastructure, urban policy and governance, and water have been introduced in the literature (Sharifi, 2020a, 2021a). Technological advances, specially those based on Information and Communication Technologies (ICTs), could also contribute to climate change mitigation. In the context of cities, such technological advances are often deployed under the banner of smart cities. In fact, since more than 3 decades ago initiatives have been taken in different parts of the world to utilize smart and digital technologies for improving efficiency and effectiveness of urban operations and functions (Sharifi, Allam, Feizizadeh, & Ghamari, 2021). Such initiatives have also been supported and facilitated by major ICT corporations such as Cisco and IBM (Allam & Newman, 2018; IBM, 2010; Swabey, 2012). The initial major investments by these corporations demonstrated the benefits of smart initiatives to different stakeholders, leading to their increased adoption in many parts of the world (Gascó-Hernandez, 2018; IBM, 2010). The COVID-19 pandemic and its impacts on urban life have further accelerated interest in smart city initiatives (Sharifi, Khavarian-Garmsir, & Kummitha, 2021). Also, recent activities in novel technologies such as digital twins and metaverse herald a promising future for smart cities.

While climate change mitigation targets cannot be achieved by only focusing on technology-based solutions, the increasing uptake of smart solutions and technologies could provide opportunities to leverage mitigation efforts and improve their efficiency and effectiveness. In this chapter, we provide an overview of the applications of smart solutions and technologies in different sectors, including urban planning and policy making, transportation, building, waste management, water, energy, infrastructure, economy, and governance. For this purpose, we rely on the text mining abilities of VOSviewer, which is a software tool for bibliometric analysis (Van Eck & Waltman, 2009). This overview analysis is useful for raising awareness about potential contributions of smart solutions and technologies to climate change mitigation and could lead to their further uptake to deal with climate change impacts.

The materials and methods are presented in the next section. Section 5.3 presents the findings and provides some interpretations. Finally, Section 5.4 concludes the study by summarizing the results and making recommendations for future research.

5.2 Materials and methods

Meta-analysis and systematic review are two commonly used methods for reviewing and synthesizing academic literature. They can be used to obtain detailed knowledge about the structure of a field and deal with specific review questions. However, conducting meta-analyses and systematic reviews will be difficult, if not impossible, when the number of papers to be reviewed is large. Nowadays, a large volume of research is published annually on some research topics such as climate change and smart cities and these fields are constantly evolving. It is, therefore, needed to rely on alternative methods to be able to keep pace with the rapid publication of new studies. This issue can be, partially, resolved by using bibliometric analysis techniques. In the last 2 decades, several bibliometric analysis software tools have been developed for this purpose (Sharifi, 2020b, 2021b; Van Eck & Waltman, 2009). These tools use text mining algorithms that allow them to understand overall structure and trends of literature (Sharifi, 2021d) by analyzing bibliometric data that are archived in academic databases (Van Eck & Waltman, 2009).

The input data for bibliometric analysis are bibliographic information of academic publications that can be downloaded from scholarly databases such as the *Web of Science* (WoS), Scopus, Semantic Scholar, and Dimensions. For the purpose of this chapter, we obtained the necessary bibliometric data from the WoS that is a reputable database indexing quality peer-reviewed publications. Similar to what was explained for the case of contributions of smart solutions and technologies to climate change adaptation, broad-based search strings were developed to include as many relevant papers as possible in the study (see Table 5.1). It can be seen from Table 5.1 that a common smart city search string (indicated as “A”) has been used to retrieve literature related to different urban sectors and issues. This search string includes different terms related to smart solutions and technologies such as digitalization, digital technologies, ICT, Internet of Things (IoT), Artificial Intelligence (AI), machine learning, blockchain, virtual reality, augmented reality, 3D printing, cloud computing, Big Data analytics, 5G, 6G, smart home, smart city, home energy management systems, industry 4, industry 5, robotic, automation, unmanned aerial vehicle, smart meter, smart grid, vehicle to vehicle communication, and machine to machine communication.

To explore linkages between smart solutions and different urban sectors and issues, the core search string (i.e., “A”) was combined with search terms related to that specific urban sector. For instance, in the case of energy sector, the following search string was used: TS= ((“transport*” OR “mobility” OR “transit”) AND (“climat* change*” OR “global warming” OR “climat*”) AND (“mitigat*” OR “emission*”) AND (A)). In each case, we searched in the Titles, Abstracts, and Keywords of literature indexed in the WoS to retrieve relevant literature. Also, there was no time restriction, meaning that all papers indexed until December 9, 2020 (the date of literature search) were included in the analysis.

As mentioned earlier, for bibliometric analysis we used VOSviewer (Van Eck & Waltman, 2009). Various types of bibliometric analyses such as co-citation and bibliographic coupling that can be used to understand interlinkages between different authors, publications, journals, institutions, and countries can be conducted using the software. Based on these interlinkages, it is also possible to identify the most influential authors, publications, journals, institutions, and countries. The software can also be used for term co-occurrence analysis. It provides useful insights on the major knowledge structure and thematic focus of a research field. As can be seen in Fig. 5.1, the output of term co-occurrence analysis is a network of nodes and links. Each node represents a key term and node size is proportional to its frequency of co-occurrence with other terms. Also, links indicate that two terms are connected (have co-occurred) and thickness of links is proportional to the strength of connections between two nodes. Terms that have co-occurred frequently form thematic clusters that are shown in different colors. Results related to each analysis are presented and discussed in the next section.

TABLE 5.1 The search strings used for retrieving literature related to linkages between smart solutions and climate change mitigation from the *Web of Science* (WoS).

Topic	Search string	No. articles
Smart city search string (A)	("digitali*ation" OR "digital technolog*" OR "Information and communication technolog*" OR "ict" OR "information technolog*" OR "internet of things" OR "iot" OR "artificial intelligence" or "AI" or "machine learning" OR "blockchain" OR "virtual reality" OR "VR" OR "augmented reality" OR "AR" OR "3D print*" OR "three-dimensional printing" OR "cloud computing" OR "big data" OR "5G" OR "6G" OR "Smart technolog*" OR "smart home*" OR "smart house*" OR "smart cit*" OR "home energy management system*" OR "industry 4*" OR "society 5*" OR "robotic*" OR "automation" OR "unmanned aerial vehicle*" OR "UAV*" OR "smart meter*" OR "smart grid" OR "vehicle-to-vehicle communication" OR "machine-to-machine communication")	NA
General urban issues	TS=(("urban" OR "city" OR "cities") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	393
Integrated urban planning and policy making	TS=(("urban planning" OR "spatial planning" OR "city planning" OR "urban policy making" OR "urban management") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	41
Transportation systems	TS=(("transport*" OR "mobility" OR "transit") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	321
Building systems	TS=(("building*" OR "housing") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	239
Urban waste management	TS=(("waste") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	65
Water	TS=(("*water*") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	403
Energy	TS=(("energ*") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	646
Urban infrastructure (other)	TS=(("green infrastructure" OR "blue infrastructure" OR "critical infrastructure") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	16
Economy	TS=(("economy" OR "economic") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	338
Urban governance	TS=(("governance*") AND ("urban" OR "city" OR "cities") AND ("climat* change*" OR "global warming" OR "climat*") AND ("mitigat*" OR "emission*") AND (A))	27

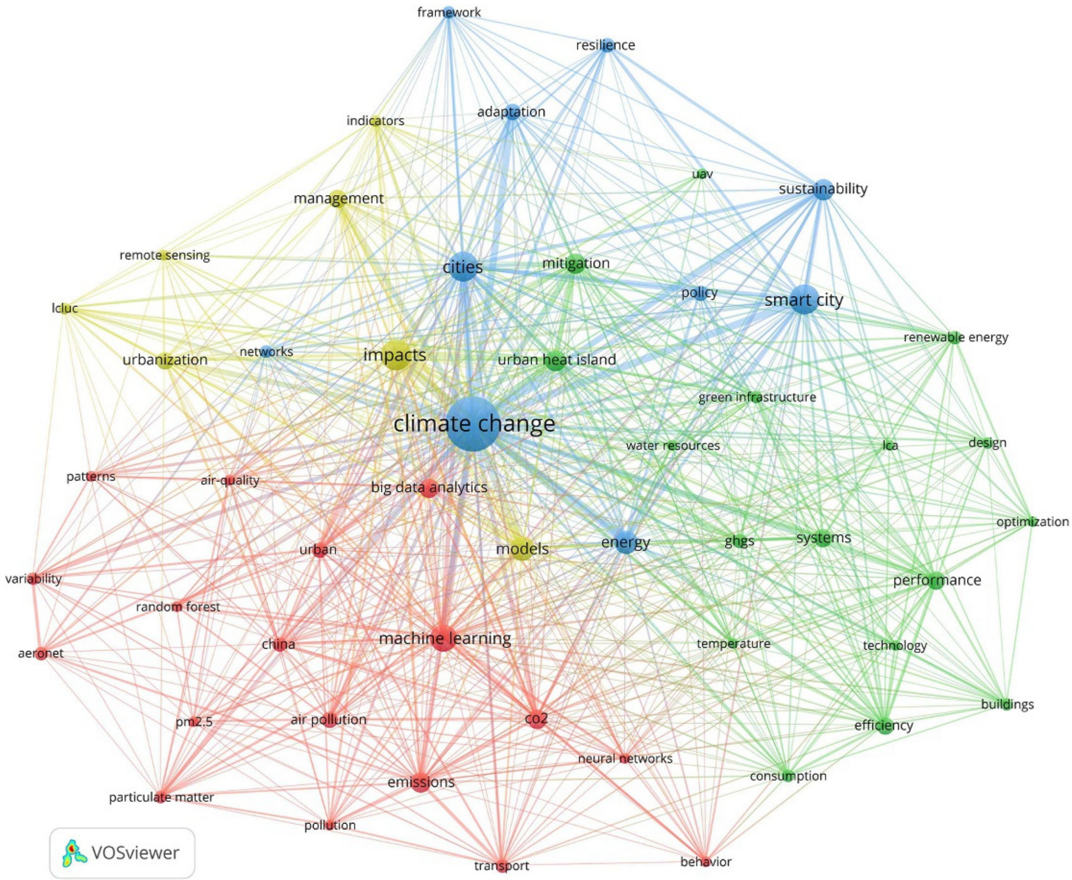

FIG. 5.1 General overview of existing literature on the linkages between smart solutions and technologies and urban climate change mitigation.

5.3 Results and discussions

Results of the term co-occurrence analysis for the general linkages between smart city solutions and technologies and urban climate change mitigation are presented in Section 5.3.1. Following that, results related to linkages and contributions to urban planning, transportation systems, building systems, waste management, water sector, energy sector, urban infrastructure, urban economy, and urban governance are presented in Sections 5.3.2 through 5.3.10, respectively.

5.3.1 General overview

Fig. 5.1 shows that research on the general linkages between smart city solutions/technologies and urban climate change mitigation can be divided into four major clusters shown using red, green, blue, and yellow colors. The red cluster is focused on Big Data analytics and major smart solutions and techniques for data analysis such as machine learning and random forest; the green cluster is focused on issues related to performance of energy sector and infrastructure systems; issues related to implications of smart city initiatives for sustainability and resilience are dominant in the blue cluster; and finally, the yellow cluster includes terms related to management of the climate change impacts and existing approaches and tools such as indicator frameworks and remote sensing techniques.

The red cluster is focused on Big Data analytics and major smart solutions and techniques for data analysis such as machine learning, random forest, and neural networks. The cluster shows that terms related to these techniques have co-occurred frequently with the term CO_2 and terms related to air quality, such as pollution and particular matter. There is, indeed, a lot of literature exploring applications of these techniques to account for CO_2 and other emissions. Existing research has particularly emphasized the suitability of such techniques for predicting emission patterns. For instance, Magazzino, Mele, and Schneider (2021) used machine learning methods to examined the relationship among solar and wind energy production, coal consumption, GDP, and CO_2 emissions in China, India, and the United States. In another study focused on Europe, machine learning methods have been used to forecast CO_2 emission intensities of power grid (Leerbeck et al., 2020). Studies employing Big Data analytics and machine learning methods for air quality prediction and management are also abound. For instance, random forest and stacked ensemble have been used in a study focused on mapping urban air quality using mobile sampling in Seoul, South Korea (Lim et al., 2019). Some sectors such as transport have received more attention as can be seen from Fig. 5.1. As a case in point, Fabregat, Vázquez, and Vernet (2021) have used machine learning to estimate the impact of ports and cruise ship traffic on urban air quality in Barcelona, Spain. Overall, Big Data analytics and machine learning techniques have been effective in facilitating a better understanding of behavior and patterns of CO_2 emissions and other pollutants in urban areas.

The green cluster is focused on issues related to performance of energy sector and infrastructure systems. Smart solutions and technologies are expected to enhance efficiency of energy systems and contribute to optimization of energy and other resources in buildings and cities. For instance, IoT-based smart metering systems can be used for management and optimization of consumer energy consumption (Pereira et al., 2015). This, in turn, can contribute to climate change mitigation by reducing CO_2 emissions. Furthermore, co-benefits for sustainability and climate change adaptation can also be achieved. Major co-benefit for sustainability would be reducing extraction and consumption of natural materials. Also, a noteworthy co-benefit for climate change adaptation could be reduction in heat exhaust (of air conditioners) that contributes to mitigating the urban heat island effect (Sharifi, 2021a, 2021c).

Issues related to implications of smart city initiatives for sustainability and resilience are further highlighted in the blue cluster. This indicates the increasing recognition of the actual and potential contributions of smart city solutions and technologies to achievement of these societal targets. For instance, a study of interlinkages between smart city indicators and sustainability highlights multiple interlinkages with different social, economic, environmental, and institutional dimensions of sustainability (Sharifi & Allam, 2022). The same study shows how smart cities can strengthen planning, absorption, recovery, and adaptation abilities related to urban resilience. Multiple con-benefits and contributions of smart cities to resilience were also demonstrated during the recent COVID-19 pandemic (Hassankhani, Alidadi, Sharifi, & Azhdari, 2021; Sharifi, 2021b; Sharifi & Khavarian-Garmsir, 2020; Sharifi, Khavarian-Garmsir, & Kummitha, 2021).

Finally, the yellow cluster includes terms related to management of the climate change impacts and existing approaches and tools such as indicator frameworks and remote sensing techniques. Use of mart solutions in modeling and understanding climatic impacts is also becoming increasingly common. For instance, machine learning approaches have been widely used for enhanced spatio-temporal analysis of land use and land cover changes based on remote sensing data (Kulithalai Shiyam Sundar & Deka, 2021). In addition to informing adaptation efforts, results of such analyses can also be used to estimate potential implications for climate change mitigation.

5.3.2 Integrated urban planning and policy making for climate change adaptation

Fig. 5.2 shows that, overall, research on the contributions of smart solutions and technologies to climate change mitigation by facilitating integrated urban planning is limited. However, the fact that the term "smart city" is closely linked to "climate change," "sustainable cities," and "sustainability" indicates that smart city initiatives have the potential to facilitate integrated planning approaches that can lead to maximizing synergies and minimizing trade-offs. As also mentioned in the case of climate adaptation, this would be a paradigm shift from conventional planning approaches that are often practiced in a silo-based manner. Given multiple interactions between different urban sectors, integrated approaches are necessary to ensure that mitigation in one sector will not lead to additional emissions in other sectors. In addition, integrated approaches could be used to obtain other synergistic benefits and avoid trade-offs. For instance, in the absence of integrated approaches, measures aimed at enhancing climate change mitigation may lead to mitigation trade-offs (Sharifi, 2020a).

Both "mitigation" and "adaptation" have central positions in Fig. 5.2. This is a clear indication that the significance of using smart solutions to promote integrated approaches that consider both mitigation and adaptation simultaneously is well recognized in the literature. The terms "density" and "urban heat island" are highlighted in Fig. 5.2. This is unsurprising as the need for optimal levels of density to reduce energy consumption without intensifying the urban heat island effect is well discussed in the literature (Sharifi, 2020a, 2021a). Overall, as mentioned in the chapter on contributions of smart solutions to climate change adaptation, combining multiple smart solutions and technologies such as IoT sensors, machine learning algorithms, and Big Data analytics allows developing integrated systems that can be used to understand and deal with dynamic urban interactions in a systemic manner. For instance, Urban Observatories that have been developed and implemented in cities such as Newcastle, UK, have proved effective in collecting, processing, and analyzing large volumes of real-time data on various measures related to air quality, travel patterns, and climatic conditions. Such observatories function as integrated platforms that allow planners and decision makers better understand how to quickly respond to changing circumstances. For instance, in case of route closures due to storm surges, they can rapidly inform citizens and transit service providers of necessary changes that need to be made and the alternative routes that are available to minimize functionality loss. The utility of such observatories was also demonstrated during the

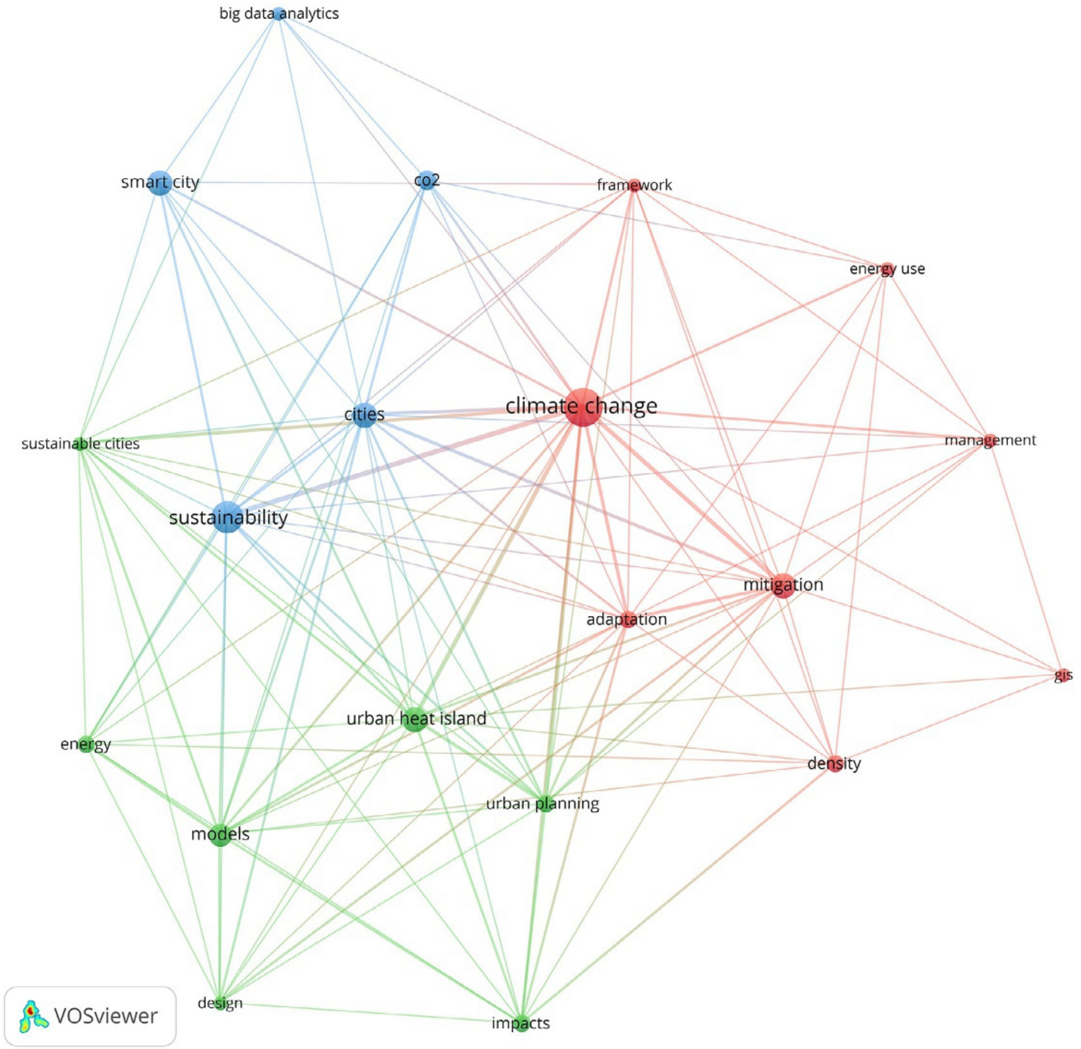

FIG. 5.2 Thematic focus of existing literature on the linkages between smart solutions and technologies, urban planning, and urban climate change mitigation.

COVID-19 pandemic as they enabled authorities to take evidence-based decisions in response to the pandemic (James, Das, Jalosinska, & Smith, 2020; Sharifi & Khavarian-Garmsir, 2020).

5.3.3 Transportation systems

Applications of smart city solutions and technologies in the transportation sector have been widely discussed in the literature (Sharifi, Allam, et al., 2021). Indeed, recent advances in Information and Communication Technologies and IoT made significant contributions to performance improvements in transportation systems (Saarika, Sandhya, & Sudha, 2017). For example, such technologies have been utilized to facilitate better parking management, enhance journey planning, and enable better control of traffic signals, better traffic monitoring and management, and improved traffic safety. In addition, new technologies such as vehicle to vehicle communication and also communication between vehicles and any other entities that may interaction with them (vehicle to everything). Overall, these advancements have provided opportunities to achieve multiple benefits such reduced congestion, energy saving, and traffic safety (Lee & Chiu, 2020; Lin, Hsieh, & Li, 2018; Saarika et al., 2017).

Fig. 5.3 shows that research related to the linkages between smart transportation technologies and climate change mitigation can be divided into two major clusters in terms of thematic focus. The red cluster is mainly focused on issues related to energy consumption and associated GHG emissions of the transportation sector. There is vast body of research on how Big Data analytics can contribute to optimizing performance of transportation systems (Sai & Wang, 2021; Yan, Wang, & Psaraftis, 2021). Among other things, this is expected to also help reduce energy consumption and facilitate achievement of sustainable development and climate mitigation targets. For instance, Ağbulut (2022) has utilized machine learning algorithms, namely, deep learning (DL), support vector machine (SVM), and artificial neural network (ANN) to forecast the transportation-based-CO_2 emission and energy demand in Turkey. As transportation sector is a major contributor to global GHG emissions, such algorithms and enhanced forecasting capacities can be used to inform transportation planners and policy makers of actions that need to be taken to optimize transportation energy performance and reduce transport emissions.

The green cluster is mainly focused on topics related to air quality. This indicates that studies focused on the contributions of smart solutions to mitigating transportation emissions have also widely examined the co-benefits for air quality improvement. This is not surprising as decarbonizing transportation sector by promoting clean and renewable energy technologies will also be beneficial for reducing air pollution in cities.

5.3.4 Building systems

Applications of smart city solutions and technologies in the building sector have also been widely explored in the literature. This covers various issues and technologies such as smart home management systems, building information modeling, real-time task scheduling, and smart meters and other smart devices for efficient water and energy management (Guerriero, Kubicki, Berroir, & Lemaire, 2017; Hui, Sherratt, & Sánchez, 2017; Lee & Bahn, 2013).

Based on Fig. 5.4, the existing research has focused on three major thematic areas: contributions to optimizing energy performance in buildings (blue cluster), use of smart solutions to promote further integration of renewable energy technologies (red cluster), and co-benefits of integrating smart technologies in buildings for sustainability and resilience.

The blue cluster is dominated by terms such as "machine learning," "Big Data analytics," "neural networks," and "AI" and these are linked to terms related to energy consumption. Indeed, such smart solutions have been frequently used to develop simulation models for estimating energy consumption and performance at the building scale (Revati et al., 2021;

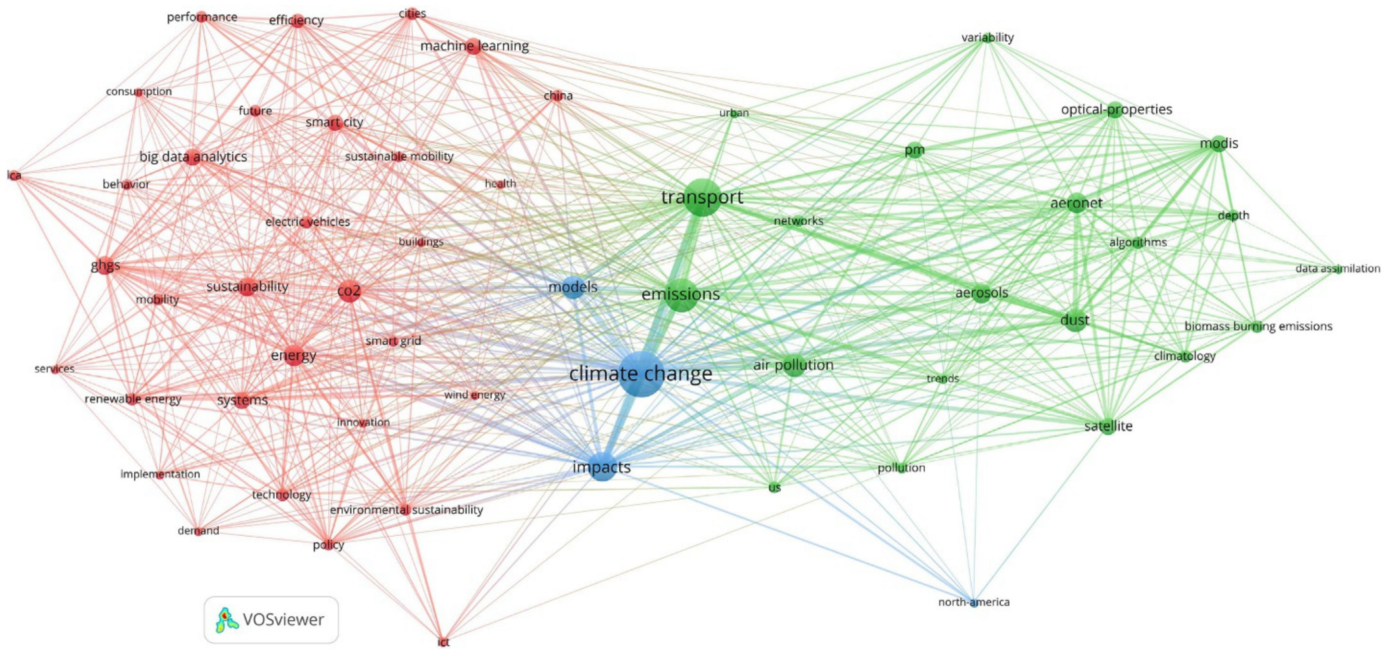

FIG. 5.3 Thematic focus of existing literature on the linkages between smart solutions and technologies, transportation, and urban climate change mitigation.

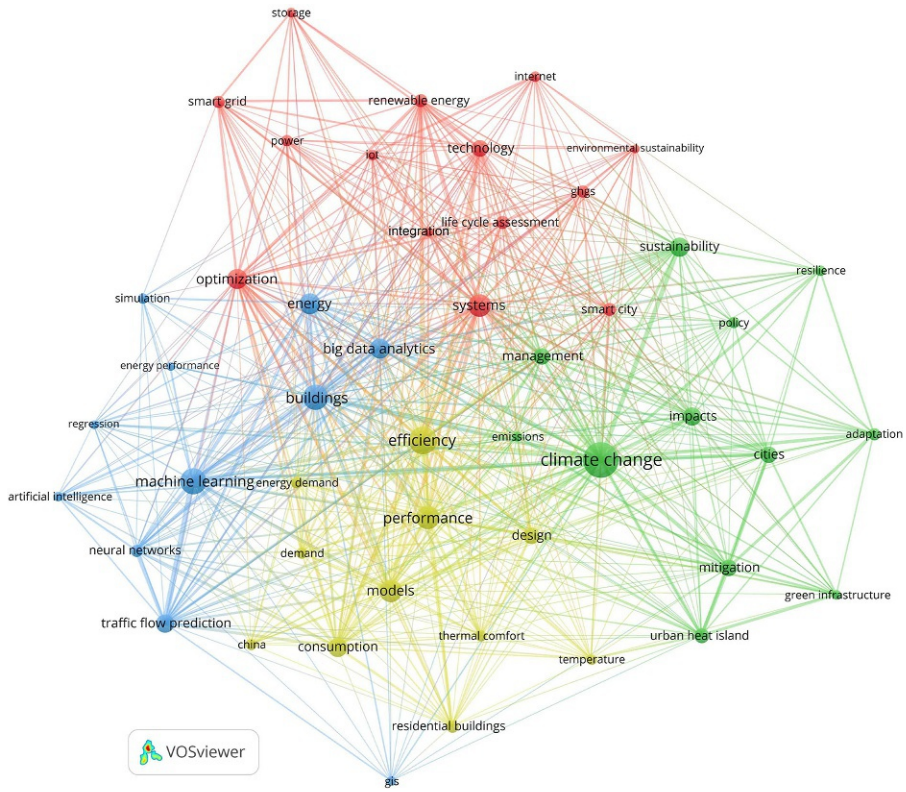

FIG. 5.4 Thematic focus of existing literature on the linkages between smart solutions and technologies, buildings, and urban climate change mitigation.

Seyedzadeh, Rahimian, Glesk, & Roper, 2018). Closely related to this, the red cluster highlights capacities of smart solutions for facilitating integrated energy management in buildings, and thereby, facilitating energy efficiency and environmental sustainability. For instance, integration of technologies such as smart grid, distributed energy generation, energy storage systems, and vehicle to grid (V2G) systems can improve efficiency of building energy systems and also provide co-benefits for other sectors such as transportation (Aparicio & Grijalva, 2021; Yusuf & Ula, 2020). This, in turn, will provide environmental and economic sustainability co-benefits.

The co-benefits are further highlighted in the yellow and green clusters. In particular, co-benefits for resilience and climate change adaptation can be noted. Literature shows that through facilitating integrated energy management systems based on locally generated renewable sources, smart solutions enhance urban energy resilience (Sharifi & Yamagata, 2016). As mentioned several times in this volume, if coupled with other measures such as green infrastructures, building-integrated smart solutions and technologies can also provide multiple co-benefits for climate change adaptation and sustainability (Sharifi, 2021a, 2021c).

5.3.5 Urban waste management

Various smart technologies have been utilized to improve municipal and household waste management. For example, integrating radio frequency identification (RFID) tags with sensors and cloud-based software tools allows developing web-based platforms and dashboards to facilitate better waste management (Catarinucci et al., 2019). As mentioned in the case of contributions to climate change adaptation, several IoT- and sensor-based algorithms have been proposed for more effective and efficient waste collection and their benefits compared to conventional collection methods have also been demonstrated (Pardini, Rodrigues, Hassan, Kumar, & Furtado, 2018; Shyam, Manvi, & Bharti, 2017). Recent advances in IoT and machine learning also enable better waste sorting and recycling, thereby improving waste management practices (Dubey, Singh, Yadav, & Singh, 2020). A key feature of these smart solution is that not only was collection agencies but also citizens can be engaged in the waste collection processes. For instance, IoT-based methods can inform citizens of the filling level of waste bins and allow them to make adjustments to improve efficiency of waste management processes (Pardini et al., 2020).

From Fig. 5.5, it can be seen that contributions of smart solutions and technologies to mitigating climate change are relatively underexplored compared to other sectors such as

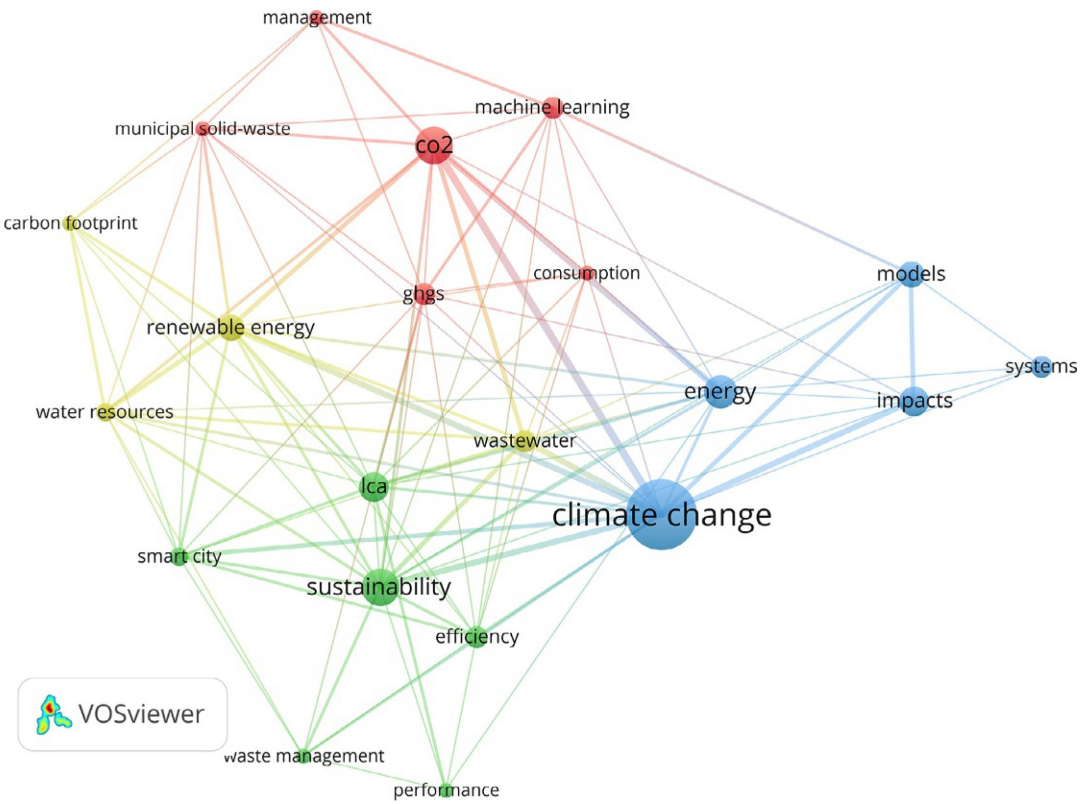

FIG. 5.5 Thematic focus of existing literature on the linkages between smart solutions and technologies, waste management, and urban climate change mitigation.

building and transportation that were discussed earlier and sectors such as water, energy, and economy that will be discussed in the remainder of this chapter. The figure shows that "machine learning" is the most commonly used smart solution that has been linked to municipal solid waste management and related terms such as "CO_2," "management," and "GHGs." In their literature review, Xia, Jiang, Chen, and Zhao (2022) discuss how machine learning algorithms can be used in the whole process of municipal solid waste management, from waste generation to collection and transportation to final disposal. Among other things, such algorithms can enable planners and managers to estimate the GHG emissions of solid waste management (Magazzino, Mele, & Schneider, 2020). Machine learning algorithms such as random forest have also been used for prediction of energy consumption of wastewater treatment plants. Unlike conventional models, such algorithms allow accounting for the nonlinear functions and behaviors of the plants (Zhang, Wang, & Keller, 2021). Machine learning algorithms such as ANN have also been used to provide solutions for Integrating waste management companies in micro grids (Aggarwal et al., 2021). This way renewable energy sources will be further promoted, contributing to the reduction of urban carbon footprint. Terms such as sustainability and life cycle assessment have also occurred frequently, indicating that efficiency improvements facilitated by smart solutions can reduce life cycle impacts and contribute to sustainability through promoting circular economy.

5.3.6 Water

It can be seen from Fig. 5.6 that issues related to management of water resources using smart solutions have been well discussed in the literature. Given the water-energy nexus, efficient management of water resources is of critical importance for climate change mitigation (Sharifi & Yamagata, 2016). Similar to what was discussed for other sectors, smart solutions can be utilized to improve efficiency of water resource management.

The figure shows that existing research has focused on four broad issues: use of different smart solutions for improved water resource management and associated energy efficiency enhancements (green and red clusters); estimation of impacts on GHGs (CO_2, N_2O, and methane), as shown in the yellow cluster; and other co-benefits for reducing impacts associated with drought and/or stormwater runoff, as shown in the blue cluster.

Different studies have shown how machine learning algorithms and Big Data analytics allow better and more efficient management and prediction of water supply, demand, distribution, quality, and usage (Assem et al., 2017; Rozos, 2019). Such efficiency improvements also yield energy efficiency improvements given the fact and water and energy sectors are tightly interlinked. Furthermore, application of machine learning algorithms and Big Data analytics is conducive to better understanding of the patterns of water-energy nexus and this could be facilitated for better planning and management (Zaidi et al., 2018). Such efficiency improvements will, in turn, contribute to the reduction of energy consumption, thereby helping to achieve climate change mitigation targets.

Apart from mitigation benefits, application of smart solutions in the water sector will be beneficial for resilience and climate change adaptation. Improved water efficiency, particularly in water-stressed areas, will be critical for drought resilience. Prediction of future water supply and demand patterns using Big Data analytics and machine learning algorithms will

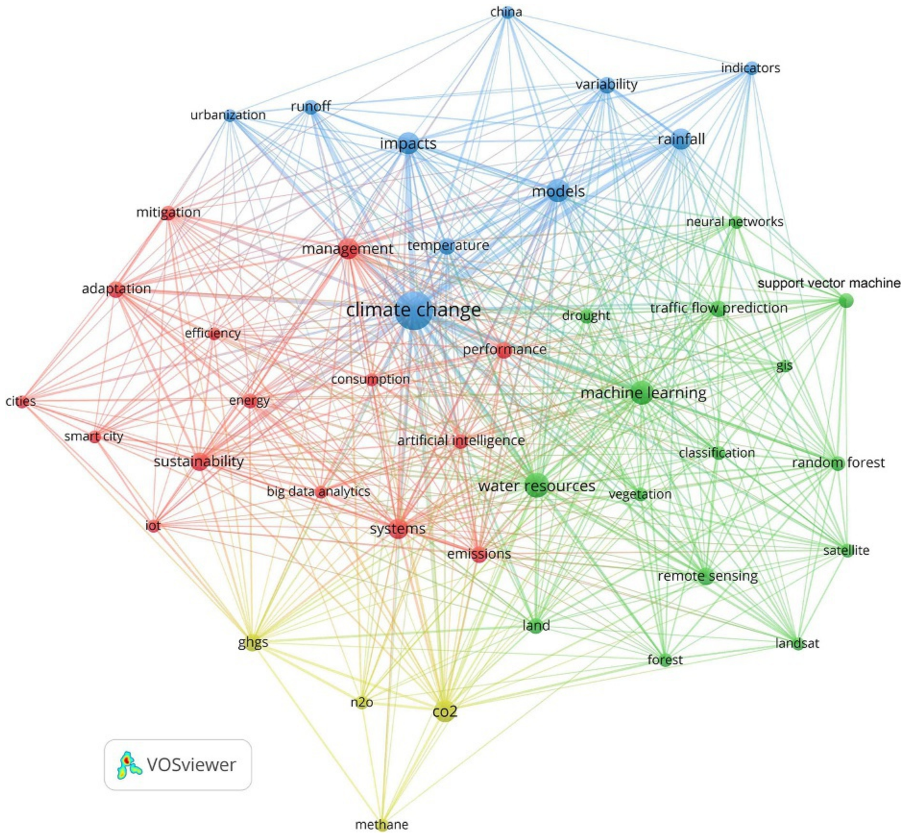

FIG. 5.6 Thematic focus of existing literature on the linkages between smart solutions and technologies, water management, and urban climate change mitigation.

further improve resilience and adaptive capacities by strengthening planning and absorption capacities to ensure sustained supply of water resources minimize potential disruptions (Imani, Hasan, Bittencourt, McClymont, & Kapelan, 2021; Sharifi & Yamagata, 2016).

5.3.7 Energy

A lot of research has been published on the applications of smart solutions and technologies in the energy sector (Sharifi, Allam, et al., 2021). Fig. 5.7 shows that linkages between energy-related smart technologies and climate change mitigation is also well studied in the literature. The term co-occurrence map shows that three major benefits of smart technologies have received relatively more attention in the literature: efficiency improvement (red cluster), optimization and enhanced integration of renewable energy (blue cluster), and general contributions to environmental and economic sustainability (green and yellow clusters).

As for efficiency improvement (red cluster), that "machine learning," "AI," and "neural networks" are major smart solutions and technologies that have co-occurred frequently with

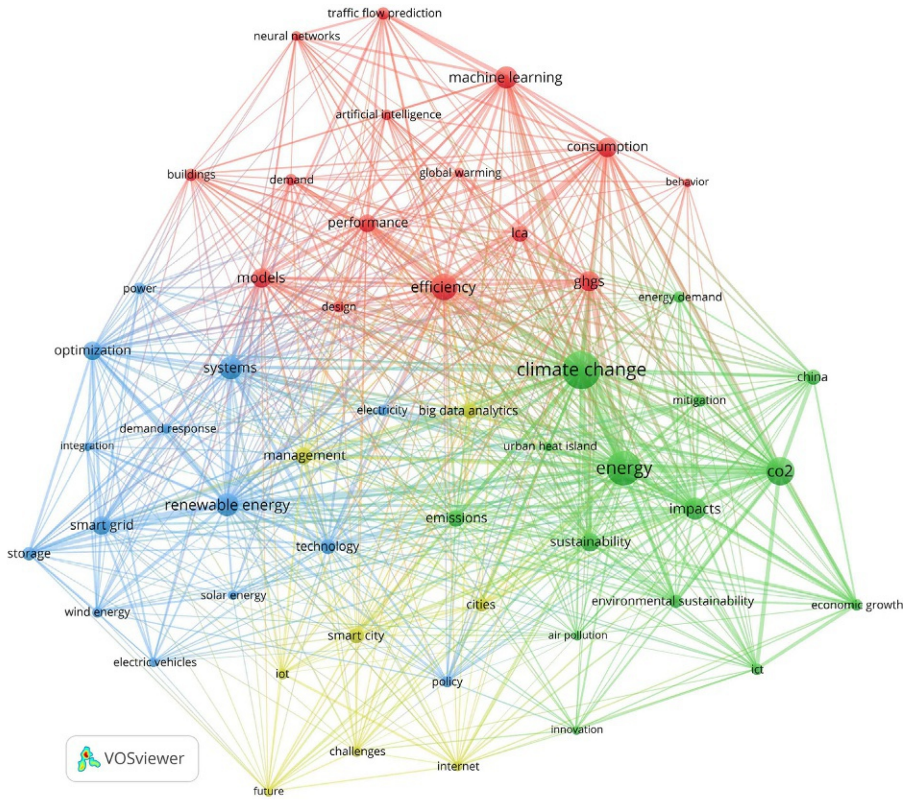

FIG. 5.7 Thematic focus of existing literature on the linkages between smart solutions and technologies, energy management, and urban climate change mitigation.

terms such as efficiency and consumption. This shows contributions of such technologies to enhancing energy efficiency in different sectors, including building and transportation. As was discussed earlier, among other things, this can be achieved through better energy management, improved prediction capacities, and promotion of environmentally friendly and responsible consumption. There are, indeed, many studies demonstrating how machine learning algorithms and Big Data analytics can provide efficiency improvement in building and transport sectors through improving consumption prediction and management (Pham, Ngo, Ha Truong, Huynh, & Truong, 2020; Shams Amiri, Mostafavi, Lee, & Hoque, 2020).

As discussed earlier, optimization and enhanced integration of renewable energy is another major contribution of smart solutions and technologies (blue cluster). Currently, different types of renewable energy sources exist. However, these are not always well interconnected, resulting in inefficient operation. This issue can be, to some extent, addressed through solutions such a smart grid, vehicle to grid, vehicle to community, and optimized utilization of storage utilities. Benefits related to smart grid and vehicle to grid technologies were earlier discussed. Smart solutions can also offer solutions to optimize battery storage to overcome the issue of fluctuations in renewable energy supply (Sathishkumar & Karthikeyan, 2020). Further, machine learning algorithms facilitate application of demand–response programs that are essential for adaptive load forecasting and management (Pallonetto, Jin, & Mangina, 2022).

Smart solutions and IoT-based devices can also provide other benefits for climate change adaptation, environmental sustainability, and economic growth and resilience. Such technologies and devices facilitate real-time interactive communication with residents through smart metering systems and web-based dashboards, thereby providing opportunities for efficient energy consumption and behavior change toward more sustainable consumption patterns. Furthermore, smart devices can facilitate real-time communication of energy system performance to utility managers, enabling them to rapidly respond to potential disruptions in energy supply (Al-Ali, Zualkernan, Rashid, Gupta, & Alikarar, 2017). In addition to environmental sustainability and resilience co-benefits, such functionalities and utilities of smart solutions will also yield economic benefits at individual, organizational, and community levels. Overall, smart technologies provide multiple benefits for climate change mitigation and adaptation, sustainability, and resilience. It is, therefore, critical to further utilize smart solutions and technologies in the energy sector.

5.3.8 Urban infrastructure

Smart solutions and technologies are increasingly being integrated into urban infrastructure systems. Fig. 5.8, however, shows that impacts of such integrations on climate change mitigation are not well explored in the literature. The term “green infrastructure” is dominant in the figure, indicating that existing research on this topic has mainly been discussed in relation to green infrastructure systems. Green infrastructure refers to different types of measures taken to increase the fraction of natural and semi-natural areas in cities. Various types of green infrastructure such as green roofs and walls, urban forestry, and sustainable stormwater management systems have been proposed that contribute to climate change mitigation through enhancing thermal conditions in the built environment and, thereby, reducing energy consumption (Sharifi, 2021a). Integration of smart solutions into green infrastructure is likely to enhance effectiveness of green infrastructure measures. For instance, research shows that data-driven modeling based on machine learning algorithms can be used to estimate the impacts of green infrastructure on regulating temperature (Zumwald, Baumberger, Bresch, & Knutti, 2021). This could help infrastructure planners develop better strategies for improving performance of green infrastructure that can also provide co-benefits for heat island mitigation and provide other ecosystem services. Hashad et al. (2021) show that machine learning techniques can be used for optimized design of roadside vegetation barriers. For this purpose, they “investigated five machine learning (ML) methods, including linear regression (LR), support vector machine (SVM), random forest (RF), XGBoost (XGB), and neural networks (NN), to predict size-resolved and locationally dependent particle concentrations downwind of various vegetation barrier designs” (Hashad et al., 2021).

Use of smart solutions will also offer unprecedented opportunities for real-time monitoring of the performance of infrastructure systems, including green infrastructure. This will increase urban resilience by facilitating early detection of potentially damaged areas and

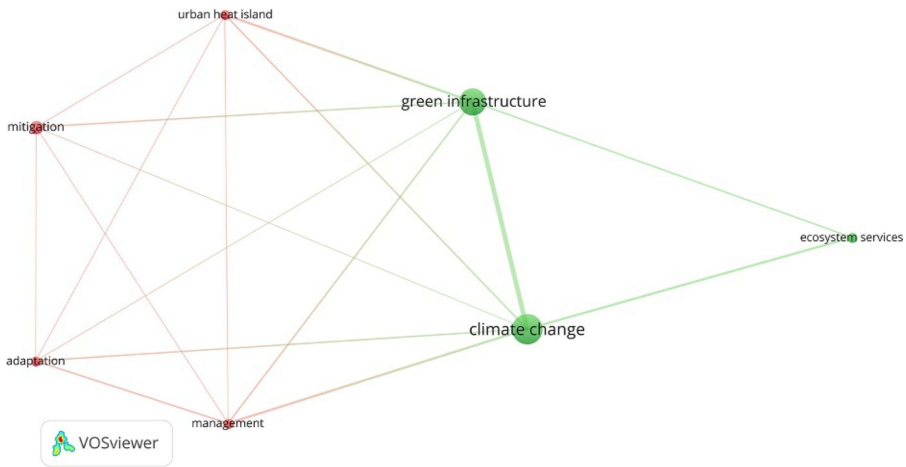

FIG. 5.8 Thematic focus of existing literature on the linkages between smart solutions and technologies, urban infrastructure, and urban climate change mitigation.

ensuring proper system functionality. For instance, IoT can be utilized to develop monitoring and control systems to ensure effective operation of urban stormwater management systems (Xie, Wang, Yang, & Cheng, 2021). Overall, smart solutions and technologies have a high potential to enhance climate change adaptation and mitigation capacities and should be appropriately integrated into critical infrastructure systems.

5.3.9 Economy

Various terms related to different aspects of smart city solutions and technologies have been included in Fig. 5.9, indicating that links to economy and economic impacts have been widely discussed in the literature. In the green cluster, it can be seen that terms such as energy, CO_2, and economic growth are dominant and tightly interlinked. The issue of decoupling economic growth from CO_2 emission and energy consumption is highly important. Through better prediction abilities and efficiency improvements, smart solutions enabled by ICT, Big Data analytics, and IoT are expected to contribute to this decoupling process.

The red cluster is mainly focused on renewable energy sources and technologies and associated terms such as solar energy, wind energy, smart grid, and storage. As discussed in detail earlier, smart solutions can facilitate better integration of renewable energy technologies into the energy, transportation, and building systems. This is expected to provide optimization benefits, thereby reducing the overall operation costs. Such efficiency improvements will also help people and businesses avoid high utility bills. Indirectly, energy efficiency improvements could also contribute to economy by, among other things, reducing the health costs associated with air pollution. It should, however, be noted that initial installation and operation of smart solution may be costly, and this is a challenge that needs to be addressed.

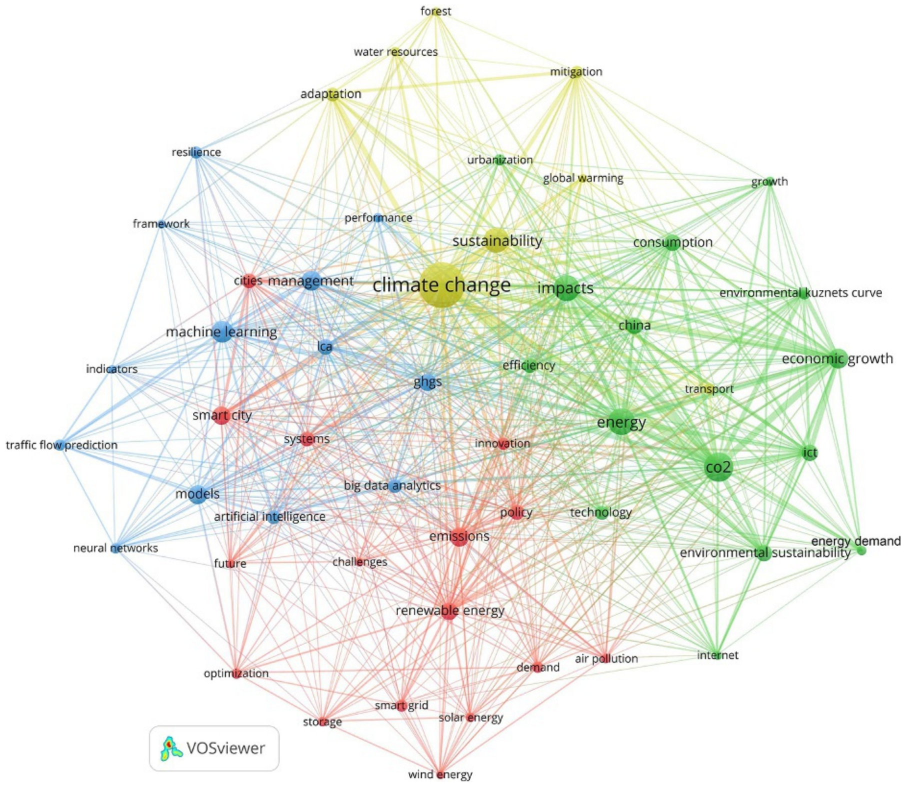

FIG. 5.9 Thematic focus of existing literature on the linkages between smart solutions and technologies, economy, and urban climate change mitigation.

Among other things, two points can be highlighted from the blue cluster. The term LCA is highlighted, and this may indicate that smart solutions can contribute to reducing life cycle costs and promoting circular economy through efficiency improvements. Furthermore, the dominance of terms related to smart solutions (e.g., machine learning, AI, neural networks, and Big Data analytics), and their linkages to models show that such solutions can improving modeling and simulation abilities, thereby allowing better prediction of future patterns and dynamics. This could, in turn, facilitate better planning and preparation and offer economic benefits.

The yellow cluster is focused on three major societal goals, namely sustainability, climate change adaptation, and climate change mitigation. Obviously, economy is one of the major dimensions of sustainability and any efforts to enhance sustainability through smart solutions and initiatives are also expected to provide economic benefits too. As for climate change mitigation and adaptation, the key issue is perhaps taking early actions to minimize and avoid of more costly options in the future. For instance, delaying mitigation could lead to more severe climatic impacts in the coming decades, and this could result in significantly higher economic losses. The prediction capacities provided by smart solutions and technologies can enable them to function as early warning systems and allow planners and decision makers to take necessary actions in a timely manner. In the case of disaster risk management, for instance, such early actions would be essential for avoiding major human and economic losses in the future. Otherwise, major disasters induced by climatic changes could not only result in significant economic losses but also necessitate allocating large amounts of budget for recovery. As mentioned in the chapter on the contributions of smart solutions to adaptation, a report by World Bank estimates that annual direct loss from natural disasters in cities will be several hundred billion US dollars in the coming decades unless cities take necessary actions to enhance their resilience (Sharifi, 2019; World Bank (WB), 2015). In this regard, more effective integration of smart solutions and technologies into planning processes could be an effective strategy for enhancing urban resilience.

5.3.10 Urban governance

Integration of smart solutions such as machine learning and Big Data analytics have provided unprecedented opportunities for revolutionizing urban governance and making it more efficient, effective, transparent, and inclusive. Furthermore, smart solutions have facilitated timelier and more evidence-based decision making through enhanced capacity to acquire and process large volumes of data in a real-time manner. A case in point is the urban observatories that were earlier discussed. Despite these potential co-benefits and the fact that integrating smart solutions into urban governance can accelerate transformation toward sustainability and addressing climate change challenges (García Fernández & Peek, 2020), issues related to the mitigation contributions of urban governance, enabled by smart solutions, are not well explored in the literature as Fig. 5.10 shows.

In addition to the benefits that were mentioned above, integration of smart solutions into urban management and governance could provide opportunities to deal with complex and dynamic interactions among different urban components and facilitate more systemic approaches that could be conducive to maximizing synergies and co-benefits between different mitigation/adaptation measures and minimizing trade-offs and conflicts (Sharifi, 2020a, 2021a). The importance of paying attention to such interactions (co-benefits, synergies, trade-offs, and conflicts) for achieving climate change mitigation/adaptation targets has been frequently discussed throughout this volume.

Furthermore, limited ability to predict future scenarios has, traditionally, always been a barrier to effective and efficient planning. This has major implications for addressing climate change given the significance of being able to predict potential future dynamics and deal with uncertainties. Since smart solutions facilitate dealing with large volumes of data, as well as interactions between different system components, they can be utilized to developed different future scenarios and use them for better-informed actions toward addressing climate change.

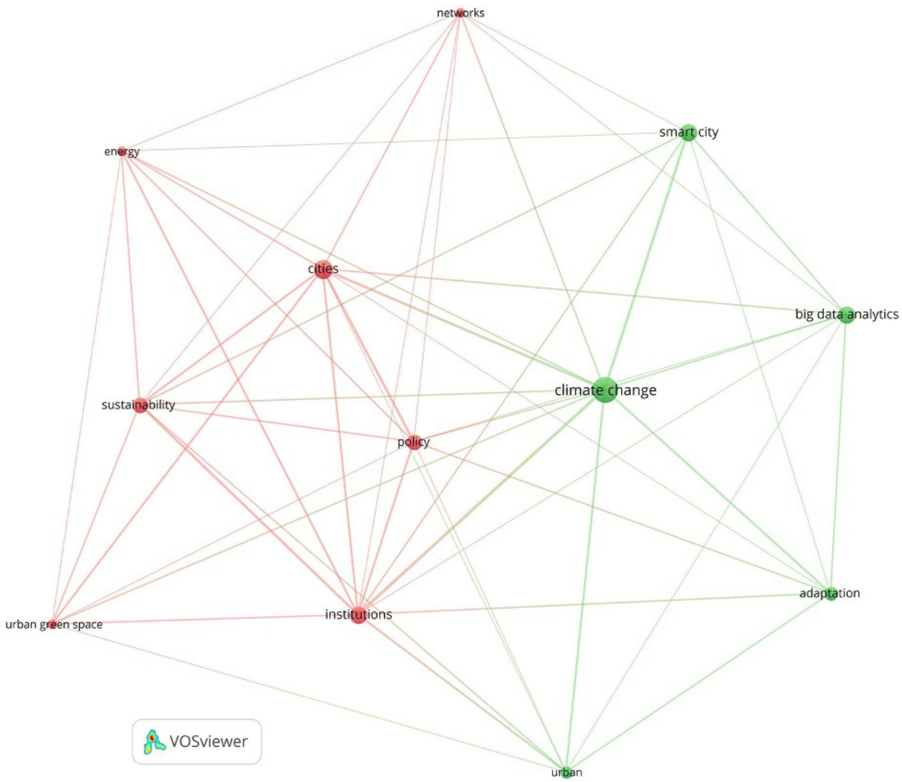

FIG. 5.10 Thematic focus of existing literature on the linkages between smart solutions and technologies, urban governance, and urban climate change mitigation.

5.4 Conclusions

Efforts aimed at addressing climate change have gained significant momentum in the past few years and following the Paris Climate Agreement. Cities are major contributors to global climate change and, therefore, are at the forefront of efforts aimed at climate change mitigation and adaptation. The main objective of this chapter was to gain an overall knowledge of the potential contributions of smart city solutions and technologies to achieving climate change mitigation targets across different urban sectors.

VOSviewer was used for this purpose and results show that potential contributions have been well discussed in the literature except for some sectors such as integrated urban planning and policy making, urban infrastructure, and urban governance. What can be learned from this overview analysis is that smart solutions mainly contribute to mitigation through either efficiency improvement or enhance predictive capacities. Regarding efficiency improvement, improved adoption, and integration of smart solutions can offer different ways to save energy, thereby contributing to climate change mitigation. Predictive capacities are also important and would allow planners and policy makers take actions to meet future societal demands in a more energy-efficient manner. Enhanced predictive capacities could also be utilized to promote a more environmentally friendly consumption behavior in the society.

An important issue to be mentioned is that although the focus on this chapter was on mitigation, co-benefits were recurring across different parts and sectors. It was found that integration of smart solutions and technologies will also facilitate multiple co-benefits for sustainability, resilience, and climate change adaptation. Based on this, it is essential to take actions to further promote integration of smart city technologies into urban planning, design, and management.

While this overview has enhanced our understanding of the actual and/or potential contributions of smart solutions and technologies to climate change mitigation, more detailed reviews related to different aspects discussed in the chapter are needed to gain a better understanding. Furthermore, as was discussed, some aspects such as integrated planning and policy making, and urban governance have received limited attention despite their importance for climate change mitigation. Future research should, therefore, pay more attention to such sectors and dimensions.

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CHAPTER

6

The fundamentals of smart city assessment

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6.1 The origin of the smart city assessment

6.1.1 What is smart city?

A smart city is an urban environment in which various electronic systems for data collection are used to improve urban management, optimize resource organization, and ensure economic services reach the people. The collected data are used to improve the overall city operations. This concept has already been applied in different parts of the world.

Many scholars defined a smart city from a technological perspective. A smart city uses tools like wireless sensors, smart meters, smart vehicles, smartphones, mobile networks, and data storage (Peng, Nunes, & Zheng, 2017). However, technology alone cannot make a city smart (Nam & Pardo, 2014) unless the citizens become smart (Ortiz-Fournier, Márquez, Flores, Rivera-Vázquez, & Colon, 2010). Recently, the emphasis of smart city studies has been on the needs and choices of smart citizens (Winkowska, Sialkot, & Peck, 2019). Initially, the smart city concept was insignificant, but since 2014, rapid growth in associated research has attested to its importance and the necessity to develop the concept further (Winkowska et al., 2019). Previous research failed to appropriately inform the smart city concept against a multifaceted futuristic vision. A lack of citizen involvement is a clear gap in the conceptual smart city development. Scholars must consider the citizens as users and give them a voice in the decision-making process (Nazarko, Glinska, Kononiuk, & Nazarko, 2013).

Data collected from residents, properties, gadgets/devices, and other sources are first broken down to scrutinize, observe, and then to manage different systems such as amenities, supply systems (water, electricity, traffic, transport, etc.), waste management, crime detection

Urban Climate Adaptation and Mitigation
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(Fourtané, 2018), facilities (hospital, school, library, community service (McLaren & Jandrić, 2015), etc., and information systems (formally sociotechnical and organizational system gathering, processing, containing, and distributing data) (Piccoli & Pigni, 2019).

A smart city combines ICT (Information and Communication Technology) and IoT (Internet of Things) with linked physical features to enhance city operations performance in serving the residents (Curiel et al., 2017). City officials can use the smart city technology for interaction between the community and infrastructure to keep an eye on the city activities and development process. Information and communication technology (ICT) can be used for various purposes like cost consumption, resource utilization, increased urban service performance and linking residents to the state (Forward, 2016). Smart city systems can maintain instant communication and monitor urban activities (Komninos, Pallot, & Schaffers, 2013). Consequently, smart cities are better equipped than traditional cities in facilitating the transactional relationships between residents and service providers. Smart cities engage residents more actively within their communities. However, smart city assessment is a comparatively underdeveloped term and open to further expositions (Cavada, Hunt, & Rogers, 2014).

6.1.2 Origin of smart city concept

The concept of a smart city is based on a number of previous paradigms like digital city, virtual city, ubiquitous city, intelligent city, creative city, knowledge city, hybrid city, information city, and wired city (Albino, Berardi, & Dangelico, 2015; Caird, 2018; Nam & Pardo, 2014; Zygiaris, 2013). Societies are experiencing rapid change through the evolution of electronic technology and prospective virtual reality. The positive benefits of telecommunication technology have shaped an emerging trend that is increasingly accepted by the general population.

6.1.3 Digital city

Since the mid-1990s, the technological development of Information and Communications Technologies has shaped our reality through features such as high-speed data transmission, computing powers of microprocessors, the World Wide Web, and the distribution of multimedia information via the internet. Far from just being an academic network, the internet has developed into a popular comprehensive global information web (Aurigi, 2016, p. 3).

In general, the digital city concept is enabled by the technologically connected web of urban space intended to facilitate better management and communication through the Internet of Things. The digital platform is designed to process enormous amounts of information, promising affordable services and amenities to residents and regular updates to urban management. The idea of digitalization is the main factor impacting the sustainability of cities and offers innovative urban logistics, mobility, and many more. Both electronic- and print media introduced premature terms related to ICT like virtual city and cyber-city (Aurigi, 2016, p. 4). This information revolution is the most significant turning point in human history since the industrial revolution (Cairncross, 2002). A practical experiment initiated by Gateway and Microsoft in a North London neighborhood provides some indications of changes in the residents' behavior while browsing the internet, as described by Judy Gibbons

(Director, Microsoft UK) (Ritterband, Thorndike, Cox, Kovatchev, & Gonder-Frederick, 2009). This 1990s London scenario has now become common in global contemporary urban culture. Interestingly, London neighbors are now less interested in physical encounters with each other after engaging in virtual communication.

During the 1990s, the internet received significant attention among European countries who invested in certain ventures to resolve urban rejuvenation problems by incorporating linked websites under the label of digital cities. Digital cities in Europe were first inspired by American and Canadian ventures like Freenets and Community Networks (Van den Besselaar & Beckers, 2003). In 1994, the Netherlands launched an experimental project called "The Digital City" (DDS), which attracted the attention of social scientists and the media. In 2001, DDS became a successful public domain and commercial digital platform.

The term "digital city" was first introduced in Amsterdam in 1993, whereby "DDS" is the abbreviation of the Dutch *De Digitale Stad.* DDS was also known as the "virtual city" until 2001. The initial application of the Digital City, as the intersection of the universal economic system and communication, was relevant to the transformation of cities (Castells, 2011; Sassen, 2013). While ICT reshaped the global economy, the digital city also became a network society enabling cities and regions to share the benefits. It created new opportunities for local economies to take part in global profit sharing. The network society (Castells, 2011) replaced the previous industrial society as it does not depend on global centers for international systems. Local communities are now experiencing higher competition than ever before as a result of ICT infrastructure.

6.1.4 Virtual city

Conceptually, a virtual city is a combination of the virtual space and the physical urban space, including its residents (Albino et al., 2015). The virtual city is a realistic model of an actual city that enables a person to experience walking or flying through it (Omer, Goldblatt, & Or, 2005).

6.1.5 Ubiquitous city

Information and Communication Technology has already taken over knowledge management and is paving the way to the age of self-managed intelligence systems (Klosterman, 1997). ICT is vital for urban planning, aiming to improve the quality of place and quality of life by covering points such as civic amenities, resource conservation, urban policy management, and collaboration between professionals and public or private interest groups. Traditional urban management includes manuals, reports, databases, and schemes in which information is not readily available to end-users. Here, ICT can serve administrators and residents by providing a wide range of services and information.

At the beginning of the 1990s, Ubiquitous Computing was first introduced at Xerox Palo Alto Research Centre in the United States (Weiser, 1993). The main objective was to facilitate connections between people and between people and goods and amenities anywhere and anytime within the urban environment (Mitchell, 1999). Immediately thereafter, the Republic of Korea adopted the Knowledge-Based Urban Development (KBUD) with the policies called Cyber Korea, *E*-Korea, and U-Korea. More specifically, U-Korea aimed for knowledge-based communities with ubiquitous computing technology and ICT within the urban areas (Lee, Han, Leem, & Yigitcanlar, 2008).

Ideally, the U-city offers services to residents without any limitations to place or time through ICT-based web services. The U-city was instrumental in transforming a traditional city into an E-city and then into a U-city through creativity, modification, and intellectual ability.

A ubiquitous computer system works with a human–computer interface to support user intention. The service is easily available through air or power sockets almost anywhere. Users need not carry any personal devices because generic ones are embedded in the environment. These anonymous devices collect information about user's natural activities and lifestyles where computers come into use rather than through users needing to access computers (Winter, 2008).

6.1.6 Intelligent city

An intelligent city makes deliberate attempts to use information technology to enhance quality of life and work (Komninos et al., 2013). The term "intelligent" refers to the ability to serve learning, technological development, and creativity within city spaces. In relation to the digital city, it must be noted that not all digital cities are intelligent cities, but all intelligent cities contain digital components, whereby the "people" component is excluded from intelligent cities but included in smart cities (Woods & Wheelock, 2013).

6.1.7 Creative city

The term "creative city" was first introduced in 1988 and has become a globally accepted city planning type (Yencken, 1988). A creative city is committed to providing suitable places with creative activities and equal opportunity experiences for residents. Creative city centers accommodate creativity within a specific structure that has three tiers of users, spaces, organizations, and institutions, namely the "upperground," "underground," and "middleground." The "upperground" includes firms and creative enterprises that can transform creative products into dispensable standard amenities. The underground integrates individual creative professionals such as inventors, writers, and artists delivering creative products to society. The middleground encompasses physical environments such as neighborhoods full of creative residents, art galleries, meeting places that attract creative people, organizations like art collectives. Areas for physical gatherings enable people to exchange ideas and work at different levels. Richard Florida pinpointed certain aspects of the creative prospects of cities and classified cities according to a creative index (Florida, 2005).

6.1.8 Knowledge city

Historically, Florence was the first knowledge city in which the urban management was based on a nexus of economic and industrial resources. A more recent example is the rise of companies such as Google and Apple in Silicon Valley in the United States. Other examples of knowledge cities are Cambridge, Manchester, Eindhoven, Bangalore, New Songdo City, and Singapore (Huston & Warren, 2013). Recently, the knowledge city has become the standard trendsetter in terms of job opportunities and attaining funding. However, the knowledge city is a disputed concept, which has resulted in various cloudy discussions. Historically, utopian master-planned cities such as "Fordlandia" and "New Australia" were unsuccessful (Grandin, 2009). Planned cities such as Abuja and Brasilia were impractical and thus malfunctioned (Mumford, 1961, p. 622). A knowledge city usually fosters knowledge (Edvinsson, 2006) and a modified urban environment promoted by a web-based cloud mechanism with an urban detection system (Albino et al., 2015), where sensors gather data and process them to improve urban functionality (Hancke & Hancke Jr, 2013). Although a knowledge city, by nature, accepts all data from any source (Mitton, Papavassiliou, Puliafito, & Trivedi, 2012), it sometimes undermines the smart city concept (Albino et al., 2015). A knowledge city is often criticized for the fact that its technical ability is more dependent on human effort, which prompts the property investment sector to consider it carefully (Huston & Warren, 2013).

6.1.9 Wired city

In the 1970s, a wired city first came into being when Japan and United States invested in interactive cable projects in the public and private sectors. Japan launched the Tama New Town project in 1972, and the National Science Foundation was launched in the United States in 1974. Later, Warner Communications started the QUEBE (30 channel cable television system) commercial project in the United States in 1977 (Targowski, 1990). These preliminary versions of a wired city served citizens with facilities like voting, shopping, and jobs, among other things (Dutton, 1987). In relation to this, the term "information economy" requires clarification: "The information economy is perceived as the production of knowledge, its distribution, acquisition, transmission and communication" (Targowski, 1990, p. 4). An information economy converts economic performance occurring in the central business districts into wired cities. It was predominantly the computer revolution that globalized the commercial and political sectors, thus expediting the formation of multinational enterprises, known as consortia, beyond local boundaries. A well-known example of this kind of borderless company in Europe is the ABB (combining Sweden's ASEA and Switzerland's Brown-Boveri), which was formed in mid-1987. Until 1990, 1000 companies from 100 different countries were united under the umbrella of ABB, which now includes well-known multinational brands such as IBM, Honda, Coke, Sony, McDonalds, and Toyota (Naisbitt & Aburdene, 1990).

An electronic global village, where international and interorganizational subsystems of computer web networks take a vital role on an interactive platform, was commercially and publicly developed. The New Economic Order, introduced in 1970, was connected to the New International Information Order (NIIO) to integrate data processing. NIIO was seeking a power shift from developed to developing nations through a solution to bring balance to the situation (Ganley & Ganley, 1989).

6.1.10 Information city

An information city is often mentioned in conjunction with the smart city and eGovernment or eGovernence, which aims to grow an information society through ICT information services that engage residents in decision-making processes (Fietkiewicz, Mainka, & Stock, 2017). Typically, "Informational World Cities" are knowledge-based, innovative, digitally interactive, and smart global cities. There are five pillars that make an information city, namely (1) information dissemination (catalogue) (online contents, usability, and accessibility) (Al-Khalifa, 2012), (2) communication (social media—Facebook, Twitter, Youtube, blogs, electronic media) (Hartmann, Mainka, & Peters, 2013), (3) transaction (eGovernment services like voter registration, driver's license renewal, public park information, booking services, tax returns, penalty or infringement payments) (Cook, 2000), (4) interoperability (integration) (sharing information between public and private organizations) (Pardo, Nam, & Burke, 2012), and (5) participation (eParticipation, political surveys, discussion forums) (Medaglia, 2012).

6.1.11 Relationship between smart city, knowledge city, U-city, and virtual city

A ubiquitous city is similar to a smart city or knowledge city, which makes access to computing available to the urban residents in all buildings, infrastructures, and public spaces. In general, a ubiquitous city is an advanced version of a smart city, which ensures better accessibility to universal computers to urban elements (people, infrastructure, and places) anywhere and anytime (Greenfield, 2006; Townsend, 2013). There is a significant difference between a U-city and a virtual city. A virtual city regenerates urban elements in its own relevant cyberspace, while a U-city is created by the computer chips and sensors incorporated into these urban elements. The main unit of a U-city works with the sensor and webs to constantly share information with computers placed with citizens, buildings, infrastructure, and any urban space gadget. Real-time communications connect user to user, user to object, and object to object—whereby computers are invisible. It is clear that of the urban components, people are the cornerstone of a smart city that is missing the other concepts and thus make a big difference here.

6.2 Different approaches to smart city assessment

Studies on Smart City Assessment (SCA) tools are limited, and the field requires further research. Of the two main approaches adopted by researchers, one is providing an overview of tools, and the other is presenting a detailed analysis of the tools to explain their subject-based typological indicators (Sharifi, 2019, 2020a, 2020b; Sharifi & Allam, 2022) (see Table 6.1).

6.2.1 Overview of tools

Smart ranking system, University of Vienna

Recently, a smart city ranking system, using an analogical set of indicators to compare differences and drawbacks, was introduced in Europe. Further to defining differences, the smart ranking system illustrates viewpoints for progressive targets and pinpoints strong and weak issues in a comparative manner (Giffinger et al., 2007).

In order to confront new challenges that affect economic and technological advancement, European cities decided to be competitive and aimed to meet sustainable targets. This

TABLE 6.1 Different SCA approaches.

	Approach	Initiator/Origin	References
1	Smart ranking system	University of Vienna	Albino et al. (2015)
2	Smart 21 communities	The Intelligent Community Forum	Albino et al. (2015)
3	The Global Power City Index	Institute for Urban Strategies The Mori Memorial Foundation	Albino et al. (2015) and Ichikawa, Yamato, and Dustan (2017)
4	Smarter Cities Ranking	Natural Resources Defense Council, USA	Albino et al. (2015)
5	The World's Smartest Cities	Joel Kotkin	Albino et al. (2015)
6	IBM Smarter City Ranking	The IBM Smart City	Alizadeh (2017) and Albino et al. (2015)
7	The City 600	The McKinsey Global Institute rankings	Dobbs et al. (2011) and Albino et al. (2015)
8	The Smart City Maturity Model	The Scottish Government and Scottish Cites Alliance	The Scottish Government (2014) and Caird (2018)
9	The Smart City Reference Model	Smart Cities Association	Caird (2018)
10	The European Smart Cities Ranking (ESCR) Model	Vienna University of Technology; University of Ljubljana; and Delft University of Technology (www.smart-cities.eu)	Caird (2018), Giffinger, Fertner, Kramar, and Meijers (2007)
11	The Smart City Index Master Indicators (SCIMI) framework	Smart Cities Council	Caird (2018) and Cohen (2014)
12	The Ericsson Networked Society City Index	Ericsson Limited	Ericsson Ltd (2014) and Caird (2018)
13	The Cities of Opportunity Index	PricewaterhouseCoopers/Partnership for New York City	Caird (2018)

initiative tackles a few prominent issues such as housing, economy, culture, and social and ecological conditions but considers only medium-sized European cities with populations of 100,000–500,000 citizens. To achieve optimal outcomes, a smart city considers 81 components, 28 domains, and 6 key fields (smart economy, smart governance, smart living, smart people, smart environment, and smart mobility) chronologically.

A smart city operation is based on 6 characteristics, each characteristic is defined by 31 factors, and each factor is described by 74 indicators. However, operational systems now include "transformational ability" and "political issues and viewpoints," which is an underdeveloped field that still lacks data.

In the following, the characteristics of a smart city are briefly described. A smart economy (competitiveness) is based on an innovative spirit, entrepreneurship, economic goodwill and branding, productivity, a flexible labor market, international involvement, and transformability; smart people (social and human resource) value qualifications, long-term learning, socioethnic multiplicity, adjustability, innovativeness, and are easy going; smart governance (participation) includes taking part in decision-making, public amenities, clear administration, political vision; smart mobility (transportation and ICT) encompasses local and global accessibility, ICT being readily available, and resilient transportation; smart environment (natural resources) consists of appealing natural conditions, addressing contamination, ecological protection, resilient resource management systems; and smart living (quality of life) considers the availability of cultural resources, health, personal safety, quality housing, quality education, touristic value, and social integrity.

In a city ranking involving cities from different regions (Giffinger et al., 2007), Luxembourg, Aarhus, and Turku come out on top with a big gap between them and the other ranked cities. Craiova, Pleven, and Ruse ranked lowest on the list. The smart city ranking system is more focused on informing indicators rather than achieving higher positions for medium-sized cities. This system includes the cities that are generally overlooked in favor of the larger international mega cities. Information gathered from various sources, including public-, private-, and independent authorities. The indicators used in the smart ranking system are based on strong and weak applications, respectively. A positive side effect of this assessment system is that low-performing cities can learn from the high-performing ones to inform their own progress.

Smart 21 communities

A nonprofit research organization named The Intelligent Community Forum (ICF) investigates the socioeconomic development of 21st century communities. In this industrialized era, developing nations and communities are facing a greater challenge in the development of jobs, investment, and experience in balance with smart communication (Albino et al., 2015). The Intelligent Community Forum introduced an annual awarding system called Smart 21 communities with the five main components of broadband connectivity, learned workforce, digitalization, creativity, marketing, and advocacy. The ICF works to bring together the world's sustainable communities on a common platform by adjusting the demands of a Broadband Economy toward a sustainable future. The ICF mainly conducts research, organize conferences, publications, and offers annual awards to inspire its community members (Intelligent Community Forum, 2021).

The Smart 21 community objectives challenge several traditional issues. Broadband economy prefers adaptability to legacy, skills to resources, and creativity to geographic position. In this community, there is not a single "best" example. Each community has its own unique challenge and strategy to survive. Success and failure stories are shared in the communities to share the advantage of learning from experience. The ICF shares, celebrates, and brands the best examples through annual awards. According to the ICF, a town, village, city, urban area, state, province, or any other type of region is considered a "community." Since 1999, the award has been presented at the ICF's meeting at New York City, in partnership with the Polytechnic Institute of the New York University.

Global power city index (GPCI)

The Institute for Urban Strategies, the Mori Memorial Foundation, initiated the GPCI ranking system based on "magnetism," or significant attraction factor, to unite people, resources, and ventures around the globe (Ichikawa et al., 2017). This ranking system is based on multifaceted considerations of the six factors of economy, research and development, cultural mix, livability, environment, and accessibility. The GPCI's top 10 ranked cities are London, New York, Tokyo, Paris, Singapore, Amsterdam, Berlin, Seoul, Hong Kong, and Shanghai. Since 2020, London, New York, and Tokyo have kept their top three positions. The ranking might change according to varying components (Institute for Urban Strategies, 2020).

The smarter city ranking

In the United States, the Natural Resources Defense Council annually releases a smarter cities ranking through their website (Smartcitiesdive, 2021). Cities with a population of over 50,000 are considered in their ranking. Cities are categorized into three groups to compare them against others with similar environmental-, social-, and economic conditions. The main components considered in this ranking system are air quality, energy generation and preservation, ecological benchmarks and participation, recycling, transportation, green buildings, green spaces, living standards, and water quality and conservation. The smarter cities ranking system collects data from the US Census Bureau and the National Geographic Society (Green Guide), which assesses medium-size cities against 30 categories. The data are sorted into four main categories for each of which a city can score a maximum of either 5 or 10 points. The summation of points for these four categories determines the city's ranking. The four categories are electricity (10 points), transportation (10 points), green living (5 points), and recycling and green perspectives (5 points). The score for electricity is determined by renewable resources such as solar, wind, biomass, and private power resources such as personal solar arrays. The use of public transportation and carpooling determines the scores in the transportation category. The green living score depends on the US Green Building Council's rating as well as the proportion of available green spaces, public parks, and natural restorations. The recycling and green perspective score depends on recycling programs and resident participation (White & Duram, 2013, pp. 186, 187).

The world's smartest cities

Joel Kotkin (Albino et al., 2015) published a list of the world's smartest cities based mainly on compactness, performance, and economic stability. Joel's ranking inspires a city to be a business hub, engage in international trade, and attract global capital. This ranking leans more toward ecological or green indicators and thus excludes many mega cities such as New York, Tokyo, Sao Paulo, and Mexico City. This ranking considers less dynamic economies such as Portland, Oregon, Honolulu, and Scandinavian capitals. Joel Kotkin has attributed a similar importance to economic basics as living conditions and urban infrastructure. These cities are less risky than mega cities, which suffer from uncontrollable property prices, congestion, and expanding income disparities.

On the other hand, today's smart cities tend to be smaller, such as Amsterdam, Seattle, Singapore, Curitiba, and Monterrey. Singapore is considered the present-day Venice due to its comparatively low population, robust income status, high per capita GDP, and because it has one of the best-educated populations compared to European mega cities. Singapore Airport is the world's fifth largest, the seaport has the second-largest cargo volume capacity worldwide, and substantial foreign investment includes more than 6000 multinational companies and 3600 regional headquarters. Recently, the World Bank's International Finance Corporation considered Singapore the top place to do business. Even after an economic downturn, their quick recovery is noteworthy and far surpasses that of other Chinese and other Asian economies.

Hong Kong is rated as the world's third favorite place to do business according to the World Bank. Hong Kong enjoys greater privileges and freedoms than mainland China. Hong Kong has the world's third-largest container port, a quality airport, and wider entrepreneurship facilities.

Aside from Singapore and Hong Kong, there are some cities such as Curitiba that perform very well in terms of telecommunications, incomparable specialized chemical industries, and commercial machinery. Their uncommon initiatives like a library for the disadvantaged community has set an example for the rest of the world.

Amsterdam is a well-established European financial hub that has been attracting foreign investors (primarily American) due to low taxes. Amsterdam has benefitted from an educated society, a diverse population, and minimum political corruption (Kotkin, 2009).

Canada also seems to be the home of a number of smart cities such as Calgary and Alberta. Worldwide, the top-ranked cites are (1) Singapore, (2) Hong Kong, (3) Curitaba, Brazil, (4) Monterrey, Mexico, (5) Amsterdam, (6) Seattle, (7) Houston, (8) Charleston, (9) Huntsville, and (10) Calgary.

IBM smarter city index

IBM introduced their smarter city index in 2010 to address the 21st century challenges with their local government partners in 130 cities around the world (Alizadeh, 2017). This approach is used for multidimensional integration in the process of forming cities as it offers a new concept of private–public collaboration, and, in some cases, seeks smart strategies through digital enterprises when national and regional support is lacking. Here, the local scale governance is closely connected with global technological giants.

Smart cities are urban areas that invest in telecommunication technologies to increase their citizens' quality life, working conditions, and resilience (Deakin, 2013). From a strategic planning perspective, there are a few pitfalls in smart city discourse. First, empirical research on smart city approaches is rare. Second, there is a distinct lack of smart city studies on various localities. Third, joint ventures and coinitiatives among interest groups (local councils, scholars, root-level initiatives, community interests, and technical bodies, etc.) mostly come about as the result of conflict rather than cooperation. There is no single remedy or panacea (Kitchin, 2014) that is applicable to the various socioeconomic contexts to achieve the smart city goals (Neirotti, De Marco, Cagliano, Mangano, & Scorrano, 2014).

IBM launched the Smarter Cities Challenge in 2011 and recruited 800 specialists to work with 130 city governments to address their urban challenges. The teams worked on digital solutions in different fields like resident participation, safety and security, transportation, resilience, economic growth, social amenities, and land development. Based on previous initiatives (i.e., Paul et al., 2011; Kehoe, 2011), IBM categorizes the strategies into the five main areas of water management, public safety, transport, buildings, and energy supply. IBM emphasizes interdomain integration among the five aforementioned areas, which directly challenges the classic government model that only focuses on infrastructure and civic services. IBM enforced the application of interconnected networks-based technology to understand and control the operations, optimize the utilization of resources, and achieve better solutions.

IBM was the first to realize the importance of the digital urban paradigm involving global digital enterprises like Google, Cisco, and Siemens. IBM is also suspected of having the attitude of carrying out free testing first and charging later (McNeill, 2015).

The IBM Smarter Cities Challenge considers different types of cities with various geographic positions, population sizes, and densities. Those cities are then filtered to subcategorize the medium-sized cities with populations between 500,000 and 2,000,000. Cities are selected from North America (39), Europe (18), South America, Africa, Asia (30), Oceania (6), and Australia (5), and the cities are grouped into the four categories of small (<500,000), mid-sized (500,000–2,000,000), large (2,000,000–10,000,000), and mega (more than 10,000,000). Cities of various sizes are included. For instance, the smallest city is Makati (22 m^2) in the Philippines, and the largest is Pingtung (2776 m^2) in Taiwan. The Asian cities have a higher population density than the North American cities of similar population size. About half of the cities are medium sized.

A smart city is not a dedicated notion that is only applicable to larger cities anymore as half of the participating cities in this ranking system are mid-sized. That means that any city can participate in the IBM smarter city ranking, irrespective of its size (Alizadeh, 2017).

This IBM ranking system analyzes cities on two levels. First, the majority of participating cities (75%) deal with a single challenge, while less than a quarter of cities (24%) want to address more than one challenge in collaboration with IBM, and only one city has already worked with IBM in looking for digital solutions to three urban challenges (economic, health, and education), namely Chonburi, Thailand (population size of 219,000). Second, 10 topics have been defined to address the challenges of administration, citizen engagement, economic development, education and workforce, environment, social services, transportation, and urban planning. The administration falls under the overarching category of E-government.

The majority (84%) of mid-sized cities are focused on only one topic, while the rest (14%) are focused on two topics. None of the cities in this category focus on three topics. In this category, economic development is the most popular topic, followed by transportation and the environment. Further analysis has organized the data to find a comparative city wise income level and the popular topics of Smarter City Challenge like administration, citizen engagement, economic development, education & workforce, environment, public safety, social services, transportation, and urban planning (Alizadeh, 2017, p. 77). The environment topic in many cities.

Lessons and criticism: As 75% of all participating cities and 85% of mid-sized cities focused on just one topic, the multidimensional approach of the IBM smarter city challenge is somewhat pointless (Alizadeh, 2017). Moreover, IBM was not able to carry out its multidimensional approach for every city. However, IBM is supporting local governments who are already under pressure due to very limited support from federal and state government. The role of the local governments as the host organizations has been questioned. Further research is required to define the role of local government in the policy-making road map. International collaboration is a determining factor in this regard that requires information sharing among participating interest groups.

The McKinsey global institute rankings

McKinsey, a management consulting firm established in 1926, advocates strategic management solutions to governments, corporations, and organizations. The McKinsey global institute ranking considers 600 cities around the globe under the five categories of megacities (23 cities with a population of over 10 million), large middleweights (45 cities with 5–10 million inhabitants), midsize middleweights (143 cities with 2–5 million inhabitants), small middleweights (389 cities with a population of 15,000 to 2 million), and other cities and rural areas (Dobbs et al., 2011). There are 1.5 billion people living in these 600 cities, which is about 22% of the global population and includes about 485 million households with an average per capita GDP of US$ 20,000. It is estimated that about 2 billion people will be living in these 600 cities by 2025. This will include 500 million households with an average per capita GDP of US$ 32,000 and a further 235 million households in developing world cities with an average income of above $20,000 per annum.

According to McKinsey, the 600 cities will reach global growth by 2025, which means that the middleweight cities will be gaining ground on the mega cities, approximately three-quarters of the cities' economies will be emerging, the populations of the 600 cities will grow 1.6 times faster than the global average, emerging economy cities will have greater income levels than developed cities by 2025, and clusters of cities will have great market economy potential that companies should consider (Dobbs et al., 2011).

The smart city maturity model

A collaboration between the Scottish government and the Scottish cities Alliance was commissioned to develop the smart cities maturity model and self-assessment tool to promote the following:

- identify current status to determine a starting point for the smart city roadmap;
- estimate the future position for 2020 according to strategic preferences;
- determine the required investments and adjustments; and
- look for potential partnerships with other cities.

One main objective of this model is to outline the investments for the Scottish Cities Alliance to inform the application for the European Structural Funds 2014–20 program by early 2015. The Scottish Government used this maturity model to not only meet the aforementioned objectives but also to reuse it for different communities.

The Smart City Maturity Model (see Table 6.2) is useful to determine a city's current status, whereby the following table is reproduced. The key dimensions for this model are strategic intent, data, technology, governance and service, and stakeholder engagement. These dimensions provide the frame of reference for the set of evaluation questions.

The smart city maturity model seeks to optimize outcomes by beginning from the current status, which is determined based on five levels. This model guides cities to involve consistent planning and deliver amenities, such as transport, within an interconnected system. This system is linked and backed up by information, digital technologies to convert services, governance, and stakeholder involvement. Through the self-assessment stage, cities are required to define their level of achievement toward their goals. The investment planning is determined in accordance with relevant sectors, namely public transport, energy, water, waste, economy, and health. Cities are prompted to analyze their domain against drawbacks and attempts to offer local government to achieve digital smart solutions anywhere (Alizadeh, 2017, p. 78).

TABLE 6.2 Smart City Maturity Model (The Scottish Government, 2014).

	Level 1 Ad hoc	**Level 2 Opportunistic**	**Level 3 Purposeful and repeatable**	**Level 4 Operationalized**	**Level 5 Optimized**
City management status	Siloed	System collaboration	System integration	Managed system	Sustainable and open "system of systems"
Smart City status	Operation focused digital and data driven service improvement	Holistic system thinking and emergent sharing of data	Strategy led and outcome driven. enabled by system—wide technology investment	Technology and data enabled dynamic sense and response systems	Continuously adaptive city—wide "smart" deployment
Effect on outcomes	Capturing evidence and building business case	Cross boundary partnerships emerging to focus on shared outcomes	Shared accountability for outcomes and joint system—wide investment program	Improved prediction, prevention and real-time response delivers improved outcomes	City—wide open "system of systems" approach drives innovation that enhances city competitiveness

The smart city reference model

The smart city reference model is an attempt to assemble smart city narratives like green, interconnected, instrumented, open, integrated, intelligent and creative layers to compose a planning framework. This model could be used in a range of smart programs involving green, broadband, and urban economy agendas. A smart city planner might benefit from this model by using any of its layers. There are seven layers in this model (Zygiaris, 2013).

- *Layer 0*: The City (components: governance, orchestration, infrastructure alignment, district regeneration, smart urban planning, smart identity branding, community involvement).
- *Layer 1*: The Green City Layer (components: alternative energy master plan, water conservation, green transport, green building policy, CO_2 reduction master plan).
- *Layer 2*: The Interconnection Layer (components: WiFi 802.11, Wi-Max 802.16, Radio communication, satellite communication, 3G+, ethernet, fiber optics, BPL, city-wide broadband, economy enabling infrastructure plan).
- *Layer 3*: The Instrumentation Layer (components: sensors, activators, WSAN, B_WISE, RFID, Internet of Things, city's infrastructure for "real and connected" life).
- *Layer 4*: The Open Integration Layer (components: urban OS, geospatial, smart grids, ontologies, semantic WEB, linked APIs, cloud, open and integrated urban operating system).
- *Layer 5*: The Application Layer (components: i-energy, i-transport, i-democracy, i-government, i-services, i-home, added value city-wide intelligent services).
- *Layer 6*: The Innovation Layer (components: new business models, living labs, creative class, Web of Trust-WoT, new business models for smart growth and quality of life).

European smart cities ranking (ESCR) model

The ESCR model was first introduced in 2007 and aimed to assess 90 medium-sized (300,000–1 million residents) European cities from 21 countries. This model uses 6 dimensions, 90 indicators (15 economy, 10 governance, 31 smart living, 11 smart people, 10 environmental, and 13 mobility indicators) (Escolar et al., 2019). The ESCR model applies development and performance indicators based on local, regional, and national data from European nations (Giffinger et al., 2007).

The European Smart Cities Ranking (ESCR) Model offers the six indicators of governance, economy, people, living standard, environment, and mobility (Giffinger et al., 2007).

The Smart City index master indicators framework

The Smart City Council founded the longest-running global smart cities ecosystem named The Smart City Index Master Indicators Framework in 2012. This framework uses different components of environment, mobility, governance, economy, and people (Cohen, 2014). The Smart Cities Council expanded their scope to various regions such as Southeast Asia, Australia, New Zealand, Europe, India, North America, and other locations worldwide. The Smart Cities Council also expanded their scope beyond the single city concept and began working at different scales, including metropolitan regions, conglomerations, regional cooperation, districts, neighborhoods, rural areas, campuses, and military setups. This framework considers significant driving forces such as growing urbanization, growing stress, inadequate infrastructure, growing economic competition, emerging environmental challenges, the capability of technological development, and many more. The considered barriers are the fragmental implementation approach, emerging expectations, uninformed residents, shrinking budget, and a lack of investment capital. The set goals include enhancing livability, improving quality of life, creating job opportunities, and improving sustainability (Caird & Hallett, 2019). The SCIMI framework works similarly to the ESCR model but includes more international data sources of buildings and cities (Cohen, 2014).

The Ericsson networked society city (ENSC) index

Ericsson Limited and Sweco Limited established The Ericsson Networked Society City (ENSC) Index, which determines the ICT maturity against infrastructure, readiness, and usages that correspond to the development, discharge, and adjustment of ICT infrastructure and technology. Here, a strong relationship between ICT maturity and sustainability (triple concept of economy, society, and ecology) is maintained (Caird & Hallett, 2019). This index is intended to work on a networked society to address the sustainable development challenges of global climate change, air pollution, fossil-fuel dependency and meeting socioeconomic targets. The ENSC vision is intended to make use of ICT in new urban planning, policy development, resilience, participation, mobility, and collaboration to create an attractive image of the future of the Networked City (Ericsson Ltd, 2014).

The cities of opportunity index

PricewaterhouseCoopers/Partnership for New York City established The Cites of Opportunity (CoO) index, which measures smartness, quality of life (QOL), and economic components of the world's leading cities (Caird & Hallett, 2019) using open data sources. This general index considers intellectual capital and innovation, technology readiness, and city gateway indicators. In a rapidly growing era of urbanization, the CoO index assesses the best possible options for the people, which it investigates through different considerations like education and technology, quality of life, health and well-being, happiness, and sustainability. For instance, 59 observation-based data points from 30 cities that have been considered for "Cities of Opportunity 6" and some key considerations are highlighted. First, there is a lot to learn from the top-ranking cities as they lead by example. Second, various indicators matter in a city ranking—not just its size and population. Third, according to the quality of life indicator, smaller cities rank higher. Fourth, technology has the capacity to not only connect developed and developing cities but also to link geographical and cultural indicators to set new trends based on traditional practices to challenge the competition. The performance of the top 10 cities is based on their openness to the world, like Paris, London, which is a global hub, and the rest are port cities, and only Beijing and Madrid are inland. Fifth, small cities are considered beautiful, safe, and healthy. A commendable example is Singapore, which also benefits from positive variables in terms of assessing funds, housing quality, and availability. Moreover, sustainability is strongly linked with health and safety. As a whole, this index promotes many interesting and exceptional qualitative approaches like collective behavior change (i.e., healthy eating) in the list (PWC, 2016).

Conclusion

From the observation of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC), it is clear that there is as yet no standard smart city indicator that is accepted. However, certain works are in progress to address smart city evaluation and measurement, including works of International Standards Organization (ISO), European Committee for Standardization, BSI, and many other benchmark organizations (SSCC-CG, 2015). There is no single remedy for smart city solutions (BSI, 2014).

6.3 Underlying principles of smart city assessment

A smart city is constructed on various *principles* (Wang, Li, Cheng, & Li, 2020).

1) The principle of objectivity confirms the aims, facilitates an equitable evaluation, helps in developing a reliable assessment system to reach the target, and ensures reliability, perfectness, and a logical comparison of information sources.
2) The systematic principles connect the different parts of the evaluation system and internal indicators to reflect the global system.
3) The principle of validity ensures consistency with the understanding and structure of the object being assessed and can represent the level of intelligence of the city.
4) The principle of comparability ensures the assessment is configured and comparable, whereby the understanding, quantification, timeframe, and clarity of scope for indicators should be specifically comparable horizontally and vertically to apply to various cities. It should also be applicable to different development phases of the same city.
5) The principle of sustainability not only assures the default condition for a smart city but also evaluates the smart urban development process. The static and dynamic indicators represent the current and future urban intelligence. Indicators should be flexible and open to accepting change at any stage of development.

6.3.1 Importance of smart city ranking

Cities are becoming more involved in worldwide competition than ever before in addressing the ongoing challenges of confronting planning strategies despite changing circumstances. City rankings are gaining traction globally and locally at various scales ranging from metropolitan areas to municipalities, districts, and even neighborhoods. City ranking systems have great potential to contribute to urban planning and management. City rankings are useful for different sectors and stakeholders, including the investment sectors (property development), tourism, labor market, and international event management (Olympics, world cup, and many more) (Begg, 1999). Unfortunately, most of the current ranking systems often fail to inform the relevant indicators (Schönert, 2003), motives, and objectives.

The ranking of cities is often known by different terms like benchmarking, standardization, comparison of cities, city scan, and so on. At least two cities are normally required for a ranking. With scarce literature on the topic, the ranking objectives are not only to address its target group but also to define its spatial scope of work, relevant issues and, most importantly, generate indicators for the ranking. The ranking methodology should consider the shortcomings as well as collecting data. The distribution of outcomes depends on how the results are assessed, analyzed, and displayed (Giffinger et al., 2007).

6.3.2 Dimensions of smart city ranking/benchmarking

Limited research on smart city definitions is insufficient to allow any single definition. However, the six dimensions that have been informed by scholars (Giffinger et al., 2007) are economy, people, governance, mobility, environment, and living. The eight success factors are management and organization, technology, governance, policy, people and communities, economy, existing infrastructure, and natural environment (Chourabi et al., 2012). The five groups of performance indicators are smart governance (participant), human capital (people), environment (natural resources), living (quality of life), and economy (competitiveness) (Lombardi, Giordano, Farouh, & Yousef, 2012). Based on existing research, Liao, Chen, Qian, and Shen (2017) defined five important dimensions for ranking or benchmarking smart city indicators:

1. *ICT infrastructure*: ICT infrastructure consists of wireless web networks like WiFi networks, wireless hotspots, kiosks, fiberoptic channels (Al-Hader, Rodzi, Sharif, & Ahmad, 2009), and service-oriented information systems (Anthopoulos & Fitsilis, 2009).
2. *Economy*: As one of the primary dimensions, the economy can significantly impact the smart city development project. With a higher economic ranking, a smart city could be in a privileged position (Chourabi et al., 2012) and be more competitive in terms of creativity, new business opportunities, trademarks, productivity, an adaptable labor market, and links to local and global markets (Chourabi et al., 2012).
3. *Governance and policy*: Major governance factors are joint ventures, supervision, and advocacy, participation and partnership, communication, data sharing, service and application, accountability, and clarity (Chourabi et al., 2012).
4. *People*: In a smart city assessment, people are considered to play a primary role in changing, adapting, and contributing to the development of smart city assessment. People control

accessibility patterns, guard the community, and are shareholders in partnerships, linking, learning, quality of life, and accessibility (Chourabi et al., 2012).

5. *Natural environment*: The natural environment considers the ecological aspects of conservation, resource management, and energy production-based activities that are directly related to economy (Toli & Murtagh, 2020). Urban resilience is strongly related to natural environment management, but this needs further clarification in terms of smart city ranking.

Researchers have strongly recommended three pillars for smart city development (Tcholtchev & Schieferdecker, 2021).

1. Design principles to develop steady and sustainable ICT for smart cities.
2. A solid prescriptive guideline to dealing with technical and organizational issues.
3. Consistent quality control, certification to ensure security of IT, and information systems in the urban environment.

According to Tcholtchev and Schieferdecker (2021), design principles for sustainable and resilient smart cities are based on various aspects likely blueprints (ICT reference architectures for smart cities, open urban platforms, and standard of belonging), sustainability (sustainable development goals, open benchmarks, open interfaces, open source, open data), resilience (reliable ICT, dependable systems), technology (state of the art, growing technologies), and quality assurance (testing and certification, cyber security, and performance).

6.3.3 Reference models

Reference architecture models are proposed (see Table 6.3) to achieve a horizontal approach. Most of these reference architectures have evolved to include design principles such as open interactive interfaces, open benchmark/standards, open-source information, and artifacts toward ICT improvement and creation (Tcholtchev & Schieferdecker, 2021).

6.3.4 Sustainability, dependability, and reliability

Sustainability is relevant to reliability or dependability, which is the potential of a system or product to perform accurately according to an optimum level within a defined timeframe and with a successful outcome. Dependable systems are frequently mentioned in various studies (Laprie, 1992; Randell, 1998).

TABLE 6.3 Reference architecture models with sources.

	Reference architecture model	Initiator
1	EIP SCC	Heuser, Jeroen Scheer, Pieter den Hamer, and Bart de Lathouwer (2017)
2	DIN OUP	Cuno, Bruns, Tcholtchev, Lämmel, and Schieferdecker (2019)
3	Espresso reference architecture	(Exner, 2016)
4	STREETLIFE project	CORDIS (2016)

6.3.5 Quality assurance for ICT technology

Quality assurance for urban ICT is crucial to achieving dependable, smart city ICT components. Recent research is available that supports industry initiatives to launch quality assurance in the form of smaller-scale single components geared toward a generic goal. Quality assurance has two primary objectives:

a) processing during developing and
b) testing of complex services or systems to establish and run alongside the development process.

Testing is required to address further functional and nonfunctional aspects of both single and multiple components to achieve the overall target. Testing approaches are composed of conformance testing, interoperability testing, load and performance, security and penetration, and usability and acceptance testing (ETSI, 2020). All these aspects are required to provide ICT infrastructures on a greater scale to ensure positive outcomes toward achieving smart city development principles. These aspects are very important for a reliable ICT urban infrastructure to act as a mainframe guideline to follow. The overall structure of dependability consists of three components and their subcomponents. The three components are attributes (availability, reliability, safety, confidentiality, integrity, and maintainability), means (fault prevention, fault tolerance, fault removal, and fault forecasting), and impairments (faults, errors, and failures) (Tcholtchev & Schieferdecker, 2021. pp. 162–163).

6.3.6 Open urban platforms, smart cities, and ICT reference architecture models

Reference architecture models are a prerequisite for blueprints of the ICT infrastructure, which were introduced and modified in parallel to open urban platforms (OUP), initially for Europe (https://eu-smartcities.eu), and later benchmarked (https://www.din.de/en/wdcbeuth:din21:281077528) by quality control bodies like the German DIN. OUP ensure a greater readiness to distribute open interfaces and open standards for data sharing among infrastructure components, systems, and services within the smart city environment. OUP promote the use of open data and open-source tools for data sharing and to achieve the objectives of code transparency. OUP work with different layers, namely common service capabilities, privacy and security capabilities, stakeholder engagement and collaboration capabilities, city or community capabilities, generic city or community capabilities, integration, choreography and orchestration capabilities, data management and analytics capabilities, device asset management and operational services capabilities, communications, network and transport capabilities, and field equipment/device capabilities (Tcholtchev & Schieferdecker, 2021, p. 164).

6.3.7 Quality assurance perspective on smart cities

Fraunhofer FOKUS introduced and developed oupPLUS (Tcholtchev, Lämmel, Scholz, Konitzer, & Schieferdecker, 2018) to ensure quality assurance and to provide services like security and reliability inspired by other models like the Triangulum reference model

(Schieferdecker, Tcholtchev, Lämmel, Scholz, & Lapi, 2017) and the Espresso reference model (Exner, 2016). The oupPLUS, with its firm standing, offers quality technological service.

OUP create a new scope for the smart city through:

- internal operational capability to provide many solutions in different physical environments;
- reproducing and reusing smart city solutions in different cities;
- the invention of a useful ICT ecosystem in urban areas or local communities incorporating the participation of smaller and medium-sized enterprises;
- enhanced usability of open sources;
- avoiding vendor lock-in as the last choice;
- systematic quality assurance; and
- internal confirmation of ICT components, outcomes, and complex systems for a smart city.

6.4 Smart city assessment and climate-resilient planning

It is evident that the climate is changing, and human actions have increasingly been expediting it during the last century. As a result, we are facing more severe weather conditions, a warmer climate, acidification, and droughts that impact our socioeconomic life. Climate resilience is the ability to prepare ourselves to cope with the changes, recover from any prevailing or future harmful situations, and achieve adaptability skills to better handle unfavorable situations. In general, climate resilience is the adaptive capacity of the socioecological system to assimilate stress and manage to perform under the external pressures of climate change and to adjust, organize, and develop to achieve better arrangements toward improved sustenance of the process (Folke, 2006), to be better prepared to face the future climate change challenges (Nelson, Adger, & Brown, 2007). Resilience is often related to sustainability as an integral part of an elaborate climate action plan to better handle climate change. The term "resilience" is generally used in a global sense to refer to local issues of various scope and scales ranging from neighborhood to city level. Resilient action plans could not only minimize risks by protecting people and property but also boost economic gain with better job opportunities and development.

Climate change causes excess rainfall, extreme storms, and other natural disasters that are creating pressures on urban systems, infrastructures, buildings, amenities, and overall management of cities. Cities should take initiatives to retain their prevailing vibrancy, standard feasibility, and operational capability to cope with changing circumstances. However, traditionally international and national governments are not capable of handling local planning issues, as few cities attempt to adapt to changing climatic conditions (Granberg & Elander, 2007; Schreurs, 2008). Local climate adaptation has the three aims of accommodation, protection, and retreat (Carmin, Roberts, & Anguelovski, 2009). While it may seem obvious that it is necessary to understand the driving forces behind climate change in order to plan adaptation measures, the interest in this matter is minimal. Few studies addressed adaptation issues such as the cost and benefit in application (Tol, Downing, Kuik, & Smith, 2004), the necessity to prosecute (Smit, Burton, Klein, & Wandel, 2000), and the emergence of an endangered population (Adger, Paavola, Huq, & Mace, 2006).

6.4.1 Defining climate resilience

Defining climate resilience is an ongoing matter of discussion. Ideally and practically, climate resilience is strongly linked to climate change adaptation covering actor-based or system-based attempts to enhance steadiness of efforts. Nowadays, climate resilience mainly concentrates on the maintenance of existing structures and environments. Of the various available definitions, there are three that focus on absorption, adaptation, and transformation (Boyd & Juhola, 2015; Cooper & Wheeler, 2015; French, Trundle, Korte, & Koto, 2021; Keshavarz & Moqadas, 2021; Lloyd, Peel, & Duck, 2013). The socioecological perspective is a prominent concept of capacity building for the development and auto-regeneration, considering disturbance as a potential for creative invention or way finding to develop existing system's capability to adjust to upcoming changes at the macroscale (Sharifi & Yamagata, 2016; Tompkins & Adger, 2004).

6.4.2 Climate resilience and climate adaptation

Climate resilience distinguishes between the elements of shock absorption and self-renewal when considering climate adaptation. Adaptation is a set of processes and steps that guide an existing system in terms of how to adapt to an existing change or prepare for a foreseeable scenario. From the policy-making viewpoint, the dominating decision-making procedures of climate adaptation differ from climate resilience and could be altered to be more adaptive to changes and thus more productive (Nelson et al., 2007).

6.4.3 Links between climate resilience, climate change, adaptability, and vulnerability

Climate resilience is directly related to climate change, adaptability, and vulnerability. Generally, resilience is a strategy to face an undesirable situation, while climate change adaptation prescribes ground works for recovery from that situation as is applicable to a certain community. This framework results from preconceived ideas about unfavorable impacts of climate change on ecosystems and their services (Smit & Wandel, 2006). Attempts to improve the resiliency might result in adaptive-, nonadaptive-, or a combination of both measures. In the case of an unequal adaptation, the solution would be distributive justice to ensure maximum advantage for the underprivileged population. Various issues require negotiation in terms of defining vulnerable people to confront bias. Vulnerability has two aspects, namely qualitative (contextual) and quantitative (outcome), which requires combined action to determine the state of vulnerability of a certain community. As vulnerability is an ever-changing state resulting from the unwanted effects of climate change, adaptive strategies must prescribe more than one option to achieve the best outcome. Interrelationship of resilience, climate change, adaptation, and vulnerability are clearly shown in Fig. 6.1.

Climate resilience is a new term, but it dates back to the 1960s, when it was used in a biological sense to explain the existence and adaptive measures to assimilate different parameters and components, including state variables and driving variables (Holing, 1973). Ecological equilibrium is the fundamental idea of the natural system being able to maintain

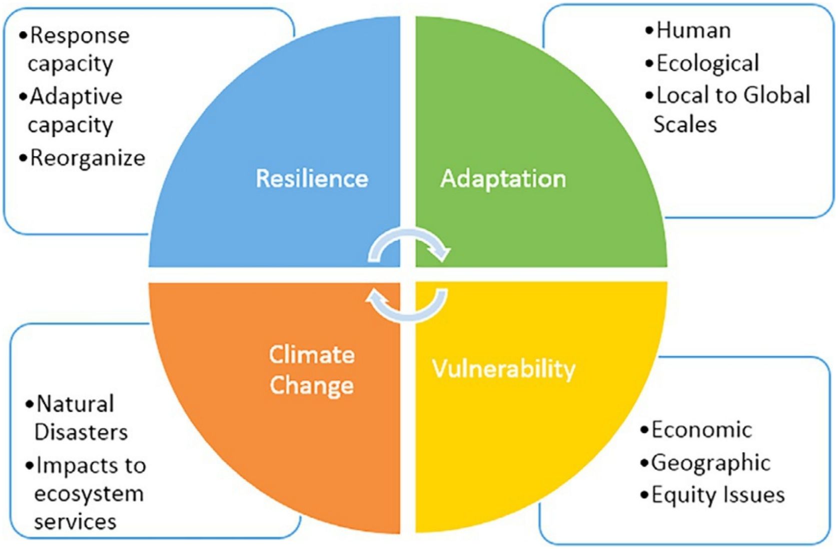

FIG. 6.1 Graphical representation of the connection between climate change, climate resilience, adaptability, and vulnerability (Wikipedia, 2022).

balance, sensitively react to unwanted change, and attempt to minimize its effects to regain the previous stage.

Later research advanced our understanding of the state variables by evolving a new baseline rather than working on a preconceived equilibrium, which means that a mitigating approach is replaced by an incorporated approach to better cope with uncertain situations. This updated perspective works coherently along with components of uncertainty and entropy to first enable changes in different areas, such as adaptive management and natural resources and was thus developed based on initial contributions of Holling (Schoon, 2005).

Resilience began attracting more attention in the field of cultural theory, anthropology, social science, and other relevant fields of study. Since the mid-1970s, resilience began forming as an overarching concept. Concurrently, resilience began shifting from an equilibrium-oriented overview toward a more adaptable ecological system, whereby resilience began to encounter classical schools of thoughts from different backgrounds (Vayda & McCay, 1975).

Since the late 1980s, resilience became established in the literature of socioecological systems, management, integration, and utilization as a defined concept. Rather than functioning purely as a shock absorber, the paradigm of resilience began actively gathering information to better adapt and adopt upcoming challenges. Eventually, with the momentum of climate change and global warming, the concept of resilience emerged in parallel. Various stakeholders now consider climate resilience to be a critical concept in confronting the current and future impacts of climate change. A few concepts have recently become popular in a short period of time that are relevant to sustainable development, nature conservation, and climate resilience. Of these, EbA (Ecosystem-based Adaptation), introduced by the IUCN (International Union of Conservation of Nature) in 2008, is considered to be significant.

The EbA uses biodiversity as part of an overarching strategy to guide residents through the harmful impacts of climate change.

6.4.4 Resilience framework performance on vulnerability

The climate resilience framework acknowledges our understanding of natural processes and enables us to upgrade public and private sector instruments to develop sustainable solutions to managing the impacts of climate change. First, based on the climate resilience framework, a multistable socioecological system was introduced based on a stable equilibrium perspective that only aims to achieve recovery from negative impacts. By contrast, the contemporary interpretations of resilience include the mitigation of various issues associated with the changing circumstances. Second, climate resilience focuses on preventative actions when measuring the impacts of changing climatic conditions, wherein adaptation is a crucial factor. It is difficult to change or return to the initial stage after a climatic change has taken place. Policy-making authorities and stakeholders could achieve better outcomes by limiting the scope of adverse impacts long before they occur (Nelson et al., 2007). Finally, climate resilience fosters interdisciplinary discussions and the exchange of ideas rather than depending solely on literature. The strategy of maintaining a local-, state-, and national adaptation mechanism system will keep it of limited capacity and vulnerable to different risk. A resilient climate adaptation mechanism requires further interactive, communicative, creative, and holistic interpretation to confront climate change (Malhi et al., 2008; Nelson et al., 2007).

6.4.5 Vulnerability

In general, vulnerability is defined as climate vulnerability or climate risk vulnerability or climate change vulnerability. A vulnerability assessment, which determines a region's vulnerability to climate change, is often central in the societal response to climate change as it addresses climate change adaptation, climate risk evaluation, and configuring climate justice. Climate vulnerability is a vast concept covering various definitions, circumstances, and backgrounds. Since 2005, climate vulnerability data have been informing academic research (Füssel, 2007). According to the third International Panel on Climate Change (IPCC) report, vulnerability is the level or degree to which a system is unable to adjust to the harmful impacts of climate change (Bernstein et al., 2008). Vulnerability can take one of two forms, namely economic vulnerability and geographic vulnerability. Vulnerability studies focus on various factors such as equity (local, national, and international), environmental justice, climate justice, and the climate gap.

6.4.6 Emergence of climate resilience

Society is more inclined than ever to develop resilience to the adverse climatic changes taking place. While there are various available tools, strategies, and approaches, there is a need to define an overarching target of developing and managing societal resilience. Climatic resilience must take the study of urban resilience and human resilience seriously.

6.4.7 Urban resilience

Due to the rapidly growing population in the world's urban areas, the adverse effects of climate change on urban areas are receiving significant attention. In urban resilience theory, enhancing the capacity to absorb environmental disturbances is very important. A proposed model for an urban resilience framework has stressed three components that are critical in locally based international level urban resilience planning (Tyler & Moench, 2012).

The first component considers the physical infrastructure-based urban system. This component focuses on connecting maintenance support systems. For instance, primary facilities such as water, electricity, or gas are an integral aspect for urban citizens and failures or interruptions to those services seriously affects their quality of life. Communities should achieve a certain level of resilience to ensure uninterrupted supply or at least safe failure of those urban amenities. Moreover, a resilient system should provide a functional aspect by restoring continuous connection to the system (Tyler & Moench, 2012). Environmental disturbances are obvious, which is why it is important to consider a safe failure.

The second component is the ability to bounce back. In disaster literature, is it considered important to identify the bounce-back capability of a city, which is defined as the capability of a city to regenerate to the point of achieving a functional state after the shock absorption of environmental disturbances due to a disaster. Thus, "bounce-back" has become an integral part of the climate resilience framework (Coaffee, 2013). The focus on "bouncing back" as opposed to "bouncing forward" has been questioned by critics (O'Hare, White, & Connelly, 2016).

The third element focuses on social actors or social agents in the existing urban areas. These urban actors or agents works within the community for their own common interest or gains to preserve, restore, and maintain the existing environment (Tyler & Moench, 2012). Urban agents play a vital role in decision-making by participating in various activities through local governments, community organizations, and active groups, which is critical to their capability and effectiveness in contributing to the resilient urban framework. Therefore, these agents should develop skills and equip themselves to ensure resourcefulness and responsiveness within the framework. Resourcefulness requires a higher capability of mobilizing and managing assets and resources in the urban area.

Finally, urban governance is very important in achieving urban resilience that includes existing social and political organizations in the urban centers. According to climate justice, the least responsible societies and regions are equally affected by climatic disturbances. For instance, rich countries are primarily responsible for carbon emissions through their luxurious lifestyle, while underdeveloped countries have no say in the global decision-making process at all. This is a huge gap that must be addressed in the resilience framework (Lebel et al., 2006). Furthermore, these social and political agents can promptly circulate the public information to the relevant community to ensure a timely response to the anticipated disturbances and threats (Satterthwaite, Huq, Pelling, Reid, & Lankao, 2007).

6.4.8 Human resilience

The global population is more exposed to environmental harms and unfavorable weather conditions than ever before. The ability of each society to deal with these environmental threats differs due to existing conditions and factors such as infrastructure, maintenance capacity, monitoring capacity, preparedness, and their recovery action plan. Considering these differences in resilience, the emergence of a common platform to ensure the development of a maintenance support system is foreseeable (Keim, 2008).

Resilience can take two forms, whereby one is nature-based resilience and the other is human action- or interaction-based resilience. The first one is linked to natural systems like the water cycle or the carbon cycle, which naturally find balance and reach the previous state in a certain period of time. On the other hand, there is the human effort of raising awareness through social organizations to minimize vulnerability to climate change and other unwanted weather conditions. There are two types of vulnerability to climatic disturbances. One is the level of exposure to natural hazards, and the other is the ability to recover from a disaster, also called resilience (Keim, 2008).

Around the world, people are seeking solutions to the threats of extreme climatic conditions. International approaches are widely focused on postimpact activities known as reconstruction, recovery, or regeneration. This trend is beginning to pivot toward a more preimpact disaster risk reduction known as prevention, preparedness, and mitigation (McMichael, Woodruff, & Hales, 2006).

6.4.9 Climate resilience in practice

Climate resilience development requires the active engagement of residents, communities, political organizations, municipalities, the public sector (local, state, and national), the private sector, and international stakeholders. A climate resilience action plan ensures the increased capability of social structures, commercial enterprises, and ecological setups to mitigate the impacts of climate change (Moser & Boykoff, 2013). A recent literature review clearly indicates that successful climate resilience relies upon universal initiatives to ensure firm socioeconomic and political precautions and predictions long before a change occurs. Studies show that countries, states, and communities benefit from a better economic situation when adopting such initiatives (Satterthwaite, 2013). That is why it is an inevitable challenge to confront anticipated social and economic inequalities. National and international interest groups should work together to eliminate poverty and build commercial prosperity and food justice. Although the most climate-resilient cities learned from previous experiences during disasters, real-time initiatives can be undertaken at every level. A climate-resilient framework is highly dependent on several social and political institutions such as democracy, campaigns, and decentralization (Berkhout, Hertin, & Gann, 2006).

6.5 Final remarks

The smart city assessment is a comparatively young concept that has not reached maturity. The smart city has been criticized for being claimed by the private sector and local government partnership, which remains a utopian thought (Hollands, 2020). Even CISCO questioned whether a smart city is mostly a physical design complicated by engineering and architectural ideas and backed by a variety of technologies.

The technological focus of the smart city concept might be more pervasive if more attention was given to advancing automated sensors for energy calculation, water metering, outdoor air quality monitoring, traffic monitoring, and waste management. A smart city assessment should focus on identifying existing gaps to achieve the best outcome through a robust process. The SCA must not limit itself to achieving a good overall rating but should rather offer various dimensional comparative analyzes at different scales for stakeholders. Historical relevance, evolutionary connections, and heritage overview should not be overlooked for the sake of technology. The influential interest of city authorities, investors, scholars, and residents should be considered seriously in the SCA process.

The development of the SCA concept is highly focused on technological advancement and the development of technical tools, which means the other factors are not adequately considered. One major, potentially influential factor is the role of citizens, which is largely overlooked by scholars. From the detailed analysis in Section 6.2, it is obvious that the conceptual development of the smart city slogan of a "multidimensional" approach is a missed opportunity and often overemphasized for some indicators. One possible reason might be the lack of adaptability in planning and strategy. Moreover, SCA often fails to create and work toward a vision of achieving an robust overarching policy to integrate important components strongly linked to relevant factors for the welfare of the city's future. It, therefore, seems appropriate to develop an approach of foresight and to involve residents as a partner as well as a user in the process of smart city development.

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CHAPTER

7

Assessment tools and indicators for smart city assessment

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7.1 Introduction: An overview of the existing assessment tools

There has been an increasing interest in developing and implementing tools and indicators for smart city assessment in the recent years (Sharifi & Allam, 2021). In this chapter, an overview of existing smart city assessment tools is presented through investigating the literature. In the literature, assessment tools are reviewed from both theoretical and empirical perspectives. Sharifi (2019) partially covered this subject in depth and investigated strengths and weakness of smart city assessment tools in different levels and dimensions. He examined the main features of smart city including stakeholder engagement, context specificity, alignment with city vision, crisis management, addressing temporal dynamism issues, flexibility, feasibility, presentation style, and communication of the results.

To build on the earlier work by Sharifi (2019), we try to provide detailed information of existing assessment schemes to provide urban planners with a comprehensive knowledge of smart city assessment tools and enable them to make effective decisions to cope with difficulties in cities. In the following, some general information of characteristics such as geographical focus, scale, target audience, and strategies for development of assessment tools and indicator sets is provided.

To review the existing assessment tools, all existing smart city schemes are studied and scrutinized including how many schemes are developed each year, their frequency according to the scale, geographical focus, target groups, approaches, thematic focus, data format of the schemes, the type of the labels used to show smart city performance, percentage of distribution of smart city dimensions in each scheme, source of and type of data used for assessment, weighting approaches used, and feasibility.

Urban Climate Adaptation and Mitigation
https://doi.org/10.1016/B978-0-323-85552-5.00009-9

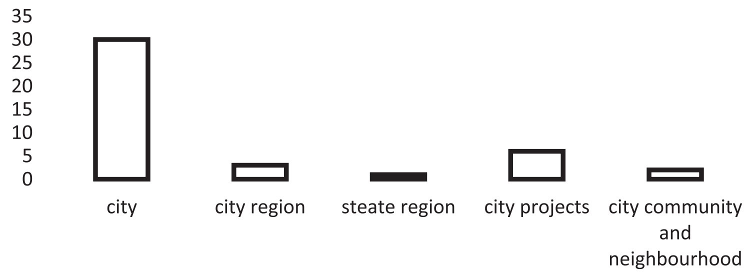

FIG. 7.1 Percentage distribution of smart city schemes at different scales.

According to the information (Fig. 7.1), smart city projects are conducted at different scales, including city, city region, state region, community, and neighborhood. However, according to the existing schemes, the most common scale to conduct smart city assessment is city and the least common one is state region.

According to the literature, these schemes have a diverse target audience. Meanwhile, the main target audiences are policy makers, decision makers, and city authorities (Fig. 7.2).

Almost all the schemes apply two types of assessment: formative and summative. Formative assessment is to monitor the performance of smart cities and provide feedbacks during the process to improve the overall practice and performance. On the other hand, the aim of summative assessment is to evaluate the performance of a smart city in the end of the project to have a final judgment about the outcomes and achievements. Accordingly, unlike the formative approach, summative approach is not process based. Meanwhile, according to the pie chart below which is driven from the existing schemes, most assessment schemes follow a summative approach (Fig. 7.3).

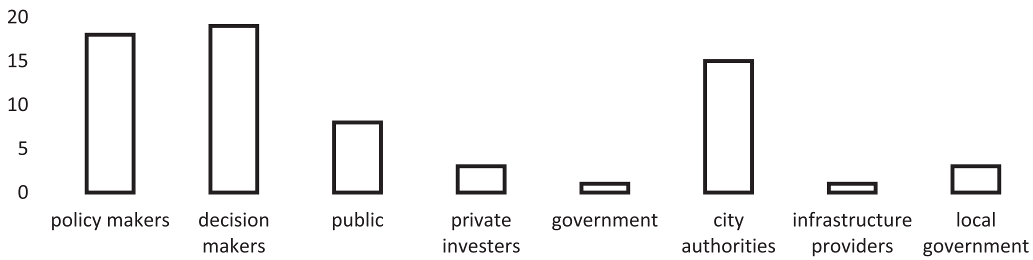

FIG. 7.2 Target audiences of smart city assessment schemes.

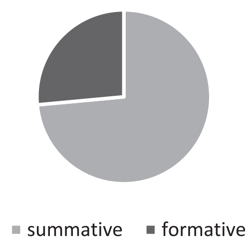

FIG. 7.3 Type of smart city assessment tools.

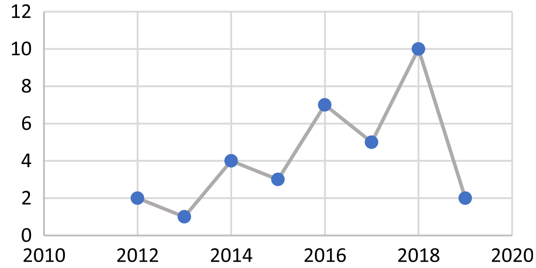

FIG. 7.4 Number of smart city schemes per year since 2012–2019.

We also studied each scheme by the year of publication. It was found that interest in this topic has initiated in 2012, and the majority of the schemes have been developed in 2018 (Fig. 7.4).

In terms of geographical distribution, results show that more work has been conducted in China, United Kingdom, and the United states (Fig. 7.5). It can be seen that countries in the Global South are underrepresented in this regard.

In terms of smart city themes and dimensions, several dimensions such as economy, environment, general smartness, sustainability, quality of life, infrastructure and mobility, and governance could be identified. Most of the schemes are focused on general smartness and governance, and environment has received limited attention (Table 7.1, Fig. 7.6).

The other matter that is studied in this review is the data that the schemes have used, including source of data, type of data, and approaches toward weighting. Data sources include primary, secondary, and both. The majority of the schemes have used secondary data, followed by both types of data (i.e., primary and secondary). Meanwhile, types of data include qualitative and qualitaive. Most of the schems have used both types for performance assessment. Finally, the share of schems which did not use equal weighitng is more than those that use equal weighting (Figs. 7.7–7.9).

Generally, assessment tools follow diverse approaches in terms of the type of data they use, source of data, their thematic focus, their target audiences, and the scale in which the smart

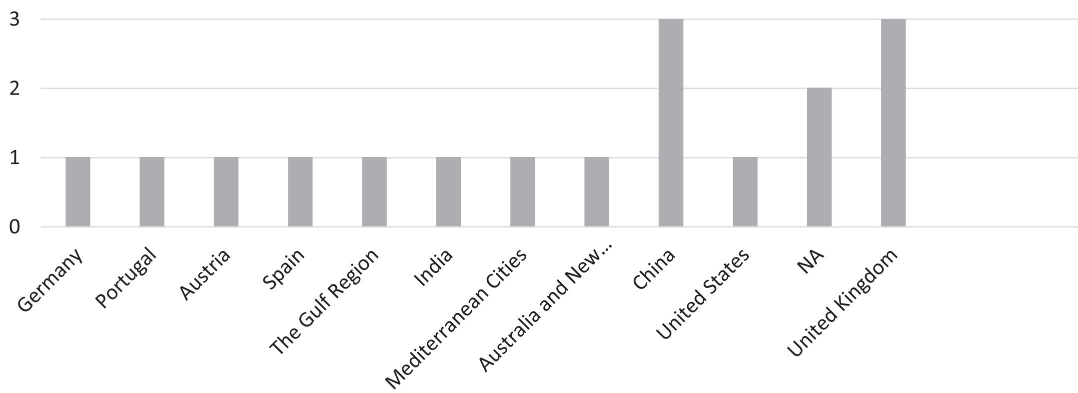

FIG. 7.5 Geographical distribution of assessment schemes across different countries.

TABLE 7.1 Dominant themes in the studied assessment schemes.

Dimensions	Economy	Environment	General smartness	Sustainability	Quality of life	Infrastructure and mobility	Governance	Other themes
Number	6	2	17	7	8	4	2	4
Schemes	LRSC, SSCC, ICI, ASCIMER, JUNIPER, CoO	LRSC, SCP	CIMI, CSCP, SCI-I, Juniper, Citykeys, GSSCI, SCSGM, City-IQ, IDC, ITU-T, EU-MSC, Royd-Cohen, MSC-EU, UCLG, U4SSC, NSCI, EDCi	CIMI, SCC, CSC, ASCIMER U4SSC, NSCI, ITU-T	LRSC, SCC, CSC, ASCIMER, U4SSC, Juniper, CoO, EU-MSC	SSCC, EP, SCBC, CKPI	SCG, WWC	GPCI, IES-City, ASCIMER, UK-SCI

See the appendix for a complete list of the assessment schemes.

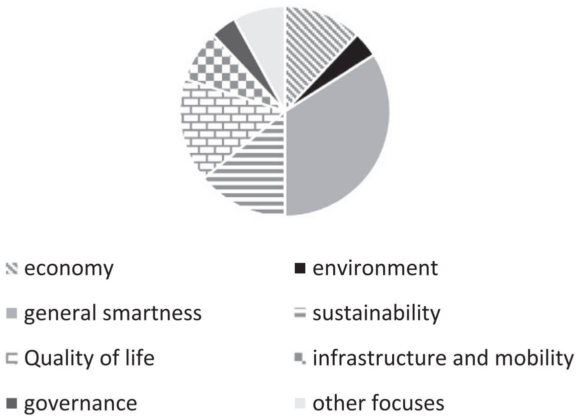

FIG. 7.6 The extent of attention to different smart city dimensions.

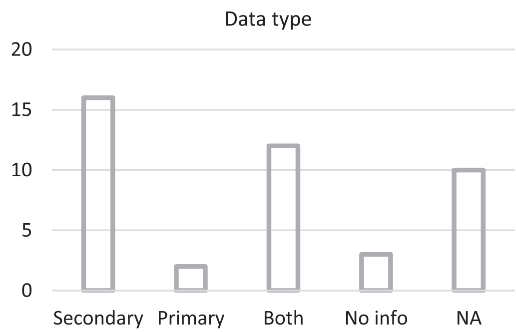

FIG. 7.7 Distribution of the selected schemes by the source of data.

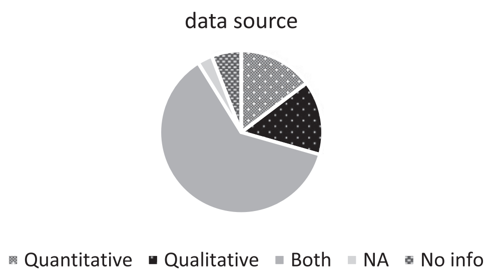

FIG. 7.8 Distribution of the selected schemes by the type of data.

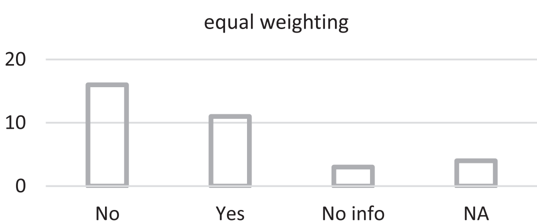

FIG. 7.9 Distribution of the selected tools in terms of weighting approach.

city project is conducted. The literature was reviewed until 2018 to find out the existing assessment tools and due to this investigation, most of the schemes are conducted in 2018.

7.2 Different approaches toward smart city assessment

Different approaches can be taken for assessing smart city performance. Some major approaches mentioned in the literature are benchmarking, baseline assessment, maturity assessment, assessment against peers, assessment against targets, and scenario making (Fig. 7.10) (Sharifi, 2019, 2020b). This chapter explores and explains these assessment approaches.

7.2.1 Benchmarking

Using benchmarking approach provides planners and cities with different learning opportunities. Benchmarking involves comparing performance against peers. It is an effective approach that does not only serve branding purposes without learning mutual benefits. The main functions of benchmarking are to assess impacts of smart city developments and to monitor the process of implementation smart city initiatives. As the data may not always be comparative in nature and also contextual differences may exist between cities, benchmarking should be conducted carefully. When major contextual differences exist, it is suggested to apply weighting factors to facilitate meaningful comparison (Wendling, Huovila, Zu Castell-Rüdenhausen, Hukkalainen, & Airaksinen, 2018).

If implemented appropriately, benchmarking would allow finding out the most constructive practices that can be replicated to improve smart city performance (Bellini, Nesi, Paolucci, & Zaza, 2018). In addition, it could provide ideas for dealing with potential challenges and barriers.

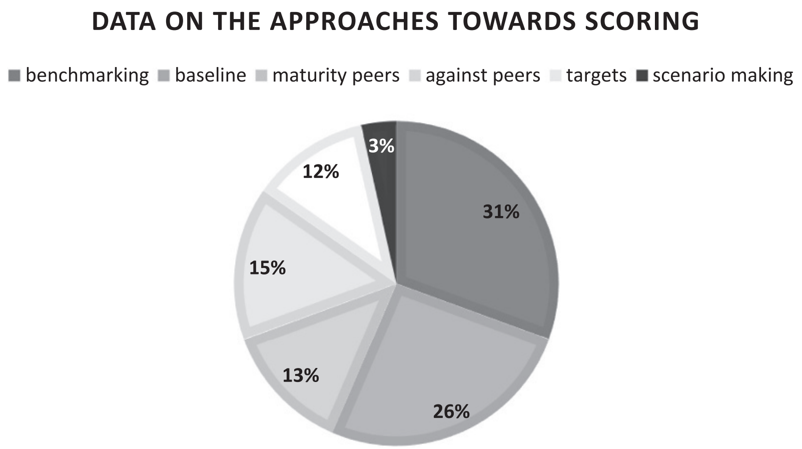

FIG. 7.10 Percentage distribution of the selected tools in terms of approaches toward scoring and assessment.

7.2.2 Baseline assessment

Longitudinal analysis can be used to compare smart city performance over time. Baseline assessment is needed for that purpose. In other words, the main function of baseline assessment is to monitor changes over time. This may provide opportunities to track progress over time and offer insights about areas that need to be improved. Generally, baseline assessment is applied to understand the current situation of a city, highlight areas that need improvement, and help stakeholders design roadmaps and business models for future improvement (Lee et al., 2021). Results of baseline assessment can also be used for benchmarking city performance. However, in cases when cities may have different starting conditions, it will be needed to apply adjustment factors.

7.2.3 Maturity assessment tools

To measure the quality, competency, and level of sophistication of smart city initiatives, maturity assessment tools can be applied. Maturity assessment tools have been developed to qualitatively measure the extent of fulfillment of specific targets and goals. There is close link between maturity and performance. In other words, achieving the highest possible level of performance would be indicative of the highest level of maturity (Torrinha & Machado, 2017).

Maturity can be described in different levels in terms of goals, common achievements, and key performance indicators. To study maturity in smart city, different aspects of maturity should be taken into consideration, including economic, environmental, and social.

- *Economic*: This refers to the extent to which a smart city can help cities flourish economically and improve the quality life of the citizens.
- *Environment*: Refers to how smart city initiatives are aligned with sustainability goals and to what extent they are ecological friendly.
- *Social*: This dimension is used to ensure that smart city initiatives provide citizens with their basic needs such as safety, health, and education. Additionally, issues related to equity and justice are emphasized.

7.2.4 Assessment against peers

In this type of assessment, the performance of one city will be considered as ideal and the performance of other cities will be compared against it. In other words, performance of other cities will be evaluated relative to the ideal city. This approach often involves using some forms of normalization techniques. For instance, in the literature, the performance of some cities in Europe has been evaluated based on the performance of other similar European cities (Giffinger & Gudrun, 2010). In terms of normalization, the *Z*-transformation method is a common way to obtain standardized values suitable for comparison.

7.2.5 Assessment against target values

This refers to a situation when cities set a specific types of target values to be achieved at a certain point in time and then assess the extent to which those target values have been achieved. This approach is particularly suitable to be applied at the end of a project to evaluate the overall performance. To design appropriate target values, different aspects including project context, requirements, timetable, and resources should be considered (Emmerich et al., 2021).

7.2.6 Scenario making

Although baseline assessment provides some useful information about the smart city initiatives and could be used to understand to what extent they are successful or unsuccessful, it fails to take future conditions into account. Smart city assessment should take modeling and scenario-making methods into consideration to have a realistic prediction of urban capacities and enable cities to have better knowledge of the interconnected components and future pathways of the urban system. Taking modeling and scenario-making approaches allows planners to have a quicker response to emergencies and emergent needs of cities, to identify priority action areas, and to develop more efficient strategies that could facilitate long-term urban resilience. Modeling and scenario making are, however, not commonly used in smart city assessment tools. This is probably due to limited modeling capacity of the planners and/or difficulties and complexities of data collection and analysis. Future advancements in field of Big Data and machine learning are likely to contribute to solving this issue (Srinivas, Singh, Jain, & Sharma, 2020).

7.3 Various dimensions of smart cities

Smart city is a new approach to cope with complex issues in areas such as transportation, water management, waste management, energy, living conditions, and governance. One major role of smart city planning is to help cities meet sustainable developments goals to deal with different kind of current and future difficulties and challenges. To do so, a smart city should be able to cover different aspects of urban life (Nam & Pardo, 2011). It is important to evaluate to what extent smart city initiatives affect quality of life in different levels and dimensions. Six major smart city dimensions have been identified and emphasized in the literature. These are, namely, smart economy, smart people, smart governance, smart living, smart mobility, and smart data (Fig. 7.11). Each dimension entails a number of indicators to enable us to assess the performance of smart city initiatives (Albino, Berardi, & Dangelico, 2015).

7.3.1 Economy

Cities are the responsible of most of the economic growth in countries. Smart economy highly depends on data and is an increasingly popular concept that is linked to a wide range of other concepts such as the smart urban design and urban planning, economic development, strategic planning, and city branding (Kumar & Dahiya, 2017). Smart economy is considered as an important goal of smart city planning to ensure better welfare by promoting responsible economic growth, attracting investment, offering job opportunities, promoting

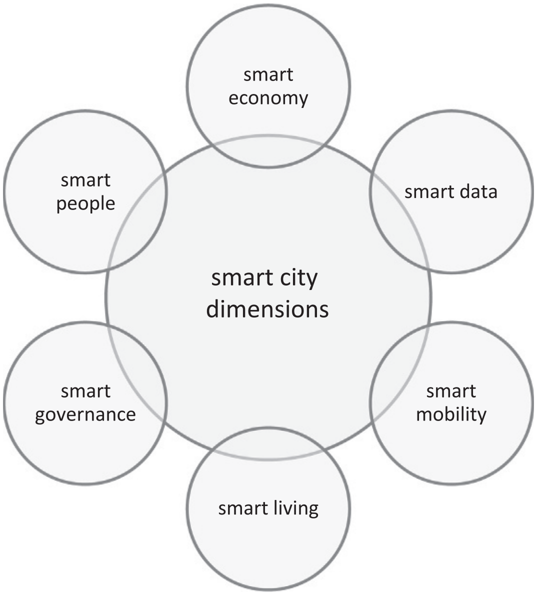

FIG. 7.11 Smart city dimensions.

business innovation, and optimizing market opportunities. A smart economy can change the traditional ways and parameters of business to increase productivity and efficiency.

In the literature, smart economy is commonly recognized by some features such as entrepreneurship, productivity, competitiveness, tourist attraction, and training. Meanwhile, according to the European 2020 framework, a smart economy should promote smart growth, sustainable growth, and intensive growth. Smart economy can be defined by five subthemes, as shown in Fig. 7.12. These are, namely, innovation and knowledge economy, employment opportunities, global interconnectedness, productivity and efficacy, and flexibility (Kézai, Fischer, & Lados, 2020; Sharifi, 2019, 2020b).

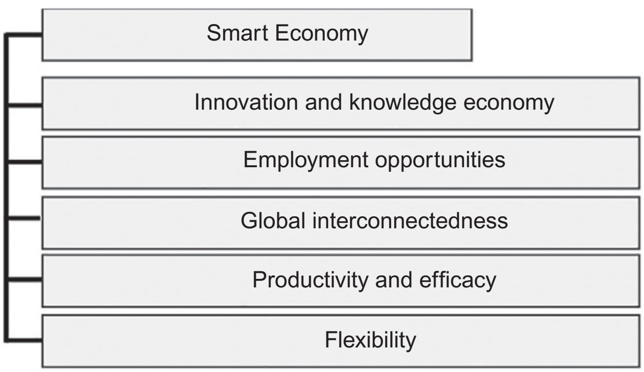

FIG. 7.12 Major components of smart economy.

7.3.2 People

People are core components of smart city planning (Hassankhani, Alidadi, Sharifi, & Azhdari, 2021). This means that while technology can be adopted to increase quality of life of citizens, smartness cannot be only achieved through focusing on technological solutions. Smart people would ensure seamless implementation of smart city projects and could also support innovation in cities. The smart people concept has become increasingly important in recent years (Luterek, 2019). This concept emphasizes issues such as diversity, flexibility, creativity, inclusive engagement of citizens, justice and equal accessibility to services, innovation and entrepreneurial culture, education, and talent development.

Smart people can use technology to better interact with each other as well as with urban authorities. In addition, smart people is linked to the way education and work, labor market choices, and training and learning are facilitated by technology. Smart people ensure long-term prosperity and innovation within a city or community (Xu & Geng, 2019). Human development is considered as a core aspect of smart city planning. Other indicators of smart people in smart city are level of qualification and ICT skills, open-mindedness, flexibility to adapt to changes in the environment, creativity, and the extent of engagement in democratic processes. Overall, smart people can be defined by three subthemes, as shown in Fig. 7.13 (Gupta, Mustafa, & Kumar, 2017).

7.3.3 Smart governance

The core aim of smart governance is to enhance governmental transparency and improve connections between local governments and stakeholders. Smart governance aims to enhance operational efficiency and address traditional governance difficulties by applying innovative methods. It refers to the extent to which government is successful in providing public services, promoting participatory planning, and encouraging active engagement of citizens in decision-making processes.

Smart governance has four subdimensions including data, stakeholders, collaboration, and technology as shown in Fig. 7.14 (Paskaleva et al., 2017). According to what was mentioned earlier, smart governance is about applying smart technologies such as sensors, monitoring tools, and social media to capture and generate data to increase collaboration of stakeholders in decision-making process. Generally, the most important function of smart governance is to enhance transparency and facilitate participatory processes.

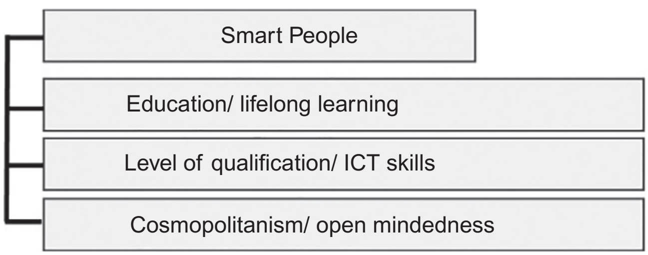

FIG. 7.13 Major components of the smart people theme.

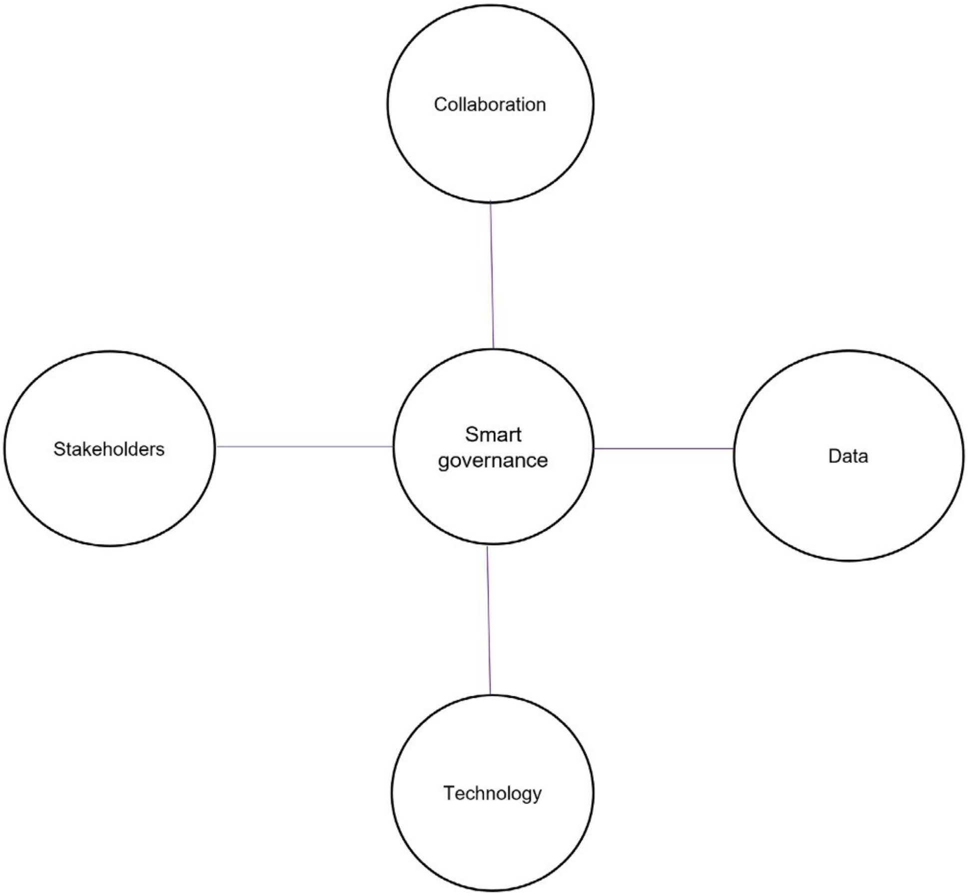

FIG. 7.14 Four major subdimensions of smart governance.

Smart governance offers benefits to promote inclusive and unified strategies. It can be promoted through new methodologies and techniques such as cocreation or crowdsourcing. Major subcomponents of smart governance that are mentioned in the literature are visioning and leadership, transparent governance, management of public and social services, and efficient urban management (Fig. 7.15).

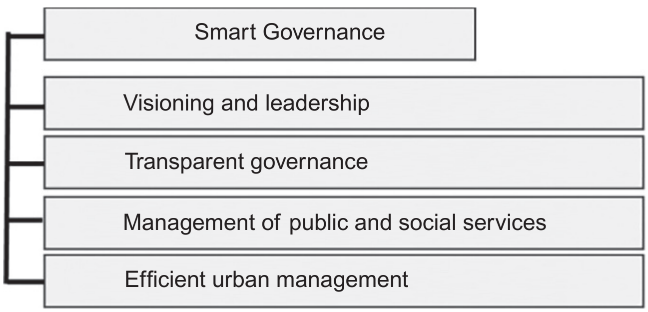

FIG. 7.15 Major components of smart governance.

7.3.4 Smart living

The ultimate goal of smart cities is to enhance quality of life of people. People and their living conditions and quality of life are central to smart city initiatives as they are the end users of smart cities. It is, therefore, unsurprising that smart city assessment tools include indicators for assessing quality of life. Among other things, smart city initiatives intend to improve quality of life of residents through advanced and innovative technological solutions. It is, however, worth noting that benefits of smart cities for quality of life are not always quantifiable. This can be explained by the fact that many issues related to quality of life are inherently qualitative. Livability and enhancement of the living environment should be taken into consideration at the same time to bring maximum benefits to stakeholders. In smart city planning, quality of life covers diverse aspects ranging from social cohesion to justice, healthcare, safety etc. Collectively, this will ensure improving resident welfare. Major subcomponent of smart living, including, social cohesion and inclusion, equity and justice, cultural development, healthcare, safety and security, and skills and education are shown in Fig. 7.16 (Gupta et al., 2017; Sharifi, 2019, 2020a, 2020b).

7.3.5 Smart mobility

Smart mobility is a costumer-centric approach that aims to promote technology to enhance the quality and efficiency of transportation in cities. Through technological improvements, smart mobility can provide multiple benefits such as efficiency and affordability. It can also reduce the adverse environmental impacts of the transportation sector. Smart mobility applies information and communication technologies (ICTs) to enhance accessibility at different scales, ranging from neighborhoods to cities and regions. In addition to accessibility, smart mobility should enhance connectivity and provide the residents with diverse types of transportation services depending on their needs. This should, however, be achieved by paying attention to the sustainability limits to minimize potential detrimental impacts on the environment. Additionally, socioeconomic issues such as equity and safety should also be

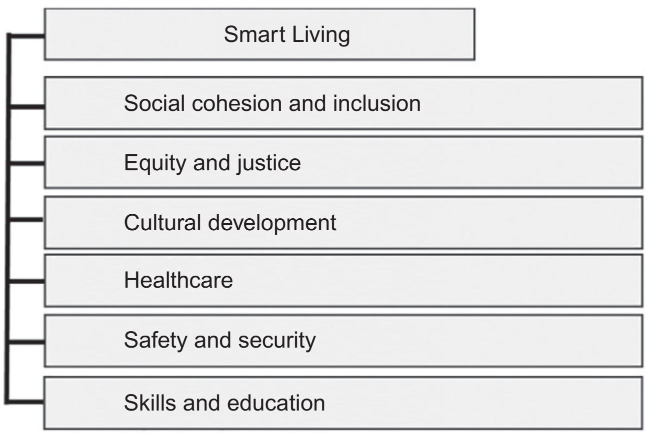

FIG. 7.16 Major components of smart living.

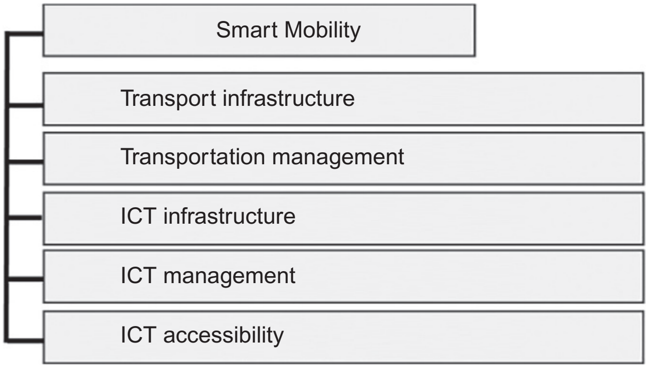

FIG. 7.17 Major components of smart mobility.

prioritized. As shown in Fig. 7.17, smart to assess smart mobility, various issues such as transport infrastructure, transportation management, ICT infrastructure, ICT management, and ICT accessibility should be considered (Gupta et al., 2017; Sharifi, 2019, 2020a, 2020b).

7.3.6 Smart data

Smart city is driven by data and cannot be implemented without having access to reliable data. The role of data to deal with critical problems of cities is, therefore, undeniable. One feature of smart city is its ability to capture and use real data to pave the path for decision making. Data can be gathered using different technological advancements, such as social media, remote sensing techniques, and monitoring sensors. It can be said that technological advancements provide cities with opportunity of having access to Big Data, which is one of the requirements of smart city planning and development. Big Data bring multiple advantages to smart city planning. In the other words, big/real-time data are essential for smart cities. Cloud-based IoT applications provide planners with opportunities to collect, analyze, and process data to assist decision-making process. Smart city assessment should include indicators to evaluate performance with respect to sensing and collecting data, data analytics, reacting, and learning, as shown in Fig. 7.18 (Sharifi, 2019, 2020b).

7.4 Criteria and indicators for smart city assessment

As explained in the previous sections, smart city initiatives intend to contribute to the development of ecologically sound urban environments that also provide socioeconomic benefits. Various sets of indicators have been introduced in the literature to assess the extent of success of smart cities in achieving these objectives. In fact, there is now an increasing interest in applying smart city tools, frameworks, and indicators in cities.

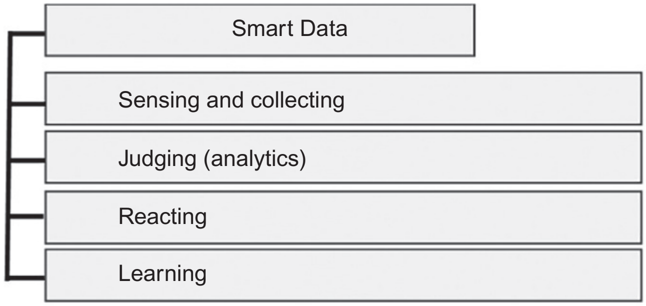

FIG. 7.18 Major components of smart data.

TABLE 7.2 The most common used themes and factors in smart city schemes (Sharifi, 2019, 2020a, 2020b).

Clustering component	Most used items
Dimensions	Economy, environment, governance, mobility, living, people, data
Factors	Education, infrastructure, health, services, innovation, culture, transportation, environment, inclusion, safety, governance, energy, business, pollution, planning, entrepreneurship, sustainability, security, accessibility, water, resources, technology, building, participation, social, efficiency, productivity, economy, connectivity, traffic, employment, housing

Six major dimensions of smart city were introduced in the previous section. Existing smart city assessment tools have adopted either two-tiered or three-tiered approaches. In the former, a set of indicators are introduced directly under each dimension. However, in the three-tiered approach, there is another layer in between dimensions and indicators that is referred to as "factors." The specific indicators are then introduced under respective factors. The list of commonly used factors is shown in Table 7.2. It should be noted that different assessment tools may apply different terms to refer to dimensions and/or factors. For example, terms are "transportation" and "mobility" are sometimes used interchangeably. However, the terms listed in Table 7.2 are more common.

The most commonly used indicators related to the smart city dimensions are listed in Tables 7.3–7.8. These lists are drawn from Sharifi (2019).

7.5 Inclusion of climate resilience criteria and indicators in smart city assessment tools

Cities around the world are increasingly exposed to the impacts of climate change. Dealing with climate change in its different levels to meet sustainable development goals requires both mitigation and adaptation. Mitigation leads to reducing greenhouse emissions and adaptation makes cities more resilient to climate change effects. Smart city initiatives can be used to streamline and facilitate climate change adaptation and mitigation in cities.

TABLE 7.3 Smart economy indicators (Sharifi, 2019, 2020a, 2020b).

Factor	Criteria/indicator
Innovation and knowledge economy	Green economy
	Share of investment in smart industries, cooperation between different stakeholders (industry, academia, policy sectors, etc.)
	Contribution of smart industries to GDP, number of start-ups and new start-ups
Employment opportunities	Employment rate
	Employment rate improved by smart city solutions, online and ICT-enabled tourism promotion (information dissemination, booking, etc.)
	Number of tourists visiting the city (and staying overmighty)
Global interconnectedness	Presence of international and demotic enterprises with headquarters in the city
	City internationalization (e.g., number of international congress and fairs attendees of freight and passengers, etc.)
Productivity	GDP per capita (or per employed person)
	Increase in employee productivity attributable to ICT, budget efficiency
	Costs of development, operation, and maintenance of smart city solutions
	Life-cycle cost savings attributable to smart city solutions, payback period (years needed for return of the initial investment)
	Annual household and industry cost savings attributable to smart city projects
Flexibility	Use of ICT to enhance flexibility
	Home-based work and workspace flexibilization (e.g., teleworking)
	Timetable flexibilization, working hour flexibility

7.5.1 Mitigation

As mentioned, mitigation deals with the way cities cope with greenhouse gases emission from different sources such as electricity generation and transportation. In this regard, smart cities can provide advantages such as

- Make energy usage efficient
- Reuse the existing building and infrastructures to save energy
- Make cities compact to reduce transportation distance
- Develop green spaces and green infrastructure

It is worth mentioning that such benefits cannot be only achieved through ICT-based technological solutions and attention to other planning strategies is also needed.

TABLE 7.4 Smart people indicators (Sharifi, 2019, 2020a, 2020b).

Factor	Criteria/indicator
Education/lifelong learning	Importance as a knowledge hub (e.g., presence of flagship/highly ranked universities)
	Percentage of population working in higher education and R&D sectors
	Update and adjustment of educational facilities, curricula, and material to improve digital skills and meet current needs of the labor market
	Measures to improve quality of educational infrastructure and to promote lifelong learning and skill development
	Adult literacy trends (accessibility and quality of education)
	Availability and penetration of e-learning and distance (remote) education systems
	Application of ICT technology, analytics platforms, and e-learning in schools/universities
	IT training and raising awareness about smart city benefits to make services accessible to all and ensure engagement of all in the smart city making process (improving ICT literacy)
	Student/teacher ratio; quality of school education
Level of qualification/ICT skills	Percentage of population with secondary-level education
	Percentage of population with tertiary-level education
	Foreign language skills of the citizens
	Individual level of computer skills (hardware and software); math and science skills
	Internet penetration (netizen ratio)
	Social networking penetration
	Level of digital and ICT literacy and technical capability
Cosmopolitanism/open mindedness	Inhabitants' attitude toward international treaties/agreements and toward immigration
	Share of foreigners and nationals born abroad
	Use of ICT measures to create an immigrant-friendly environment

7.5.2 Adaptation

Impacts of climate change on cities become more evident with each passing day. These include storms, flooding, drought, heat waves, rising see levels, etc. Knowing these impacts and addressing them is vital to the sustainability of cities. Among other things, smart strategies can make advantages like:

- Identifying vulnerable areas to climate change impacts
- Facilitating early warning to better respond to climate change impacts
- Preventing development in areas that are prone to climatic impacts
- Promoting green spaces and green infrastructure

TABLE 7.5 Smart governance indicators (Sharifi, 2019, 2020a, 2020b).

Factor	Criteria/indicator
Visioning and leadership	Clear and inclusive smart city vision and roadmap with clear milestones
	Leadership's commitment to secure internal and external funding and support
	Availability of risk governance and resilience plans
Transport governance	Improvement of turnout at voting and city hearing by mean of ICT
	Citizen participation for collecting real-time data and using them (e-citizen)
	e-Governance and online civic engagement and feedback system
	Open data and its quality
Public and social services	One-stop online accessibility and coordination to all urban public services
	Smart pricing
	Existence of digital benefit payment (e.g., social security) to citizens
	Public entities in social networks
	Government access to cloud services
	Use of platforms for digital and mobile payment
Efficient and urban management	Integration and interconnection of services, interoperability between urban system and subsystems (using open standards)
	Application of Big Data
	Multilevel governance and collaboration among different sectors and jurisdictions

- Promoting integrated decision-making systems that can facilitate better communication across different sectors, thereby allowing better response and recovery
- Promoting resource efficiency (water, energy, waste, etc.)
- Upgrading stormwater infrastructure
- Developing intelligent and sustainable buildings

7.5.3 Transformation toward smart and climate resilient cities

It can be argued that using smart solutions and technologies to facilitate climate change mitigation and adaptation in cities can facilitate transition toward smart and climate resilient cities. In this regard, we argue that economic, environmental, infrastructural, governance, and social dimensions should be taken into account (Fig. 7.19).

- Economic dimension

  This dimension is focused on economic activities to ensure that economic benefits are achieved in a sustainable and climate resilient manner. This could, for example, include refurbishing building stock to improve energy efficiency and reduce material use.
- Environmental dimension

TABLE 7.6 Smart living indicators (Sharifi, 2019, 2020a, 2020b).

Factor	Criteria/indicator
Social cohesion and inclusion	Using ICT to improve accessibility and participation of people with special needs, using ICT for promoting voluntary service, using ICT for promoting community connectivity and reciprocity
Equity and justice	Physical access to amenities, costs of living, avoiding digital divide, equal access to ICTs, percentage of population with authorized and sustainable access to services
Cultural development	Percentage of municipal budget allocated to culture, size and quality of public indoor and outdoor recreation space, using ICT for cultural promotion, protection and management of cultural heritage, cultural and leisure time enhancement attributable to smart solutions, using ICT for promotion of sport and physical activity
Healthcare	Healthcare expenditure; ICT reducing these costs, health care services and infrastructure per capita; using ICT and smart technologies for promoting wellbeing; using ICT to monitor and control diseases, using ICT to track food and drug; percentage of hospitals archiving electric health records; sharing rate of records, information, and resources among clinics and hospitals; adoption of telemedicine and telecare services
Safety and security	Disaster risk monitoring; using ICT for disaster prevention, prediction and control and emergency response; damage expenditure and economic loss reduction attribution to ICT usage, response time for police department, transportation damage reduction attributable to ICT usage; using ICT to prevent crime and enhance public safety
Skills and education	The extent of application of e-learning in schools/universities; IT training to make services accessible to all; individual level of computer skills; use of internet by city dwellers

Environmental dimension specifically deals with issues related to protecting biodiversity and conserving natural resources. This will ensure sustainable accessibility to ecosystem services in cities.

- Infrastructural dimension

  This dimension mainly focuses on roles of different kinds of infrastructure such as buildings, transportation, and communication network and facilities. In many existing cities, infrastructure systems are old and inefficient and need to be retrofitted. In addition, given the long life time of urban infrastructure, more resource-efficient infrastructure development strategies are needed to ensure that infrastructure development in newly built cities will be based on climate resilience and sustainability principles.
- Governance dimension

  Governance is a central component of this process. Transparent governance based on participatory approaches could provide multiple benefits for transition toward climate resilience in cities. Among other things, it will enhance the sense of trust between residents and local authorities and will also facilitate responsible urban management.
- Social dimension

  This dimension generally emphasizes some factors such as physical and mental health, educational opportunities, and safety. Enhanced health and well-being will be essential for enhancing adaptive capacity of residents. Social dimension should also include issues related to equity given that some societal groups are expected to be disproportionately

TABLE 7.7 Smart mobility indicators (Sharifi, 2019, 2020a, 2020b).

Factor	Criteria/indicator
Transport infrastructure	Green transportation modes (e.g., percentage of green vehicles, EVs, etc., on total registered vehicles)
	Number of EV charging stations in the city
	Autonomous vehicle (AV) testing and deployment
	Public transport system and its quality, diversity, and multi-modality
	Private car ownership rate
	Car and bike sharing services (per 100,000 population); ridesharing, etc.
	Cycling infrastructure options and facilities (e.g., % of length of bike routes in relation to length of streets)
	Pedestrian environment and walking options, walkability, and interconnectivity
	Street/pedestrian area smart/automatic lighting management system using ICT
Transportation management	Strategic transportation network management
	Smart pricing, smart price policies, demand-based pricing (e.g., "congestion pricing, congestion charging, variably priced toll lanes, variably priced parking spaces")
	Trackability and traceability of goods and vehicles (using GIS and GPS systems)
	Sensing and monitoring for real-time, smart, and automated traffic management (e.g., road sensing, traffic signal control, speed limit control, parking, highway entry control, auto drive, transit signal priority, traffic flow prediction, toll collection, communication and guidance between emergency vehicles and drivers, etc.); intelligent traffic management
	Private car traffic restriction
	ICT-enabled transportation damage and fatalities reduction
	Road safety, rate of traffic accidents (leading to material and nonmaterial damage), e.g., number of deaths per 100,000 population
	Road traffic efficiency, travel time, congestion levels, congestion management
	Real-time information about transit services and parking (digital bulletin boards for user-infrastructure communication); parking guidance system, smart parking, journey planner, etc. (related to mobility as service)
	Performance, safety, and efficiency of public transportation (e.g., environmental performance; ratio of travel time by private car and by public transportation); commuting time and ease of commute
	Share of total trips made by active (nonmotorized)/public transport modes; public transport ridership
	Travel distance (VMT/KMT); reduction in travel distance

Continued

TABLE 7.7 Smart mobility indicators (Sharifi, 2019, 2020a, 2020b)—cont'd

Factor	Criteria/indicator
ICT infrastructure	Availability of IT and digital infrastructure (Wi-Fi networks, wireless hotspots, kiosks, digital broadcasting, etc.) for instrumentation (as enabler and accelerator); average network bandwidth
	Broadband internet (average broadband bandwidth available for data-intensive applications), fiberoptic channels, etc.
	Maintenance and regular revision of the ICT infrastructure; upgrading existing assets
	Integrated platform for real-time smart city operation and management using interoperable, flexible, and open standards
	Fixed phone (landline) and mobile phone network coverage
	Rate of coverage by mobile broadband (3G, 4G, 5G); Mobile broadband speed
	Availability of apps (parking, multimodal transportation, car sharing, crime reporting, e-payment etc.); apps using open data platforms
	Availability of smart computing technologies and platforms
ICT management	Quality of internet service (e.g., download and upload speed, broadband reliability, etc.)
	Information privacy and security management; digital security (against hackers, etc.), cybersecurity
	Existence of systems, rules, and regulations to ensure child online protection
	Application of cloud computing services
	Diversity of booking/payment options, digital transactions (tools, tickets, parking fees, etc.); electronic payment methods
	Integrated fare/payment system for interservice digital fare collection capability (e.g., unified smart cards for different transit modes)
ICT accessibility	Physical accessibility of IT infrastructure (e.g., distance to Wi-Fi networks, wireless hotspots, fiberoptic channels, kiosks, etc.)
	Socio-economic accessibility to digital technologies; ICT affordability (fixed broadband and mobile cellular tariffs), etc.; digital inclusion and strategies for avoiding digital divide
	Per-capita public/private ICT expenditure; ICT expenditure of households
	Fixed and wireless broadband subscriptions (% of population); internet penetration; subscription per 100 inhabitants
	Smartphone penetration
	Free Wi-Fi coverage in public spaces (Wi-Fi hotspots) (e.g., % of the area of public spaces covered by Wi-Fi)

TABLE 7.8 Smart data indicators (Sharifi, 2019, 2020a, 2020b).

Factor	Criteria/indicator
Sensing and collecting	Infrastructure, systems and strategies for data collection (sensing, mining, etc.); application of Big Data
	Strategies and infrastructure for autonomous real-time sensing of data (sensors, mobile network, RFIDs, etc.)
	Strategies and infrastructure for autonomous real-time sensing of data (sensors, mobile network, RFIDs, etc.)
	Infrastructure for storing and structuring data
	Systems, strategies, protocols, and infrastructure for timely data communication, sharing and reporting
Judging (analytics)	Data quality management (data integrity, quality control)
	Strategies, tools, and infrastructure for data filtering and classification and for structuring data in a standardized format suitable for promoting interoperability
	Systems, strategies, protocols, tools, and infrastructure for data processing, analysis, and judgment; data analytics
	Strategies, tools, and infrastructure to evaluate data and use it for making predictions and understanding trends, etc.
Reacting	Government decision making (indicators examining whether results have been used by decision makers, for example, to improve customer service) based on data and evidence
	Enterprise decision making (indicators examining whether results have been used by enterprises)
	Citizen decision making (indicators examining whether results have been used by citizens, behavior change, etc.)
Learning	Mode upgrading indicators measuring whether results of data analysis (smart solutions) have provided lessons that have been used to upgrade the mode of operation (operational optimization)
	Process upgrading indicators measuring whether results of data analysis (smart solutions) have provided lessons that have been used to upgrade the mode of planning process (feedback system)
	Experience upgrading indicators measuring whether results of data analysis (smart solutions) have provided lessons that have been used to upgrade the way different agents behave and interact

affected by the impacts of climate change. Furthermore, promoting equity is essential to encourage joint efforts and commitment toward climate change adaptation in cities.

To examine the extent of alignment with these dimensions in the selected smart city assessment tools, we have developed a list of indicators that is shown in Table 7.9. To determine the state of inclusion of these indicators in smart city assessment tools, we applied a quantitative process. We made a matrix with climate resilience indicators (30 indicators) on the columns and the individual smart city assessment tools on the rows. The level of inclusion was scored

TABLE 7.9 Climate resilience indicators.

Environmental	Biodiversity and green spaces
	Land consumption
	Water management
	Air quality
	Waste management
Infrastructure	Stormwater management
	Settlements and their structure
	Accessibility to green spaces
	Energy and green buildings
	ICT accessibility and management
Economy	Innovation
	Knowledge economy
	Employment
	Economic stability
	Economic growth
	Poverty
Social	Investment in R&D
	Disaster awareness
	Healthcare accessibility and availability
	Employment rate
	Safety amenities
	Education levels
	Gender equality
Governance	Government effectiveness
	Accountability
	Participation
	Municipal budget
	Environmental plans and strategies
	Climate change regulations
	Cooperation with experts

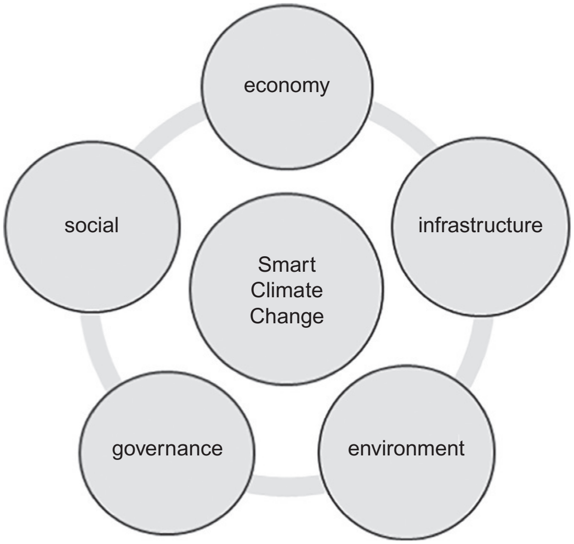

FIG. 7.19 Different dimensions that need to be considered for transition toward smart and climate resilient cities.

on a scale ranging from 1 to 3, where 3 and 1 indicated the highest and lowest levels of relevance, respectively. Also, 2 indicated partial relevance. Then these scores were normalized and scored on a 0–100 scale (Fig. 7.20). According to the results of this process, environmental dimension has the highest level of inclusion in smart city assessment tools, followed by the social dimension. However, it can be seen that the infrastructural dimension has not been well integrated into the existing assessment tools.

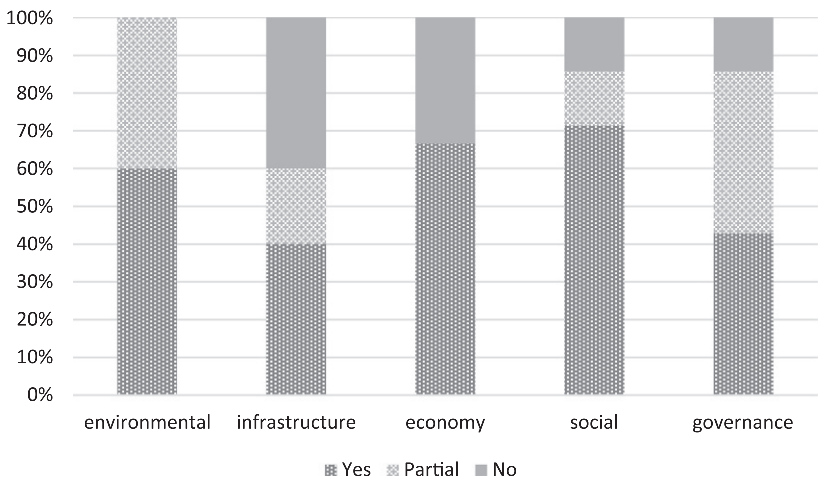

FIG. 7.20 The extent of Inclusion of climate change resilience indicators in smart city assessment tools.

7.6 Summary

Smart city assessment tools are applied to evaluate the performance of smart cities in different levels. This chapter provided an overview of existing smart city assessment tools developed since 2012. Different aspects of smart city assessment tools including scale, target groups, type of data, source of data, and geographical focus were studied. There are different types of smart city assessment tools, and they should be applied by taking contextual factors into account. Major approaches to assessment include benchmarking, baseline assessment, maturity assessment, assessment against peers, assessment against desirable targets, and scenario making. Currently, benchmarking is the most popular approach. However, depending on the specific needs of a development, other approaches may also be used to better inform decision making toward climate-resilient cities.

As mentioned, smart city should be evaluated in different levels and dimensions. There are six dimensions to cover all aspects of smart city including smart economy, smart people, smart mobility, smart governance, smart living, and smart data. Different indicators related to these dimensions have been provided that can inform planners and policy makers in their efforts.

One increasingly important function of smart city assessment tools is evaluating performance in terms of contributions to climate resilience. It was found that existing assessment tools are relatively suitable for informing planning and policy making related to environmental and social dimensions. However, better integration of issues and indicators related to other dimensions such as infrastructure is needed. We hope these will be further investigated in the future research.

Appendix

The list of selected assessment tools (Sharifi, 2019).

Framework/indicator set	Acronym	Year	Primary developer (s)
Lisbon ranking for smart sustainable cities	LRSC	2019	Akande, Cabral, Gomes, and Casteleyn (2019)
Smart Sustainable Cities China	SSCC	2019	Li, Fong, Dai, and Li (2019)
Cities in Motion Index	CIMI	2018	Center for Globalization and Strategy and IESE Business School's Department of Strategy
Global Power City Index	GPCI	2018	The Mori Memorial Foundation's Institute for Urban Strategies
Innovation Cities Index	ICI	2018	China Academy of Telecommunication Research and China Communications Standards Association
EasyPark	EP	2018	EasyPark group
IOT-Enabled Smart city framework	IES-City	2018	National Institute of Standards and Technology

The list of selected assessment tools (Sharifi, 2019)—cont'd

Framework/indicator set	Acronym	Year	Primary developer (s)
Smart Cities Council's tools and frameworks	SCC	2018	Smart Cities Council, Australia and New Zealand
What Works Cities	WWC	2018	Bloomberg Philanthropies
Code for Smart Communities	CSC	2018	Smart Cities Council Australian New Zealand and the Green Building Council of Australia
China Smart City Performance	CSCP	2018	Shen, Huang, Wong, Liao, and Lou (2018)
Smart City Governments	SCG	2018	Eden Strategy Institute and ONG&ONG Pte Ltd.
Assessing Smart City Initiatives for the Mediterranean Region	ASCIMER	2017	Universidad Politécnica of Madrid (UPM)
Smart Cities Index—India	SCI-I	2017	Indian School of Business
Juniper Research smart city frameworks	Juniper	2017	Juniper Research
UK Smart Cities Index	UK-SCI	2017	Navigant Research
CITYkeys	CITYkeys	2016	Netherlands Organization for Applied Scientific Research (TNO)
Networked Society City Index	NSCI	2016	Ericsson in collaboration with Sweco
Cities of Opportunity	CoO	2016	PricewaterhouseCoopers (pwc)
Community KPIs for the IoT and Smart Cities	CKPI	2016	Future Everything
Gulf States Smart Cities Index	GSSCI	2016	Navigant Research
European Digital Cities Index	EDCi	2016	Nesta
Smart City Strategic Growth Map	SCSGM	2016	ESPRESSO, European Commission
City IQ Evaluation System	City-IQ	2015	Wu, Pan, Ye, and Kong (2016)
International Data Corporation (IDC) Smart City Analysis	IDC	2015	IDC
Telecommunication and Standardization Sector of International Telecommunication Union (ITU)	ITU-T	2015	ITU-T Focus Group on Smart Sustainable Cities
United Nations Economic Commission for Europe-ITU Smart Sustainable Cities Indicators	UNECE–ITU	2015	UNECE Committee on Housing and Land Management; Environment Agency Austria, and ITU
Smart Cities Ranking of European Medium-sized Cities	EU-MSC	2014	TU Vienna, in cooperation with the University of Ljubljana and the TU of Delft
Boyd-Cohen Smart City Index	Boyd-Cohen	2014	Boyd-Cohen

Continued

The list of selected assessment tools (Sharifi, 2019)—cont'd

Framework/indicator set	Acronym	Year	Primary developer (s)
Mapping Smart Cities in the EU	MSC-EU	2014	RAND Europe, European Union (EU)
Smart City Maturity Model and Self-Assessment Tool	SCMM	2014	The Scottish Government and Scottish Cities Alliance
Smart City Profiles	SCP	2013	Austrian Climate and Energy Fund and Environment Agency Austria
United Cities and Local Governments (UCLG) smart cities study	UCLG	2012	City of Bilbao and Committee of Digital and Knowledge-based Cities of UCLG
Smart Cities Benchmarking in China	SCBC	2012	China Academy of Telecommunication Research and China Communications Standards Association

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CHAPTER

8

The extent of inclusion of smart city indicators in existing urban sustainability assessment tools

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8.1 Assessment tools as decision-support systems

Evaluation or assessment is an inseparable part of planning practice and process. Measuring what has been done and what should be done would be clarified through assessment tools. As Böhringer and Jochem (2007) emphasized, *an issue that cannot be clearly measured will be difficult to improve* (p. 1). The aim, concept, and methodology of assessment efforts are different based on the perception of planning nature (Khakee, 1998). For example, if we consider planning as a frame for decision justification, evaluation is a methodological reflection of planning function to improve the justification (Faludi & Altes, 1997). Nowadays, cities face global and local challenges that require planning interventions to mitigate the negative effects of climate change and reach sustainability. In this context, assessment tools, as decision support systems, play a critical role in analyzing these interventions (Sharifi, Kawakubo, & Milovidova, 2020). Assessment refers to evaluating the planning processes (with a performance-based approach) or planning outcomes (with a conformance-based approach) that are highly associated with policy analysis with positive or normative backgrounds (Alexander, 2012; Khakee, Hull, Miller, & Woltjer, 2016). Furthermore, assessment tools could be measurement-oriented, descriptive, judgmental, or interactive with objective, subjective, or decision-centered perspectives (Alexander & Faludi, 1989). Planning can be evaluated before (ex ante), after (ex post), or simultaneous with implementation depending on the needs

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and requirements of a *plan maker*, *plan user*, or *independent evaluator* (Khakee, 1998; Korthals Altes, 2008).

Assessment tools are a set of frameworks and indicators that can be applied in different scales ranging from international to building levels and provide information for decision making and guiding development directions (Jackson, 2016). To do so, indicator-based assessment tools are developed in sustainability studies to give a more straightforward process and outcome of planning interventions and policy implementation. If applied appropriately and adequately, assessment tools could be used efficiently in policy making and decision taking (Agol, Latawiec, & Strassburg, 2014). The integration of assessment tools and planning practice is essential for an efficient and productive decision-making process. As assessment tools provide information about the potential consequences of planning interventions and, on the other hand, evaluate the processes and outcomes of planning projects, they help decision making to reduce past mistakes and design a better future. Assessment tools provide valuable information and feedback to decision making by simplifying the processes and contents of planning intervention and policies. They can also clarify planning goals and highlight potential costs and benefits (Dizdaroglu, 2017).

Assessment tools encompass three main features: *context features* that is about planting and implementing assessment in relation to the context, *process features* that are related to the qualities of the evaluators and time of assessment, and *features within the assessment* that concerns about the content and expected outcomes of assessment (Hacking & Guthrie, 2008). Assessment tools in the past decades have been developed, adopted, and justified to new problems, issues, and planning requirements in various parts of the world. Regardless of the aim and objective of the assessment, these tools play a critical role in planning, operation, maintenance, and evaluation of policy making, project implementation, and governance processes. In this chapter, we have scrutinized the importance of assessment tools as decision-support systems, the way they have been used in the context of sustainable development, their implementation in city and neighborhood scale, and how smartness and climate resilience have been included in these assessment tools.

8.2 Sustainability assessment

In the past 3 decades, sustainable development has been a guiding agenda for urban planning and practice and has gained governmental and political support in all scales (Bond & Morrison-Saunders, 2011). Sustainability has three main pillars, social, economic, environmental. Waas, Hug'e, Verbruggen, and Wright (2011) and Sharifi and Murayama (2013) emphasized that the institutional dimension is essential to ensure proper implementation and achievement of other dimensions. Kaur and Garg (2019) added culture as the fifth dimension of sustainability through an exhaustive literature review mainly focused on esthetic and cultural heritage as an asset that enhances sustainability. However, while sustainability, for example, is about integrating different dimensions in the decision-making process, paying attention to trade-offs and balancing all dimensions is essential (Waas et al., 2011). Assessing sustainability is highly dependent on the dimensions that have been the focus and target of planning implementation. Sustainability assessment tools are instruments for conceptualizing and operationalizing urban sustainability for policy and practice (Cohen, 2017).

Sustainability assessment is very complex due to the multidisciplinary, context-dependent, and value-based nature of the sustainability concept (Sala, Ciuffo, & Nijkamp, 2015). Waas et al. (2011) identified four main groups of fundamental principles from literature including *normativity*, *equity*, *integration*, and *dynamism* principles. Böhringer and Jochem (2007) through a critical review found five requirements of sustainability assessment (SA) indices including *connection to sustainability definitions*, *representing the holistic field*, *measurability and quantification potential of indicators*, *process-oriented indicator selection*, and *deriving political (sub) objectives potential*. They also added normalization, weighting, and aggregation of selected variables as the requirements of indicators, logically and statistically. Colantonio and Dixon (2011) emphasized four critical issues in sustainability assessment tools, including (1) addressing the integration of techniques and themes, (2) being multicriteria, (3) emphasizing the objectives and principle settings, and (4) engaging different stakeholders.

Sustainability assessment tools should have a number of features to be effective in practice; holistic vision, integrated framework, comparative and alternative assessment capacity, and community engagement potentials (Jackson, 2016). Sharifi, Dawodu, and Cheshmehzangi (2021a) discussed that the success factor of sustainability assessment tools could be identified in two main categories: structure and methods and procedure and outcomes. From a structure and methods perspective, sustainability assessment tools should improve over time, be measurable, consider context, cover all dimensions, reveal the interaction between indicators, and be attractive to users. And from a procedure and outcome perspective, they should improve sustainability performance, promote sustainable design, address priorities, facilitate engagement and transparency, and inform the decision-making system (Sharifi, Dawodu, & Cheshmehzangi, 2021a). Agol et al. (2014) also found some key issues to the success of sustainability assessment tools, specifically in Global South countries. They emphasized that sustainability assessment tools are recommended to be flexible and context dependent, provide indicators for ex ante and ex post evaluation, have robust data gathering and monitoring approaches, consider previous experiences in the context, and acknowledge the limitations of assessment (Agol et al., 2014). Some of these features and characteristics will be further discussed in the remainder of this chapter.

8.2.1 Integration and comprehensiveness

Integration is a multidimensional concept that entails different meanings in different contexts. Integration may refer to *comprehensiveness*, *holistic*, *coordination and cooperation*, *partnership*, *horizontal and vertical relation*, *multilevel coaligning*, *synchronization*, *linking policy and action or practice and idea*, and so on (Dadashpoor & Alidadi, 2020; Healey, 2006; Van Straalen, 2012). Accordingly, in assessment tools, integration means combining different impact types (i.e., natural and socio-economic), integrating impact assessments in different planning steps and scales, and connecting assessment outcomes to policy making. In other words, sustainability assessment tools should *comprehensively, simultaneously, and equally cover all sustainability themes* (Hacking & Guthrie, 2008). While quantifiability is one of the principles of sustainability assessment tools, the comprehensiveness principle emphasizes that some aspects of sustainability cannot be quantified. For example, safety, social connectedness, sense of place and other qualitative variables cannot always be measured quantitatively. Moreover, the institutional aspect of sustainability and urban governance processes, dynamics, and legislation should be covered by assessment tools, while these areas might not always be easily convertible to numbers (Sharifi, Dawodu, & Cheshmehzangi, 2021a).

8.2.2 Contextuality

Sustainability is a buzzword in planning practice/research and policy and the public domain. So, there is no specific and dominant meaning of sustainability applicable in all contexts and scales. In other words, there is no ubiquitous sustainable development policy applicable in all contexts and geographies. Accordingly, assessment tools that should be constructed based on different perceptions of sustainability are highly context-dependent, subjectively and geographically. The flexibility of sustainability assessment tools is essential for their applicability in different regions of the world (Dawodu, Cheshmehzangi, & Sharifi, 2020). For example, *smart city* principles that have been reflected in sustainability assessment tools have different meanings in the United States and China (Kaur & Garg, 2019). Moreover, sustainability assessment tools should consider where and when actions related to sustainable development are taken (Agol et al., 2014). While one of the critical and fundamental factors of assessment tools is to be comparable, the capacity to consider local peculiarities in these rating systems is also important. As local areas have their own conditions, processes, governance systems, planning targets, and priorities, they should have adaptation capacity to assess sustainability (Xia, Chen, Skitmore, Zuo, & Li, 2015). One of the main shortcomings of many sustainability assessment tools is their *one-fit-for-all* approach (Boyle, Michell, & Viruly, 2018). Sharifi, Dawodu, and Cheshmehzangi (2021b) emphasized the importance of adaptation and flexibility capacities of assessment tools as a success factor. Specifically, in the era of environmental determinism, other aspects of sustainability might be ignored if assessment tools do not provide space for context and local specificity (Sharifi, Dawodu, & Cheshmehzangi, 2021b).

8.2.3 Measurability or quantifiability

Measurability is one of the main critical success factors of sustainability assessment tools (Dizdaroglu, 2017; Sharifi, Dawodu, & Cheshmehzangi, 2021b). Assessment tools have become popular in planning research and practice just because using them allows judging and evaluating the performance of policies accurately and comparatively. It is worth mentioning that some qualities of sustainable development, such as happiness, cannot be measured through quantitative indicators dominated and widely used in sustainability assessment tools (Boyle et al., 2018). However, the only way to evaluate the performance of planning interventions, specifically sustainability, is to simplify them and make them comparable through a clear and understandable process. In this way, planners, authorities, organizations, and governments would improve their performance and manage their functionality (Bell & Morse, 2012). When sustainability performances are quantified, the processes and outcomes that have the potential to be improved would be identified based on comparisons with other cases and with other elements of sustainable development. Moreover, quantified issues are more understandable in the planning context as the audience of these interventions are stakeholders from different backgrounds and the general public (Mori & Christodoulou, 2012). Quantification of sustainability performances is not only about measuring some aspects of development in different stages. Quantification also entails some requirements regarding data, reliability, consistency, and other statistical issues that should be taken into consideration (Dizdaroglu, 2017). Beyond these arguments, assessment tools are systems that evaluate the sustainability of housing, neighborhoods, cities, regions, and nations through indicator-based frameworks. This fact brings the quantification or measurability of assessment tools to a high level of importance.

8.2.4 Participatory capacity

Participatory capacity and community engagement are essential to make sustainability assessment tools legitimate and transparent. Assessment tools, as mentioned, are considered as decision-making support systems. Transparency is a critical issue that will increase the strength and applicability of development policies and projects and allow having more effective decision support systems (Pol'ıvka & Reicher, 2019). Accountability and citizen engagement in the decision-making and planning process would improve the acceptability of projects (Ammons & Madej, 2018). The failure of governments and planning institutions to underpin the causes of unsustainable development and effectively provide services for citizens could make the public skeptical about planning efforts. Various natural, social, and economic crises in the past decades have shown that urban development plans have not always been successful (Pint'er, Hardi, Martinuzzi, & Hall, 2012). Sustainability assessment tools should have the capacity for the involvement of all stakeholders as the active and real engagement would ensure more reliable outcomes for decision making. While assessment tools usually are applied by a third party or independent institution, the participation of actors and stakeholders will contribute to more accurate and reliable results. Public engagement increases reliability and reflects the priorities of stakeholders (Sharifi, Dawodu, & Cheshmehzangi, 2021a).

8.3 City sustainability assessment tools

Sustainability assessment criteria highly depend on the definition and interpretation of sustainable development and sustainability. S*ustainable city* and *urban sustainability* refer to states of sustainability, while *sustainable urbanization* or *sustainable urban development* addresses the process of sustainability (Shen, Ochoa, Shah, & Zhang, 2011). In this section, we will focus on specific assessment tools that mainly address the state of sustainability.

Sustainability assessment tools have been applied widely in small scales such as buildings. The main reason for the widespread application of sustainability assessment tools in buildings is that construction standards at the building scale could be easily quantified and implemented. However, the necessity of promoting sustainability in all scales has increased the request for scaling up assessment tools. While city sustainability assessment entails higher complexity and uncertainties, due to comprehensiveness and integrative nature of cities, sustainable development policy implementation could be reachable on this scale (Pedro, Silva, &

Pinheiro, 2018). Scaling up of sustainability assessment tools has contributed to development of revised versions of toolkits and new methodological improvements in sustainability research and practice (Grazieschi, Asdrubali, & Guattari, 2020). Sustainability assessment tools in the literature are diverse based on different perceptions, targets, and perspectives of researchers and policy makers. They could be categorized based on assessment methods (index-oriented systems, rating systems, impact assessment, etc.), sustainability principles (socioecological integration, (intra-)intergenerational equity, resource maintenance and efficiency), and sustainability dimensions (social, economic, institutional, cultural, environmental, energy, etc.) that may have differences and similarities (Cohen, 2017).

Sustainability assessment tools at the city scale entail some limitations and barriers that should be thought or adjusted. One of the main barriers to sustainability assessment at the urban scale is limited data availability. As sustainable assessment is about quantification of impacts and consequences, data availability plays a critical role (Pedro et al., 2018). The required data should be available in all city zones in a normalizable state to be comparative.

In this section, we will introduce the four most common urban sustainability assessment tools that have been theoretically developed and practically applied in case studies: International Urban Sustainability Indicators List (IUSIL), LEED for cities and communities (LEED Cities form now on), sustainability assessment tool, Comprehensive Assessment System for Built Environment Efficiency (CASBEE), and Chilean Center for Sustainable Urban Development (CEDEUS).

8.3.1 IUSIL

IUSIL is an international sustainability assessment tool that analyzes the performance of cities based on their environmental, economic, social, and governance functions. IUSIL includes 10, 5, 18, and 4 indicators of environmental, economic, social and governance sustainability, respectively. These indicators contain 117 subindicators that are used to analyze plans both comparatively and individually. As discussed in the previous section, sustainability assessment tools have different functions and each of them might have its drawback. The main challenge of this assessment tool is the lack of capacity to consider the context of planning and practice. However, it is developed to compare global cases. Shen et al. (2011) applied and assessed the quality of this assessment tool in nine case studies around the world. They analyzed the planning practice in these case studies and found that the comparative nature of IUSIL will provide an opportunity to compare the drivers and goals of selected practices and share sustainability knowledge. This assessment tool has been applied in different case studies and practices around the world since 2011. Empirical results have shown that while generalization and comparability of assessment tools are critical to assessment efficiency, the contextuality of assessment should not be ignored. So, Shen et al. (2011) suggest that the number and type of indicators introduced in this assessment tool could be changed based on the target and context of the assessment.

8.3.2 LEED for cities and communities

LEED sustainability assessment tools are one of the best-developed toolkits to analyze and assess planning interventions. LEED assessment tools are available for different scales, including cities, neighborhoods, and buildings. In this section, we will focus on LEED for cities and communities. The pilot and formal versions of the toolkit for cities and communities were released in 2016 and 2018, respectively. LEED for Cities and Communities is a rating system and certification program for evaluating the sustainability of urban development and the quality of life of urban communities. It is argued that principles promoted by LEED for Cities and Communities will contribute to more sustainable, equitable, and resilient cities around the world. The latest versions of this system include frameworks for both existing and future cities. The main themes are Integrative Processes (IP), Ecology and Natural Systems (EN), Transportation and Land Use (TR), Water (WE), Energy and Greenhouse Gas Emission (EN), Materials and Resources (MR), and Quality of Life (QL). This assessment tool is a certificate for rating and assessing the performance of urban projects throughout the world. This tool is increasingly gaining global recognition, and international companies use it to demonstrate the reliability and credibility of their performance (Dang et al., 2020). The final outcome of the assessment process is a certificate that rates planning policies, projects, and intervention plans on a 110 points scale. The minimum value for certification is 40. The categories are certified (40–49), Silver (50–59), Gold (60–79) and Platinum (80 and more) (USGBC, 2021b).

8.3.3 CASBEE for cities

CASBEE was developed jointly by academics, research institutions, and governmental bodies in Japan. It is a method for evaluating and rating the environmental efficiency of buildings, neighborhoods, and cities. Originally, this assessment tool was developed by a collaborative committee established in 2001, including the Japan Sustainable Building Consortium (JSBC), Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), academics, local governments, and industries. CASBEE has several versions that could be employed for buildings, neighborhoods, and cities. CASBEE for cities was released in 2015 and is meant to be useful for evaluating the environmental performance of cities in different contexts. The release of this assessment tool was simultaneous with the 2015 United Nations Framework Convention on Climate Change. The assessment tool is constructed based on two pillars, reducing the Load on the environment (L) and increasing the Quality of the built environment (Q). Quality improvement has three main dimensions of environmental, social, and economic that have 4, 3, and 3 indicators, respectively. Totally 20 subindicators are used to evaluate the quality performance of cities. Environmental Load reduction also has two indicators, including carbon emission from energy and nonenergy sources. The former has four subindicators and the latter is assessed by one subindicator. The assessment outputs are visualized in four areas of social aspects, economic aspects, environmental aspects, and environmental load. Also, the outcome of this assessment tool would be scored between 0 and 100 for Q and L. As CASBEE provides value for before and after implementing a policy or a project, the efficiency of interventions could be easily presented by this assessment tool (Junichi, Murakami, Ikaga, & Kawakubo, 2016). CASBEE also ranks cities based on their Built Environment Efficiency (BEE) value of $Q1$ (environmental), $Q2$ (social), $Q3$ (economic), $L1$, and $L2$. The final assessment brands could be either Excellent, Very Good, Good, Fairly Poor, and Poor (Sharifi et al., 2020).

8.3.4 CEDEUS

Since the 1990s, most sustainable development assessment tools and frameworks have been developed and applied in the Global North. However, some aspects of sustainability, such as social inequality and poor infrastructures, are the main feature of urbanization in the Global South. In the last couple of decades, the Chilean National Commission for the Environment has invested in providing a sustainability assessment framework suitable for the urban areas of the Global South. CEDEUS is the result of these efforts by the Chilean government and universities along with other international institutions. The main critical issues to building this assessment tool were transparency, participation, accountability, and data availability in developing countries. Additionally, alignment with sustainable development goals (SDGs) is another important issue that was taken into consideration. The final version of CEDEUS was expert-led but with extensive public participation. The assessment tool was developed in many phases including indicators selection, subindicators selection, application of the indicators in selected cities in Chile, evaluation of the results of the empirical analyses, and finally providing sustainability standards. The final version of CEDEUS includes 29 indicators under the following main themes: access and mobility, environment and sanitation, governance, health, and social equity. While it was supposed to cover most of the sustainable development goals, as the final version of this assessment tool was released (2014) a year before SDGs final draft, CEDEUS mainly covers some SDGs, namely, 1,2,3, 8, 9, 10, 11, 13, and 16. Steiniger et al. (2020) implemented this framework in five selected cities in Chile and suggested that it has a unique approach as it focuses on the percentage of people with good conditions and their distribution through the whole city.

8.4 Neighborhood sustainability assessment tools

Sustainability assessment tools, as mentioned, could be implemented in all scales ranging from the state level to regions, cities, neighborhoods, and buildings. However, the neighborhood is one of the most desirable and efficient scales for analyzing sustainability capacities. On the one hand, the neighborhood is small enough to intervene through planning and design initiatives; on the other hand, it is large enough to reflect the socioeconomic and political dynamics of the planning process (Sharifi, Dawodu, & Cheshmehzangi, 2021a). Therefore, in practice, the result of sustainability assessment tools would be more applicable on neighborhood scale than higher and lower scales.

Several movements in the past century or so have contributed to the evolution of sustainable neighborhoods. For example, in the United States after the 90*s*, due to the dominance of the *New Urbanism* movement, the focus on walkable and attractive street spaces was the most definitive sustainability factor, while in the last decade, energy efficiency has received more attention in efforts aimed at promoting sustainable neighborhoods (Grazieschi et al., 2020). While tens of sustainability assessment tools for neighborhoods are developed throughout the world, in this research, we have focused on and analyzed three of them that are commonly used in planning research and practice. These are LEED for Neighborhood Development (LEED ND), Building Research Establishment Environmental Assessment Method (BREEAM), and Green Star Communities (GSC).

8.4.1 LEED ND

LEED ND is one of the most well-established and common assessment tools at the neighborhood scale developed by the US Green Building Council (USGBC), in collaboration with the Congress for the New Urbanism and the Natural Resources Defense Council in 2007. LEED ND combines smart growth, planning regulations, and green design and sustainable development principles in an integrated framework. As sustainability issues at the neighborhood scale are more suitable and measurable than lower and higher scales, this assessment tool has gained more currency in planning practice and research. LEED ND covers different phases of project implementation, including design, construction, evaluation, and maintenance. Additionally, it provides various frameworks and criteria to reach a more sustainable neighborhood design and planning (Diaz-Sarachaga, Jato-Espino, & Castro-Fresno, 2018). Following the smart growth movement, LEED ND was initially developed to analyze the effects of low-density development in North American cities (Sharifi et al., 2020). However, it has been adjusted to international contexts and has been used in different countries by governmental bodies and private developers and investors. The assessment tool focuses on five main themes, namely, *Smart Location and Linkage* (SLL), *Neighborhood Pattern and Design* (NPD), *Green Infrastructure and Buildings* (GIB), *Innovation* (IN), and *Regional Priority* (RP). Each of these dimensions has several indicators that would be scored by a detailed scoring system. The final score would be reported in each dimension and the total obtainable score is 110. Depending on the overall score, developments will be branded as either Certified (40–49), Silver (50–59), Gold (60–79), or Platinum (80 and more) (USGBC, 2021a).

8.4.2 BREEAM communities

BREEAM was initially established by Building Research Establishment (BRE) Global to address various aspects of sustainability in building construction. Then, they adjusted the indicators and themes to be applicable at the neighborhood scale (Sharifi & Murayama, 2013). It was first released in 1990 to analyze and assess the sustainability of master planning, infrastructure, and building construction. BREEAM is the first and one of the most recognized international certification systems to assess environmental, social and economic sustainability of projects and mitigate the adverse environmental effects of urbanization by standard indicators developed by BRE (BREEAM, 2012). This assessment tool is useful for various stakeholders, including planning agencies, authorities, private developers, and other customers. It also has a bespoke version to ensure applicability in different contexts (Kaur & Garg, 2019). Technically, BREEAM is developed for various purposes, including *communities*, *In-use*, *New construction*, *Infrastructure* and *Refurbishment and fitness*. This research focuses on BREEAM communities that covers various aspects of sustainable development in *governance*, *Social and Economic Well-being*, *Transport and Movement*, *Land use and Ecology*, *Resource and Energy* and *Innovation* dimensions. Each of these aspects contains more sub-categories and indicators. The final score of the BREEAM certificate would be reported in four main categories: Good (45–55), Very Good (55–70), Excellent (70–85), and Outstanding (More than 85) (BREEAM, 2012).

8.4.3 GSC

GSC is an internationally recognized sustainable assessment tool developed by the Green Building Council of Australia (GBCA) released in 2012 and revised in 2016. The main mission of GBCA has been transforming Australian cities to more livable, productive, healthy, resilient, and sustainable communities. GSC provides a holistic rating and assessment framework for individual buildings, neighborhoods, and communities scales. This rating system was developed through an active engagement of local governments, academics, social planners, agronomists, and other stakeholders. GSC covers six main themes, including *Governance*, *Design*, *Livability*, *Economic Prosperity*, *Environment*, and *Innovation*. Scoring community sustainability would be done by 38 credits applied to the planning, design, and delivery stages of the projects. These indicators would be scored in relation to planning and development (strategic, master planning, development control, sustainability/environment, social planning, and economic) and assets and operation (asset management, community facilities, waste, water, and sewerage) (GBCA, 2014). GSC is among the pioneer assessment tools and rating systems that consider urban governance into their focus themes (Sharifi & Murayama, 2013). This assessment tool has good applicability in an international context as it has provided some space for adaptation to different subjects and contexts (Sharifi, Dawodu, & Cheshmehzangi, 2021a). Moreover, other success factors of GSC are facilitating stakeholder engagement and attention to different sustainable development dimensions (Sharifi, Dawodu, & Cheshmehzangi, 2021b).

8.5 The extent of inclusion of smartness indicators in sustainability assessment tools

Smart city has been massively used as an urban planning approach to combat the adverse effects of climate change and reach sustainable development in urban areas. While a lot of literature exists about different aspects, principles, requirements, and processes of smart city policy implementation, there is no universally accepted definition for this concept. However, the most intuitive aspect of smart city is about using technology to improve urban functions, increase urban resilience, and enhance community well-being (Hassankhani, Alidadi, Sharifi, & Azhdari, 2021). The nature of the smart city approach in planning has experienced a focus shift from technology deployment as an outcome of planning to a planning policy that should be implemented through a participatory and collaborative process (Kummitha, 2020). Technology deployment and smart cities have evolved in the last couple of decades exponentially. Accordingly, evaluation and assessment of smart city policy, principles, implementation, processes, outcomes, and consequences have gained attention (Sharifi, 2019, 2020). A variety of assessment tools have been developed to analyze different aspects of a smart city. These assessment tools are used to, among other things, understand the shortcomings of smart city projects and provide opportunities for more efficient and sustainable smart city development (Caird, 2018). In this section, we focus on indicators of smartness and their extent of inclusion in sustainability assessment tools. To do so, first, we will review the different dimensions of a smart city. One of the main sources of smart cities indicators is the list proposed by Sharifi (2019). According to this study, six major smart city dimensions exist, as shown in Table 8.1.

TABLE 8.1 Smart city dimensions and variable.

Dimensions	Variables
Economy	Innovation and innovation culture, knowledge economy, entrepreneurship, finance, tourism, employment, local and global interconnectedness (international embeddedness), productivity and efficiency, flexibility of the labor market, impacts
People	Education/lifelong learning, level of qualification/ICT skills, cosmopolitanism/open mindedness
Governance	Visioning and leadership, legal and regulatory frameworks, participation, transparency, public and social services, efficient and integrated urban management
Environment	Environmental monitoring and management, general infrastructure, built environment/planning and design, materials, energy resources, water resources, waste (solid waste, waste water, sewage) environmental quality/pollution
Living	Social cohesion/inclusion, equity and justice, cultural development, housing/livelihood quality, healthcare, safety and security, convenience and satisfaction/subjective well-being
Mobility	Transport infrastructure, transportation accessibility, transportation management, ICT infrastructure, ICT management, ICT accessibility

Sustainability and smartness of urbanization and urban development are different approaches that might have some principles and goals in common. While the sustainability of urban development has a comprehensive and holistic emphasis, the economy has been the dominant goal of a smart city (Monfaredzadeh & Berardi, 2015). Accordingly, there are some similarities and differences between smartness and sustainability assessment tools. In this section, the alignment of these two types of rating systems will be scrutinized. While smart city has various dimensions, in this research, we have focused on six of them that each contains a number of variables and indicators. These dimensions are economy, people, environment, governance and institutions, living, and mobility. The seven previously introduced sustainability assessment tools at the city (IUSIL, LEED cities, CASBEE cities, and CEDEUS) and neighborhood (LEED ND, BREEANM, and GSC) scales are analyzed to examine the extent of inclusion of smart city indicators in sustainability assessment tools.

A quantification process is applied to analyze the inclusion of smartness indicators in assessment tools. We have made a matrix with smart indicators (40 main indicators) on the columns and the seven assessment tools on the rows. This matrix is used to understand the extent of the inclusion of smart city indicators in the sustainability assessment tools. The level of relevance is scored from 0 (lowest alignment) to 4 (highest alignment). Then, as each dimension of the smart city has various indicators, the score for each dimension is normalized and converted to a 0–100 scale. Overall, it is found that Smart city indicators have some level of alignment with indicators of sustainability assessment tools. However, the extent of inclusion of these indicators is not the same for all dimensions. As can be seen from Fig. 8.1, the smart environment has the highest share of inclusion in the selected sustainability assessment tools. The mean value for the inclusion of smartness indicators in the chosen sustainability assessment tools is more than 83%. Comparatively, the mean values for smart living, smart governance, and smart mobility are 68.3%, 54.6%, and 47.5%, respectively. Smart economy indicators have the least degree of alignment with sustainability assessment tools, with a mean value of 31%. Our analysis showed that sustainability assessment tools are mainly focused on the environmental, institutional, and well-being of residents, while smart city tools

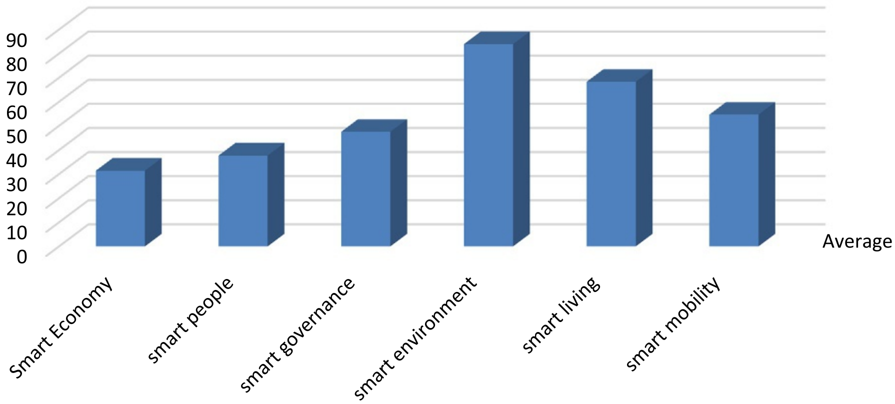


FIG. 8.1 The extent of inclusion (percent) of smart city indicators in the selected sustainability assessment tools.

and indicators have mainly focused on economic development. The result of our analysis for each dimension is presented in the next section.

8.5.1 Economy

Smart economy is one of the main pillars of smart city initiatives. Employing entrepreneurial and innovative production and business and marketing strategies play a critical role in making smart cities. A smart economy is concerned with the different aspects of urban economy such as creativity, innovation, efficiency, localization of processes, sustainable economic growth, human capital, tourism, and sharing and green economy (Kumar & Dahiya, 2017). Regarding indicators and assessment tools, smart economy addresses various aspects such as innovation (culture), knowledge economy, entrepreneurship, finance, tourism, employment, local and global embeddedness, flexibility, productivity, efficiency, and impacts of smart city initiatives (Sharifi, 2019).

The extent of inclusion of smart economy indicators in the seven previously mentioned sustainability assessment tools was examined. The results are presented in Fig. 8.2. As can be seen, the inclusiveness of smart economy indicators in sustainability assessment tools is divergent. As mentioned earlier, the smart economy is the least emphasized aspect in sustainability assessment tools. However, among the selected SATs, CASBEE Cities has the highest level of alignment with smart economy indicators. It is followed by GSC, where about 40% of the smart economy indicators are included. The extent of inclusion in IUSIL, LEED cities, LEED ND, and BREEAM is about 20%–30%. The results show that there is no tangible difference between neighborhood and city assessment tools regarding the extent of inclusion of smart economy indicators.

8.5.2 People

People are the core components of the smart city approach along with technology and processes (Anthopoulos & Tsoukalas, 2006). As discussed, one of the main paradigm shifts of

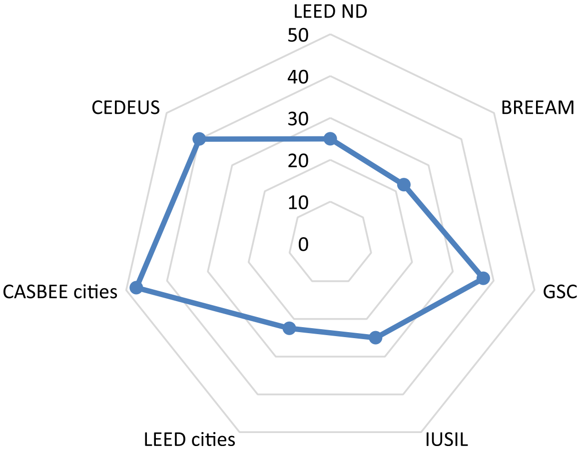


FIG. 8.2 The extent of inclusion (percent) of smart economy indictors in the selected sustainability assessment tools.

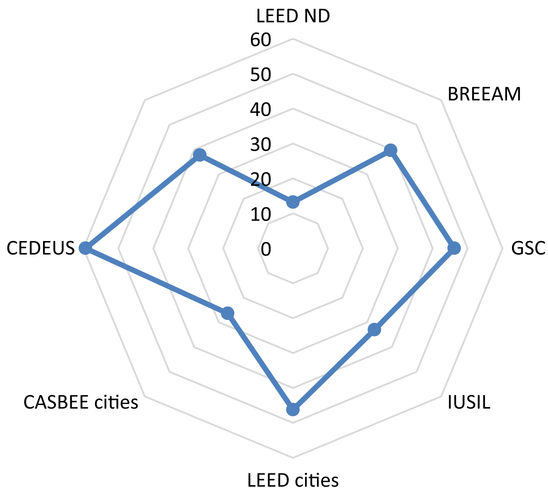
smart city approaches in urban planning has been the changing role of people in conceptualizing, implementing, and management of smartness and technology deployment (Kummitha, 2020). Citizens play a critical role in ensuring the effectiveness, efficiency, and productivity of smart cities. That is why the top-down approaches that have ignored the role of people have failed to reach their goals. Empowering population, enhancing technical literacy, and improving educational systems to deliver technology-based services are subjects that are critical for successful implementation of smart city initiatives (Gooch, Wolff, Kortuem, & Brown, 2015). Therefore, some main variables related to people have been developed to analyze the effectiveness and efficiency of smart city projects such as education and lifelong learning, level of qualification and ICT skills, cosmopolitanism, and open mindedness (Sharifi, 2019).

As discussed earlier, while people are at the core of smart city initiatives and associated assessment tools, their role has not been well reflected in the selected sustainability assessment tools. Fig. 8.3 presents the results of the analysis. The extent of inclusion of smart people indicators in the selected sustainability assessment tools was 13% and 60% in CEDEUS and LEED ND, respectively. GSC and LEED cities have the same level of inclusion by 46%. There is no tangible difference between neighborhood and city assessment tools.

8.5.3 Governance and institutions

Smart city approach, policy, and practice provide great opportunities toward smart governance through the capacities provided by Information and Communication Technologies (ICT). Smart governance facilitates good governance by connecting governmental bodies to people and people themselves to each other (Rajput, Li, Zhang, & Mostafavi, 2020). Additionally, smart city initiatives empower citizens to participate, increase accountability and transparency of governmental processes, and enhance active public engagement (specifically for vulnerable populations) that all are the main concerns of SDGs and urban resilience frameworks (Bertot, Jaeger, Munson, & Glaisyer, 2010; Levenda, Keough, Rock, & Miller, 2020). Accordingly, smart governance indicators and assessment tools focus on the potential benefits of

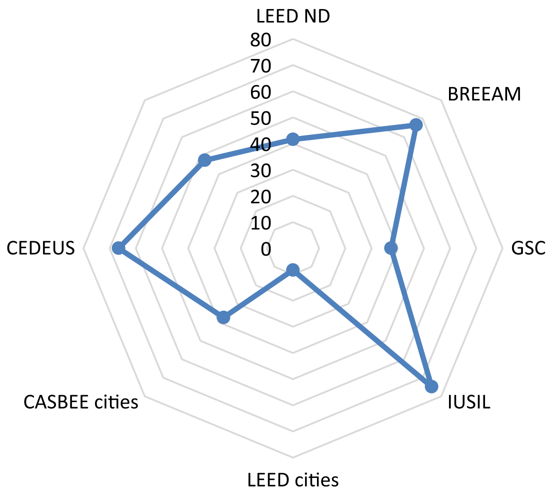
FIG. 8.3 The extent of inclusion (percent) of smart people indicators in selected sustainability assessment tools.



smart city initiatives, including visioning and leadership, legal and regulatory frameworks, participation, transparency, public and social services, and efficient and integrated urban management (Sharifi, 2019).

Governance and institutions are one of the main pillars of both smart city and sustainability approaches. Accordingly, on average, half of the smart governance indicators are similarly emphasized in the selected sustainability assessment tools. However, it is worth mentioning that there is a large variance among the selected sustainability assessment tools in terms of the extent of inclusion of smart governance indicators. While IUSIL contains about 75% of smart governance indicators, the alignment is less than 10% in LEED cities. BREEAM Communities and CEDEUS have reflected the same share of smart governance indicators in their rating system by about 66% of inclusion. LEED ND and CASBEE cities have also included about 37% of smart governance indicators, as shown in Fig. 8.4. There is no considerable difference in the pattern of inclusion among the city and neighborhood assessment tools.

FIG. 8.4 The extent of inclusion (percent) of smart governance indictors in selected sustainability assessment tools.



8.5.4 Environment

Smart city is one of the widely used solutions to cope with the adverse effects of climate change and urbanization. Therefore, the need for conformity of smart city principles and policies with sustainable development has gained attention. Flexibility and productivity of smart solutions, smart waste management, smart regeneration, smart recycling, smart infrastructure, and smart preservation contribute to environmental sustainability (Toli & Murtagh, 2020). While smart city initiatives do not directly contain natural environment issues, this target could be met by putting livability at the core of smart city programs (Alawadhi et al., 2012). Various variables and indicators have been developed to assess the extent of alignment of smart city initiatives with environmental sustainability that contain issues such as environmental monitoring and management, green infrastructure, built environment planning and design, materials, energy resources, water resources, waste, and environmental pollution and quality (Sharifi, 2019).

As expected, among different smart city dimensions, the highest level of inclusion in sustainability assessment tools was observed for the environmental dimension (84%). Except for LEED cities, other sustainability assessment tools in both neighborhood and city scale have included more than 80% of smart environment indicators. This shows that smartness and sustainability both have much in common regarding environmental issues. Moreover, comparative studies have shown that cities are employing technology-based solutions to reach sustainability (Lee, Park, & Schuetze, 2015). The main reason for such an alignment is that fundamentally sustainability assessment tools were developed to protect the environment in the first place but then covered other areas too. This critical issue is so important that some have criticized the overemphasis on the environmental dimension in assessment tools (Sharifi, Dawodu, & Cheshmehzangi, 2021b). The result of the extent of inclusion of the environmental dimension is presented in Fig. 8.5. As shown, six of the selected assessment tools have considered more than 80% of smart environment indicators. LEED cities are the only assessment tool that has less than 60% of alignment with smart environment indicators.

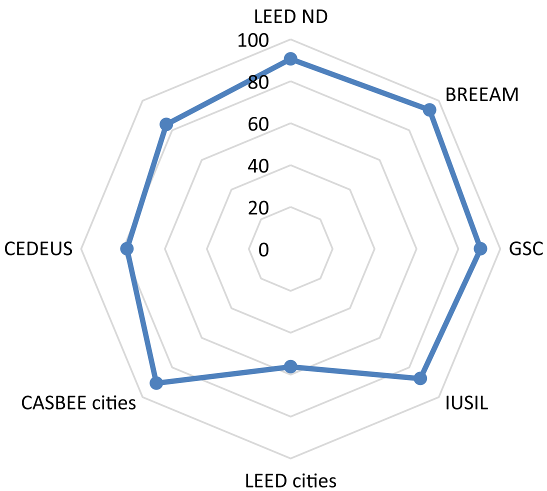


FIG. 8.5 The extent of inclusion (percent) of smart environment indictors in the selected sustainability assessment tools.

8.5.5 Living

Smart city initiatives affect various aspects of urban life. Living conditions socially, culturally, and politically should be considered in smart city projects. The technology could be used to reduce inequalities and disparities and contribute to a more inclusive, healthy, just, and secure society. However, this target could only be achieved if the planning process is transparent, participatory, and accountable (Levenda et al., 2020; Rajput et al., 2020). The evolution of the smart city from expert-led to human-led policy making has been an initiative to democratize the process and actively engage more people (Kummitha, 2020). The success of smart city initiatives is highly dependent on different aspects of living conditions of residents and the processes that contribute to these conditions (Sharifi, 2020). A large number of variables and indicators have been developed to assess smart city initiatives in seven main themes, namely, social cohesion, equity and justice, cultural development, housing quality, healthcare, safety and security, and satisfaction and subjective well-being (Sharifi, 2019).

Living as one of the main dimensions of a smart city has not been directly reflected in sustainability assessment tools. However, some indicators are indirectly aligned with sustainability assessment tools. The results of the extent of inclusion of smart living indicators in the selected sustainability assessment systems are presented in Fig. 8.6. On average, 68% of smart living indicators are included in the selected sustainability assessment tools. CEDEUS has the highest level of inclusion by about 90%. IUSIL and CASBEE cities assessment tools contain more than 80% of smart living indicators. Except for LEED cities, a pattern can be seen from our analysis; city assessment tools have better inclusion of living conditions of residents and communities than neighborhood rating systems.

8.5.6 Mobility

Urban mobility is one of the most problematic issues in urban planning. Transportation planning is highly dependent on simulation, and all policies are based on real-time data that

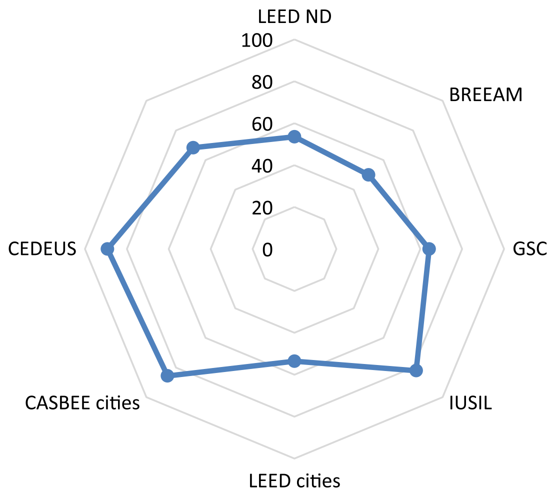


FIG. 8.6 The extent of inclusion (percent) of smart living indictors in selected sustainability assessment tools.

could be improved through smart city development. Moreover, as mobility in urban areas is the main source of pollution and carbon emissions, it has always been at the core of sustainable development concerns (Mitchell, Borroni-Bird, & Burns, 2010). By providing information, simulating behaviors and patterns, reducing energy consumption, recommending efficient solutions, and saving time, smart cities can positively affect urban mobility (Aletà, Alonso, & Ruiz, 2017). Additionally, as the movement of people, transactions and mobility directions are based on mobile applications smart city initiatives can increase the efficiency and quality of mobility (Sharifi, 2020). Various aspects of smart city initiatives could be assessed to analyze their effectiveness for smart mobility in areas such as transportation infrastructure, management and accessibility, and ICT infrastructure (Sharifi, 2019).

In our analysis, smart mobility includes transportation and ICT indicators. However, the results examining the extent of inclusion show that these two factors are not appropriately reflected in sustainability assessment tools. In other words, while, on average, 83% of transportation infrastructure, accessibility and management indicators are included in sustainability assessment tools, the extent of inclusion of ICT indicators is only about 26%. As shown in Fig. 8.7, regarding the inclusion of smart transportation indicators, CABEE cities and LEED cities have a perfect level of inclusion. However, less than 50% of ICT indicators are included in these tools. BREEAM Communities and CEDEUS both have included more than 90% of transportation indicators. The former has less than 10% alignment with ICT indicators, but the latter has more than 80%. Similar patterns can also be observed for GSC, IUSIL, and LEED cities. There is no significant difference between the assessment tools for neighborhoods and cities regarding the extent of inclusion of smart mobility indicators.

8.6 Integration of indicators related to climate resilience into the assessment tools

Climate change is one of the most critical and influential threats to human beings and urban settlements. Cities worldwide have put their efforts into strategies and policies to cope

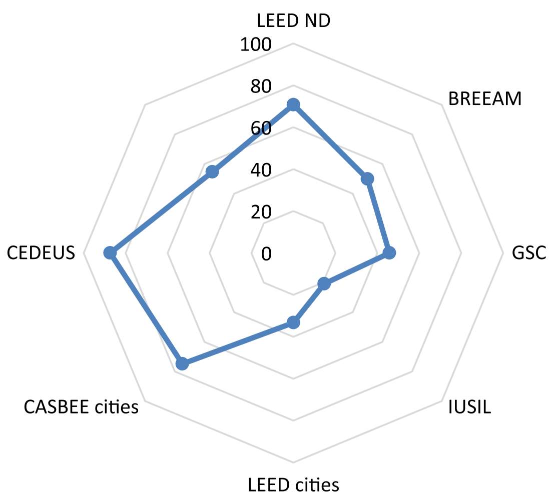


FIG. 8.7 The extent of inclusion (percent) of smart mobility indictors in selected sustainability assessment tools.

with the adverse effects of this stressor (Sharifi, Dawodu, & Cheshmehzangi, 2021b). More importantly, climate change is at the core of the urban resilience paradigm. Additionally, sustainable development policies and principles have emphasized different aspects of climate change to govern the balanced relationship between human beings and nature (Waas et al., 2011). Thus, bringing climate change effects and factors into planning practice has normatively and positively become a necessity. Accordingly, indicators of climate resilience should be included in sustainability assessment tools. On the other hand, a smart city as a solution and instrument to increase sustainability has gained currency in the last couple of decades (Hassankhani et al., 2021; Sharifi, Khavarian-Garmsir, & Kummitha, 2021). In Chapter 7, the inclusion of climate resilience in smart city assessment tools was investigated. So, this section analyzes the extent of the inclusion of smart indicators related to climate resilience in the sustainability assessment tools. To do so, first, we have outlined different dimensions of climate resilience and their associated assessment indicators. Then, the inclusion of smart city indicators related to climate resilience in the seven selected sustainability assessment tools is scrutinized.

Despite various skeptical political and academic positions, climate change is still the most important threat to human beings (Allam & Jones, 2019). Analytically, climate change has five main pillars, each of which includes different factors and indicators addressed in climate resilience assessment tools (Welle, Witting, Birkmann, & Brossmann, 2014). Although there are some arguments about these dimensions and perceptions of climate change resilience, they are beyond the aim of this research. So, this study focuses on these five dimensions (environmental, social, economic, infrastructure, and governance).

Environmental dimension of climate change refers to the diversity and state of the natural environment that sustains ecological functions and ecosystem services for the human being. Environmental climate resilience indicators include various issues such as biodiversity, deforestation, energy sources, and water sources. **Social** aspect of climate change concerns different dimensions of community well-being, health and social capitals, and networks. The associated indicators of the social dimension contain healthcare, the sociodemographic structure of society, social awareness and capital, and civil society. The **economic** dimension of climate change deals with the economic state of communities. It contains indicators related to businesses, the economic structure of the societies, finance, and the green economy. The **infrastructure** dimension is about all physical assets in the environment that can affect climate change and affect climate events during and after disturbances. Housing, traffic, telecommunication, energy infrastructure, and water infrastructure are examples of such indicators. The **governance** dimension addresses the processes and institutional dynamics of actions that could and should be done to mitigate the adverse effects of climate change. This dimension facilitates awareness, citizen engagement, and proper implementation of policies. Different indicators are included in this aspect, including the participation capacities, institutional capacities, investment and planning strategies, and administration of the processes (Feldmeyer et al., 2019; Welle et al., 2014).

In this section, we have focused on smartness indicators related to climate resilience. The basis of our analysis is indicators identified related to smartness in Chapter 7. The climate resilience indicators that have “fully” or “partially” been included in smart city indicators are considered. This framework includes 25 indicators in environmental, economic, social, infrastructure, and governance dimensions (see Table 8.2). We have created a comparison

TABLE 8.2 Climate resilience related smartness dimensions and indicators.

Dimensions	Variables
Environment	Biodiversity and green spaces, land consumption, water management, air quality, waste management
Infrastructure	Settlements, accessibility to green spaces, energy and green buildings, ICT accessibility and management
Economic	Innovation, knowledge economy, employment, economic stability
Social	Research projects, health accessibility and availability, employment rate, safety amenities, education levels, gender inequality
Governance	Government effectiveness, accountability, participation, environmental plans and strategies, climate change regulations, cooperation of specialists

matrix to know the extent of the inclusion of smart city indicators related to climate resilience in the seven selected sustainability assessment tools. The overall result of our analysis revealed that, on average, about 66% of investigated smart city indicators related to climate change are included in the selected sustainability assessment tools. There is a divergence in terms of the average value for different dimensions of climate change. The environmental dimension has been well included in the sustainability assessment tool (on average more than 83%). This is followed by infrastructure at 73%. However, the economic dimension of climate change has received the least attention at around 54% (see Fig. 8.8). On average, among the selected assessment tools GSC, on average, has the highest level of inclusion by more than 87% of coverage. CEDEUS, IUSIL, and CASBEE cities come after GSC by 77.5%, 75.7%, and 75.2%, respectively (Fig. 8.9). Neighborhood assessment tools, on average, include 44%–59% of smart city indicators related to climate resilience. These results show that city scale tools perform better in terms of the integration of smart city indicators.

The details of our analysis for all dimensions are presented in Fig. 8.10. Environmental indicators have the highest share in all assessment tools. IUSIL fully covers environmental indicators, while CASBEE cities and CEDEUS included 95% and 90% of indicators, respectively. Other assessment tools also cover between 70% and 80% of indicators. The infrastructure

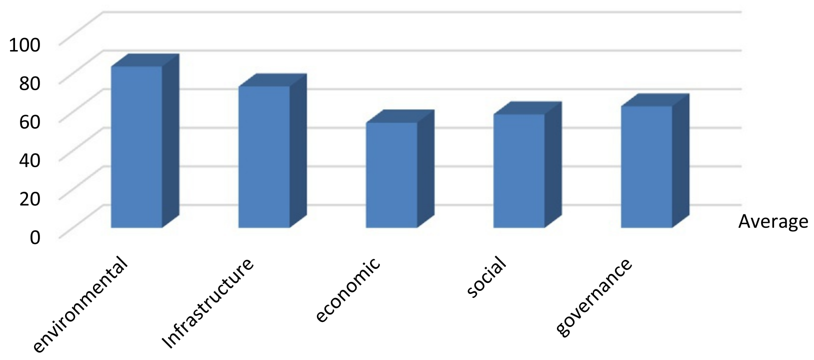


FIG. 8.8 The extent of inclusion (percent) of smart city indicators related to climate resilience in the selected sustainability assessment tools.

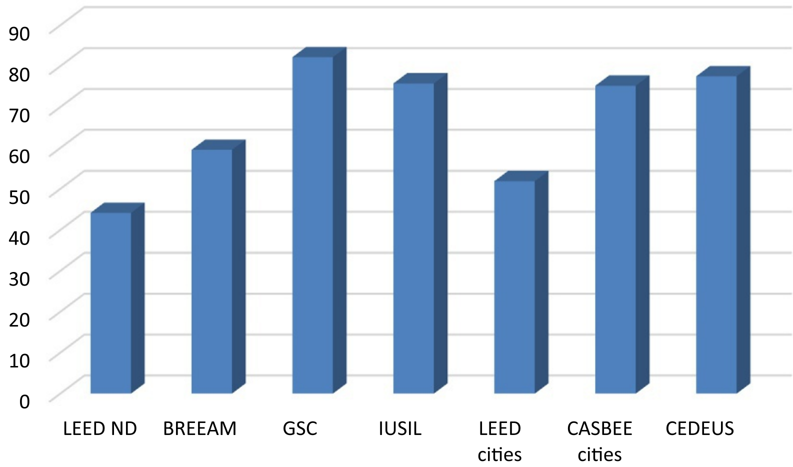


FIG. 8.9 The extent of inclusion (percent) of smart city indicators related to climate resilience in the selected assessment tools.

dimension stands at the second rank in terms of inclusion in sustainability assessment tools. GSC, CASBEE cities, and CEDEUS all contain more than 87% of indicators related to infrastructure. LEED cities cover just half of these indicators and have the lowest level of inclusion in this regard. A large variance between different assessment tools was observed for governance indicators. While CEDEUS included 83% of indicators, LEED ND covered just 29%. From the social perspective, there is even more variance between the selected assessment tools. Although the average is just less than 60%, LEED ND and CEDEUS have the highest and lowest indicators by 83% and 16.6%, respectively. The least covered dimension is economy. GSC included more than 93% of indicators related to this dimension and was followed by CASBEE cities at 81%. The rest of the assessment tools did not appropriately include indicators related to the economy.

8.7 Summary

Sustainability and urban resilience have been two main paradigms of planning and policy making in the past decades. While they have differences in terms of targets, principles, dimensions, and indicators, there are also similarities between the two concepts. Smart city initiatives are widely believed to have the potential to contribute to achieving urban resilience and sustainability. Analyzing the relationship between sustainability, resilience, and smartness has gained attraction in planning research in recent years. However, limited research exists on how their indicators are related. It is argued that assessment tools make more systematic, integrated, and flexible decisions in urban areas. Accordingly, many tools have been developed for assessing the sustainability, smartness, and resilience of cities. This research has focused on the relationship and alignment of these types of indicators.

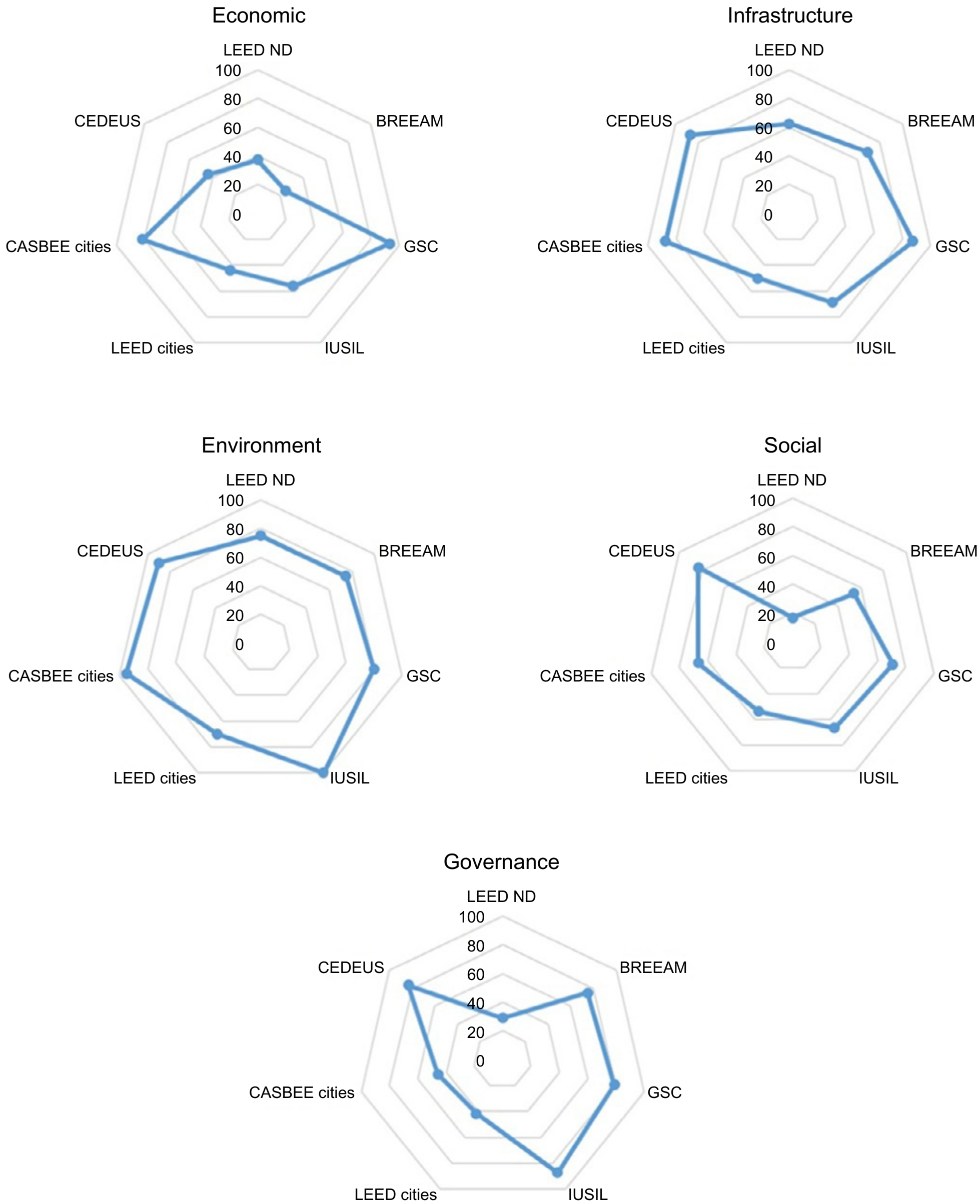


FIG. 8.10 The extent of inclusion of smart city indicators related to climate resilience in the selected sustainability assessment tools.

First, we analyzed different aspects of sustainability assessment tools. Then seven sustainability assessment tools were selected and introduced. In the next step, the extent of the inclusion of smart city indicators in the selected sustainability assessment tools was investigated. Finally, the extent of integration of smart city indicators related to climate resilience in the selected sustainability assessment tools was explored.

The results of our analysis showed that, on average, more than half of the smart city indicators are covered by selected sustainability assessment tools. However, the extent of coverage was not the same across all dimensions. Dimensions such as environment and smart living have been better included in the sustainability assessment tools than the smart economy and smart people dimensions. CEDEUS includes the highest percentage of smartness indicators among the selected sustainability assessment tools, while LEED cities include the lowest percentage. There is no considerable difference between neighborhood and city scales of sustainability assessment tools in terms of smartness inclusion.

As for the extent of inclusion of smart city indicators related to climate resilience in sustainability assessment tools, we found a better state of inclusion than general smartness indicators. The results of our inclusion analysis showed that the environmental dimension has received the most attention and has been well addressed in sustainability assessment tools. However, the economic dimension of climate change is the least covered one in sustainability assessment tools. Also, overall, city level sustainability assessment tools have more indicators in their system than neighborhood scale ones.

Overall, the results of this research show that more efforts are needed to better integrate smart city and climate resilience indicators into sustainability assessment tools. It is hoped that the developers of assessment tools will consider this issue when revising their assessment tools.

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CHAPTER

9

Indicators to assess contributions of smart city solutions and technologies to urban resilience

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9.1 Introduction

The growing trends in the concentration of people and properties in urban areas have increased their significance in global, national, and regional policy making. On the one hand, in the era of global change, there are concerns that unbridled urbanization may lead to undesirable consequences and externalities. Among other things, it could cause problems such as inequitable distribution and access to resources that is manifested in slums and informal settlements, air pollution, increased energy consumption, ecosystem degradation, and high concentration of resources in risk-prone areas that increase exposure to natural- and human-made hazards (Kuddus, Tynan, & McBryde, 2020; Patra, Sahoo, Mishra, & Mahapatra, 2018). On the other hand, cities have traditionally been considered as centers of innovation and economic growth, and it is hoped that innovative solutions such as efficiency improvements can reduce socioeconomic and environmental externalities of cities and contribute to addressing challenges of sustainability and climate change (Shahidehpour, Li, & Ganji, 2018). Therefore, depending on how cities are developed and managed, they can be parts of the problem or the solution.

Against this background, the increasing investment in smart city projects, which can be observed in many cities around the world, could be considered as an effort to strengthen the position of cities as part of the solution toward sustainability and resilience. The first smart

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city initiatives emerged about 3 decades ago and the field has been constantly growing ever since. Rapid advances in smart city solutions enabled by Information and Communication Technologies (ICTs) have created new opportunities to deal with increasing societal challenges, such as climate change, pandemics, and socioeconomic inequalities. In fact, recent advances in smart solutions have transformed many aspects of everyday life. ICTs, Internet of Things (IoT), Artificial Intelligence (AI), machine learning, and Big Data analytics, among other things, enable these smart solutions (Sharifi, Allam, Feizizadeh, & Ghamari, 2021). These technologies have the potential to improve quality of life, enhance societal capacities to deal with increasing challenges caused by global change, and support efforts aimed at achieving the Sustainable Development Goals (SDGs). However, despite increasing recognition of the significance of smart city solutions for creating just, resilient, and sustainable cities, existing knowledge on the actual and/or potential contributions of such solutions is limited. There is, particularly, limited knowledge on how smart cities can contribute to urban resilience.

In much the same way as the smart city concept, urban resilience is a relatively new concept that has gained ground over the past 2 decades or so (Sharifi, 2020c). The surge of interest in the concept could be explained by the rising trend of natural and human-made disasters and threats over the past few decades. Climate change is expected to further increase the frequency and intensity of natural disasters. Accordingly, there is now consensus among urban researchers, planners, and policy makers that resilience-building actions are essential to minimize potential human and property losses from future adverse events. This has led to a wealth of research on multiple aspects of urban resilience (Sharifi, 2020c; Yang, Yang, Li, Liang, & Zhang, 2021). Despite this, there is still no universally accepted definition for urban resilience (Sharifi et al., 2017). In this chapter, we define resilience as the "ability to plan and prepare for, absorb, recover from, and more successfully adapt to actual or potential adverse events" (Cutter et al., 2013). This definition is well aligned with different stages of disaster risk management. Therefore, it is suitable for exploring actual and/or potential linkages between the selected indicators and resilience. It is also worth mentioning that this definition refers to actual or potential adverse events. In that sense, and in the context of climate change, it can be argued that this definition relates to both climate change adaptation and mitigation. In terms of adaptation, it is related to dealing with current, as well as, future impacts of climate change. Also, in terms of mitigation, it is relevant as mitigation actions can reduce the intensity of future climate-induced stressors and, thereby, can contribute to planning and absorption abilities of resilience (Sharifi, 2021).

Developing indicators that are related to both resilience and smartness is desirable as it allows simultaneous assessment of both qualities/goals (i.e., resilience and smartness). Currently, these are often assessed separately. In fact, there are now multiple tools and indicator sets for assessing either resilience (Sharifi, 2016) or smartness (Sharifi, 2020b; Sharifi & Allam, 2022). This amount of interest in assessment tools and indicator sets is not surprising given the multiple benefits that they can provide to different stakeholders. For instance, they can improve the transparency of decision making, show the extent of success in achieving predetermined goals, foster mutual learning through meaningful benchmarking with peers, raise awareness of stakeholders, and encourage stakeholder engagement if designed and implemented in a participatory manner. Despite these multiple utilities, given the resource limitations (skilled personnel, budget, data, etc.), not all developers and/or local authorities may have enough capacity to develop and implement tools for assessment resilience or smartness. It is, therefore, desirable to develop tools and indicator sets that can be used to simultaneously cover both concepts (at least partially). This may also lead to other efficiency improvements and synergistic benefits. Accordingly, to fill this gap, in this chapter, we propose a set of indicators related to multiple dimensions of smart cities, namely, environment, economy, people, data, living, mobility, and governance, and discuss how they may relate to resilience abilities.

The chapter is organized as follows. Section 9.2 briefly explains the methods used to prepare the list of indicators. Following that, the indicators are introduced in Section 9.3 and their potential linkages to resilience are also indicated. Finally, Section 9.4 discusses the results and concludes the study with some suggestions for future research.

9.2 Materials and methods

As mentioned in the previous section, there are many tools and indicator sets for assessment resilience and smartness at various scales, ranging from projects to neighborhoods, cities, and city regions (Sharifi, 2016, 2019, 2020a; Sharifi & Allam, 2022). Also, there have been some efforts to link city indicators to resilience abilities (Sharifi & Yamagata, 2016a). To select indicators that reflect both resilience and smartness characteristics, we have relied on the existing studies mentioned above. In particular, we have adopted the indicator selection and categorization approach taken by Sharifi (2019) that provides a detailed list of indicators for smart city assessment. This list has been developed based on content analysis of 34 existing assessment tools and review of relevant literature. As shown in Fig. 9.1, the indicators are divided into seven categories, namely, economy, people, governance, environment, living, mobility, and data. Each of these categories is then divided into several subcategories.

The "economy" category includes indicators related to innovation/innovation culture, knowledge economy, entrepreneurship, finance, tourism, employment, local and global interconnectedness, productivity and efficiency, flexibility of the labor market, and economic impacts of smart cities. The "people" category includes indicators related to the use of smart solutions and technologies for education/lifelong learning, improvement of qualifications and ICT skills, and enhancing cosmopolitan thinking and sense of open mindedness. The "governance" category consists of indicators related to visioning and leadership of smart cities, legal and regulatory frameworks for smart city governance, stakeholder participation, transparent governance, digitalization of public and social services, and smart solutions for efficient and integrated urban management. The "environment" category includes indicators related to environmental monitoring and management, promotion of green infrastructure, improved planning and design of the built environment, material efficiency and recycling, use of clean and renewable sources of energy, enhancing water quality and ensuring efficient use of water resources, waste reduction and recycling, and overall enhancement of environmental quality and reduction of air, noise, soil, and water pollution. The "living" category deals with issues related to the quality of life and social structure of cities. These include social cohesion, equity and justice, cultural development, quality of housing and livelihood, healthcare facilities and services, safety and security, and subjective well-being and satisfaction with the quality of life. The "mobility" category is composed of indicators related to the availability and quality of transportation and ICT services. These include indicators related to various modes of transportation, their accessibility, and their efficient management.

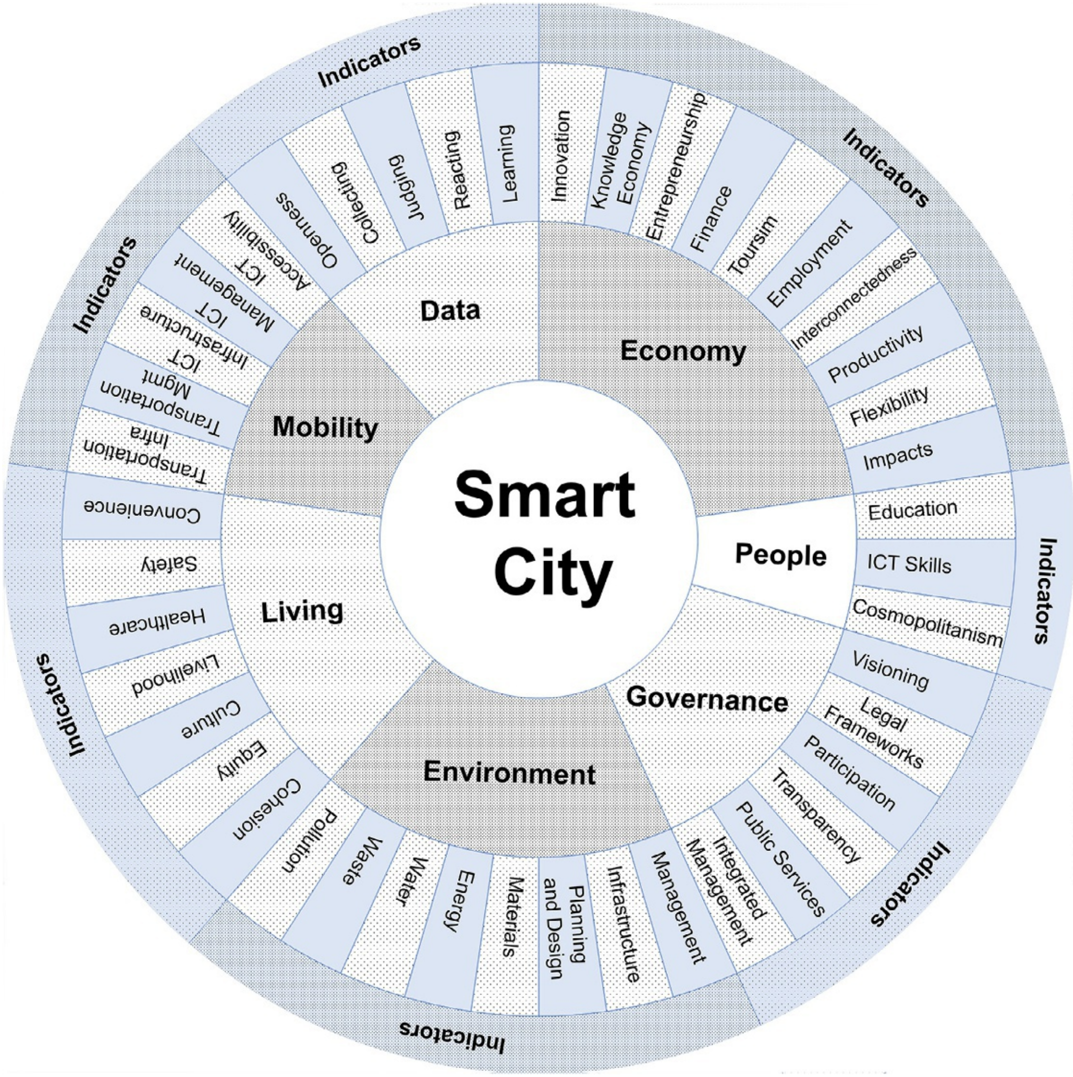

FIG. 9.1 Various dimensions and subdimensions related to smart cities (Sharifi, 2019).

In addition, it deals with appropriate provision of ICT infrastructure, their efficient management and maintenance, and measures to ensure their accessibility. Finally, the "data category" includes indicators related to open access to data, and appropriate measures for data collection and analytics, and use of data for better decision making and continuous performance improvement.

Ideally, for each indicator mentioned in Fig. 9.1, an indicator should have been proposed in Section 9.3 of this chapter (i.e., 268 indicators in total). However, not all indicators of Fig. 9.1 are directly related to smart solutions and linkages between some of them and resilience abilities are not clear. Therefore, only 98 indicators are introduced in this chapter. In some cases, we have changed the indicators to make sure that they are based on smart solutions and technologies. For this, we have relied on our previous experience with smart city literature. Also, some new indicators have been added by reviewing newly published research on smart cities.

Linking indicators to resilience abilities has also been done using a subjective method and based on the authors' previous research on urban resilience abilities (Sharifi & Yamagata, 2016a, 2016b). As mentioned earlier, these abilities are planning, absorption, recovery, and adaptation. Planning refers to any measures taken before the occurrence of a disaster/adverse event that contributes to mitigating risks and ensure better response and recovery. This could, for instance, include preparing hazard maps, setting regulations to limit development in risk-prone areas, and development of emergency management plans, infrastructure development, and personnel training. Absorption refers to actions that are taken in the immediate aftermath of a disaster to minimize the overall human and property losses and ensure maintaining some levels of system functionality. For instance, this may include the rapid provision of emergency services to the affected groups and their evacuation to safe areas and measures to avoid cascading effects. Recovery refers to activities that often start few hours or several days after the disaster occurs and is aimed to return the system to its pre-disaster state. This should, ideally, be achieved in a timely manner. Finally, adaptation means that the system should have the ability to learn lessons from the disaster in order to improve the system deficiencies and respond better to future similar events. In other words, a system should be able to not only bounce back to its predisaster equilibrium state but also bounce forward to a more advanced state that would ensure better performance under future adverse events that may be even more intensive. As will be seen in the next section, some of the indicators could be relevant to more than one resilience ability.

9.3 Results: The indicators

Each of the seven sets of indicators is briefly explained in the following section. These indicators are mainly based on ICTs. It should be noted, however, that some of the planning-related indicators are not directly related to smart solutions. Despite this, they have been included since they can be considered as precondition (prerequirement) factors for effective implementation of smart city solutions. For instance, distributed energy infrastructure is critical for energy resilience. Centralized energy systems can be equipped with smart technologies. However, in case of major disruptions, such smart technologies would make limited contribution to enhancing resilience and energy supply would not be maintained. Similar arguments can be made for other indicators, for example, those related to resilient urban development.

9.3.1 Indicators related to economy

The 12 indicators related to the economy are listed in Table 9.1. It can be seen that these indicators are mainly related to adaptation and absorption abilities of resilience. However,

TABLE 9.1 Indicators related to economy and their potential linkages to resilience abilities.

No.	Indicator	Planning	Absorption	Recovery	Adaptation
Ec1	Share of e-business and e-commerce transactions	✓	✓		✓
Ec2	Contribution of knowledge economy and ICT initiatives to GDP (%)	✓	✓	✓	✓
Ec3	Number of start-ups	✓			✓
Ec4	Funding for smart city projects (public/private finance, crowd sourced, etc.)	✓			
Ec5	Online and ICT-enabled tourism promotion	✓	✓		✓
Ec6	Smart pricing (e.g., apply time of use tariffs for energy/water conservation, especially under emergency conditions; demand-based pricing; congestion pricing)		✓		✓
Ec7	Avoided damage attributable to smart solutions		✓	✓	
Ec8	Home-based work and workspace flexibilization (teleworking)		✓		✓
Ec9	Timetable flexibilization, working hour flexibility		✓		✓
Ec10	Use of smart solutions to reduce recovery costs			✓	
Ec11	Long-term contribution of smart solutions to household and municipal cost saving	✓			✓
Ec12	ICT-enabled flexibility (e.g., online job advertisement and application, etc.) and improvement of traditional industry and job market		✓		✓
Total number		6	8	3	9
Percentage		50	67	25	75

some can also be linked to planning and recovery abilities. In terms of planning ability, it can be argued that measures such as increasing share of e-businesses, better development of knowledge economy, promotion of ICT-enabled tourism, and investment on smart infrastructure are planning and preparation efforts that enhance abilities to deal with risks. For instance, during the COVID-19 pandemic, it was demonstrated that cities with better digital infrastructure are better prepared and have more capacities to address the crisis (Sharifi & Khavarian-Garmsir, 2020). Similarly, digitalizing economy enhances the capacity to absorb shocks and minimize functionality loss. This is achieved by integrating diversity and redundancy features into the economic structure so that unaffected parts/components could compensate for the potential functionality loss of the others. For instance, teleworking and other teleservices allow sustaining urban functionality under adverse events when mobility is restricted. Reducing functionality loss would also benefit the recovery process as less effort and resources would be needed to return to normal conditions. In addition, smart and innovative solutions may contribute to reducing overall recovery costs and provide cities with additional revenues to sustain their activities under difficult circumstances. In terms of adaptation, in the long run, smart solutions and efforts to digitalize economic sectors are expected to enable the overall performance of cities and enable them to better deal with shocks. For instance, they may lead to a more flexible economic structure that has more capacity to accommodate shocks (Zhou, Zhu, Qiao, Zhang, & Chen, 2021).

9.3.2 Indicators related to people

Indicators related to this category are mainly linked to people's level of ICT literacy and their abilities to utilize smart technologies in their daily lives and under emergency conditions. As evident from Table 9.2, these indicators can be associated with all four resilience abilities. Obviously, educational programs and lifelong learning are essential planning and preparation measures that can improve citizen skills and enable them to use smart technologies effectively. These should, of course, be coupled with measures aimed at increasing penetration rate of internet and social networking services among citizens. Enhanced ICT literacy and better accessibility to internet and smart technologies can, in turn, strengthen absorption and recovery abilities. Timely access to credible sources of information is critical for enhancing the situational awareness of citizens and absorbing the initial shocks of disasters (Luna & Pennock, 2018). Internet-based services are increasingly used for disseminating early warnings and necessary emergency response information. Access to such services and ability to use them effectively is, therefore, vital for risk absorption. Such services have also proven effective for timely recovery. For instance, they can facilitate maintaining social connections that are needed to collectively overcome challenges and return to normal conditions (David Ramírez & Jorge Ramírez, 2017; Zhou et al., 2021). Finally, lifelong education and investment on improving ICT literacy can, in the long run, improve the overall capacity of communities and enable them to better adapt to adverse events.

TABLE 9.2 Indicators related to people and their potential linkages to resilience abilities.

No.	Indicator	Planning	Absorption	Recovery	Adaptation
P1	Level of digital and ICT literacy and technical capability		✓	✓	
P2	Educational programs to improve digital skills	✓			✓
P3	Internet penetration rate	✓	✓	✓	
P4	Social networking penetration rate	✓	✓	✓	✓
P5	Implementation of e-learning programs (reducing the need for physical presence under undesirable conditions)	✓	✓		✓
Total number		4	4	3	3
Percentage		80	80	60	60

9.3.3 Indicators related to governance

Urban governance is one of the sectors that has been highly influenced by advances in ICTs. In fact, smart solutions and technologies have provided urban authorities with unprecedented opportunities to develop and implement more evidence based and inclusive governance mechanisms. As shown in Table 9.3, there are 19 governance-related indicators that can

TABLE 9.3 Indicators related to governance and their potential linkages to resilience abilities.

No.	Indicator	Planning	Absorption	Recovery	Adaptation
G1	Availability of city resilience plans and strategies	✓	✓	✓	
G2	Availability of smart city vision and roadmap	✓			✓
G3	Plans and strategies for performance monitoring and assessment of smart cities	✓			✓
G4	Availability of risk governance plans and integration of smart solutions in them	✓	✓	✓	
G5	Laws and regulatory frameworks for smart city planning that include strategies to protect consumer privacy and regulate data ownership and access	✓			✓
G6	Availability of a one-stop platform for data integration and for online accessibility and coordination of city services	✓	✓	✓	
G7	Availability of online civic engagement and feedback systems	✓	✓	✓	✓
G8	Data sharing policies and the state of data/information sharing among various institutions	✓	✓	✓	✓
G9	Shared architecture for multilevel governance and interagency collaboration	✓	✓	✓	✓
G10	Implementation of ICT-enabled scenario making	✓	✓	✓	✓
G11	Trained personnel to respond to cyber security threats	✓	✓	✓	✓
G12	Trained personnel to operate ICT-enabled systems	✓			✓
G13	Install early warning systems for disaster risk management	✓	✓		
G14	Implementation of early warning systems to communicate emergency information to stakeholders	✓	✓		
G15	Use real-time data obtained during emergency conditions to update scenarios and estimate impacts		✓		
G16	Use platforms/applications for communication between authorities and citizens during the recovery process (feedback mechanisms)			✓	

TABLE 9.3 Indicators related to governance and their potential linkages to resilience abilities—cont'd

No.	Indicator	Planning	Absorption	Recovery	Adaptation
G17	Enable real-time tracking of situations by authorities during the recovery process (e.g., data on supply and demand of resources, monitoring progress, etc.)			✓	
G18	Prepare and disseminate information related to disruptive event and its impacts to raise awareness and ensure enhancing coping capacity in the future	✓	✓		✓
G19	Use lessons learned from the event to improve governance procedures	✓			✓
Total number		16	12	10	11
Percentage		84	63	53	58

be linked to planning, absorption, recovery, and adaptation abilities of resilience. There are several indicators related to the availability of plans and strategies that can assess the extent of preparation ability. It is, particularly, important to pay attention to risk governance plans and plans and strategies for performance monitoring and assessment. Other noteworthy governance-related issues that contribute to strengthening preparation capacity include training personnel, developing integrated platforms for decision making, and building infrastructure for civic engagement, data analytics, data sharing, and timely communication of information (including early warning systems).

Having plans and strategies in place would facilitate better and more timely response in the face of risks. This way, it is more likely to absorb the initial shocks and minimize functionality loss. Integrated platforms for real-time data collection and analysis are also important for risk absorption and effective response, as they can facilitate real-time and evidence-based response depending on how conditions evolve after disaster occurrence. There are cases of successful deployment of integrated platforms such as urban observatories in cities such as New Delhi and Newcastle. Under adverse events such as the COVID-19 pandemic, such observatories have been effective in facilitating integrated and collaborative governance across multiple sectors and updating city management plans and operation mechanisms according to the changing demands and conditions (James, Das, Jalosinska, & Smith, 2020; Sharifi & Khavarian-Garmsir, 2020). Given the projected increase in the intensity and frequency of climate-induced disasters, development of integrated platforms for urban management should be prioritized in cities around the world. In much the same way, availability of risk management plans and integrated platforms for data collection and analysis and information dissemination can enable more effective and efficient recovery processes. Cities that have prepared plans for different risk scenarios will not be surprised by the disaster impacts and will have better capacities to quickly recover to normal conditions. Furthermore, integrated platforms help to avoid silo-based approaches and potential conflicts of responsibilities between different sectors involved in the recovery process.

Adaptation abilities can also be strengthened via smart governance approaches. Regular update of plans, strategies, and regulations based on lessons learned from previous disasters enhances the overall capacity of communities and increases their resilience to future hazards. Scenario making processes will be essential in this regard as they will enhance foresight capacity of communities. Improved collaboration and enhanced risk awareness are other possible ways that smart governance solutions contribute to better adaptation capacity. As discussed, collaboration can be promoted through integrated platforms for data and information sharing. Such platforms should, however, also provide information to the public in order to raise their awareness about risks and possible ways to deal with them. Additionally, smart technologies offer unprecedented opportunities to develop tools for more active civic engagement in urban decision making. Urban authorities can tap into this opportunity to better communicate with the citizens and also encourage them to share their opinions that can be used to make more inclusive decisions with better prospects of implementation.

9.3.4 Indicators related to environment

As mentioned in Section 9.1, there are hopes that smart technologies will provide solutions to major societal challenges. Given the increasing environmental footprint of cities, it is not a surprise that a, relatively, large number of indicators can be used to assess the contributions of smart cities to environmental protection and resilience. In terms of planning and preparation, providing infrastructure for monitoring and prediction can enable decision makers of potential future changes and allow them to design appropriate plans to meet future demands. Other noteworthy measures are investment on decentralized energy infrastructure based on clean energy sources, improvement of energy-saving infrastructure to enable smart energy control, and attention to sustainable and resilient urban planning and design principles. The latter is critical to avoid lock-in into undesirable patterns that may make it challenging to integrate smart technologies into cities in the future. As Table 9.4 indicates, environmental indicators are tightly linked to the absorption ability. Monitoring systems, and home energy/water management, and smart metering systems allow users and authorities to regulate resource consumption during times of resource scarcity. In other words, they facilitate efficiency improvements that contribute to absorbing resource shortages. Promoting diverse and decentralized energy infrastructure that features functional interoperability facilitates hedging risk by enhancing redundancy characteristics of the system. For instance, in case power plants located in coastal areas become disrupted due to sea-level rise or major storms, availability of other energy sources allows absorbing shocks and maintaining minimal system functionality. Other noteworthy measures that can contribute to absorption ability are using ICT-based measures for real-time detection of failures and taking timely reparatory actions (e.g., leakage, water contamination, sewage discharge, energy theft, pressure anomality, etc.), implementing measures to facilitate (real-time) communication between consumers and utilities during emergencies to improve resource conservation, and taking measurements for real-time communication of air/water quality to residents during emergency conditions. These measures also contribute to timely recovery by minimizing the overall functionality loss of the system. Other measures with direct relation to recovery could also be mentioned. For instance, location finding technologies such as RFID can be used for locating infrastructure buried under debris and for expediting the clean-up process. As for renewable energy systems, decentralized energy/water systems enabled by ICT can be used to maintain

TABLE 9.4 Indicators related to environment and their potential linkages to resilience abilities.

No.	Indicator	Planning	Absorption	Recovery	Adaptation
E1	Availability of water quality monitoring sensors (ICT enabled)	✓	✓		
E2	Availability of air quality monitoring sensors (ICT enabled)	✓	✓		
E3	Availability of smart metering systems (water/ energy)	✓	✓		✓
E4	Prediction of water, energy, and food requirements using consumption data (for resource demand management)	✓			
E5	Energy/water demand management through home energy/water management systems that provide real-time information to residents for behavior change	✓	✓		✓
E6	Decentralized and modular infrastructure systems that function inter-operably	✓	✓		
E7	Penetration of clean and renewable energy sources	✓			✓
E8	Penetration of smart grids	✓	✓		
E9	Availability of energy-saving infrastructure to enable smart energy control (e.g., large-scale deployment of solar PVs, Vehicle to grid, etc.)	✓	✓		✓
E10	Integration of smart solutions in waste collection, disposal, and treatment	✓			✓
E11	Resilient urban development (mixed use, compact, job-housing proximity, etc.)	✓	✓	✓	✓
E12	Take measures for automatic isolation of disrupted components (of energy/water systems) to avoid domino effects		✓		
E13	Use ICT and take measures for real-time detection of failures (e.g., leakage, water contamination, sewage discharge, energy theft, pressure anomality, etc.)		✓		
E14	Implement measures to facilitate (real-time) communication between consumers and utilities during emergencies to improve resource conservation		✓		✓
E15	Take measure for real-time communication of air/ water quality to residents during emergency conditions		✓		✓
E16	Use smart location finding technologies such as RFID for locating infrastructure buried under debris and for expediting the clean-up process		✓	✓	

Continued

TABLE 9.4 Indicators related to environment and their potential linkages to resilience abilities—cont'd

No.	Indicator	Planning	Absorption	Recovery	Adaptation
E17	Utilize decentralized energy/water systems enabled by ICT to maintain resource supply during the recovery process (e.g., integration of PV, EV, and Home Energy Management Systems)			✓	
E18	Use event-detection software such as CANARY to monitor quality of resources during the recovery stage			✓	
E19	Promoting environmental-friendly behavior through illustrative methods for communication of consumption patterns using smart devices				✓
E20	Use ICT to restore/reconstruct the energy/water infrastructure in a way that less resources will be consumed in the future			✓	✓
E21	Seizing the disaster as an opportunity for technological upgrade				✓
E22	Long-term contributions of smart solutions to resource conservation				✓
Total number		11	13	5	12
Percentage		50	59	23	55

resource supply during the recovery process (e.g., integration of PV, EV, and Home Energy Management Systems). Also, software tools have been developed that can be used to monitor quality of resources (e.g., water) during recovery processes. As for adaptation ability, similar to what was discussed for the other categories, the main contribution will be through providing lessons from the past events and raising public awareness so that the overall performance of the system can be improved following successful disaster recovery. For instance, it is expected that installing equipment such as home energy/water management and smart metering systems or any other measures that provide information on resource consumption may, in the long run, lead to more efficient resource use, thereby contributing to resilience against resource scarcities induced by climatic or non-climatic stressors. At the end of this section, it should be noted that, if not designed and managed appropriately, from a life-cycle perspective, smart technologies may be resource-intensive and increase the environmental footprint of cities (Zhou et al., 2021). Therefore, efforts should be made to minimize potential negative ecological impacts of smart city solutions and technologies.

9.3.5 Indicators related to living

As shown in Table 9.5, indicators related to this category are mainly linked to health/well-being and safety and security. The development of telemedicine infrastructure and digital health portals is an effective strategy to prepare for adverse events that may have negative impacts on human mobility. Such services may become even more popular considering

TABLE 9.5 Indicators related to living and their potential linkages to resilience abilities.

No.	Indicator	Planning	Absorption	Recovery	Adaptation
L1	Availability of digital health portals and hospitals archiving/using electronic health records	✓	✓		
L2	Availability of telemedicine infrastructure (for disaster response, assisting aging population, etc.)	✓	✓		
L3	Installing surveillance systems for crime protection	✓			
L4	Use of ICT and smart technologies for monitoring and control of diseases and for Improving diagnostic, operation, and treatment methods		✓		
L5	Use of telemedicine solutions to provide healthcare services to disaster affected areas			✓	
L6	Long-term contribution of smart solutions to demand reductions in the society				✓
L7	Long-term contributions of smart solutions to safety and security				✓
L8	Effectiveness of ICT solutions in improving general well-being				✓
L9	Universal design of ICT tools and services to ensure service accessibility for people with disabilities and special needs	✓			
L10	Affordability and accessibility of smart devices and ICT services	✓			
Total number		5	3	1	3
Percentage		50	30	10	30

the fact that in some countries, the population is rapidly aging. Well-developed telemedicine and digital health platforms can make significant contributions to absorbing disaster shocks as was demonstrated during the COVID-19 pandemic. Such services proved effective in reducing pressure on the already overstretched medical facilities and also contributed to better containment of the virus by reducing the need to visit hospitals (i.e., making it easier to comply with social distancing measures) (Sharifi & Khavarian-Garmsir, 2020). Related to health, during the pandemic, smart technologies such as surveillance systems were also widely used for tracing and tracking on patients and for ensuring compliance with quarantine measures. These have contributed to controlling the spread of the virus in countries such as China, Singapore, and Taiwan.

Crime reduction and security improvement are other notable contributions of smart solutions to resilience. Technologies such as surveillance systems can be used to minimize crime occurrence in urban environments. In the long-run, widespread use of such technologies may lead to crime reduction. However, there are some concerns regarding the use of such technologies to reinforce power relations in the society and breach citizen privacy. Such concerns should be properly addressed to ensure large-scale uptake of the technologies. Other issues that need attention are the universal design and affordability of technologies to ensure their accessibility and avoid the digital divide.

9.3.6 Indicators related to mobility

Smart solutions are increasingly integrated into the mobility sector. In fact, it could be argued that smart city projects have had a specific focus on the mobility sector. As shown in Table 9.6, mobility indicators are mainly related to transportation and ICT infrastructure and are mainly linked to the planning and absorption abilities of resilience. Investment on ICT infrastructure and different modes of green transportation enables cities to prepare for potential future events and response in a nimbler manner if needed. Penetration level of broadband internet connection is a prerequisite for effective deployment of smart solutions and technologies and should be prioritized in efforts for planning and development of smart cities. Equally important is the need for regular upgrading and maintenance of ICT infrastructure to ensure their continuous functionality. Such infrastructure can provide multiple benefits during adverse events. For instance, early warning systems can collect and process data in a real-time manner and inform different stakeholders of potential risks. In the transportation system, availability of real-time information about transit services and parking is important to inform people of the most effective mobility options (e.g., during evacuation). Paying attention to multimodal transportation and using smart technologies to promote it is also essential. Public transportation system is, particularly, argued to be more resilient than other modes during adverse events and should be promoted.

Smart solutions can also facilitate better recovery from disasters. For instance, autonomous vehicles may be deployed to speed up the recovery process. Internet of Things (IoT) devices could also be used to improve situational awareness and facilitate collaboration and resource sharing between different groups during the post-disaster recovery process. Also, smart solutions such as Vehicular Ad-hoc Networks (VANETs) can be utilized to facilitate emergency communication between vehicles in order to reduce evacuation chaos and optimize the access of rescue teams, thereby contributing to absorption and recovery processes.

In terms of adaptation, it is expected that through promoting more sustainable and resilient modes of transportation, smart technologies can foster sustainable travel behavior in the long

TABLE 9.6 Indicators related to mobility and their potential linkages to resilience abilities.

No.	Indicator	Planning	Absorption	Recovery	Adaptation
M1	Availability of infrastructure to collect real-time traffic flow information (intelligent traffic management)	✓	✓		
M2	Availability of wireless infrastructure (hotspots, etc.)	✓			
M3	Integrate Web 3.0 into disaster management	✓	✓		
M4	Car and bike sharing services, ridesharing, etc.	✓			✓

TABLE 9.6 Indicators related to mobility and their potential linkages to resilience abilities—cont'd

No.	Indicator	Planning	Absorption	Recovery	Adaptation
M5	Autonomous vehicle (AV) testing and deployment	✓	✓	✓	✓
M6	Penetration level of green transportation modes and infrastructure (e.g., EVs, EV charging stations, etc.)	✓			✓
M7	Availability of real-time information about transit services and parking	✓	✓		
M8	Penetration level of broadband internet connection	✓	✓		
M9	Quality of internet service (rate of coverage by mobile broadband)	✓	✓		
M10	ICT accessibility (e.g., smartphone penetration, PC ownership rate, internet penetration, etc.)	✓	✓		
M11	Availability of ad hoc solutions to maintain network connectivity in case the conventional cellular network is disrupted (e.g., Drone empowered small cellular networks)	✓	✓		
M12	Multimodal public transportation	✓	✓		
M13	Maintenance and regular revision of the ICT infrastructure	✓	✓		
M14	Use of IOT devices to improve situational awareness and facilitate collaboration and resource sharing between different groups during the post-disaster recovery process (use of IOT-based communication)			✓	
M15	Use of smart solutions such as Vehicular Ad-hoc Networks (VANETs) (V2V, V2I, V2X) to facilitate emergency communication between vehicles in order to reduce evacuation chaos and optimize access of rescue teams		✓	✓	
M16	Use the disruptive event to upgrade the transportation system to become more climate resilient and user friendly				✓
M17	Update configuration and structure of ICT devices to improve communication performance in the future				✓
M18	Long-term transportation demand trends, effectiveness of smart solutions in reducing vehicle ownership and transportation demand/ travel distance				✓
M19	ICT-enabled transportation damage and fatalities reduction				✓
Total number		13	11	3	7
Percentage		68	58	16	37

run, thereby contributing to better adaptation to future adverse events. Overall, adverse events and lessons that they provide should be considered as opportunities to upgrade transportation and ICT infrastructures to make them more resilient against future shocks. Such upgrading and reconfiguration efforts would also provide co-benefits for climate change mitigation. For instance, given the significant contributions of the transportation sector to global emissions, transition toward more sustainable transportation modes would be critical for climate change mitigation.

9.3.7 Indicators related to data

Data are the backbone of smart city projects. As shown in Table 9.7, various indicators related to data collection, processing, and analysis can be used to measure potential contributions of smart city projects to resilience. Infrastructure for data collection helps cities collect data related to various urban sectors during different times. The collected data can then be

TABLE 9.7 Indicators related to data and their potential linkages to resilience abilities.

No.	Indicator	Planning	Absorption	Recovery	Adaptation
D1	Infrastructure for data collection and storage	✓	✓	✓	
D2	Measures for crowd-sourced data collection	✓	✓	✓	
D3	Open data platforms for making information (governmental, etc.) open to the public	✓	✓	✓	✓
D4	Implementation of cyber security measures (backup systems, virus and threat protection, firewall and network protection systems, etc.)	✓	✓	✓	
D5	Big data analytics capabilities for data quality control, data classification, and data processing	✓	✓	✓	
D6	Apply measures to isolate contaminated data to avert system-wide losses		✓		
D7	Use of cloud computing services for collection and sharing of data related to the disaster		✓	✓	
D8	Link data platforms to each other (to promote interoperability)	✓	✓	✓	
D9	Use data collected during the disruptive event to improve future projections	✓			✓
D10	Evidenced-based planning and decision making informed by big data analytics	✓			✓
D11	Big data analytics' contribution to upgrading on modes of operation and planning process	✓			✓
Total number		9	8	7	4
Percentage		82	73	64	36

used during different stages of disaster risk management. Given that data collection could be resource-intensive, promotion of crowd-sourced data collection methods could be an effective measure to enhance the efficiency of the process. Crowdsourced data collection methods could particularly be useful during times of crises when conventional methods may not be applicable. In addition to data collection, cyber security measures (e.g., backup systems, virus and threat protection, firewall and network protection systems, etc.) should be applied to ensure data can be maintained and accessed continuously and under different conditions. Using new technologies such as blockchain could be effective in this regard and contribute to better data protection and security. Blockchain technologies could also enhance redundancy characteristics of the system which is essential for improving resilience. Such technologies and other methods for sharing data should also be promoted to ensure efficient data collection and use. An effective way for data sharing could be using could-based techniques for linking data platforms. This may, however, require setting necessary rules and regulations to ensure proper use of data and avoid conflicts.

Big Data analytics and capability of data quality control, data classification, and data processing are essential to not only improve planning abilities, but also facilitate timely response and recovery. In fact, having capacity to quickly analyze data collected from various sensors and crowdsourced methods helps gain a better understanding of the conditions during absorption and recovery phases and this will facilitate better performance. Before analysis, however, it is needed to apply data cleaning procedures to ensure reliability and accuracy of the data.

As for adaptation, the results of the data analytics should inform better planning and policy making that will lead to improved performance in the future. In other words, based on the results of data analytics, related authorities and stakeholders should be able to identify areas that need to be improved and make evidence-based decisions toward enhancing community resilience in the long run. One particular benefit of big data analytics is the possibility of considering and analyzing data from different sources and related to different sectors. This would facilitate taking integrated approaches that lead to synergies and can minimize trade-offs.

9.4 Conclusions

There has been a growing interest in smart cities over the past 2–3 decades and given the rapid advances in ICTs, IoTs, cloud-based computing, machine learning, and other technologies, an upward trend in smart city development is expected in the coming decades. Human society is now facing numerous challenges caused by various factors such as global environmental changes, population increase, rapid urbanization, and geopolitical transformations. It is hoped that smart solutions and technologies will provide new and innovative solutions to these challenges. One noteworthy challenge is the increase in the intensity and frequency of adverse events induced by climate- and nonclimatic factors. These include, but are not limited to, adverse events such as flooding, heat stress, storms, and pandemics. To deal with such threats, the concept of resilience has been widely used in the past 2–3 decades in science and policy circles. Through resilience-building activities, communities around the world are aiming to minimize human and property loss from disasters.

TABLE 9.8 The percentage of indicators related to each smart city dimension that can be linked to the resilience abilities.

Dimension	Planning (%)	Absorption (%)	Recovery (%)	Adaptation (%)
Economy	50	67	25	75
People	80	80	60	60
Governance	84	63	53	58
Environment	50	59	23	55
Living	50	30	10	30
Mobility	68	58	16	37
Data	82	73	64	36
Overall	65	60	33	50

While smart city solutions and technologies are expected to contribute to urban resilience, interactions between smart city and resilience are not well studied in the literature. Also, despite the utility of indicators and assessment tools for guiding transition toward resilient smart cities, there is still no assessment tool for this purpose. To fill this gap, in this chapter, we proposed a set of indicators related to multiple dimensions of smart cities, namely, environment, economy, people, data, living, mobility, and governance. Overall, 98 indicators have been identified and their potential linkages to resilience abilities are also highlighted and discussed. It was found that, overall, these indicators mainly contribute to planning and preparation ability, followed by absorption, adaptation, and recovery abilities. The extent of relevance of indicators associated with each smart city dimension to resilience abilities is shown in Table 9.8. As can be seen, depending on the dimension, the extent of relevance may be different. For instance, indicators related to the "economy" dimension are mainly linked to the absorption ability of resilience.

While this analysis has improved our understanding of the potential linkages between smart cities and resilience, a better understanding of the interaction requires more research. The types of relations and interactions were determined based on the personal experience of the authors in this study. However, it is needed to involve the opinions of more experts to gain a more accurate understanding. More engagement with experts and additional literature review is also needed to update and complete the proposed list of indicators. Additionally, the proposed framework needs to be pilot tested through empirical case studies to examine its effectiveness and identify potential areas for improvement.

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CHAPTER

10

Contributions of smart technologies to disaster resilience

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10.1 Introduction

Amidst increasing trends in climate-induced adverse events, building urban resilience has become a priority for many cities around the world. Due to historical emissions, even under the most stringent climate mitigation scenarios, there is now consensus that the frequency and intensity of climate-induced adverse events such as floods, torrential rains, storms and cyclones, sea-level rise, and extreme heat events will increase in the coming decades. The devastating climate impacts and unregulated economic growth policies will also accelerate the degradation of natural ecosystems that provide multiple provisioning, regulating, supporting, and cultural ecosystem services to humans. Furthermore, unregulated human–environment interactions and increasing encroachment on natural ecosystems may lead to the spread of infectious diseases and epidemics that can significantly disrupt human life, as shown during the COVID-19 pandemic.

Cities are on the frontline of climate action plans as they are home to more than 50% of the global population and host a large share of global economic activities (accounting for more than 80% of global GDP). They are also responsible for about 70% of global CO_2 emissions, indicating that urban climate actions may significantly impact the frequency and intensity of future climate impacts. While taking actions to mitigate future impacts is necessary, dealing with current impacts should also be emphasized. Every year hundreds of millions of urban residents around the world are exposed to different types of climate-induced stressors such as floods, storm surges, extreme heat events, and sea-level rise. Some cities are also exposed to other nonclimate-induced hazards such as earthquakes, making it even more essential to

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enhance urban resilience. Recognizing this need, many cities around the world are increasingly developing plans and strategies for improving their resilience. These plans and strategies are diverse and address various socioeconomic, environmental, and institutional aspects (Sharifi, 2016; Sharifi & Yamagata, 2016a).

Amidst increasing recognition of the importance of enhancing urban resilience, significant advances have been made in Information and Communication Technologies (ICTs). This has led to the emergence and spread of smart city programs around the world that are enabled by ICTs and related technologies such as the Internet of Things (IoT), machine learning (ML), blockchain, and cloud computing. Some efforts have been made to assess the potential contributions of smart cities to societal goals such as resilience and sustainability (Sharifi, 2019, 2020a, 2020b; Sharifi & Allam, 2022). While there are some concerns regarding the environmental impacts of smart technologies, these rapid advances have increased hopes of accelerating the transition toward sustainable development and addressing societal challenges such as inequality and environmental degradation. Resilience and smartness are two unique concepts. However, they are not mutually exclusive. For instance, enhancing efficiency and reducing overall operational costs are characteristics that contribute to both resilience and smartness. There are, however, some characteristics that differentiate the two concepts. For instance, rapid recovery is essential for enhancing resilience, and this may require additional costs. On the other hand, achieving resilience may require having redundant capacity in the system that may undermine its efficiency (Marchese, Jin, Fox-Lent, & Linkov, 2020; Sharifi & Yamagata, 2016b). Irrespective of these differences, it is expected that smartness and resilience can go hand in hand. In fact, there are hopes that smart solutions and technologies will provide cities with better means to deal with adverse events, thereby contributing to their overall resilience.

While smart cities are expected to contribute to urban resilience, existing literature on actual and/or potential contributions of smart city solutions and technologies to urban resilience is scarce and fragmented. As a step toward filling this gap, this chapter discusses how smart technologies can be utilized across different sectors and under different conditions to enhance urban resilience.

10.2 Contributions of smart cities to resilience

10.2.1 General contributions under disruptive events

When disasters occur, timely access to accurate and reliable information is essential for various reasons. Effective communication before and in the immediate aftermath of disasters helps to minimize the potential impacts (Ahmed, 2018). For instance, timely warning about impending hazards (e.g., storms, flooding, and extreme heat) and communicating necessary mitigation and response actions (e.g., location of nearby shelters, traffic restrictions, etc.) could reduce human and asset losses. While traditional ways of communication (e.g., through television networks or announcements by local authorities) can be used, they may not be as effective as desired and not reach all members of the community. Given the increasing penetration rate of smartphones, they can be utilized for more effective outreach. Smart solutions could further leverage communication during adverse events to provide redundant communication options. Depending on the intensity of disasters, some communication options (e.g., through TV networks) may become unavailable. Under such conditions, communication options enabled by smart solutions can be utilized to ensure continuity of communication, which is essential for effective disaster response. Additionally, being linked with geographic positioning systems is a unique feature of modern communication tools such as smartphones that could help emergency response personnel in their efforts to survive people affected by disasters.

Use of IoT technology is also recommended for better communication during disasters. Kamruzzaman, Sarkar, Gutierrez, and Ray (2017) argue that conventional communication systems for disaster management are vulnerable to disasters as traditional networks such as landline and mobile networks and Wi-Fi hotspots are likely to be disrupted during disasters due to physical damage or information overflow. In addition, conventional Bluetooth systems need manual configuration, resulting in delayed communication among devices. Similar issues impact the effectiveness of Wi-Fi in Ad Hoc mode. To solve these issues, they propose an IoT-based communication framework where all mobile phones switch to "disaster mode" when a traditional cellular network is not available. This will allow increasing the battery life and will also enable device to device (D2D) communications. During this process, some devices will function as relay agents and communicate the exchanged information with the broader network when the conventional cellular network is restored.

Social media can also contribute to better resilience against disasters in different ways. Big Data analytics of geo-located social media feeds (e.g., Twitter data) could inform related authorities of the evolving needs of citizens and priority areas for action. Such information may also help gain media attention and mobilize resources for more effective disaster response and recovery (Wang, Wu, Sankar, & Lu, 2015). Jurgens and Helsloot (2018) further highlight at least four critical thematic areas that which social media have been deemed to help enhance resilience, especially in the scope of urbanism. These include information gathering, information dissemination, collaborative problem solving, and coping; each, at an individual and collective level, is critical and act as modern tools for enhancing self-resilience and community resilience. Concerning information gathering, different social media platforms are becoming part of the basic and established sources of data; which, in many cases, have helped address some critical urban challenges, like terrorism as in the case of Jarkata in 2016 (Sitinjak, Meidityawati, Ichwan, Onggosandojo, & Aryani, 2018), or as in the recent COVID-19 pandemic (Allam, 2020; Allam, 2020a; Allam et al., 2020; Allam & Jones, 2020; Sharifi, 2021; Sharifi & Khavarian-Garmsir, 2020; Sharifi, Khavarian-Garmsir, & Kummitha, 2021). Further, where the world is under duress due to the impacts of COVID-19, Mano (2020) notes that social media has had practical uses, especially in forging residence. Social media is instrumental when dealing with the young generation, which has been identified as the most dominant user demographic (Hruska & Maresova, 2020). With social media, young individuals are provided with a haven for entertainment, social interaction, identity formation, and other social aspects that reinforce community bonds and provide support systems during periods when different parts of the globe were stressed under lockdown (Ifinedo, 2016). Social media can further help eliminate dimensions of time and distance, which have often hindered connectivity; hence, it has allowed for real-time dissemination of information.

Social media does not only help address resilience issues when a crisis has already happened, but it is seen as a critical tool for warning and collaboration in finding ways to avoid or solve crises even before they occur (Allam, 2020e, 2020f). While there are possibilities of some infrastructures supporting communication to be affected by certain urban crises like flooding, hurricanes, and others, thus affecting social media through disrupted connectivity, it is worthwhile to note that the high diversity of social media platforms makes them indispensable such that even when one of them is "down," others, that equally critical would be "up and active"; hence, reaching targeted audience in real time.

10.2.2 Geographical information systems (GIS), remote sensing, and global positioning system

GIS systems have advanced significantly over the past several decades and have made significant contributions to have better informed and more evidence-based decision-making. Given their capacity of processing large amounts of geolocated data GIS systems could be utilized for more effective identification of risk-prone areas, prioritizing areas for resource allocation, determining the most optimum routes for evacuation and emergency access, and providing necessary geolocated information for disaster response and recovery to different stakeholders (Wang et al., 2015). These functions will facilitate better decision making and contribute to better disaster preparation, response, and recovery.

Remote sensing techniques could complement GIS systems by providing disaster response teams with high-resolution images of the area that can help them make more appropriate decisions. Images obtained in this way are critical for making accurate initial assessments of the scope of the disaster and the extent of damages (Wang et al., 2015). However, the utility of remote sensing images is not just limited to the disaster response and absorption stage. Continuous environmental monitoring using satellite images could detect potential irregularities that may lead to disastrous events. For instance, detecting medium- and long-term changes in terrain structure and properties may predict potential changes under disruptive events (e.g., potential landslides). Based on such predictions, necessary effective actions can be made to minimize the overall impacts and losses. In addition to preparation and absorption, remote sensing images could also contribute to better recovery from disasters. In fact, using time-series remote sensing data provides additional information on the state of progress in returning to normal conditions and could facilitate a more effective recovery process (Wang et al., 2015).

Global positioning systems (GPS) and their increasing integration with smart devices allow optimizing the functionality of GIS and remote sensing systems. Such systems facilitate understanding the exact location of damage sites, thereby improving the efficiency of emergency response services. Furthermore, analysis of geo-tagged data could facilitate a more accurate understanding of the dynamics of the adverse events and allow tracking the threats more effectively (e.g., tracking the progress of floods or storms). This is likely to contribute to minimizing potential losses. Finally, as mentioned earlier, GPS data could help emergency personnel better locate the stranded individuals, which may lead to saving more lives (Wang et al., 2015).

10.2.3 Radio-frequency identification (RFID)

Radio-frequency identification (RFID) systems are argued to contribute to a better understanding of the evolving conditions and facilitate better response by providing access to more detailed and real-time location-based data. Such data could also enable monitoring conditions of facilities (e.g., flood protection infrastructure) and allow detecting potential changes and irregularities. Given the real-time nature of such information, effective mitigation, and reparatory actions can be made in a timely manner to avoid major damages (Wang et al., 2015). Wang et al. (2015) discuss the limitations of paper-based maps and GIS maps for locating buried critical facilities such as water pipelines and power lines that may result in major damage to the critical infrastructure during cleanup processes following disasters and delay the recovery process. Their case study analysis in Gulf Shores, Alabama, shows that using RFID during the disaster recovery process to locate critical facilities buried by debris reduces recovery time, enhances accuracy, minimizes damage caused by excavators, and reduces the overall costs despite the initial investment costs for setting up RFID technologies (Wang et al., 2015). They tested the effectiveness of three IT scenarios for recovering facilities buried under debris. These were GPS, RFID together with Magnetic Locator, and RFID together with Magnetic Locator and GPS. It was found that the third scenario offers faster, more accurate, and less costly performance (Wang et al., 2015).

RFID can also assist in addressing authentication, automation, and information management issues, identified as the bane of many traditional methods like GIS maps, barcodes, and other tools (Sabbaghi & Vaidyanathan, 2008). The advantages of RFIDs are derived from contact-less capabilities, making this technology important in cases of tracking and identification of objects and people who may be in places that they cannot be physically accessed, especially during natural or manmade disasters, as established by (Jain, Kulshrestra, & Vyas, 2017). Their ability to store substantially more information than most other tools also provides an edge, especially in data generation, which—when processed—then becomes critical in decision making.

Another area where RFID is of significant influence is achieving resilience in building maintenance. Ko (2009) notes that when RFIDs are coupled with web-based systems and databases, and scheduled modules for building maintenances, a notable enhanced and improved facility and equipment maintenance efficiency is observed; thus, aiding in the actualization of resilient urban infrastructures. This is important as most buildings are now exposed to numerous urban vulnerabilities such as flooding, excessive heat, and others (Stagrum, Andenæs, Kvande, & Lohne, 2020). They, therefore, require regular maintenance, and the information management capabilities of RFID can aid in automating the scheduling of such practices (Valero, Adan, & Cerrada, 2015). Their cost-effective and inexpensive character in large quantities further renders them attractive, especially in areas where real-time tracking is being sought (Jung & Lee, 2015). RFID has also enhanced safety concerns in many instances, especially in the healthcare sector where the safety of patients, healthcare workers, and equipment is critically important (Haddara & Staaby, 2020). It has been noted to be critical in supply chain systems in varying sectors; hence, affirming its critical nature given that the supply chain systems impact on the resilience of urban areas, more so in areas like manufacturing, construction, and environmental sectors (Valero et al., 2015).

10.2.4 Early warning systems

The ability to predict adverse events is critical for enhancing preparation capacities and taking necessary mitigation actions. These could be, for instance, applying mobility restrictions, preparing shelters and evacuation sites, installing defense infrastructure, and activating mitigation mechanisms. Traditionally, authorities have relied on modeling, simulation, and scenario-making techniques to predict occurrence patterns of adverse events. These, however, entail large levels of uncertainty and would not be sufficient for hedging risks. Enabled by advances in ICTs, different types of early warning systems have been developed to make significant contributions to disaster preparation efforts. These include, but are not limited to, float level sensors, radar level sensors, ultrasonic and infrared sensors, satellite data for flood management; bubbler gauges, underwater pressure transducers, radar gauges, high-frequency radar, acoustic gauges, deep-ocean tsunami detection buoys, Doppler radar, hook echo, dual-polarization radar, multi-radar, and multi-sensor (MRMS) system for tsunami prediction and management; gravity recovery and climate experiment (GRACE) satellites for drought prediction and management; humidity sensors, temperature sensors, pyranometer, weather Radar, satellite, and freezing-rain and ice detectors for extreme heat prevention and management; LARA—long-range avalanche radar, SARA—short-range avalanche radar, IDA—infrasound detection system, PETRA—people tracking radar, and use of satellite radar for avalanche detection; wireless sensor network, optical fiber sensor, satellite remote sensing imagery, and MEMS tilting sensors for detection of landslides (Kavitha & Saraswathi, 2018).

The different early warning systems highlighted here can significantly enhance early planning and initiation of appropriate mitigation actions, which are essential in saving lives and protecting livelihoods, assets, and infrastructures. Pandya (2021) presented a report highlighting that having early warning systems allows for constructive and proactive collaboration between different stakeholders, including planners, financiers, policy makers, and others. This ensures that the most potent action plans are formulated, adopted, and pursued to safeguard different sectors within an economy.

Early warning systems have been lauded particularly for their contribution to resilience in the agricultural sector, especially in vulnerable countries. In a report submitted by the International Centre for Tropical Agriculture (CIAT) to UNFCCC (Ciffey et al., 2015), it was highlighted that early warning has allowed for earlier dissemination of information to a wider target actors, who in turn have enabled for actions to reduce the need for emergency interventions through enhanced food security. Indeed, it has been argued that early warning systems manage to help reduce extra costs (Balbi, Villa, Mojtahed, & Giupponi, 2014). For instance, Jha and Stanton-Geddes (2013) argued that for every unit ($1) dollar invested in early warning systems, there is an almost guarantee of $3–$4 return with respect to damages and losses averted. This cost–benefit ratio is seen to provide countries the impetus to increase investments in early warning systems, with the example of China noting to derive a 1:35 to 1:40 ratio (Jha & Stanton-Geddes, 2013). That is, for every unit of investment in early warning, the country gets 35–40 units of return in terms of resiliency. There is evidence of little or no commitment in early warning systems; hence little resilience developed, countries are exposed to substantive fiscal, socioeconomic, and environmental impacts. Such impacts, in turn, have negative impacts on countries' GDP, with substantial percentages of the public expenditure directed toward recovery and compensations. For instance, it has been established that in the Solomon Islands, over 95% of the national budget was directed toward recovery after the 2007 Tsunami disaster (Risley, 2013). This expenditure is further compounded by the loss of lives, psychological impacts, and others (Prasad & Francescutti, 2017). Therefore, it behooves the need to emphasize the need for timely investment in early warning systems, especially those hinged on modern ICT technologies to ensure that countries and urban areas can achieve meaningful resilience levels.

10.2.5 Building management systems

Building management systems refer to computer-based systems designed to monitor and regulate different building-level operations such as heating, cooling, lighting, ventilation, and fire systems. Using multiple sensors and devices, building management systems provide an integrated platform to collect dynamic information on various building operations and provide controlling mechanisms for improving operational efficiency. Obviously, such a system can be useful to gain information related to damaged parts during times of disaster, thereby facilitating rapid and effective recovery (Wang et al., 2015). However, other resilience benefits can also be accrued from building management systems. For instance, they can instigate behavior changes, thereby contributing to climate change mitigation and adaptation. Such adaptation benefits can be achieved under normal conditions and also during recovery processes after major disasters. For instance, Tsuchiya (2019) explains how in the post-Great East Japan 2011 Earthquake (i.e., during postdisaster public housing construction) adaptation efforts have been made through smart communication of consumption patterns to promote environmental behavior. The distribution of tablets among public housing residents has allowed them to monitor the patterns of energy generation and consumption in their households and districts through user-friendly communication and visualization techniques. This has enhanced their awareness of the significance of energy resource management and could contribute to energy conservation.

In terms of energy management, it has been demonstrated that building energy management systems (BEMS) can play critical role in disaster events. For instance, drawing on different demonstration projects of smart city development in the post-Great East Japan Earthquake, Tsuchiya (2019) showed how smart solutions can be used to maintain the stability of energy supply following disasters through a combination of Home Energy Management Systems (HEMS), BEMS, Photovoltaics (PVs), and Electric Vehicle (EV) systems. Under such circumstances, building management systems contribute to resilience by improving system modularity. Smart solutions and technologies can also provide multiple co-benefits for addressing climate change challenges. Energy management systems empowered by smart technologies and integrated with renewable energy sources could enhance consumption efficiency and save energy resources. This could be achieved by improving the efficiency of appliances, reducing potential energy losses, and also fostering environmental-friendly and resource-conscious behavioral changes. Energy savings could contribute to resilience against potential energy shortages that may occur due to climatic changes. For instance, severe storms may disrupt the energy supply and result in energy shortages. Or, energy shortages may occur due to extreme weather events that result in a sudden surge in demand. Under such circumstances, energy management systems would be essential for maintaining the continuity of energy supply. Other co-benefits of such energy management systems could be reducing energy costs that contribute to economic resilience and minimizing energy-related GHG emissions critical for climate change mitigation (Tsuchiya, 2019). It should be noted that the energy-saving benefits of energy management systems are not just limited to the building level and can be extended to neighborhood and city scales.

Another notable strategy that has emerged with the evolution of ICT is the use of smart metering systems; helpful in assisting energy management through informing both consumers and energy suppliers of the amount of energy produced and the subsequent amount consumed by individuals. Pereira et al. (2015) support that smart meters have the capacity and ability to communicate the measured data to the stakeholders as mentioned above, thereby providing them with the aspect of smartness. Such smart aspects include other elements like energy flow and pricing, which allow consumers to make an informed decision, and as proposed above, those elements would influence behavior changes in energy consumption. On this, De Dominicis, Sokoloski, Jaeger, and Schultz (2019) advance that smart meters serve as tools that could entice consumers to adopt prudent energy consumption strategies, positively impacting conservation sustainability efforts. On their part, consumers benefit through money-saving while also adhering to responsible consumption, which reverberates positively regarding sustainability (Rausser, Strielkowski, & Štreimikienė, 2017).

With respect to energy suppliers, smart metering can increase energy efficiency, especially by keeping track of peak usage timings, allowing for real-time advice to the clients on energy consumption. It is also argued by Pereira et al. (2015) that the adoption of smart metering systems in place of the traditional electricity metering can help in better energy management by increasing accuracy, privacy, security, and other features that allow suppliers to improve their service delivery to clients. The same is noted to have positive impacts in preventing and reducing electricity theft, which reduces the burden of the costs on the consumers, who are often made to offset the extra costs from unaccounted for power energy. For instance, in Kenya, due to a lack of smart metering, the country's power supplier lost an equivalent of 19.9% of electricity power, amounting to approximately 1.77 billion Kenyan Shillings; a substantive cost, unfortunately, passed onto consumers (Alushula, 2020). The most outstanding contribution of smart metering in energy management is its ability to be integrated into electric grids, and the data obtained from all those sources can influence the adoption of responsible consumption and renewable energies through both sales and consumption, through a two-way traffic (Velásquez, Castaño, & Franco, 2014).

Smart solutions and technologies have also proved effective in enhancing water consumption efficiency at different scales. Sensor-based smart water systems can provide multiple benefits. For instance, they can help detect possible leakages, contaminations, and blockages (Marchese et al., 2020). Furthermore, smart water systems could control and regulate water demand through collecting and processing real-time data, thereby contributing to water saving (Marchese et al., 2020). It is argued that smart technologies have transformed water systems into "cyberphysical systems" that have revolutionized water treatment and distribution mechanisms through enhancing control, regulation functions (Marchese et al., 2020). As a result, the ability to deal with demand fluctuations, detect irregularities and leakages, minimize contamination, conduct self-repair operations, and communicate with water users has improved significantly (Marchese et al., 2020). Various smart water systems have been discussed in the literature, including "Supervisory control and data acquisition (SCADA) systems, online continuous monitoring (OCM) sensors, and advanced metering infrastructure (AMI)." "SCADA systems provide utility operators an interface to monitor sensor data, and remotely control actuated devices (pumps, valves, switches, etc.)" (Marchese et al., 2020). SCADA systems have been widely incorporated into water treatment and distribution networks and, through becoming available online, they have facilitate remote access and control of equipment and operations (Marchese et al., 2020). Recent advances in IoT have boosted such systems by allowing them to collect, store, and analyze large volumes of data continuously and for different objectives. "The IoT further facilitates two-way communication between IP-indexed devices, paving the way for automatic responses to predetermined sensor thresholds without direct human interaction. Such improvements in communications technologies have facilitated the implementation of OCM sensors to detect contamination, intentional or otherwise, in the distribution system (Banna et al., 2014), and AMI that accurately captures, collects, and communicates end user consumption information in near real time (Stewart, Willis, Giurco, Panuwatwanich, & Capati, 2010), or at least much more frequently than manual or ad hoc methods. In this way, smart technologies can help preemptively detect and prevent some hazards, provide the tools for recovery from other hazards, and adapt to persistent and progressive threats, thus enhancing resilience" (Marchese et al., 2020).

In addition to quality improvements and customer satisfaction, these have led to improvements in water conservation activities. Saving water resources is critical for climate change adaptation as water scarcity is projected to be a major climate change impact in many locations. Given the water-energy nexus, saving water resources could also contribute to energy resilience (Sharifi & Yamagata, 2016b).

10.2.6 Safety and security

The global sphere is increasingly concerned with diverse security and safety concerns, ranging from threats of terrorism, cyber-insecurity, incidences of fire outbreaks, and a myriad of naturally triggered incidences (Elmaghraby & Losavio, 2014; Jianhua, 2018; Kendra & Wachtendorf, 2003; Yang, Yang, Li, Liang, & Zhang, 2021). However, amid the increase in those concerns, technological advancement has brought some leverage in addressing some by fostering the sharing of information and data, allowing for real-time detection and streamlining collaboration between different departments and stakeholders (Allam, 2020e).

In the case of fire outbreaks and subsequent impacts, it is reported that there are some notable shifts, with world fires decreasing by about 25% in the past decades (Andela et al., 2017), while outbreaks in built environments are deemed to be increasing. This is credited to the expansion of cities and urban areas due to increasing urbanization, population increase, climate change, and economic situations' dynamics (Vasiutinska & Barbashev, 2018). Dutta, Das, and Aryal (2016) note that those fires' intensity and frequency are increasing, with substantial economic, social, and environmental impacts as an aftermath. For instance, according to the Insurance Information Institute, it is recorded that in the United States, losses from fires between 2010 and 2019 have been on the rise with over 53.5% and 28.7% increase in losses recorded in 2017 and 2018, respectively, and the bulk of those losses was incurred by home owners (58.4%) (Insurance Information Institute, 2020).

While homeowners may not have much influence in preventing fires, floods, tsunamis, and other disasters, smart technologies have made it possible to adopt digital solutions that could help prevent outbreaks in their home. In case of fires, such include advanced smoke detectors, smart plugs, smart stovetops, and smart fire detectors, among others. New networking systems have also made it possible to link numerous smart devices into central control centers, allowing data to be shared in real-time to homeowners, and where the need arises, to firefighters and other disaster management agencies, depending on the type of disaster. Lorenzi (2021) notes that smart technologies are interestingly making it possible to integrate fire sensors with cameras such that footage of events is recorded, allowing for easier identification of the origins of fires. Such information then becomes insightful to homeowners and builders, utility companies, devices and home appliance makers, policy makers, fire departments, and others. Robson et al. (2020) also note that smart devices and sensors have made it possible to reduce incidences of false fire alarms, especially in places like mental health settings, increasing the safety of both patients and caregivers.

Technology such as AI and ML has also been lauded for their critical role in weather forecasting and prediction, especially in alerting agencies and stakeholders of eminent flooding, cyclones, heatwaves, and other weather-related disasters. Such information allows for predisaster planning and preparedness, including in the construction sector, where buildings are oriented to withstand floods, heatwaves, and strong winds. In cases like the recent disaster of COVID-19, technology has robustly been deployed to enhance the security and safety of people. For instance, to mitigate the further spread of the virus, some countries such as South Korea and China were reported to have used mobile APPs to conduct contract tracing and disseminate critical information to people (Choon, 2020; Sison, 2020). Some countries went further to use drones to deliver medical supplies and record body temperatures, to name a few issues (Sharifi, Khavarian-Garmsir, & Kummitha, 2021).

Further, globally, there is an increased use of sensors in entry points like airports and ports to detect people showing signs of COVID-19 by detecting their body temperatures and other health parameters (Allam, 2020). In Haiti, it is reported that after the 2010 earthquake and subsequent cholera outbreak in the same year, mobile phone technologies were used to monitor and track population movement; hence, reducing morbidity and mortality (Bengtsson, Lu, Thorson, Garfield, & von Schreeb, 2011). Such technologies showcase that the digital era is unlimited in pursuing safety and security amid pandemics and disasters.

10.2.7 Could computing

The distributed structure is a common feature of resilient systems that enables them to disperse risk. Cloud computing services facilitate distributed data computation. The redundant data centers, hosted in different locations provided for cloud computing are conducive to resilience. Individual data centers are likely to be damaged during major disasters. Cloud computing further improves disaster resilience by facilitating information sharing between different actors involved in the disaster response and recovery processes. The additional capacity offered by these redundant and geographically distributed data centers allows integrating Big Data gathered in the postdisaster stage (via social media, sensors, etc.) with other types of data (e.g., environmental, satellite imagery, socioeconomic status, population, etc.) to make more informed decisions (Akerkar, 2018). The distributed architecture of cloud computing helps to protect user data as data servers are located in different locations away from the disaster site, and only minimal costs for recovering the local computers will be needed (Akerkar, 2018). Cloud computing can also contribute to economic resilience. It allows businesses and organizations to reduce operational costs by abolishing the need to host and install software and hardware and allowing rental services. This also allows avoiding maintenance costs (Alazawi, Abdljabar, Altowaijri, Vegni, & Mehmood, 2012).

In the wake of the outbreak and spread of the COVID-19 pandemic, which can be termed among the most disruptive global pandemics felt in the last decades, cloud computing has aided in promoting different levels of resilience in varying geographies across the globe. A case in point, as observed by Lucus-McEwen (2012), assists the work-from-home protocol proposed and observed in many institutions. Cloud computing services, such as conferencing and collaborations, have been allowed different organizations, including schools (through e-learning), to continue amid lockdowns and social distancing, and in most cases, such services experienced little or no substantial interruptions, since the architecture has the capacity for increased data storage and handling capacities (Gartner, 2021). It is by allowing some levels of operation to remain afloat during the pandemic that some economies, especially service-oriented ones, to remain resilient and avoid total collapse.

The power of cloud computing has further been observed in ensuring continuous communication, and a wide reach of target audiences, especially in the case of social media and large technology providers and their ecosystems. Greer and Ngo (2012) note that platforms such as Google, Twitter, Facebook, and different mobile technologies as case studies that demonstrate the versatile nature of cloud computing during pandemics. The real-time sharing of information during and after disasters, courtesy of those platforms, has been lauded for helping reduce psychological issues and helping governments and other agencies communicate and reach those requiring assistance. Clouding services are therefore argued to be dependable, as they are available whenever needed, even in the middle of disasters, as the destruction of local infrastructures does not impact data stored (Mesbahi, Rahmani, & Hosseinzadeh, 2018). While cloud computing is subject to downsides through connection challenges during a disaster and is also affected by security concerns, those are deemed surmountable compared to the numerous challenges associated with traditional computing methods.

10.2.8 Big Data analytics

The emergence of Big Data analytics has brought a shift in how data from different sources can be collected, stored, processed, and analyzed. Different stakeholders have access to large-scale data sets that allow for insightful conclusions and interventions with Big Data. As Akerkar (2018) expressed, Big Data technology is key in addressing accessibility, distribution, and presentation of results obtained after complete analysis. According to the author, this has allowed the technology to become helpful in emergencies. On this, it has been established that Big Data analysis is not only critical during and after a disaster has occurred but it is also equally important prior to the emergence of a disaster in view of aiding preparedness.

Predisaster, Big Data analytics has been lauded for allowing for preparation and preparedness in anticipation of any disasters; hence, it allows for avoidance or quick intervention to mitigate widespread impacts. Early data analysis helps in informed planning, resource mobilization, training of relevant, diverse agencies, simulations, and formulation of policies, helpful in capacity building (Khan et al., 2018). In cases where such early interventions are absent, like with the COVID-19 outbreak that had not been anticipated, the consequences in all spheres are dire and with far-reaching outcomes. However, as posited by Iglesias, Favenza, and Carrera (2020), maximum leverage of Big Data analytics, together with other modern technologies like AI and ML, has the potential to ensure that disaster responses are activated. This could be true even in the current case of COVID-19, as the already available data from different sources could help plan to prevent further spread, help in vaccine inoculation drives, and prevent further spread (Alsunaidi et al., 2021; Sharifi et al., 2021).

During disasters, Big Data analytics further help build resilience by ensuring that proactive, immediate actions prevent loss of lives and prevent the destruction of properties, assets, the environment, and others. This technology also allows stakeholders to address humanitarian concerns quickly and in a dignified manner. Further, like in the case of COVID-19, where there was a rampant deployment of Big Data analytics tools by different agencies to help understand characteristics such as transmission, risk factors, diagnostic, and others, this technology played a part in the formulation of health protocols such as social distancing and use of PPEs (Allam, 2020; Allam, 2020g; Allam & Jones, 2020, 2021; Kent, 2020; Sharifi et al., 2021). It is also through insights from the analysis of Big Data that conclusions like the need for lockdowns, border restrictions, and others were taken, and they all had impacts on reducing transmissions (Allam, 2020b, 2020c).

Post disasters, Big Data analytics are also helpful in ensuring that proactive mitigation and recovery mechanisms are deployed. The technology allows for the formulation of both short-, mid-, and long-term strategies and action plans, ensuring that impacted communities are assisted, that impacted infrastructures and properties are restored and reinstated, and institutions geared back to functional levels (Akerkar, 2018). This way, governments and various actors within an economy can restore economic operation, bring back social order and prevent further negatives in different areas like the environment, infrastructures, and properties, employment circles, health, to name a few.

10.2.9 Web 3.0

The next generation of the Internet is expected to rely on artificial intelligence and ML further. This will improve the openness and connectivity of the internet and facilitate better analysis of Big Data, leading to smarter search and processing algorithms. These capacities are essential for resilience as they allow rapid customization of websites depending on the evolving demands of individuals and communities. A. Ahmed (2018) discusses how Web 2.0 has provided multiple opportunities for compiling information about the disaster and the magnitude of impacts. It has also enabled two-way communication between officials, victims, and victim relatives. However, in Web 2.0 applications, data are collected and managed by humans resulting in problems such as overflow of data, data inaccuracy and unreliability, and risks of malicious use of technology. Web 3.0 relies on agent-based methods for collecting, classifying, and analyzing information to deal with such issues. This enables access to more accurate, personalized, and context-specific information that improves disaster preparedness and response and recovery abilities.

Integrating artificial intelligence (AI) into Web 3.0 allows end-users to access more case-specific data faster and real time. Unlike in the case of social media data, which is subject to human manipulation, data accessed from Web 3.0 have been found to be well filtered, with only legitimate results incorporated via the power of AI. This element is important in building disaster resilience, as only relevant and case-specific data are required to warrant quick and informed decision making, rendering quicker and precise actions (Doğan, Söylemez, Özcan, & İşleyen, 2018).

Web 3.0 also brings a valuable advantage over its predecessor in virtual assistance, thus allowing end-users to query the system interactively. This is critical, as already, due to the integration of AI in the Web 3.0 infrastructure, it becomes possible to train the system with specific data sets, hence allowing it to understand what specific data means. On this, Gillis (2019) notes that Web 3.0 has the capacity to learn and reason, provide case-specific solutions to different problems, and understand different languages. This means that even in the era of large datasets from different sources, end-users can always access the data they require.

Unlike its predecessors (Web 1.0 and Web 2.0), Web 3.0 has the property of ubiquitous computing, which allows accessibility in diverse everyday devices like smartphones, smart sensors, and others (Atzori, Koutrika, Pes, & Tanca, 2020). This iniquitousness then means that information and data on different aspects can be accessed from any location and from different devices. This quality makes tasks such as data mining, natural language search, and peer-to-peer (P2P) technologies to be possible to integrate. With such, end-users would benefit from even other modern technologies such as blockchain that warrant safety and distributed technologies (Madabushi, 2021).

10.2.10 Artificial intelligence

The Global Facility for Disaster Reduction and Recovery (GFDRR) (Global Facility for Disaster Reduction and Recovery, 2020) has identified some disruptive technologies supporting disaster resilience. Among these technologies are artificial intelligence, ML, IoT, and others. AI has been identified, as influential due to its ability to be integrated with other technologies, like those involved in predicting the chances of disasters. For instance, Molinario and Deparday (2019) explain how a combination of AI and ML technologies was employed in Guatemala City to identify buildings that were most likely to be affected (collapse) if an earthquake occurred. Using algorithms, the technology was able to identify those buildings and, as a result, helped in informed decision making that ultimately had an impact in planning on how to save lives and property in case the disaster was to occur. Further, Molinario and Deparday (2019) note that AI, ML, and Remote Sensing technologies, via the use of satellites, have been instrumental in planning and preparedness in cases where an anticipated disaster is eminent. On this, both AI and ML have been lauded for their capability to enhance satellite imagery and analysis, thus aiding in identifying vulnerable areas. In case of a disaster, such allow for rapid assessment of damages, priority areas, number of victims, and others. With such, different stakeholders can then take appropriate actions and come up with informed postdisaster responses.

In the disaster scenes, AI has further been found to influence resilience significantly. For instance, with AI, it has been possible for different agencies to use 3D printing technologies on disaster sites to provide robust responses and overcome supply chain challenges. For instance, Gahren (2018) explains how 3D printing has been instrumental in filling a critical gap in the medical spheres by creating and delivering low-cost, effective case-specific solutions in the production of medical parts and other critical tools that are not always available. Such capabilities have contributed to life-saving procedures and supplied communities with basic needs, like water and sanitation facilities, mostly delayed or immediately unavailable due to logistical bureaucracies and difficulties in disaster-stricken areas (McKinnon, 2016). AI can further help 3D printers to produce error-free products efficiently and cost-effectively through a reduced time of production and little or no material wastage. Further, the products obtained from the 3D printers are now deemed reliable and of comparatively improved quality as traditional means and could be customized to be case-specific (Gahren, 2018).

AI is also argued to contribute to disaster relief and help create resilience via integration into unmanned aerial vehicles, like drones, to allow them to fly at the epicenters of disasters, help to virtually identify victims and survivors, deliver crucial aid, and capture and relay all necessary data to the control centers for use by the different actors (Barmpounakis, Vlahogianni, & Golias, 2016; Stelian, Anton, & Martin, 2020). The use of AI can thus not be disregarded and is expected to gain in importance as urban centers further adopt the concept of Big Data via Smart Cities.

10.2.11 Use of smart devices to create ad hoc networks

Earlier in the chapter, it was discussed that only having ad hoc networks is not sufficient for disaster resilience as they have some shortcomings. Such networks can, however, improve resilience by enhancing diversity and redundancy features of the system, and "current infrastructure-based systems are not redundant and, in general, they are vulnerable to disasters and subsequent incidents (e.g., earthquakes often happen in series, posing a threat to terrestrial infrastructures even if the first event has left them partially or totally operational)" (Casoni et al., 2015). Ad hoc networks are useful for information sharing in the immediate aftermath of disasters and improving situational awareness. It is critical to have ad hoc solutions to maintain network connectivity in case the conventional cellular network is disrupted. For example, (Hayajneh, Zaidi, McLernon, & Ghogho, 2016) discuss drones' potential to empower small cellular networks for disaster response and emergency response. "During disaster recovery, communications satellites and mobile cellular towers may be deployed. However, communications satellites are scarce." Further, "although mobile cellular towers can be used to set up the command center and provide critical communications for rescue workers, such vehicle carried towers cannot cover all disaster areas. The limitations of terrestrial mobile networks have also been highlighted by Casoni et al. (2015). They also referred to issues such as information overload and damaged infrastructure that lead to service outages. Therefore, it is important to network smartphones with short-range radios in disaster recovery" (Lu, Cao, & Porta, 2016). Lu et al. (2016) discuss that smartphone devices have proved to be essential communication tools for disaster response and recovery. While disasters might damage cellular towers, it is possible to utilize smartphones to create ad hoc networks for information sharing between users that are within the communication range of short-range radio networks (e.g., WiFi). Lu et al. (2016) introduce the TeamPhone application that is designed to integrate "cellular networking, ad hoc networking, and opportunistic networking" to facilitate data communication and emergency message/location sharing among survivors and between survivors and rescue workers. The application features a messaging system that allows survivors to send out messages to rescue workers and a self-rescue system that facilitates the grouping of smartphones of nearby victims. It enables the discovery of messaging nodes in the vicinity to communicate emergency messages in an energy-efficient manner. This application also enables energy-saving modes to deal with the potential power outage issues (power failures) that make it difficult for battery recharging. However, it should be emphasized that only relying on ad hoc networks is not desirable and may not improve the system's resilience. For instance, Casoni et al. (2015) doubt that ad hoc solutions can be adequate to deal with issues such as information overload and damaged infrastructure and propose a hybrid architecture, integrating satellite and LTE technologies to provide broadband connectivity for public protection disaster relief (to field operators and distressed people). Such an integrated system improves resilience by enhancing redundancy, improving network accessibility and coverage, offering enhanced broadband connection, and interoperability in the sense that it also allows utilizing the terrestrial networks (in other words, it improves compatibility and flexibility of the system). LTE is the access technology in the proposed hybrid infrastructure, and satellites are the backhaul mediums to transfer coverage via LTE base stations.

10.2.12 Transportation

The transport sector is a basic pillar of most geography's economic growth. In fact, in a report by the World Bank, it is noted that most Small Islands Developing States (SIDS) rely highly on transportation infrastructures to support economic activities that support the growth of their GDP; thus, highlighting the need to prioritize disaster resilience (The World Bank, 2019). In the right to this, numerous smart solutions have emerged and prioritized in different countries to not only improve efficiency but increase passengers' experience, reduce emissions, increase safety and enhance security. Ahmed and Dey (2020) note that some emerging smart solutions that are being championed are those pursuing increased connectedness and automation of vehicles. Connectedness can enhance areas like traffic control to reduce congestion, a problem synonymous with most global cities and highly urbanized areas. It also enhances safety of both commuters and pedestrians in the case of road transport. Further, having automobiles systems interconnected would allow for better management of urban parking, further reducing emissions, congestions, and financial expenditures (Lanza et al., 2016). Potent technologies, in this case, include the Vehicular ad hoc networks (VANETS) that can allow vehicles to communicate via radio signals and sensors on issues like traffic, accidents, and others, rendering an environment where vehicles and people can exchange information for informed decisions on traffic management promptly (Alazawi, Alani, Abjljabar, & Mehmood, 2014).

Automation is another cluster of smart technology, argued to have the capacity to improve resilience, both in road transport and to some extent in air transport. For instance, in the case of air transport, the emergence of unmanned aerial vehicles like drones have been seen to be gaining traction in areas like freights and logistic (Barmpounakis et al., 2016). Such abilities increase the capacities for different agencies to continue operation even during adverse weather conditions, often perilous for conventional airplanes. They also help ensure continued service delivery during extreme congestions on-road (Kellermann, Biehle, & Fischer, 2020), during scenarios like lockdowns, as in the case of COVID-19 (Chamola, Hassija, Gupta, & Guizani, 2020; Sharifi et al., 2021), and others. They are also gaining traction in areas like traffic surveillance and monitoring, especially due to the ability for camera integration, capturing real-time images, and recording videos while communicating directly with control centers (Barmpounakis et al., 2016).

Other upcoming smart solutions include those that reduce automobile dependency like bicycles or the adoption of car-sharing platforms, discouraging the increasing trend of private vehicle usage (Pappalardo, Stamatiadis, & Cafiso, 2017; Shaaban, 2020). The use of bicycles to access short nodes within a city is also particularly fronted as a potential solution to most urban transportation challenges, including emissions, excessive time lost in traffic, increasing pedestrian accidents, and related costs (Vandy, 2020; Yang, Wu, Zhou, Gou, & Lu, 2019). With sensors, cameras, and dedicated bicycle lanes, this mode of transportation is seen to be taking center stage in urban planning circles, like the most planning model of the 15-min city concept, proposed by Carlos Moreno (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021). In the case of ridesharing, though the concept is not new, the ubiquitousness of mobile technologies, like the use of APPs, mobile enable maps and route-planning tools, and digital cash payment methods, have increased the attractiveness of this mode as alternative transportation methods. To planners and administrators, ridesharing and bicycles offer some relief on increasing demands for hard infrastructure expansion, increasing demands for more parking sports, and increasing challenges of climate change coming partly from increasing emissions and others.

10.3 Discussions and conclusions

Following the emergence of the digital era, the global sphere, especially in urban realms, has experienced notable paradigm shifts, ranging from improved safety of both residents, their livelihood, properties, and public infrastructures. The smart solutions crafted through the digital scope have also increased optimism in achieving environmental sustainability by changing the status quo in energy production, energy consumption, water extraction, collection, storage and utilization, and others (Allam, 2020e). Smart solutions have brought about efficiency in sectors such as transport, health, education, and tourism, to name a few, not only to improve residents' experience but also to render positive impacts on areas like economic growth, societal welfare, environmental sustainability, and resource management to name a few. Indeed, it is widely documented how economies that have started to embrace and implement different facets of digital solutions differ from their counterparts in terms of live ability status of their residents, health service delivery, improvement in the transport sector, increase in economic opportunities, and many other areas that make up the global fabric (Gonzalez & Ijjasz-Vasquez, 2016).

Another area that has experienced notable, positive benefits from adopting digital solutions is the creation of resilience in different spheres. For instance, in the economic sector, with the increase in solutions in different sectors such as health, education, transport, arts, creative industry, and others, numerous opportunities have emerged. For instance, with technologies such as the use of wearables to source and track health data of individuals, economies are not only saving monies on health sectors through informed decision making but are also increasing on their revenue base through increase emergence of new start-ups that join the tax brackets (Colangelo, 2020). Those new start-ups are also contributing to job creation and offering smart solutions that culminate in increased efficiency, reduced wastage, and others while increasing the urban milieu's live ability.

The bulk of all those smart solutions from different sectors within an economy is further seen to help economies develop some form of resilience, with the case of the COVID-19 pandemic being a notable case study (Allam, 2020). Here, after social restrictions and lockdowns were instituted in different countries to mitigate the spread of the virus, technologies helped many sectors to remain afloat through smart solutions like virtual conferencing, work-from-home, online shopping and trading, e-learning, and cashless transactions among others (Allam, 2020a, 2020d). Through all those approaches, economies have been seen to gain in resilience, with most countries experiencing only a temporary impact on their gross domestic product (GDP). On this, according to the World Bank, it was expected that the global GDP would contract to near collapse levels, but in 2020, the drop was only approximately 3.5%, and it is expected that in 2021, despite the global community still being threatened by the impacts of the pandemic, the global GDP is projected to grow by approximately 6% and by 4.4% in 2022 (The World Bank, 2021).

The attractiveness of smart solutions, as noted in the above sections, is that they are hinged on numerous modern technologies that have been seen to be advancing as more innovations emerge. It is noted that the ability of different technologies to help in the interconnectedness of different fabrics has improved areas like data collection and analysis, and this has had positive impacts on the quality and frequency of decision making. Unlike in the past decades, through technology, stakeholders, and different agencies are now able to collect data in real-time from the epicenters of disaster, and through this, Ahmed (2018) notes that more lives are saved and damages to properties are being reduced. For instance, the use of UAVs, as explained by Barmpounakis et al. (2016), has allowed different agencies to engage in disaster mitigation to access remote and hazardous areas at the center of disasters, thus managing to assess situations in real-time, send necessary support, and design and deploy recovery and postrecovery plans. Further, as Kamruzzaman et al. (2017) noted, smart devices have been argued to increase resilience by ensuring that valuable information is still available even after local infrastructures, like communication networks, roads, and other properties, are affected or interrupted by disasters. This ensures that there is continuity in action planning, which leads to speedy resumption of normalcy after the disasters have subsided.

However, while smart solutions can improve resilience in different frontiers of an economy, they have been noted to experience some challenges that require to be resolved. First is the challenge of cost implications. It is argued that most of those technologies are relatively expensive to acquire and implement, courtesy of factors such as lack of diverse expertise, the profit-oriented nature of the proprietary firms, and scarcity of supporting infrastructures, among others. However, this point is countered by the understanding that ultimately, the cost would be relatively low compared to the resilience created. It, therefore, behooves different stakeholders to prioritize the adoption of smart solutions, like the smart cities concept, the 15-min city concepts, and others, to facilitate resilience in areas like environment, transport, build environment, health, and others, to ensure disaster preparedness.

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CHAPTER

11

A typology analysis of smart city projects around the world

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11.1 Introduction

While approximately 30% of the world's population lived in cities in1950, it increased to 50% in 2007 and is expected to reach close to 70% by 2050. Cities are the hub of the world's economic activity and simultaneously account for a sizable portion of energy consumption and carbon emissions (Sharifi & Yamagata, 2016). Therefore, in addition to the problems such as poverty, crime, environmental pollution, inequality, and disease that urban dwellers struggled with within the twentieth century, emerging challenges, including climate change, resource depletion, recession, are added to the list of urban problems in the new century (The United for Smart Sustainable Cities, 2017). *Climate change* is an urban issue that transcends national borders and affects all cities, regardless of their size or development (Bulkeley, 2013). Because of its significance, many city leaders have been prompted to reconsider urban sectors such as transportation and mobility, energy, infrastructure, and the industry. The smart city is a crucial concept that has been introduced in response to difficulties and improved urban dwellers' quality of life (Meijer & Bolívar, 2016).

Smart cities use cutting-edge innovations and technologies to improve people's quality of life (Gori, Parcu, & Stasi, 2015). This concept has progressed from a solution and remedy for

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urban problems to a policy agenda for long-term development (Allam, 2020). Local and national governments have begun their journeys toward smart city goals, and private companies have also launched various innovative projects (Zheng, Yuan, Zhu, Zhang, & Shao, 2020). For example, IBM created the "Smarter Cities Challenge" to make better use of resources, save money, and improve the quality of life of city dwellers. Companies including Cisco, Huawei, Intel, Toshiba, Google, Bosch, and Ericsson have begun smart city projects with local and national governments in both developed and developing countries. Smart technologies including 5G, IoT, AI, Machine Learning, Big Data, sensors, WIFI, drones, GPS, electrical grids, digital platforms, smartphones, LED lighting, and CCTV cameras are used in these projects to collect real-time data for decision-making and to connect individuals and urban sectors (Sharifi, Khavarian-Garmsir, & Kummitha, 2021).

Smart city projects are developed in different sectors and dimensions. They concentrate on governance, the environment, living, people, mobility, data, and economics. On the governance front, smart technologies facilitate greater participation and integrated management by connecting and interacting the government with stakeholders. They also assist planners in the urban development strategic visioning, encourage local governments to be transparent, and promote public services provision. Smart city solutions play an important role in developing cities' environmental quality and contribute to mitigation and adaptation strategies by managing air pollution, waste, water, and energy resources. They provide possibilities for cities to have climate-sensitive urban planning and design. Smart cities pursue the quality of life, cohesion, education, public awareness, equity, livability, health, safety, security, and citizens' convenience as part of their social mission. Mobility is at the heart of smart city projects. These projects support low-carbon transportation and address traffic congestion and carbon emissions by developing innovative transportation modes. On data-related smart city projects, sensors and IoT devices collect a substantial volume of data across cities every day and help public agencies make informed decisions on coping problems. Finally, novel technologies can spur innovation and support local businesses such as tourism. They make it possible for cities to develop green economic activities while remaining efficient (Dhaliwal, 2019; Kitchin, 2014; Sharifi et al., 2021; Thite, 2011).

In light of this, the growing number of smart city projects necessitates a closer examination of the projects in this chapter. Many studies have focused on the definition, principles, dimensions, and concept, while there has been little research into smart city projects from a systematic standpoint. This chapter discusses the practical application of the smart city concept and determines the extent to which a gap exists between smart city theory and practice (Borda & Bowen, 2019).

11.2 Trends in the development of smart city projects

Although the smart city is a novel concept, it has gone through numerous stages of development in terms of ideas, design, and implementation. Three distinct generations can be identified in how cities integrate ICT into urban development processes (McKenna, 2021) (Table 11.1). The evolution of smart cities began with the domination of technology and digital projects launched by large technology companies. Then, smart cities became a part of urban management, and finally, citizens became the center of the smart city projects (Borda & Bowen, 2019).

TABLE 11.1 Generations of smart city projects.

Generation	Characteristic	Planning process	Example
First generation	The centrality of information and communication technology	Top-down	Cyberjaya and Songdo
Second generation	IT technologies as a tool for urban managers to improve quality of life	Top-down	Rio de Janeiro, Toranto, Dubline
Their generation	People-oriented urban development projects	Down-top	Vancouver, Barcelona

The first generation of smart city projects was technology-centric (Allam, 2020). At this stage, international technology corporations such as IBM, Cisco, Intel, and Hitachi played a critical role in transforming cities through technology and digital solutions. Advanced technologies were central to cities' transformation. This technology-driven perspective fostered the widespread belief that digitalization may boost job possibilities and economic growth. In general, many cities embraced this strategy and began digital city projects without fully comprehending the impact of technological solutions on city quality of life and long-term sustainability. At this point, top-down planning, led by technology companies, was the prevailing approach. The lack of interaction with citizens was a criticism of this approach. Furthermore, it was built on specific initiatives commissioned by private technology companies to boost production. This generation of smart city projects has been proposed for various geographic locales, including Plan IT in Portugal, Cyberjaya in Malaysia, and Songdo in South Korea (Monzon, 2015).

The second wave of smart city projects focused on urban management. Instead of technology corporations, city managers have taken the lead in the smart city movement. The officials explored innovative technology to alter cities and produced creative solutions that leverage information and communication technologies to improve the lives of urban dwellers. The smart city of Rio de Janeiro is an example of the second generation of smart cities, in which city officials, in conjunction with IBM, launched a comprehensive plan to deploy smart sensors for monitoring city activity. Barcelona is another example of this generation, with more than 20 regional initiatives and 100 projects. Wireless internet connection in all urban settings, smart lighting, and smart transportation infrastructure upgrades are among them. The Barcelona smart city idea aims to improve inhabitants' quality of life by leveraging new technological potential. However, the process of urban planning and management in this generation of smart cities was still top-down (Bakıcı, Almirall, & Wareham, 2013; Shelton, Zook, & Wiig, 2015).

The third generation of smart city projects was people-oriented. Central to the projects is the participation and co-creation of citizens to achieve solutions to address environmental sustainability issues. Social justice was also a key goal for the projects. They attempt to create situations that make people more actively participate in decision-making processes. Decisions were made based on a down-top approach that uses collective intelligence and people's participation to make cities smart. People were at the center of the third generation of smart city projects. Citizens' participation and co-creation of responses to environmental sustainability concerns are central to the plans (Angelidou, 2014). A major purpose of the projects was to promote social equity. They strived to create situations that encourage people to participate more actively in decision-making. Making cities smarter was made using a bottom-up strategy that relies on collective intelligence and citizen participation (Anthopoulos, 2015; Weisi & Ping, 2014).

11.3 Methodology

This chapter sheds light on smart city projects to identify the major trends in smart cities worldwide. We compiled a global database of 50 smart city projects and described them using descriptive analysis. Data on the projects' scale, ownership type, geographic focus, smart city solution type, dimension, and relationship with climate change were gathered. The majority of the projects were concerned with environmental sustainability. Around 68% of projects include measures for mitigating and adapting to climate change. Based on their scale, they were classified into building, neighborhood, street, district, city, and region levels. The majority of the projects (78%) were at the city scale. They were also classified as private, hybrid, or public based on their ownership. About 70% of the projects are public, 18% are privately owned, and 12% mix the two. While the majority of projects have a specific scope, some are transnational in scope. The United States of America, the United Kingdom, the Netherlands, Spain, Brazil, and Germany have the greatest percentages in the database. The study also included smart city projects from developing countries such as Brazil, Serbia, and Prue. IoT, smart monitoring, GPS, and digital platforms are the most commonly used innovative technologies.

We also established a link between the projects and the seven key action fields: governance, environment, living, mobility, people, and economy. Accordingly, 36% are related to smart governance, 68% to the smart environment, 36% to smart living, 44% to smart mobility, 40% to data, 6% to smart people, and 18% to the smart economy. About half of the projects are related to the energy sector and use smart technologies such as smart grids, lighting, and renewable energies to reduce carbon emissions in cities. Approximately 36% of the projects are transportation-related. These projects seek to develop self-driving cars, active transportation, public transportation, and electronic cars to reduce fuel consumption and improve air quality. Overall, around 12% of projects were urban waste and water management.

11.4 Results

11.4.1 Transport-related smart city projects

Mobility and transportation are key components of sustainable urban development. They contribute to economic prosperity by creating job opportunities while influencing environmental sustainability by producing carbon emissions (Kwan & Hashim, 2016). It has been argued that urbanization and increased car dependency in recent decades have been contributed to traffic congestion, increased pollution, and safety problems in recent years (Pojani & Stead, 2017). As a result, improving access to urban services while tackling traffic congestion, air pollution, and accidents has become a priority for many cities worldwide

(Sharifi, 2021). Since the transportation sector is responsible for the main portion of green gases produced within cities, its contribution to climate change mitigation and adaptation strategies can be considerable. Air pollution has been considered the most prominent environmental risk factor for public health in many cities. It accounts for a significant part of deaths in developed and developing countries (Clancy, Goodman, Sinclair, & Dockery, 2002).

By looking closely at the projects that emphasize transportation and mobility, one can categorize the projects, based on their goal, into themes such as sustainable travel behavior, smart parking management, public transit, and active and low-carbon transportation development. During recent years, smart cities have launched innovative projects to use smart technologies in improving citizens' travel behavior. Leveraging novel technologies, these projects help travelers make efficient decisions regarding travel mode, route, departure time, and destination. Habcab is an example of an innovative project created in New York to promote shared mobility. The digital platform developed by the MIT Senseable City Lab provides information about shared taxi users' contribution to reduced traffic congestion, air quality improvement, and saving costs. Besides, navigation applications open up possibilities for individuals to select the best route and time for daily trips. These applications are backed by real-time data collected by IoT and GPS technologies. Smart computation technologies, including AI and ML, analyze the data and show the low-congested route to achieve the destination at the shortest possible time with the lowest fuel consumption. As a result, some cities, including Antwerp, London, Bristol, and Stockholm, justify their recent investments in IoT-related infrastructures as to the necessity of addressing traffic congestion and carbon emissions and the role that innovative technologies can play to modify citizens travel behavior.

Some smart city projects have concentrated on the deployment of smart parking in downtowns and congested districts. Transportation studies show that the main section of streets traffic is caused by the drivers cruising for parking since the parking supply is limited in crowded urban areas while there is an over-demand in peak times (Arnott & Inci, 2010). In some cities, including Milton Keynes, smart technologies show the location of empty parking spaces on a digital platform, and thus, drivers can find the closest parking via their smartphone. Another group of smart parking projects has contributed to reducing pollution and traffic congestion by pricing parking spaces based on time, day, amount of traffic, and a vehicle's type. In Madrid, parking meters charge more for pollutant cars while parking is free for EVs. Hybrid cars also have lower parking fees. Overall, the projects have increased the convenience of mobility because they reduce the average time spent searching for parking. Moreover, these projects have been considered part of climate change mitigation and adaptation strategies because they can reduce energy consumption and air pollution by reducing traffic congestion and wasteful driving.

Moreover, the contribution of public transportation in addressing traffic congestion, carbon emissions, and increased air quality is widely acknowledged (Chapman, 2007). Some smart mobility projects aim to reduce car dependency and increase public transportation use. Mobility as a service (MaaS) is among the initiatives that has been launched in Stockholm. It combines public transit with other sustainable modes of transportation, such as walking, cycling, bike-sharing, and ride-hailing, to solve the first and last mile problem and reduce traffic congestion. Some smart city projects target the modernization of public transport infrastructures. The deployment of smart technologies in public vehicles provides passengers with real-time information about the location, number of passengers, and arrival time. This information makes public transportation trips more convenient and provides policymakers with necessary data for decision-making. Some innovative public transit modes are also used in smart cities. For example, the Masdar City project selected the autonomous shuttle, electric shuttle cars, and electric and public buses to support low carbon mobility.

Active transportation forms the focus of some smart mobility strategies that encourage walking, cycling, and micro-mobility and, at the same time, promote public transit. Besides, private cars are still a popular mobility option since they provide convenient door-to-door transport. Some smart city projects seek to replace polluting private cars with low-carbon cars such as electronic, hybrid, and automatic vehicles. Smart city projects in Abu Dhabi, Antwerp, Berlin, Glasgow, Lyon, and California have sought to reduce greenhouse gas emissions and adapt the transportation sector to climate change by promoting low-carbon transportation. Fig. 11.1 illustrates an overview of transport-related smart city projects.

11.4.2 Governance-related smart city projects

Increasing urbanization, climate change, and pandemic outbreak have brought about various challenges, such as congestion, disclusion, poverty and inequality, and hazards that have made cities management more complicated (Khavarian-Garmsir, Pourahmad, Hataminejad, & Farhoodi, 2019; Warner, Hamza, Oliver-Smith, Renaud, & Julca, 2010). Smart city projects come to assist urban managers in making informed decisions that can holistically

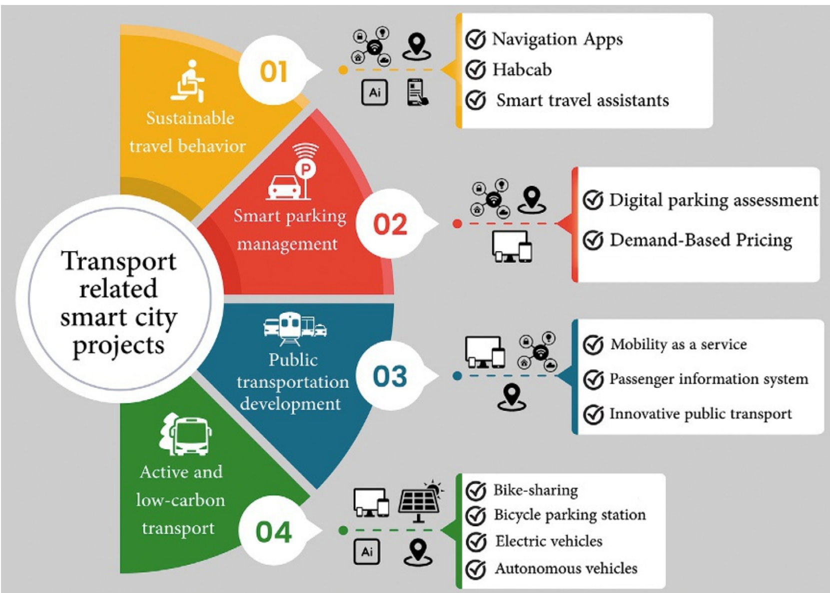

FIG. 11.1 Overview of transport-related smart city projects. *Elaborated by authors from the Freepik design.*

address these issues (Thite, 2011). Among the smart city projects selected in this chapter, we found 21 projects to increase participation, transparency, and improved public services.

As with public services, local governments are under increasing pressure to deliver various public services to all citizens (Wirtz, Müller, & Schmidt, 2020). Governments should identify citizens' different demands and provide individuals with public services in a timely, cost-effective manner (Zhang, Xie, & Ma, 2020). City smartphone apps developed by municipalities are an intelligent solution to improve service delivery. For example, the Monaco 3.0 application in Monaco aims to promote the delivery of public transport, parking, waste collection services. The mobile platform informs citizens of the wastes collection schedule, and they can pay parking charges using the app. Map portals are another smart city solution that have been used, for instance in Glasgow, to display the location of close urban services to individuals.

Besides, the advantages of smart technologies in urban services and infrastructures maintenance are acknowledged (Sharifi et al., 2021). Smart cameras and sensors are steadily monitoring municipal services and reporting any malfunctions. City apps also allow people to report public service disruptions. For example, Monaco and Rio de Janeiro city apps provide the opportunity for citizens to take and send photos of services, such as elevators, lighting, and waste collection, that are out of work.

Participation is an essential urban governance principle and an important goal of smart city projects in Berlin, Manchester, London, Stockholm, and Barcelona. Novel technologies open up possibilities to address the barriers that hindered citizens' participation in the past. For instance, digital platforms facilitate the communication between a government and stakeholders without a physical presence in the city hall. Furthermore, some cities, including Hamburg, launched digital participation systems to ask questions about and criticize urban plans. Some smart city projects use gamification to increase people's motivation in participatory urban planning and design. In Barcelona and Madrid, for example, gaming platforms have been created that offer the opportunity for people to improve the quality of their living area. These platforms inform planners and policymakers about citizens' behavior and their daily choices. They also provide individuals with critical understandings about health and climate change.

Finally, due to the widespread use of smart technologies, much data are collected, stored, and used daily. Local governments need to be transparent as the lack of transparency can lead to citizens' data misuse and safety risks. It does not only imply access to information but also includes decision-making processes. Discussion on the right to access information and decisions is out of the chapter scope. However, how individuals can have easy access to information is an issue that smart technologies offer opportunities for governments to become more transparent. In some cities like Hamburg, Bristol, London, and Chicago, documents and plans are available on urban dashboards. Timelines and decisions are visualized on the platforms, and spatial information is shown with the geographic information system (GIS) to comprehend quickly. Another part of smart city projects has concentrated on open data portals. These portals aim to increase people's knowledge about their living environment and encourage citizens to participate more actively in the community. Open data provide opportunities for new businesses and supports research and development. Finally, some cities have progressed beyond transparency and documents and broadcast decision-making meetings online on city portals. Fig. 11.2 illustrates an overview of transport-related smart city projects.

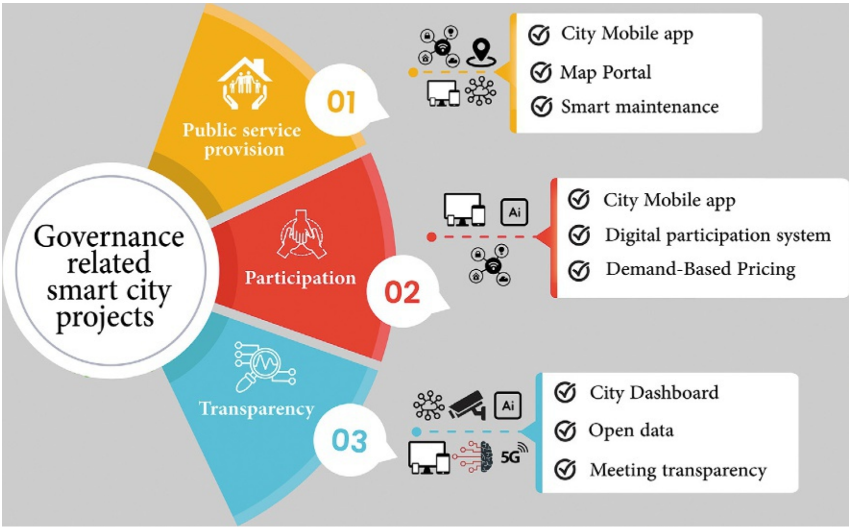

FIG. 11.2 Overview of governance-related smart city projects. *Elaborated by authors from the Freepik design.*

11.4.3 Smart city projects related to water and energy systems

Climate change has implications for critical urban resources such as water and energy. Influencing precipitation and evaporation can increase flood and drought water-related disasters (Craig, Feng, & Gilbertz, 2019; Khavarian-Garmsir et al., 2019). As far as energy is concerned, two-thirds of the world's green gases are produced by fossil fuels burned to generate the energy needed in the industry, transportation, and heating sectors (Zheng et al., 2019). This section studies the smart projects that suggest water and energy management innovations. We found 25 smart energy projects. These projects are deployed in Berlin, Valencia, Manchester, London, Chicago, Melbourne, Abu Dhabi, and Hampshire from 2010 to 2020. We also found 10 smart water management projects deployed in Rio de Janeiro, Hamburg, Valencia, and San Jose from 2006 to 2020.

Green gas emissions resulting from fossil fuels form a basis for climate change mitigation and adaptation strategies prescribed by international organizations. Therefore, sustainable energy management is of paramount importance for local and national governments. Some smart cities have created innovative solutions to reduce emissions, introduce alternative energies, and increase distribution network efficiency in response to this unmet need. Some cities are centered in the transportation sector. They adopt policy tools to encourage people to replace private cars with public and shared transportation. The shift toward EVs is another goal that can effectively reduce carbon emissions (Nanaki & Koroneos, 2016).

Some smart city projects, including Masdar City, use low-carbon materials in new buildings that significantly reduce energy consumption. Finally, smart lighting is a novel technical solution applied by many cities, including Entop, Eeneind, Schiedam, Copenhagen, Lyon, and Hampshire. Based on the IEA report, lighting uses around 19% of the world's electricity and is responsible for 6% of carbon emissions worldwide. While we collected several street smart lighting projects, the innovation is used in parks and buildings.

Some smart city projects propose renewable energies as alternatives for fossil fuels to generate electricity. Smart grids are among the novel initiatives that use solar power as renewable energy to produce electricity. It localizes the centralized energy generation systems which are reliant on nuclear and fossil power plants. Smart grid systems are a part of the power generation system in Manchester, Berlin, Vienna, Melbourne, and Yokohama. Another part of smart city projects increases energy efficiency through energy management systems (EMS). For instance, the Yokohama smart city project offers the EMS for 4000 homes, commercial and official buildings, and factories to save energy significantly.

Disasters such as floods and drought have swept through many cities globally in recent years. Surprisingly, about 74% of natural disasters between 2001 and 2018 were related to water (Connor, 2015). Therefore, smart cities emphasize water resources management and have established projects to intelligently manage water supply systems, consumption, and wastewater disposal. As with water supply systems, they have been grappling with various problems, including water linkage. Smart meters can contribute to identifying leakages in the distribution system. For example, thanks to IoT-equipped devices, the Spanish city of Burgos created an innovative water management system to identify anomalies in the system. Communication devices send data collected by smart water meters and sensors to a smart platform. The platform uses algorithms to identify leakages automatically, predict future consumption, and monitor water quality. Besides, there are some smart projects to manage water consumption. For example, local governments encourage people to use new smart water meters connected to smartphone applications. In case of water leakage in buildings, these smart meters send alarms to the person's mobile phone.

Furthermore, to save water, some high-tech companies, including Xiaomi, created smart devices equipped with sensors installed on taps and automatically turn on and off the water flow. Finally, technological innovations are used to treat wastewater to increase water reuse while reducing costs. These technological innovations can influence the water supply as measures to adapt to climate change in the water scarcity context.

11.5 Conclusion

While cities are hubs of economic growth and innovation, they also account for a sizable percentage of greenhouse gas emissions. Cities are leading the world's transition to a low-carbon economy. Due to the widespread hazards posed by climate change to cities worldwide, national and local governments have made mitigation and adaptation to the problem a priority. Cities can lower their ecological footprint while preserving their economic operations thanks to new technologies that have emerged in recent decades. This chapter aims to compile a global database of smart city initiatives and conduct a typology analysis. This will help understand the main features of solutions implemented to promote good governance and sustainable management of the transportation, water, and energy sectors.

We gathered over 50 smart city projects from both developed and developing countries. Smart transportation projects offer ways to minimize reliance on automobiles, reduce traffic congestion, reduce air pollution, and improve safety. The four key directions of smart transportation projects are the promotion of sustainable travel behavior, smart parking management, public transit development, and active and low-carbon transportation development. The projects have made use of cutting-edge technology such as IoT, GPS, AI, and smartphones to create applications that aid in navigation, travel, and shared mobility. They let travelers make more informed decisions about travel mode, route, departure time, and destination. Smart parking systems display the location of empty parking spaces as well as the pricing of parking spaces. As a result, they help to mitigate climate change regulations by lowering traffic congestion and wasted driving. Mobility as a service, modernization of public transportation infrastructure, and novel public transit modes are some of the innovative ideas offered to minimize vehicle dependence and enhance public transportation use. Finally, some smart mobility projects are centered on active transportation and low-carbon vehicles. They promote walking, cycling, micro-mobility, as well as electronic, hybrid, and automatic cars.

Some smart city projects assist urban managers in making informed decisions. We recognized smart city projects that promote participation, public services, and openness to urban government. Municipality-developed city smartphone apps are an intelligent way for improving service delivery. The map portal is another smart city option that displays nearby urban services. Furthermore, smart cameras and sensors are constantly monitoring municipal services and reporting any flaws. As with participation, new technologies open up new avenues for overcoming past public participation hurdles. Digital platforms, for example, enhance communication between a government and stakeholders who may not have a physical presence in city hall.

Furthermore, several cities have created digital participation platforms that allow citizens to raise questions about and criticize urban planning. Gamification is used in some smart city projects to boost people's motivation in participatory urban planning and design. Finally, as with transparency, urban dashboards depict timelines and decisions. Besides, open data portals seek to expand people's knowledge of their living environment and inspire individuals to participate more actively in their communities. Finally, several cities stream decision-making meetings live online through official portals.

We also concentrated on smart city projects in the water and energy sectors. Some smart cities have developed novel methods to minimize emissions, introduce alternative energies, and improve distribution network efficiency to achieve sustainable energy management. Some smart city initiatives use low-carbon building materials and encourage people to drive EVs to save energy. Smart lighting is another innovative technological solution that is employed in streets, parks, and buildings. Furthermore, several smart city projects suggest renewable energies as alternatives to fossil fuels for electricity generation. Smart grids are innovative efforts that employ solar power as a renewable energy source to generate electricity.

Finally, smart cities have prioritized water resource management, intelligently establishing initiatives to manage water supply systems, consumption, and wastewater disposal. Smart meters can help locate leaks in the distribution system. Additionally, there are several innovative water management projects. Finally, technical advances are being employed to treat wastewater to increase water reuse while decreasing costs.

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CHAPTER

12

Urban scale climate change adaptation through smart technologies

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12.1 Introduction

As one of the major threats to life, climate change has various root causes, including greenhouse gases (GHGs) emissions, the primary air pollutant (IPCC, 2013). To put it differently, as GHG emissions are among the active players in the complicated relationship between air pollution and climate change (Xu & Lamarque, 2018), cities are considered as a critical contributor to this issue. Indeed, most activities in urban environments can be the source of GHG emissions, and it has been reported that 75% of total CO_2 and the consumption of world resources are related to cities (Pacione, 2001; UN, 2020). From another perspective, global warming as a direct effect of climate change has caused several results, such as raised sea levels and frequent extreme weather events. It has been proven that these events have huge impacts on different aspects of urban environment elements like the city's infrastructures.

Impacts of climate change are, indeed, multihazard phenomena that may simultaneously include various hazards. Although droughts and floods as weather-related events have been experienced, the intensity or frequency of such events may increase the risk factors due to climate change. Moreover, new events such as severe urban heat islands or rising sea levels

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are also possible (Birkmann et al., 2010). Apart from that, air pollution can also be another consequence of climate change due to meteorological inversion. This environmental issue has been proven to have other impacts, such as deteriorating the building materials. Impacts of extreme weather events on city dwellers' well-being can be seen in all the above elements correlated to climate change.

On the other hand, since transportation and construction as two significant causes of GHG emissions that are expected to grow in cities due to the expansion of urban development, these places are the ones that the high impacts of climate change can be seen. Problems such as heat illness and air pollution as the consequence of urban heat islands are highly likely to happen in cities soon. Furthermore, due to the location of most cities near coastal lines or rivers, they would be highly vulnerable to rising sea levels and other environmental problems. Climate change is causing complex challenges in cities in areas, which requires attention via agility in response mainly by the utilization of technologies.

Since climate change is a complex phenomenon, confronting its challenges requires a comprehensive agile treatment at different levels of socioeconomic measures related to urban environments. Concurrently, conventional technologies are utilized to tackle climate change via promoting sustainable solutions for mitigation and adaptation to this emerging event. However, it has been verified that there is no unique solution to fix climate change at once, and conventional technologies need to be developed toward more enhancement of the sustainability sphere in the future (Fawzy et al., 2020).

Heavily affected by climate change, urban environments must evolve toward becoming smart by utilizing frontier technologies to tackle this environmental issue (Silva, Khan, & Han, 2018). Therefore, conventional technologies may evolve via frontier technologies to provide a more vital compound to mitigate and adapt to climate challenges. Moreover, since the complication of environmental issues is so high that it creates problems, the solutions must be of a high standard, which means continuous optimization is essential in developing green technological resolutions. Frontier technologies, such as AI, IoT, 5G, and Digital Twin, may progressively optimize conventional technologies to higher levels, promoting the expansion of technological advancement to combat climate change (ITU, 2020). Besides, in smart cities, due to the utilization of emerging technologies, the potential of solving problems correlated with both environmental and human elements may increase (Silva et al., 2018), which emphasizes the benefits of the transition from conventional to frontier technologies.

In addition, sustainable technology transfer and innovation have been considered as an essential aspects of promoting green growth in the economic sphere (Fernandes et al., 2021). Hence, the transition from conventional to frontier technologies can solve problems in smart cities and unify the interests of socioeconomic domains. Consequently, utilizing frontier technology may benefit both the development of green technology to support sustainable development criteria and the utility of advanced systems to mitigate and adapt to climate change.

While conventional technologies have brought several advantages to cope with environmental challenges, climate change's complexity, and the amount of data needed to be analyzed, the limitation of this type of technology would restrict our measures. The severity of impacts of climate change, especially in urban areas, imposes governments, scholars, and dwellers to use emerging technologies to tackle this environmental concern as it is getting more complicated daily.

To that end, this chapter aims to provide a comprehensive overview of the frontier technologies' application in mitigating and adapting to climate change one by one.

The most popular and influential technologies are studied in this chapter to clarify their implementations and their scope of influence in combating this environmental issue in urban areas and their limitations in this respect. Each technology fosters the mitigation process, and adaptation to climate is presented as a comprehensive overview of the chapter.

12.2 Overview of the current trends of modern technology applied in the urban environment to address climate change

Climate change is considered a shift in climatic conditions because of human activity or natural causes, which has been considered among the significant problems of human history (IPCC, 2014). To reduce climate change effects, serious measures must be taken; otherwise, the next generations would be in grave danger. It has been widely proven that emerging technologies are critical in achieving sustainability and mitigating climate change (Rashid, 2018) through improving communications, monitoring, or analyzing the current conditions and predicting the future environmental conditions. In other words, what these advanced technologies will bring is environmental resilience, sustainability, and in general, smartness, by which a wide range of opportunities to mitigate and adapt to climate change will be possible (UN, 2018a).

A series of global efforts have been devoted to developing frontier technologies and *information communication technologies* (ICTs) to tackle climate change as they have the potential to foster achieving *SDG 13*. Despite the daily progress of these areas, their environmental implementations have mainly been missing in the global discourse. It means the successful application of advanced technologies can change the attitude toward solving the climate change crisis and environmental protection. In order to tackle climate change problems, three main strategies are plausible; adaptation, mitigation, or both. It is essential to understand the fundamental differences between these attitudes in the technological context and then review the implementation of technologies for each strategy. While adaptation strategies to climate change have been around for a long time (Bueti & Faulkner, 2019), mitigation initiatives have been designed when the scientific community found the possible interaction between climate and human actions.

Thus, adaptation procedures can also begin with applying techniques that have already been handled and used in human communities. While mitigation is mainly connected to the energy sector, adaptation actions seem necessary for all the economy-related fields such as agriculture, water management, and health. Although there are numerous successful examples in this area, it must also be noted that technologies regarded as obsolete in some countries could be functional to tackle adaptation problems in other areas.

On the other hand, the central part of activities in mitigation of climate change needs significant investments in terms of national or international scale. Another thing to consider is that technology transfers are far more complex in adaptation processes than mitigation (ITU, 2020). The impacts of adaptation are usually site specific, which means the know-how seems less easily transferable. Despite all the positive impacts of technologies implementation in solving climate change issues, it should be noted that they could cause unintended environmental consequences that may result in peripheral effects on the environment. For example, although ICTs develop innovative solutions for climate actions, their environmental consequences are often overlooked. Issues related to their equipment's energy efficiency and generating a considerable amount of e-waste are severe concerns overusing ICTs. It is critical to consider these aspects as their environmental impacts would affect the benefits that they may bring.

It is necessary to identify effective technologies and their implementations in mitigating and adapting climate change to analyze previous efforts and develop efficient and optimum ideas. To this end, the following sections will explore technologies applied in the climate change crisis, namely:

- Artificial Intelligence
- IoT
- 5G
- Digital Twin
- Other technologies

12.3 The implication of frontier technologies to combat climate change

12.3.1 Artificial Intelligence

Background

Coined in 1955 by *John McCarthy*, professor at *Dartmouth*, Artificial Intelligence (AI) has become an essential part of scientific advances ever since (Davenport et al., 2019). Although AI was embedded in different aspects of our lives more than ever to identify and solve tractable information processing problems 1 day (Marr, 1977), it has now gone beyond conventional concerns. Goals such as increasing efficiency, increasing the accuracy of human activities, and predicting future conditions are among the main aims of AI technology. AI enables machines to learn from their experiences to reach a human-made understanding. These intelligent machines integrate cloud computing, Big Data analysis, and other different ways to learn and perform cognitive tasks such as decision-making, processing of natural languages, sensing, reasoning, and manipulating objects. It also empowers robots and software as self-growing agents to operate independently from human operators (Smith, 2018).

AI applications can change how we see societies or human behaviors and complex, severe technical problems such as climate change. This increasingly visible issue in the forms of droughts, storms, floods, and fires can heavily affect urban life, agriculture, thermal comfort, transportation, buildings, the energy sector, and numerous other areas (Stein, 2020). It is believed that climate change is one of the challenging areas where humankind needs technical assistance, which AI can provide despite its imperfections (Field et al., 2012; Rolnick et al., 2019; Romm, 2018). Tackling the problem of climate change in the urban environment involves adaptation (preparing for unavoidable consequences) and mitigation (reducing emissions) which are complex tasks. Adaptation needs strategies for giving a holistic understanding of climate, extreme events, and the concept of resilience disaster management. Mitigating GHG emissions needs reform in several areas such as transportation, industry, and buildings. As the climate change challenge in cities is a multifaced issue, it can be addressed differently.

Role of AI in mitigating climate change

AI seems an interestingly appropriate tool for addressing climate change as this area is highly complex with massive data challenges. While monitoring GHG emissions has been an ongoing task for years, it has remained challenging to comprehend (Snow, 2019). Indeed, climate science needs to acquire a considerable amount of reliable data in different variables such as humidity and temperature, which is why dealing with this data is quite challenging (Sundblad, 2018).

In this respect, it is believed that more advanced technologies such as AI can provide us with a more comprehensive analysis. Despite widely accepted Implementation of AI technology for solving different kinds of problems, its usage in mitigation and adaptation of climate change issues remains mainly academic instead of practical (Rolnick et al., 2019).

As far as the application of AI in mitigating climate change is concerned, it is mainly used for systems assessment (Reichstein et al., 2019) like atmospheric processes modeling (Rasp, Pritchard, & Gentine, 2018) of weather stations' data to model climate impacts in order to predict extreme climate events (Fletcher, Lickley, & Strzepek, 2019; McDowell et al., 2015). The real challenge in atmospheric forecasts is the uncertainties that make predictions very complicated; AI and Artificial Neural Network (ANN) algorithms can effectively reduce those uncertainties and develop more accurate climate models (Akyuz, 2015). UN environment has categorized the AI application in climate action that helps scholars analyze and review its classification for their context and reach an even more accurate grouping (Fig. 12.1).

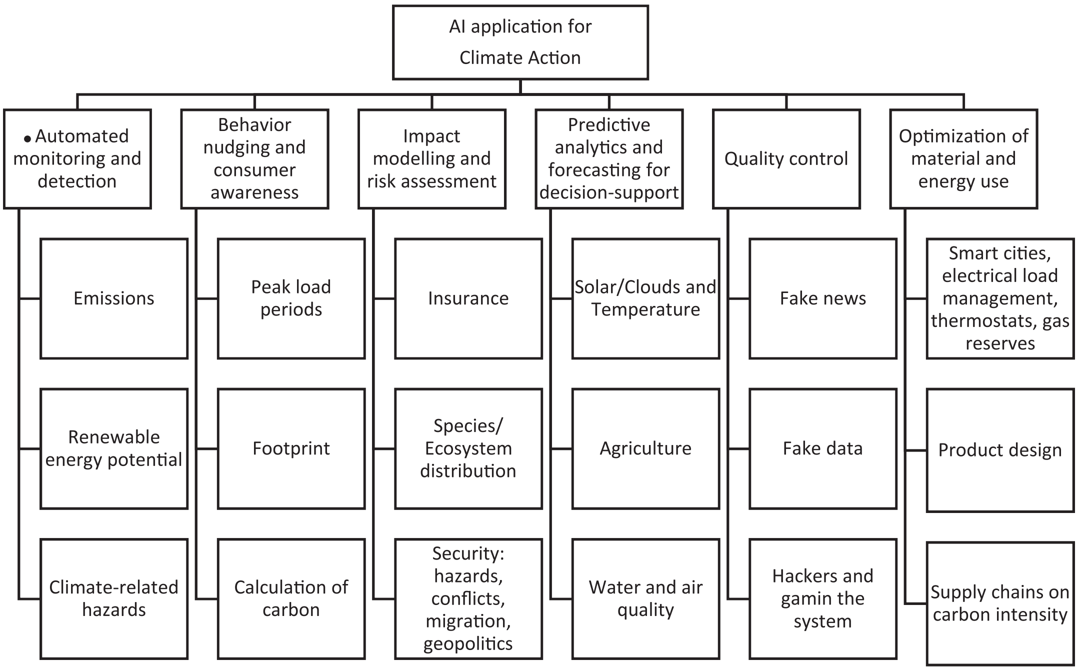

FIG. 12.1 AI applications for climate action. *Adapted from ITU. (2020). Frontier technologies to protect the environment and tackle climate change. International Telecommunication Union.*

To reach an accurate overview of how AI can mitigate and adapt to climate change in cities, detailed implementations of this technology in addressing this environmental concern are necessary. That is why in the following subsections, different applications of AI to combat climate change in cities will be thoroughly discussed which will be according to the following list:

- Monitoring urban infrastructures
- Enhancing energy efficiency in cities
- Recognizing the behavioral patterns of cities and dwellers
- Optimizing urban management

Monitoring urban infrastructures

Urban infrastructures are indeed the determining factors of dwellers' comfort in urban areas, their quality of life, and at the same time, the primary source of GHG emissions and resources usage in cities (Creutzig et al., 2016). By using AI technologies and particularly Machine Learning (ML)/Deep Learning (DL), semantic information about urban infrastructures from unstructured data sources (i.e., remote sensing) can be extracted. By specifying changes in land-use patterns and different urban spatial features, these data can show human settlement's character as it has been used widely to detect various geometric information such as building usage and location (Biljecki, Ledoux, & Stoter, 2017; Esch et al., 2017; Sturrock et al., 2018; Tusting et al., 2019; Wurm, Schmitt, & Taubenböck, 2016). Moreover, DL can provide us with abstract insights into the spatial setting of cities (Milojevic-Dupont & Creutzig, 2021).

Besides, by integrating climate semantics and big spatial data and using remote sensing to collect environmental issues such as deforestation, AI algorithms can be applied to answer complex questions in this area. Indeed, through different basic AI methods such as regression trees, deforestation of different regions' greenery (DeFries et al., 2002), or carbon emissions (Baccini et al., 2012) in cities influenced by urban growth are predictable. Moreover, DL has widely been used to identify the pattern of emissions or analyze the effectiveness of mitigation strategies. For instance, Bayesian networks have been used to find CO_2 concentration spots (Tao et al., 2014) or suitable regions for photovoltaic systems (Yu et al., 2018).

Enhancing energy efficiency in cities

As a critical factor in the urban system, energy efficiency has been a critical player in climate change mitigation. The high rate of energy consumption in cities is among the reasons behind climate change and, at the same time, is a consequence of this environmental phenomenon. That is why in order to optimize energy expenditure in cities, some areas must be at the center of authorities' attention, such as buildings and transportation modes. These areas have potentially tons of data to analyze to reach an optimized energy usage; AI, therefore, could serve as a facilitator to help experts understand the trends easier.

One of the popular applications of AI in optimizing the energy consumption of buildings is using ML algorithms to minimize energy use while attaining thermal comfort (Eslamirad et al., 2020; Shaikh et al., 2014). Also, energy consumption prediction by using energy models' outcomes is another area that AI has been widely used in (Seyedzadeh et al., 2020; Seyedzadeh & Pour Rahimian, 2021). It includes generating and mining relevant data as well as controlling end-user systems in buildings. As the rate of energy consumption and climate change have made a vicious circle, considering the impact of climate change can lead to optimized energy consumption and subsequently controlled climate change impacts. This consideration includes and is not limited to weather parameters (Bazazzadeh et al., 2021; Bazazzadeh, Nadolny, & Hashemi Safaei, 2021; Berardi & Jafarpur, 2020; Harish & Kumar, 2016).

In terms of the efficiency of the transportation system and smart vehicles, AI has various applications. For instance, it has been used to downscale national transport systems emissions (Alam et al., 2018), fleet development emissions (Krause et al., 2016), and vehicles emissions estimation by using cell phone GPS data (Lehmann & Gross, 2017). These measures can effectively reduce emissions and mitigate climate change-related issues in cities. AI algorithms in general, and ML algorithms such as SVMs in particular, can reduce emissions and offer optimized routes that shorten inner-city travels by using real-time data (Zeng, Miwa, & Morikawa, 2017). These strategies and self-driving cars can make a difference in the mitigation and adaptation of cities to climate change.

Recognizing behavioral patterns of cities and dwellers

Human activities determine the level of emissions in urban cities and that is why recognizing these patterns can lead to understanding these activities and even predicting those activities' features in the future (Creutzig et al., 2018). Using behavioral data can make society more sustainable. Indeed, by detecting human dynamic feedback to urban elements, the smart solution can be adapted for sustainable development. More precisely, as DL can collect data from images and videos, it can mine data from traffic cameras and street view images. For instance, data mining utilizing CV has been applied to identify the type of vehicles in a specific part of a city and employ convolutional neural networks to estimate income in each neighborhood (Gebru et al., 2017).

These outcomes provide valuable information about the structures of cities and some suggested solutions for the development of the structures. Such as focusing on locations in cities where dwellers show a strong tendency to go according to mobility pattern extraction (Zhao et al., 2016).

Optimizing urban management

Providing current and future strategies for managing cities and dwellers can lead to low-carbon infrastructures supported by energy efficiency models, detailed maps, and human behavior models. This smart management can be employed in various stocks, such as the building where the data are available (Zhang et al., 2018) to analyze energy end-use (Kontokosta & Tull, 2017) or identifying the most effective energy conservation Schemes (Papadopoulos, Bonczak, & Kontokosta, 2018). Coupled with public policy, smart infrastructures such as transportation or building stock can result in an actual contribution to climate change mitigation. This contribution can be found in tackling traffic problems through optimizing urban management (Yau et al., 2017) or reaching sustainability metrics through smart urban planning (Tao, Wang, & Cao, 2020; Wu et al., 2019). For example, In Oslo, studies have shown a strong relationship between driving hours and distance to the city center, and according to that, researchers came up with solutions to reduce the driving distance to mitigate climate change impacts (Ding, Cao, & Næss, 2018). Furthermore, AI can help city managers to develop low-carbon transportation modes such as optimizing charging infrastructures of electric cars (Rigas, Ramchurn, &

Bassiliades, 2015), estimating their power demand (Longo et al., 2017), even locating free bikes station, or predict their demands (Xu, Ji, & Liu, 2018).

Finally, knowledge transfer in urban management is another usage of AI in this area. More precisely, by conducting comparative studies and decoding similarities, practical measures that have reached successful practices can be distributed to other regions. For instance, by identifying the socioeconomic properties of US regions in applying green building standards and comparing them to Chinese ones, scholars have predicted that future conditions in Chinese provinces could be more sustainable (Ma & Cheng, 2017).

Risk of using AI in mitigation of climate change in cities

It is beyond doubt that AI technology, including ML, ANN, and DL, can effectively help to combat climate change and mitigate its impact in cities. Indeed, these algorithms can make the urban systems more efficient, enable automatic monitoring of urban infrastructures through remote sensing, and find optimized solutions quickly.

However, their carbon cost by no means can be ignored. This technology needs a vast sum of computing power. According to studies, a normal AI-run can have an equivalent impact as profound as 600,000 pounds of CO2 emissions. That is why until this issue can be addressed, using AI technology may have adverse effects on climate change, and employing it must be limited, mainly when it is not necessary (ITU, 2020).

12.3.2 IoT

Background

Digital technologies are revolutionizing our everyday life with the high speed of digitalization in nearly all aspects of the socio-economics of human life (Melián-González, 2019). Information technology (IT) is one of the critical elements of this transformation, and the development of internet-connected devices accelerates this trend toward more interconnection ways such as *the Internet of Things* (IoT). IoT means interconnectedness among many physical devices through sensors to conduct the streams of data and information in the network environment for different uses (Patel & Patel, 2016). Similarly, this interconnectedness creates a complex network flow of Information and Communication Technology (ICT) between the actual world and the digital representation. It has been reported that the number of devices connected to the internet is more than 40 billion (Fig. 12.2). Kevin Ashton[a] was the first person who presented a clear definition of IoT to clear things up in this area (Berte, 2018). IoT is a growing area, and its applications are increasing year by year; and one of the sectors for IoT development is smart cities (Farsi et al., 2019).

This trend has brought a massive transformation in everyday life, socioeconomic trends, and urban life, which is transforming by digitalization as a complex system (Mozuriunaite, 2016). The acceleration of connected IoT devices is increasing, and the estimation shows that dramatic growth of IoT is inevitable, and approximately 13.8 billion devices will have connectivity by 2025 (IoT-Analytics, 2020a). Moreover, IoT applications can provide a range of abilities to combat climate change and protect the environment. Utilizing these applications in

[a] Co-founder of the Auto-ID center at the Massachusetts Institute of Technology.

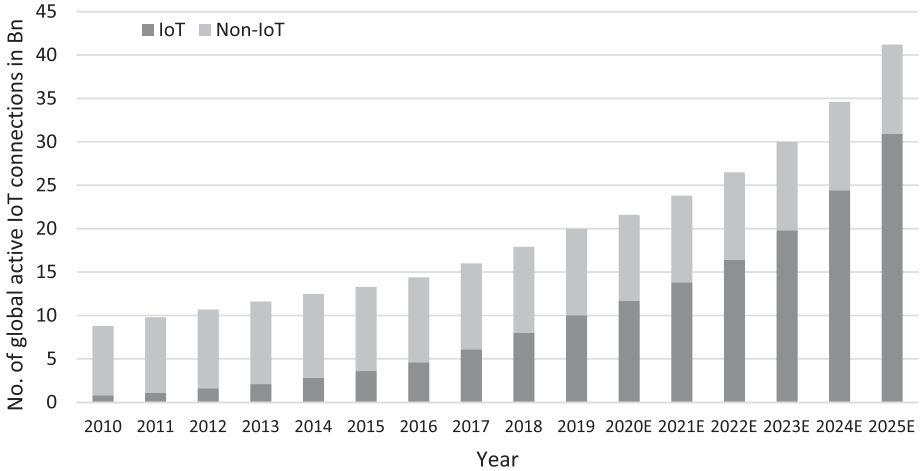

FIG. 12.2 The number of active global connections by 2025 (IoT-Analytics, 2020a).

different sectors can help reduce the adverse impacts of human-made actions on climate-related conditions (El-Mawla, Badawy, & Ali, 2019).

Role of IoT in climate mitigation and/or adaptation

It is essential to consider the possibilities of using smart technologies in favor of climate change actions to prevent a climate crisis in the modern era. Also, it is essential to raise public awareness about climate change and the fact that using digital technologies can aid us in mitigating and adapting to this phenomenon. Moreover, the utilization of IoT, ICT, AI, 5G, and Digital Twin increases efficiency in monitoring climate change and provides flexible solutions for a sustainable future (ITU, 2019). IoT can play a crucial role in environmental monitoring to help reducing greenhouse emissions (El-Mawla et al., 2019).

IoT applications can tackle climate change in smart cities and infrastructures (Fig. 12.3). Recent studies have shown, in the environment and smart cities applications, IoT can aid

FIG. 12.3 Classification of IoT applications (Hassan et al., 2020).

to monitor, manage, and control the listed criteria (Hassan et al., 2020). It has also been reported that IoT applications for smart cities consist of air quality and environmental monitoring, traffic monitoring, smart parking management, participatory sensing, smart surveillance, and smart buildings, which can support environmental protection (Righetti, Vallati, & Anastasi, 2018).

IoT role in smart cities

By increasing population in the cities and expanding urbanization in various regions of the planet, the importance of the IoT will be more acknowledged due to the valuable utilities of its peripheral smart advantages (Farsi et al., 2019). Furthermore, in smart cities' complex environments, several sectors can become interconnected by IoT networks (Marjani et al., 2017). Various sectors of smart cities are connected to smart technologies (Silva et al., 2018). However, digitalization in smart cities without a dynamic system to control the policies and data protection and information usage may create a series of challenges for experts (Patel & Patel, 2016).

Simultaneously, IoT is one of the major applications used in smart cities and other technologies to active in sustainable infrastructure development. To deal with urgent conditions such as climate change, smart cities need to have smart systems, and IoT is one of the critical criteria to provide smart solutions for complex problems (Rani, Kashyap, & Khurana, 2020). Concurrently, one of the examples of the implementation of the smart solution in smart cities is Dubai. Smart city lunched in UAE via promoting strategies based on communication, integration, and corporation to develop smart city projects (Kaur & Maheshwari, 2016).

IoT role in environment protection

IoT's function is to provide connectivity of various devices to the internet, and by that, a great degree of potential can release as an opportunity to increase the efficiency of actions and smart solutions. IoT in smart cities can provide an integrated environment via data and information to develop new services (Syed et al., 2021). This integrated system can help to protect the environment in smart cities. Concurrently, it is essential to consider that climate change is upon us, and by increasing population, the impact of artificial actions on climate will increase. Hence, IoT seems to provide various smart solutions to combat climate change via mitigation and adaption in a holistic overview. Furthermore, IoT can facilitate data gathering for climate change management (Fig. 12.4) and better control waste management and energy management to protect the environment (El-Mawla et al., 2019).

GHG emission is one of the critical factors of global warming (Tao et al., 2018). Technologies such as AI, IoT, 5G, and Digital Twin can assist us in reducing GHG emissions and air pollution, and monitor/control them to protect the environment and help policy makers make better decisions toward sustainability (ITU, 2020). It has been proven that IoT is quite efficient in monitoring GHG emissions by providing communication between different platforms and improving the management of construction emissions (Tao et al., 2018). IoT systems provide a range of advantages for our daily lives by bringing a vast network of related technologies to make human life more convenient. Simultaneously, IoT applications can be utilized in major fields such as smart cities, industry, healthcare, manufacturing, commercials, transport, education, environment protection, and governance to optimize the interconnected processes (Hassan et al., 2020).

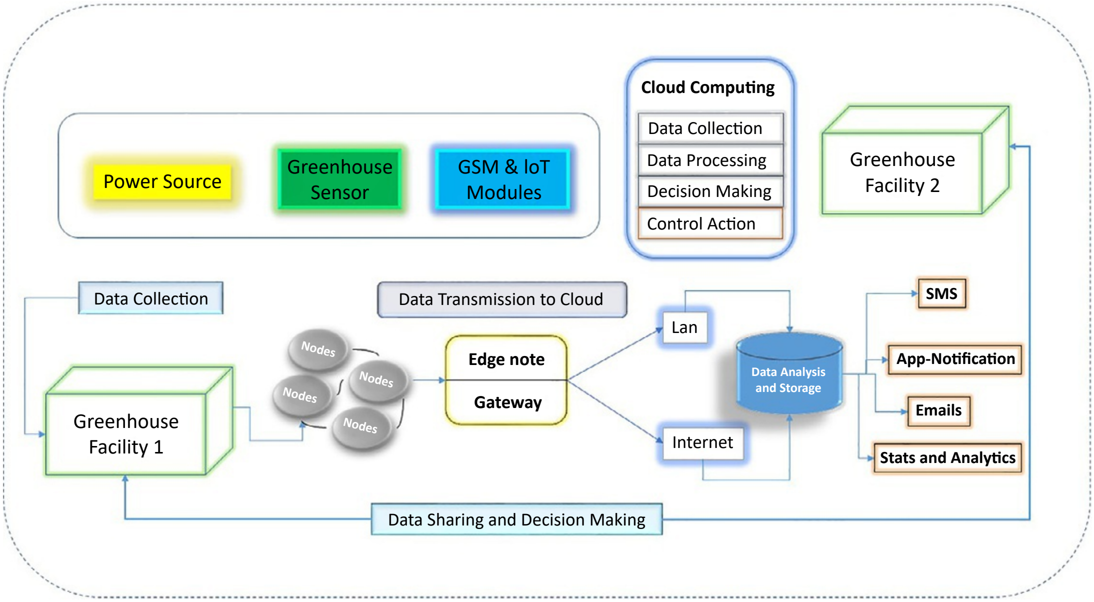

FIG. 12.4 IoT concept to gather data and monitor greenhouse environment (El-Mawla et al., 2019).

Risk and challenges ahead of IoT

IoT may improve the infrastructure of highly populated cities and smart cities and increase the quality of life in cities (Nizetic et al., 2020; Syed et al., 2021). Concurrently, challenges confronting IoT development in the cities must be considered (Fig. 12.5). A complex system such as a smart city requires high-quality designs, maintenance, services, and operational structures in many criteria to provide cost-efficient and viable solutions toward sustainability by using technologies (Silva et al., 2018). This trend may create unprecedented challenges to supply all requirements of providing high-quality standards in developed countries. However, IoT-based systems can develop various opportunities in diverse service systems such as education, healthcare, water, sanitation, finance, and agriculture to help developing countries (ITU, 2019).

One of the biggest challenges in IoT development is data security, privacy, and communication network, which requires robust security protocols to protect data and its transition units of processors (El-Mawla et al., 2019; Righetti et al., 2018). Meanwhile, IoT technologies development may speed the growth of energy consumption, electronic waste, and increasing the usage of raw materials to produce more electronic devices, which may challenge sustainability criteria to balance environmental footprints (Nizetic et al., 2020). Nevertheless, it is vital to realize that IoT potential may trigger a moral impact on human lives, which raises questions about how far the interconnectedness of technologies and humans goes and their impacts (Kassab, DeFranco, & Laplante, 2019).

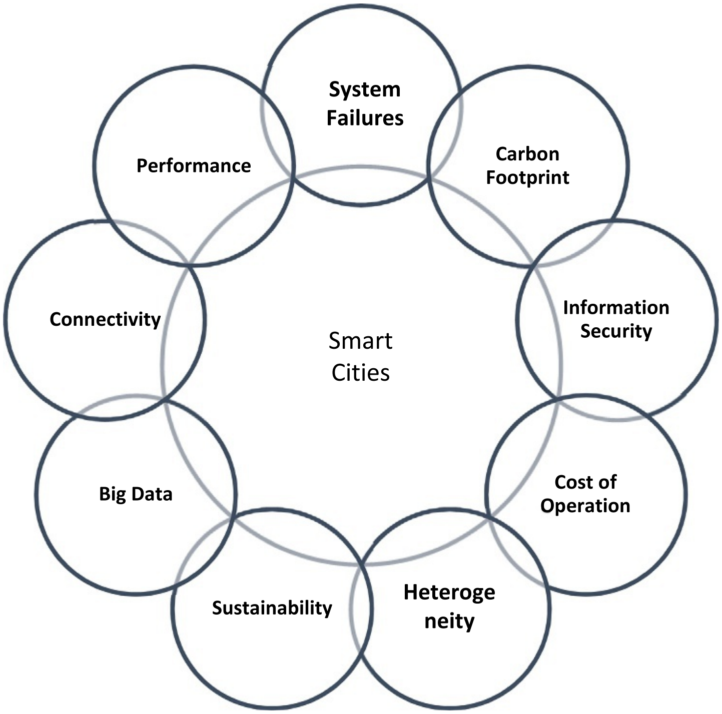

FIG. 12.5 Challenges of IoT development in smart cities (Silva et al., 2018).

12.3.3 5G

Background

Since their emergence, information and communication technologies (ICT) have always been an inseparable part of economic and social developments. They utilize different mediums and methods to facilitate information transfer at a distance between several network nodes, which can be wired or wireless (Gohar & Nencioni, 2021). Revolutions in telecommunications and wireless mobile communication have made significant progress, which developed in 5G technology, evolving within various technological steps shown in Fig. 12.6.

Started from the early 1980s by introducing the first generation of mobile technology (1G), mobile wireless technology had reached the second generation of technology (2G) by the 1990s. Subsequently, 3G emerged in the late 2000s, followed by the fourth generation (4G) mobile communication in 2008. Finally, the fifth generation of network technology (5G) offers less latency, faster speeds, and more coverage. Although 5G has not been a commercially available mobile network yet, it is pegged to be notably faster than its predecessor 4G and can enable Big Data industries like the IoT and smart homes. It is mainly expected to connect roughly 1 million devices per km^2, while existing 4G networks allow 1000 devices to be connected in the same area (Penttinen, 2019).

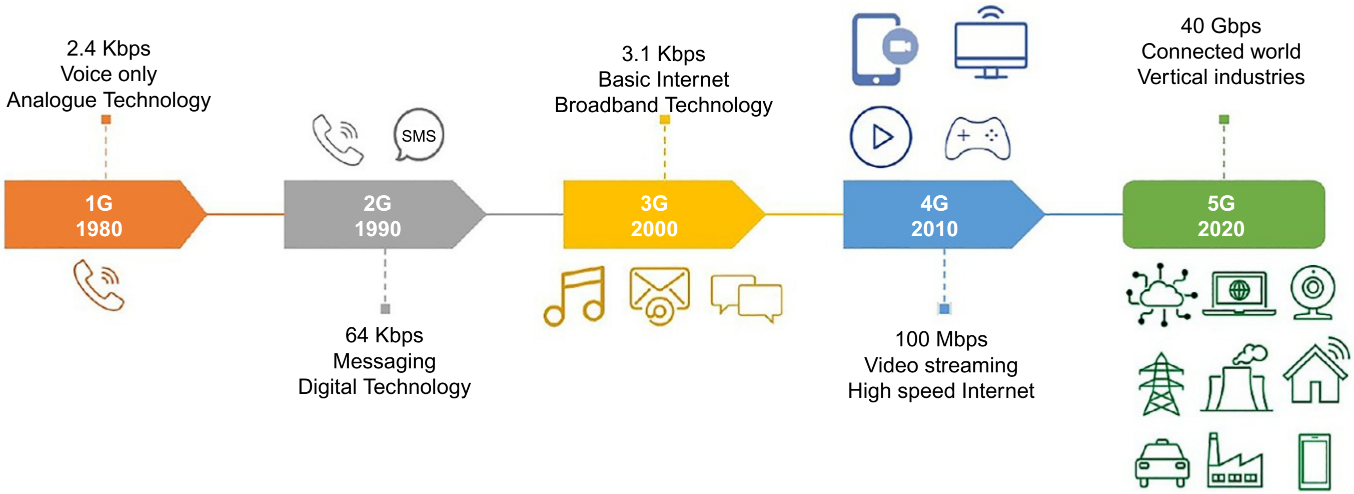

FIG. 12.6 Stages of wireless technology development (Lucky & Eisenberg, 2006).

Role of 5G in climate mitigation and/or adaptation

As 5G is expected to be more directional, more efficiency is one of its predicted features. It means it will consume less energy and power. This technology alongside IoT can foster the process of digitalization in which addressing climate change is plausible. Studies have shown that up to 15% of global emissions can potentially be reduced by 2030 by using these technologies (Malmodin & Bergmark, 2015). 5G technology lies on the frontline of digitalization as it can provide a platform for enabling AI, IoT, and extended reality (XR). That is why its applications include and are not limited to mitigating climate change, driving down energy usage, costs, emissions, and (e-)waste.

Reducing GHG emissions

The *exponential roadmap initiative* indicates that if the required solutions for each sector are taken simultaneously, Green House Gas (GHG) emissions will be halved by 2030. In terms of the urban environment, by considering the main sectors involved in GHG emissions and consequently climate change, concrete solutions have been put forward in this road map to meet 2030 targets, most heavily dependent on 5G technology (Table 12.1).

Smart (intelligent) buildings are expected to have three main components, namely, smart qualities (by using evolving technologies), sentient quality, and sustainability by using resources like energy and water efficiently (Clements-Croome, 2011; Ghaffarianhoseini et al., 2018). At the same time, the role of ICT technology and wireless communication technology have always been mentioned as one of the dimensions of smart cities and buildings (Albino, Berardi, & Dangelico, 2015). Using 5G technology in building would be possible by energy management and monitoring (Kancy, 2019). Within this opportunity, energy bills can be declined up to 5%, while environmental monitoring can also lead to a 5% reduction in waste and, in general, achieving sustainability goals in buildings through emission reduction solutions (West, 2016).

Indeed, by using data of billions of devices connected to the cloud, 5G technology will pave the way in reducing energy consumption and shaping new processes, leading to energy-efficient buildings (Malpus, 2021). It enables devices to detect environmental changes in real

TABLE 12.1 Solutions to cut GHG emissions in cities.

	Buildings	Transportation
Global emissions (Gigaton)	9.9	8.6
Possible to halve emissions by 2030?	Yes	Yes
Solutions	– Reduce the demand for building space – Reduce energy use during operation – Low-carbon cooling and heating – Retrofitting strategies – Low-carbon construction	– Increase accessibility of public transport – Mass transit and cycling – Electric vehicles – Efficient shipping – Low-emission heavy vehicle – Remote working and meeting

Adapted from Falk, J., & Gaffney, O. (2020). Scaling 36 solutions to halve emissions by 2030. Sweden: Exponential Roadmap.

time, which can foster the disaster recovery. Through enhancing digitization and automation, 5G will promise to reduce resource, energy, and material consumption (T-Mobile, 2019).

The UN has projected that roughly two-thirds of the global population will live in cities in the next 30 years (UN, 2018b). The population boom will undoubtedly lead to a series of severe challenges in urban areas, such as environmental problems (climate change) and traffic. 5G, however, can potentially minimize these issues in terms of transportation. First, thanks to 5G, the daily commute to the office could be much faster. Moreover, new traffic lights equipped with 5G technology can reduce the stopping time at red lights. 5G technology can address today's traffic problems by enabling traffic lights to collect traffic data in different ways. In this way, traffic lights can handle effectively respond to real-time traffic issues. Carnegie Mellon University has already tested this attitude and 5G implementation. To be more precise, the traffic signal system initially detects pedestrians and vehicles and compiles these data to a traveler model. Next, efficient moves for travelers will be planned through a multiobjectives-optimizing process. Finally, the traffic light through 5G technology communicates with neighboring intersections to make efficient decisions (Opdyke, 2019).

Findings indicate that while this process can lessen 40% of traffic stops and 21% of emissions, increasing commute speed by 26% will also be possible. Consequently, climate change can be mitigated in the urban environment in this way (Opdyke, 2019). Another application of 5G in achieving efficient transportation is London's smart city plan, where a data-driven design of bus routes is employed through monitoring and analyzing people movements around the city.

Water management

Another area in cities that is heavily affected by environmental issues is access to water resources. The climate crisis impacted the water system as one of the main criteria correlated to human life affairs. As the accessibility of water has become more difficult in plenty of areas, water management has become among the most challenging area due to climate change. Natural disasters similar to flooding that could be considered significant events to pollute water resources in different sectors are among the most severe impacts of climate breakdown on water governance. Simultaneously, other types of breakdowns such as droughts intensify the shortage of water and may reduce the quality of life for many peoples in some regions. That is why it is vital to apply appropriate strategies in combating climate change to secure all people's right to have access to clean water and sanitation services.

Smart, sustainable cities are expected to invest in 5G technology and sensor to upgrade treatment plants and underground pipes. Indeed, management and monitoring of water supplies are highly vital for cities with aging infrastructures. Using ICT in general, municipal water management can monitor challenges such as water loss (Van Dijk, Verberk, & De Moel, 2006). In Singapore, a combination of the smart system has been developed that focuses on water governance and water distribution as part of their Smart Sustainable City (SSC) goals via integrating water management systems with 5G technology (Smiciklas et al., 2017). An intelligent system with the water distribution capability called "*WaterWiSe*" can detect various leaks and bursts. The data-analytic tool would detect the flow of water and issues correlated to pipes, system conditions, and network stabilization using hundreds of sensors (ITU, 2020). This real-time remote sensing by using 5G technology, minimizes disruption to flows, ensures faster response times, declines sudden water shortage, more importantly promote cost saving and demand prediction in a well-structured manner.

WaterWiSe is utilized by a network of wireless sensors to scan online the whole system of water flow in the city. It requires expansion of sensors to integrate more parts, which 5G technology can help develop this process efficiently for online monitoring, thereby providing data sets for accurate analyses. 5G is necessary as previous 4G systems may have the potential to develop connectivity without real-time processing. Projections estimate that by the end of 2022, the Asia-Pacific region will have over 280 million 5G subscriptions, reaching USD 4.5 billion in profit.

5G risks for climate mitigation and adaptation

Since the competition between developed countries such as the USA and China is speeding up to dominate the 5G market globally, its possible consequence for the environment is overlooked. Environmental activists are worried that the widespread installation of 5G will likely increase GHG emissions over the next 10 years, and instead of mitigating climate change, it could worsen the condition (Keating, 2020). According to France's High Council on Climate (Haut-Conseil-Poir-le-Climat, 2020), deployment of 5G would cause roughly 4.5 million tons of CO_2-equivalent by 2030, which is a highly significant total environmental impact on the technology sector. The main impact would come from utilizing 5G and the expansion of connected devices to its network.

Inevitably, by the expansion of 5G technology, the energy consumption among consumers will increase significantly, and the more energy is consumed, the more GHG is emitted into the atmosphere. Moreover, the development of 5G infrastructure requires maintenance and support in plenty of sectors, particularly in network systems, which this trend may challenge clean environment criteria by the increase of energy consumption and wastes creation. Besides, wireless technologies such as 5G may disrupt the natural ecosystem for other birds (Curran, 2020). Therefore, as long as the developers of the frontier technologies such as 5G try to be more environmentally friendly, the adverse consequences of 5G, especially on climate change, should be considered before it is widely rolled out.

12.3.4 Digital Twin

Background

Modern advanced technologies have provided a range of possibilities to enhance continuous improvement by digitalization in many platforms. An increase in the accuracy of measurement and quality improvement are transforming our everyday life. Also, the expansion of digital smart technologies has brought many possibilities to develop advanced infrastructures. One of the emergent technologies in this area is Digital Twin (DT), which provides a digital depiction of a real-time entity or a process to aim at a set of objectives, particularly optimization, monitoring, and simulating a processor performance (Marai, Taleb, & Song, 2021). It synchronizes the virtual and physical world utilizing the data and information (Grieves, 2016). Conversely, DT has a remarkable capacity to extend the boundaries of the digital world (Liu et al., 2021). Furthermore, studies have analyzed the depth of the criteria

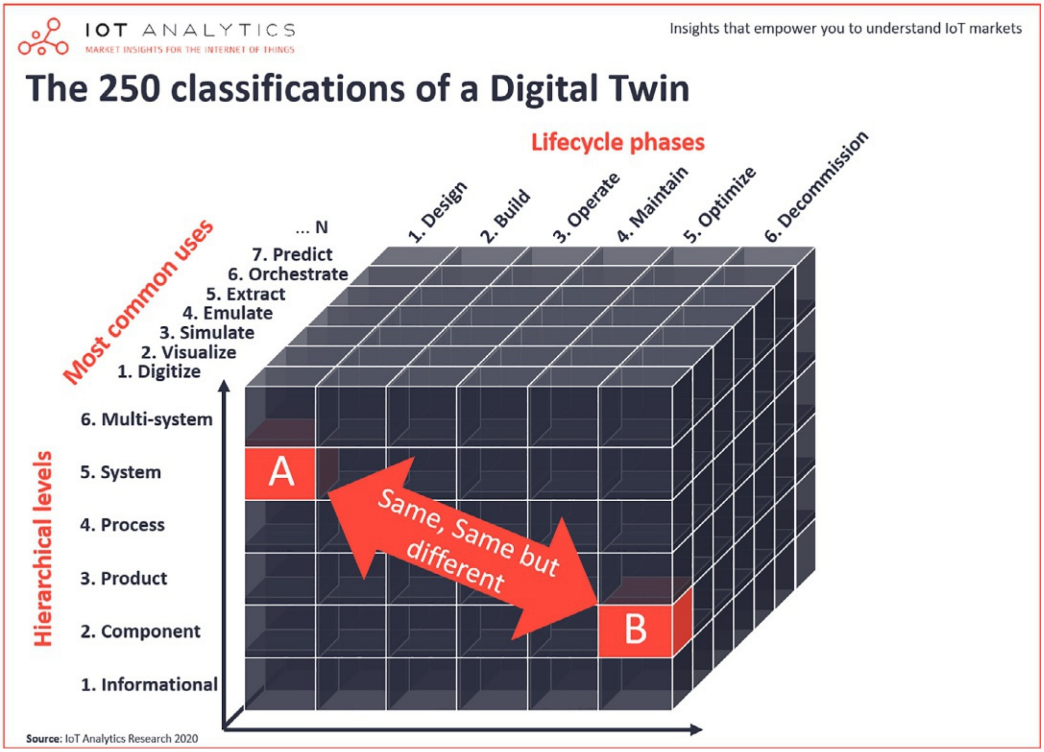

FIG. 12.7 The classification of Digital Twin (IoT-Analytics, 2020b).

correlated to the aspects of DT, led to the definition of the functionality of the DT in three dimensions (Fig. 12.7) (IoT-Analytics, 2020a).

In other words, DT represents the actual physical world with all its details and laws (Rasheed, San, & Kvamsdal, 2020). Also, DT has some degrees of dependency on the Internet of Things (IoT) sensors to accumulate actual data from the real world to the virtual world (Erkoyuncu et al., 2020). The critical concepts of DT are categorized with a short description of their functions (Table 12.2).

The Digital Twin concept is growing, and some mainstream websites such as Gartner categorized DT among the essential strategies in physical experience expansion for 2021 and beyond (Gartner, 2020).

Role of Digital Twin in urban climate change mitigation and adaptation

The concept's origin belongs to *Michael Grieves*, who introduced the concept first in *the University of Michigan* correlated with product *life-cycle management* (PLM) in 2002 (Grieves, 2016). In terms of the first implementations, NASA's famous Apollo space program had the advantage of using the twin concept (Liu et al., 2021). As far as urban environments are concerned, decision makers, policy makers, and planners of the smart cities will have more

TABLE 12.2 The concepts and description of Digital Twin (Jones et al., 2020).

Concept	Description
Digital Twin	Full Digital Twin representation of an actual entity that contains information from different scales. (From small to big scale)
Digital Twin Prototype	Creating the digital representation of a product before the physical product
Digital Twin Instance	The clear identified sample of a physical system with the linkage with DT individual through the life of the physical product
Digital Twin Aggregate	The amalgamation of all DT instances
Digital Twin Environment	A united, multifaceted real-time system for operating on DT, which include predicting the performance and integration of information

comprehensive instruments to combat climate change, adapt, and mitigate its effect on the urban areas (Dembski et al., 2020). One of the cases that employed Digital Twin with the focus on improving risk and disaster management planning is the city of *Newcastle*, UK, which used DT as a strategic deployment to combat, predict, and mitigate extreme weather events (ITU, 2020). This digital technology will bring a broad availability of valuable data to assess the wide range of possible climate change scenarios for cities and prevent the risks for adaptation to the upcoming events (Ham & Kim, 2020).

Moreover, DT may provide a transparent monitoring system for decision makers and planners to mitigate the urban climate change effect through energy, transport, building retrofit, pollution rates, and water systems toward more sustainable approaches (Pan et al., 2021). Similarly, increasing environmental resilience to prevent climate disaster is one of the essential benefits of DT. Creating a virtual model by DT from complex systems such as smart cities or a geographic location will help avoid or mitigate problems before the event (ITU, 2020).

Role of Digital Twin in smart cities

The urban environment as a complex system has recently been a challenging area for DT employment (Pan et al., 2021). One of the critical areas that makes cities a difficult subject for DT is urban climate change which is a complex phenomenon (Dembski et al., 2020), and DT can be beneficial to tune with the climate crisis and mitigate its effect in this environment (Grieves & Vickers, 2017). Therefore, DT capabilities may help future smart cities become more agile in adaptation to sudden changes and mitigate climate change impact for the welfare of future citizens. DT, as a high mass indicator for the interface and experienced segment (Gartner, 2021), has attracted attention in building information modeling (BIM) research In the context of the urban environment (Jones et al., 2020).

Initially introduced for manufacturing processes and product life cycle management (Grieves, 2016), DT is broadly utilized for academic and industry studies (Jones et al., 2020). Conversely, the development of the DT shows the capacity of this technological concept in a variety of disciplines. The urban environment and future smart cities can use this technology to provide a virtual twin of the urban infrastructure to apply mitigation and adaptation policies toward climate change (Dembski et al., 2020). Moreover, DT has interconnection with other smart technology such as IoT and 5G in terms of gathering data from the physical environment for the virtual version in a real-time process, and this can bring integration of smart technology to combat climate change (Rasheed et al., 2020).

Role of Digital Twin in environment protection

One of the ambitious implementations of DT is the *Destination Earth* (DestinE) policy by *the European Commission strategy* toward forming the future of digital Europe (European-Commission, 2021). The goal of *DestinE* is to create a virtual model of the planet earth with high accuracy in the direction of empowering the goals of sustainable development criteria. This project may help future policy makers and decision makers at all levels to act more effectively toward climate change criteria. Indeed, the DT concept is evolving toward a more environmental and sustainable development direction (Nativi, Mazzetti, & Craglia, 2021). This tendency toward sustainable development criteria can provide this technology for environmental benefits.

Jeonju city in South Korea has been witnessed another successful implementation of DT (Fig. 12.8), where researchers used geographic information system (GIS) and DT system to measure carbon emissions at urban areas by focusing on data collection, visualization, analytics, and deployment (Park & Yang, 2020).

Additionally, dependent on the actual mirroring processes from the physical world in smart cities, DT and IoT are interconnected in terms of data transition. In this sense, IoT provides the sets of data by the various type of sensors in the urban environment (Al-Ali et al., 2020) for DT and other similar platforms. This convergence between the physical and the digital version of the cities will become more entangled, and that is why DT will arise an ability to predict and prevent risks, observe the possibilities, model and mitigate the negative impact for better improvement (Rocca et al., 2020).

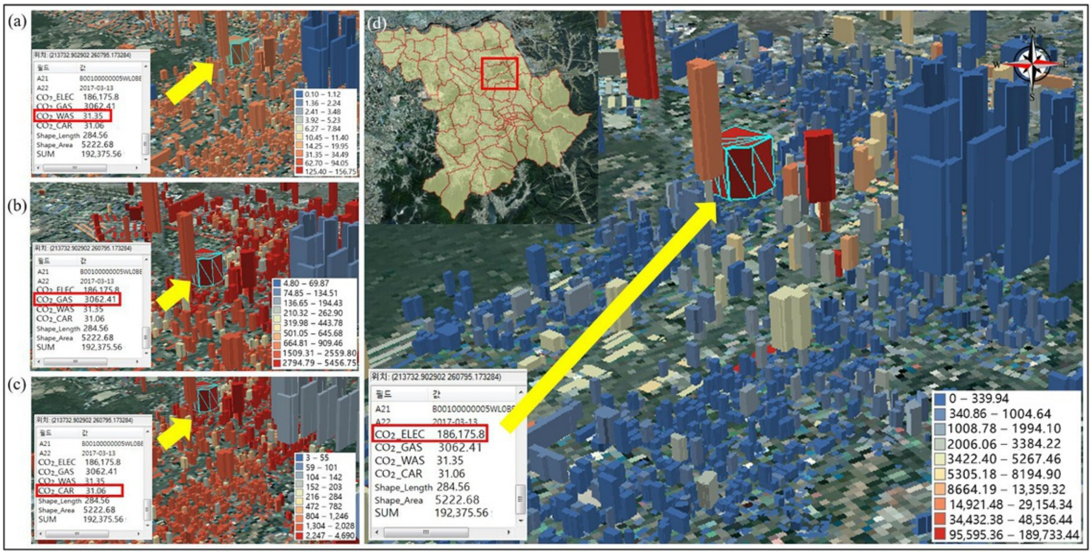

FIG. 12.8 DT system for measuring carbon emission with GIS-enabled (Park & Yang, 2020).

The advantage of the DT utilization for the urban environment may provide a range of possibilities for optimization in broad implications via different systems in the cities. The quality of the decision-making, planning, design, efficiency, and effectiveness of the complex information for planning processes and emergency management systems are among the DT implications that can be applied in the cities (Tang, Peng, & Zhou, 2020). Moreover, studies have shown that the human ability to handle massive actual data processes is limited. That is why digital technology such as DT may provide the opportunity for better assessment of data and model toward optimization in a broad overview (Grieves, 2016). To this end, *NASA* has emphasized that DT has brought a paradigm shift in integrated simulation and management systems (Glaessgen & Stargel, 2012).

Risk and challenges ahead of Digital Twin

Irrespective of all the benefits of DT, its disadvantage may lay in the context of data privacy for citizens of the cities and Big Data accumulation for data centers and server farms, which use electricity to operate. This may provide the risk of producing pollution due to the activities of these facilities for processing data and the risk of lacking synchronization between the DT and the actual physical model (Erkoyuncu et al., 2020). Since the DT concept is relatively young, it needs to evolve more toward industrial application to extend its functionality and better model complex phenomena in manufacturing (Liu et al., 2021). It has been reported that the DT challenges can be categorized in eight areas (Table 12.3) correlated with other technologies to develop, support, and improve its functionality (Rasheed et al., 2020).

To conclude, DT uses energy as the data processing needs an energy source to conclude, similar to all other technologies. Concurrently, one of the crucial aspects of technological development is providing access to clean and renewable energy systems to ensure that all benefits from these data-driven systems are working clean.

TABLE 12.3 The connection between challenges and supportive technologies for DT (Rasheed et al., 2020).

Challenges	Supporting technologies
Data management, data security and privacy, data quality	The digital platform, cryptography and blockchain, Big Data technologies
Real-time communication of data and latency	Data compression, 5G, IoT
Physical realism and future projection	Sensor technologies, high fidelity physics-based simulator, data-driven models
Real-time modeling	Hybrid analysis and modeling, reduced-order modeling, multivariate data-driven model
Continuous model update	Big Data cybernetics, hybrid analysis and modeling, data assimilation, compressed sensing, and symbolic regression
Transparency and interpretability	Explainable artificial intelligence, hybrid analysis, and modeling
Large-scale computation	Computational infrastructure, Edge, Fog, and cloud computing
Interaction with physical asset	Human-machine interface, natural language processing (NLP), visualization, augmented reality (AR), virtual reality (VR)

12.3.5 Other technologies (space 2.0, robotic, blockchain)

Space 2.0

Space technologies are proliferating, the same as other pioneer technological industries in the modern era. The development of the space industry brought a new dimension to the enhancement of technology and its integration with advanced complex operations. The impact of digitalization, growth of satellites systems, expansion of hardware and software systems via computer technologies, and progressive mentality of people in *Silicon Valley* to develop commercial space programs have brought a new shift into the industry as Space 2.0 (Pelton, 2019).

The planet Earth system is complex and realizes how this complex system operates and functions through different circumstances. Notably, the climate system is one of the most complex phenomena to observe and predict. Nowadays, human activities are accelerating climate change, and we need to utilize advanced technologies such as space 2.0. to mitigate and adapt to this phenomenon (ITU, 2020). Moreover, we use an Earth-observation satellite to monitor climate change and solar weather, giving warnings in case of emergency impacts or dangerous long-term changing climate (Pelton, 2019). These smart technologies are in use for future cities and urban management to improve the quality of urban environment systems. Space-related activities and the utilized technologies in space programs can help urban planning to achieve well-organized sustainable urban development (Fig. 12.9).

Robotics

The web of technology is classified into various branches, and each of them has different sectors, which together creates a network of advanced integrated systems. One of the pioneer areas of technology branches is robotics and peripheral systems. Robotics is connected to automation, design, construction, operation, and application in different platforms (ITU, 2020). Moreover, in a positive direction, this technology can aid humans to increase the efficiency and accuracy of the operational works and develop specific, accurate measuring tools to

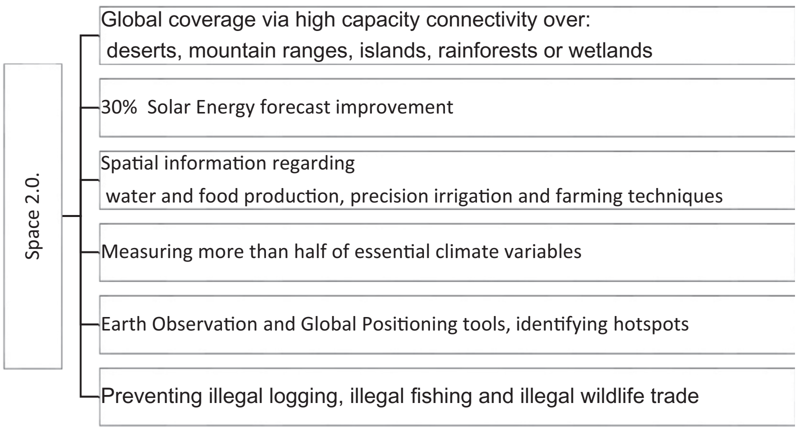

FIG. 12.9 Space 2.0 applications in space-related science. *Adapted from ITU. (2020). Frontier technologies to protect the environment and tackle climate change. International Telecommunication Union.*

reduce human error in the process of analysis in different criteria. The development of robotics from hardware and physical sectors and software and algorithm sectors (AI) is a solid alliance to increase the power of technology in levels higher than operational. However, the increase of autonomy in robotic sectors may increase uncertainty about the nature of the phenomenon and its behavior and actions toward humans. Nevertheless, robotics can be utilized in many aspects, and here the focus is on the robotics characteristic in mitigating and/or adapting to climate breakdown in the cities.

Similarly, robotics can support environmental protection and combat climate change in different areas such as monitoring and reducing dangerous emissions, improving factories processes to reduce energy consumption, optimize accuracy and increase efficiency via lighter machines, optimization of waste management, and better use of raw materials that can benefit environmental protection (ITU, 2020). In addition, by optimizing processes in all mentioned criteria, robots can benefit cities to improve their infrastructure for adaptation to climate change.

In Spain, a *STEAM* project called "*Sustainable City*" has been launched to promote pupils' knowledge about climate change with the help of robotics. Educational robots have been used to perform learning by doing projects, learning via cooperative spirit, and blended learning to help students be more familiar with the importance of climate change (Fig. 12.10). It has been concluded that the combination of robots with education about climate change and sustainability has improved the students' performance and has effectively raised the awareness of climate change impacts and risks and environmental problems (Ruiz Vicente et al., 2020).

Blockchain

Another type of technology that has been developed in the recent decade is blockchain. This technology is a distributed inalterable network of information for recording transactions, the footprint of properties, and empowering trust, which has certain vital elements according to IBM, namely:

- Distributed ledger technology:
  Everyone in the network has access to observe the transactions and distributions
- Immutable records:
  Once the transaction is recorded in the shared ledge, there is no way to edit or change
- Smart contracts:
  A smart system to speed up the transaction in between transfers (IBM, 2020).

Moreover, blockchain has other advantages: decentralization, smart system, high security, and immutability (Duan et al., 2020). It can reduce the costs for companies and systems that follow a more decentralized approach than a centralized approach with high transparency and building trust (Casino, Dasaklis, & Patsakis, 2019).

In case of climate change actions, blockchain can assist in criteria correlated to environment management, circular economy, environmental supply chain, transparency of the data from different resources to find the truth behind the schemers, protecting contents and ownership of data, transparency of IoT in data and information flow, and providing a trustful context for policy makers (Saberi, Kouhizadeh, & Sarkis, 2018). To be more precise, blockchain applications in climate change adaptation and mitigation in urban environments can be categorized in different areas (Fig. 12.11).

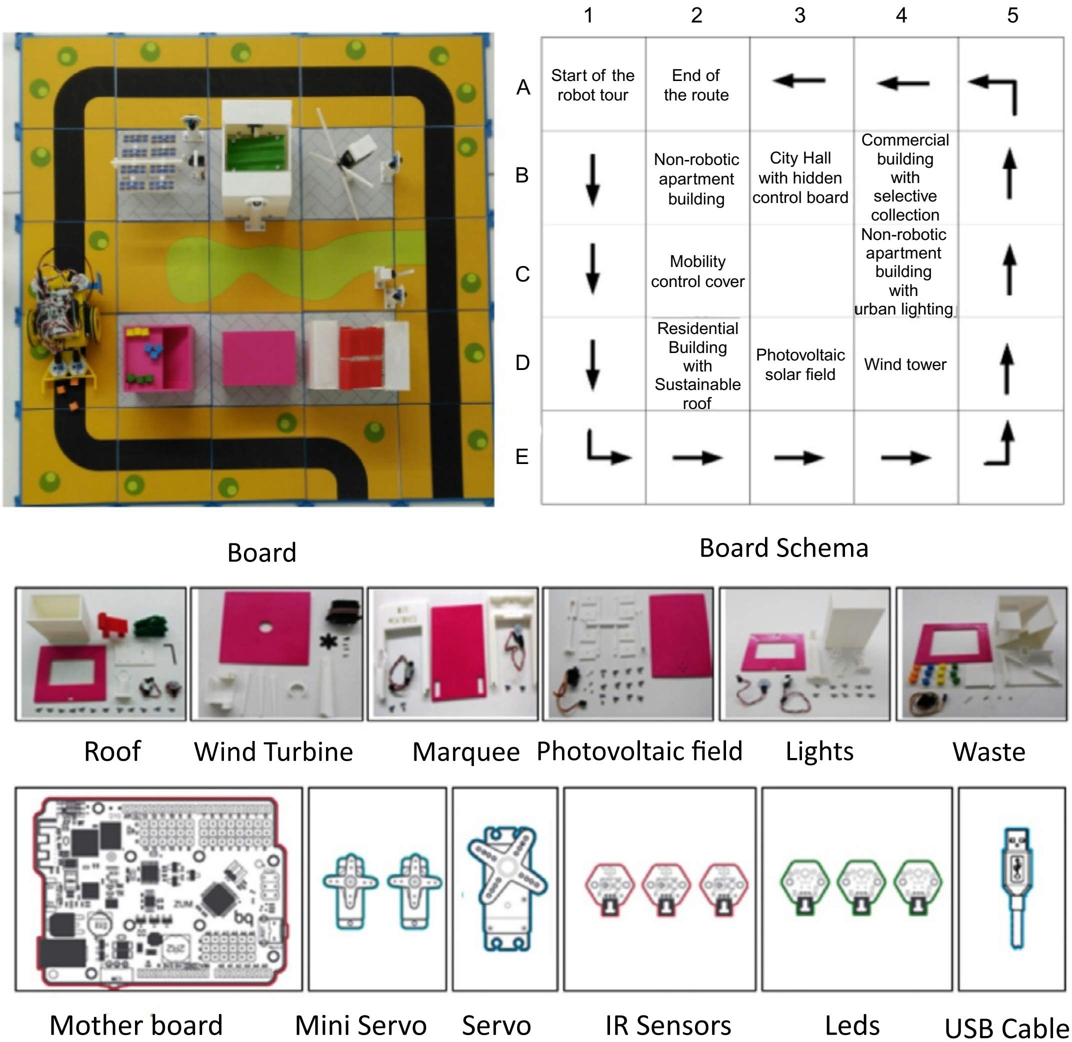

FIG. 12.10 Case study of the "sustainable city" project (Ruiz Vicente, Zapatera Llinares, & Montés Sánchez, 2020).

Improved carbon emission trading

•improving the system of carbon asset transactions

Facilitated clean energy trading

•provide position for peer-to-peer clean energy business

Advanced climate finance process

•expanding peer-to-peer financial agreements crowdfunding in tackling climate change

Optimized for monitoring and reporting of greenhouse gas (GHG) emissions reduction

•providing more transparency regarding GHG emissions

FIG. 12.11 Blockchain applications for climate action. *Adapted from UNFCCC. (2017). How blockchain technology could boost climate action.*

The actual case studies of blockchain employment are briefly discussed in this section. The first one is the *HOPU* project dedicated to displaying and monitoring the air quality data through IoT devices. Blockchain has been employed in this project to improve data quality and the protection of measurements in the different monitored environments (HOPU, 2020). In particular, *HOPU* implements the blockchain for air quality monitoring in industry, where protective restrictions for the sake of workers' health existed.

Another case study is the French start-up called *PlanetWatch* that has developed a blockchain system that monitors air quality by taking advantage of the potential of communities. According to this SME project, efforts to monitor air quality are not sufficient, and this project would encourage citizens to participate in this process. Indeed, this project aims to encourage individuals to buy inexpensive air quality sensors, install them in their houses, workplaces or even take them with them and record the data in a blockchain platform. This project will open data available to scientists and governments to fight climate change and reward users for helping in this process. In this way, when a user acquires one of its low-cost devices and activates it to monitor data, as the reward, it acquires *Planet Tokens*, utility tokens issued in a partner blockchain platform (PlanetWatch, 2021). These tokens, then, can be exchanged for *Earth Credits*, which are translated into euros and allow the purchase of new products and services on *Planet Watch*.

12.4 Conclusion

Cities are among the key players in preventing climate-induced losses and damages contributing to reducing GHG emissions. The urban environment is also an incubation area because climate technologies, especially mitigation and adaptation technologies, are experimented with and applied. That is why international communities have underlined the significance of urban-level attempts to adapt and mitigate climate change. However, we are witnessing that people will usually adjust to climate change by relocating to a different location, changing their behavioral patterns, or changing their occupations. Nevertheless, we all agree that these efforts would be more efficient using technologies, whether the hard forms of technology, such as drought-resistant seeds and elegant irrigation systems or the soft ones, such as ICTs (AI, 5G, and IoT).

At the same time, the global climate has constantly confronted human society with extreme weather events, and according to GHG scenarios, future climate change will exacerbate these events. As smart technologies have already enhanced the well-being of societies in various ways, their great potential in the fight against climate change has been discussed vastly among scholars. Deriving insights from the role of smart technologies to combat climate change in cities is a fundamental and complex matter. Frontier technologies can assist cities in mitigating and/or adapt to climate change. One of the vital essential factors for solving the issues correlated to this phenomenon in the cities and metropolitans is advanced technologies that are green and sustainable.

Nevertheless, the need to clarify modern technologies' role in adapting and mitigating the urban environment confronting climate change is still crucial as the stage of knowledge is not comprehensive enough. It is critical as the implementation of frontier technologies addresses this challenge, leading to achieving a smart, sustainable living habitat. Conversely, since urban infrastructure has already received impact by and most influential factor of climate change, focusing on the role of smart solutions and technologies in cities looks vital (Fig. 12.12).

To this end, this research has tried to clarify the implementations of smart technologies in adaptation and mitigation to urban climate crisis divided by the type of technology. However, something that should not be forgotten is that almost all these technologies act as a double-edged sword. This threat means that as much as they can be for solving climate change and mitigating its impact, they can also be detrimental to the environment and worsen the condition. Therefore, before employing these technologies, a comprehensive overview of their advantages and disadvantages in climate change is highly recommended.

AI as a disruptive paradigm has excellent potentials to predict, assess, and mitigate the risk of climate change through efficient use of data, sensing devices, and learning algorithms. Within developing effective weather forecasting models for environmental monitoring, AI provides us with an optimized comprehension of the effect of climate change on cities. AI algorithms can interpret climatic data and predict climate data and predict weather events, extreme climate events, and other socioeconomic impacts of climate change. By providing better climatic predictions, AI can find the actual source of carbon emitters. This finding helps policy makers be aware of earth hazards, rising sea levels, temperature change, hurricanes, species extinction, and even disruption to natural habitats. Nevertheless, experts and scholars have already started focusing on analyzing climatic data with AI paradigms.

IoT has played an essential role in developing sensors and expanding networks and the interconnectedness of data and information. This stream of high-level interconnection among devices provides convergence in the collaboration of different technologies such as AI, 5G, DT, and others to expand their ability to process data in a comprehensive environment. Optimal usage of this system creates a solid response to tackle climate change issues, reduce or prevent its risks in the cities.

5G will bring higher speeds, reduced latency, and countless possibilities. That is why it can revolutionize the way climate change has been addressed so far. Some of the significant benefits of 5G are improving existing energy and water networks through IoT devices, reducing (e-)waste, and connected smart grids. This benefit enables governments, businesses, and individuals to accelerate the transition to zero carbon emissions. 5G can perform real-time control across production processes that can improve efficiency and lessen emissions. 5G can also assist in reducing water waste through using sensors that utilizing 5G to warn of any detection of leaks or network abnormalities in real time. Finally, as transitioning to renewable energy will be crucial for solving the climate change issues, real-time 5G powered technology will be vital to reduce emissions by responding to fluctuating weather patterns and the interconnectivity with renewable power sources.

By providing a virtual model of a city, **DT** can offer a high range of helpful information to manage the essential criteria correlated to the infrastructure of a smart city or a metropolitan. It is worthwhile to state that this technology can help reduce and prevent risks by analyzing the possible scenarios in a virtual model before the physical event happens. Therefore, DT can play an essential role and other technologies to adapt and mitigate climate change and

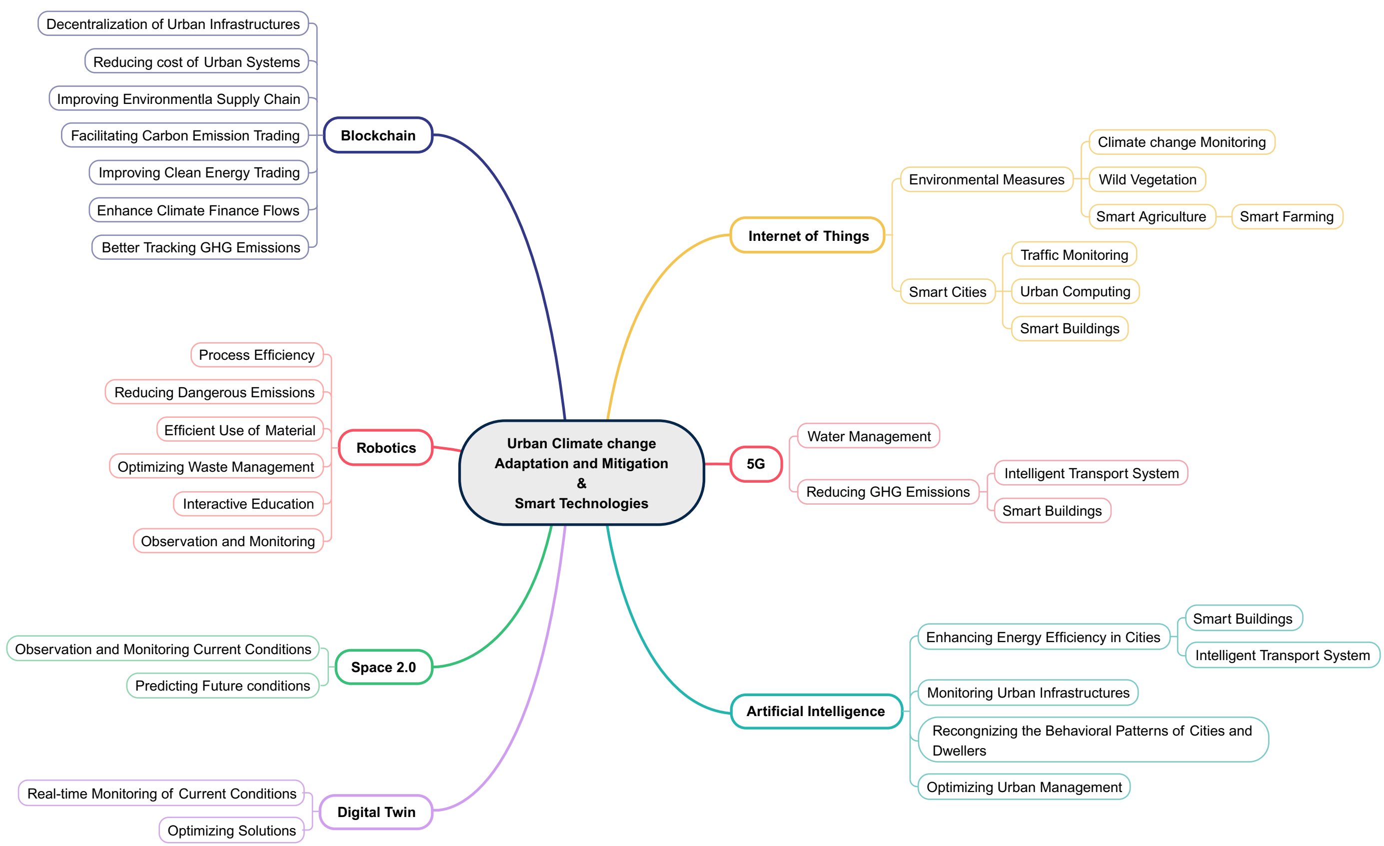

FIG. 12.12 Smart technologies applications in adapting urban climate change and mitigating its impacts.

provide better insights for decision makers and policy makers to develop solutions to combat this phenomenon.

Finally, other technologies such as **space 2.0**, **robotics**, and **blockchain** by proving platforms to observe, monitor, predict climate models, assist in raising public awareness about climate change, and improving trading, in general, can be helpful to tackle the challenge of climate change.

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CHAPTER

13

Automated object extraction of satellite imagery to estimate the loss of vegetative land cover and inform climate adaptation actions in San Antonio, Texas

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13.1 Introduction

World urban population continues to grow compared to rural population. Since 1950, where only 30% of the world's population (a 746 million) was urban, urban population has grown to 54.5% in 2014, where 3.9 billion lived in urban areas. According to The United Nations (2016), population will continue to grow by 2030, where it is projected that 60% of people globally will live in urban areas and 33% of the world population will reside in cities with at least half a million inhabitants. Ongoing urbanization is estimated to continue to add more population to urban areas by 2050, where approximately two-thirds of the world's population will live in urban areas (The United Nations, 2014). Currently, almost half of the world's urban population live in small settlements of less than 500,000 inhabitants and only around one in eight 12.5% of people live in the 28 M-cities, each with of 10 million inhabitants (The United Nations, 2014).

Changes in land surface coverage resulted from urbanization alarm environmentalist and climate change researchers. According to the 2020 report published by the Intergovernmental Panel on Climate Change (IPCC, 2020), land use changes, especially agriculture, forestry, and other uses are responsible for 23% of global greenhouse gas emissions. A shift in the ways we

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use and change land covers are needed if we are committed to a Paris Agreement compatible pathway (Yesil, Hegarty, Lejeune, Fyson, & Menke, 2020). This includes any accumulated changes in pervious surfaces in urban areas as well as other large agriculture land impacted by urban sprawl.

To counter the impact of historical changes in LCLU, several interventions are expected to play a critical role in mitigating and adapting to climate change. However, Yesil et al. (2020) warn that some may create significant trade-offs with regard to achieving the United Nation's 2015 Sustainable Development Goals (SDGs).

To develop a mitigation or adaptation policy including implementable actions, researchers have taken several methods that incorporate different geospatial models to assess the magnitude of LCLU impact on climate change in various regions. In a study by Abd El-Hamid, Caiyong, Hafiz, and Mustafa (2020), a land vulnerability assessment was conducted using unsupervised raster classification model of satellite imagery for North Ningxia region in China between 1995 and 2019. The study yielded a high level of vulnerability from 1995 to 2019 as a result of anthropogenic activities and urbanization. The study also offered a critical indicator for engineers, governmental institutions, and researchers to intervene in reducing stresses on current ecosystem.

Another study by Hirsch et al. (2018) that was based on Half a degree Additional warming, Prognosis and Projected Impacts Land-use scenario experiment, Known as HAPPI-Land model. The researchers utilized the model to examine the correlation of land use change (LUC) and low-emission scenarios in the Northern Hemisphere. Their results showed that that LUC contributes to more than 20% of the change detected in temperature extremes for large areas, and that these changes are comparable in magnitude to changes occurring from half a degree of global warming. Thus, they urged decision makers to implement LUC models to measure how it contributes to regional changes associated with sustainable development (Hirsch et al., 2018), which will require region-specific adaptation strategies. The analysis of satellite imagery, specifically using automated methods of object-extraction for measuring changes in vegetative land cover and urban tree canopies, offers replicable model that local municipalities and regional authorities could greatly benefit from and utilize to inform adaptation policies and sustainable development decisions. In their report, Lim and Spanger-Siegfried (2004) explicitly discussed adaptation strategies and offered guidance for planning and policy makers to formulate their own adaptation policy framework (APF). The report recommended that adaptation strategies should specify key groups, sectors, or defined geographic areas, include an assessment of vulnerability, and integrate findings into adaptation action. As one of the smart intervention methods, the proposed automation process in this chapter offers an implementable tool for climate adaptation strategies.

13.1.1 Urbanization and growth in historic districts

The City of San Antonio in Texas is the Bexar County's urban center and the seventh largest city in the United States. It is challenged with rapid urbanization, in its old neighborhoods and urban core, which is accompanied by socioeconomic inequality. Between 2011 and 2016, the population increased in San Antonio by 10% to reach a total of 1,439,358. The city's growth is among the top cities in Texas with Austin (16.1%), Houston (7.2%), and Dallas (6.8%) during the same time (Royall, 2017). Analysis of 2012–16, the American Community

Survey (ACS) data alerted about the rent increase throughout San Antonio and Bexar County with an average 13.26% increase ($111.63 on the County level) (Royall, 2017). A recent report also showed that that majority of this population increase is in the blocks within and around the inner core, where the price of single-family houses is above city average (NALCAB, 2018). Recent projections also showed that San Antonio will experience an increase of >80 °F in warm nights with an anticipated increase of >100 °F in hot days as well as >110 °F of very hot days, a decrease in annual rainfall, and more concentrated rain events during short periods with an increased risk of severe flooding (City of San Antonio (COSA), 2019). These changes will likely exacerbate exposure of vulnerable populations and enhance the risk of severe infrastructure damage.

Duany, Speck, and Lydon (2010) and Kamal and Proma (2016) studied the advantages of infill as a form of land development that supports urban sustainability and smart growth (Ingram, Carbonell, Hong, & Flint, 2009), enhances the conservation of environmental resources and economic investments, and strengthen social fabric by absorbing growth into existing communities and relieving growth pressures on rural and peri-urban areas. Infill development takes a wide range of typologies including building on vacant or underutilized parcels, such as parking lots and brownfield sites, to a rehabilitation or expansion of existing buildings within an existing neighborhood. Building form and height, density, and site design of each typology are subject to each municipality's development code and guidelines. In the city's urban core, infill development continues to re-shape most of the residential development, which triggered rapid urbanization in this area. Through well-planned infill development, open space areas with public benefits will be achieved. In turn, this will reduce traffic volumes and prevent costs associated with sprawl, which according to McConnell and Wiley (2010) will also lessen congestion and air pollution as two primary regional downsides.

In San Antonio historic districts and neighborhood conservation districts, municipalities and city departments impose additional context-sensitive restrictions stemmed from the Secretary of the Interior's Standards for the Treatment of Historic Properties (NPS, 2018). Although these standards encompass general concepts and guides for maintaining, repairing, and replacing historic materials, they also outline general recommendations for new construction and alterations to existing properties regarding conformity, style, proportions, and density. Yet, they rarely address environmental sustainability including a policy for making up for the loss of UTC or pervious land cover in general. The city has recently adopted a new climate adaptation plan (City of San Antonio (COSA), 2019) that addressed infrastructure resiliency and the review process for new development and renovation projects. In its seventh strategy—Climate Risk in Development Review Process—the city's near-term action plan is to conduct a questionnaire to assess climate change impact on new development and major renovation and to provide support for developers and development review process to enhance resilience.

13.1.2 Mapping and quantifying land cover change

For decades, research on the impact of climate change focused on examining vulnerability assessment methods. Despite their nuances, most of these approaches discuss best practices and offer guidance for addressing climate change adaptation based on ranking the assessed site based on land sensitivity and risk of damage due to climate change (Lim & Spanger-

Siegfried, 2004). While the assessment is critical for responding to future climate risks, its process may also improve the management of current climate risks. For example, vulnerability assessment can question incorporating future climate into development projects (Lim & Spanger-Siegfried, 2004), which is immediately relevant to the scope and interest of policymakers and land development reviewers.

Land cover, a ratio determined by development regulation and code, and local and federal guidelines of building expansions in historic districts, plays a vital role in moderating LST that causes surface urban heat island (SUHI) effect (Comarazamy, Gonzalez, Luvall, Rickman and Bornstein, 2013; Zhou, Rybski, & Kropp, 2017). Due to substantially increased LST in urban areas when compared to rural areas, SUHI poses a threat to human health and thus maintaining UTC coverage helps to improve human health and reduce energy consumption in cities (Elmes et al., 2017; Shastri & Ghosh, 2019). LST accounts for the earth surface's temperature, which also includes the temperature of bare soil, vegetation canopy, etc. (Choudhury, Kalikinkar, & Arijit, 2019). Density and biological complexity of an old, mature tree in existing neighborhoods capture, then filter and store a higher rate of precipitation than any other tree. They are very beneficial in regulating the volume of runoff, and thus protecting water quality of watersheds and surface waters. They also provide cultural and spiritual resources and offer an opportunity for passive recreation, in addition to preserving air quality and mitigating climate effects (Davey Resource Group, 2011).

Spatial distribution of UTC is best displayed as a map exemplifying the location of tree cover in a specific area or region. With the advanced geotechnology, UTC can exclusively be determined by aerial or satellite remote sensing tools (Walton, Nowak, & Greenfield, 2008). The availability of satellite imagery, spatial analysis of geographic information systems (GIS), and standardized interpretation techniques has today become simple to implement by municipalities and researchers. Remote sensing techniques often yield reliable results and require little technical capabilities to interpret tree canopies in satellite imagery sources. A knowledge of the spectral properties of the imagery is helpful to manipulate the image bands and produce a color infrared (CIR) imagery, which is useful distinguish trees, grass, vegetation and nonvegetative surfaces (Walton et al., 2008). Randomly distributed plots with dense trees could also be observed and detected, and thus an estimate of the total areas covered by UTC can be concluded (Johnston, 2014; Nowak & Greenfield, 2012; Walton et al., 2008). According to Nowak et al. (1996), UTC could also be quantified using aerial photograph interpretation techniques, and classification of high-resolution digital imagery could be produced, as explained by Myeong, Nowak, Hopkins, and Brock (2001), Zhang (2001), and Irani and Galvin (2002).

13.2 Methodology

13.2.1 Automation tools

This paper examines the changes in different categories of land covers in historic districts in San Antonio, Texas over a period of 5 years, from 2010 to 2015. Historic districts are experiencing rapid growth due to their adjacency to the downtown and the overall city center area, in addition to the affluent hospitality facilities and the myriad of architectural styles and historic landmarks, which attracts newcomers and the locals alike. The paper argues for the need to create a systematic and visualized process using reliable metrics with accuracy measures to quantify that impact of urbanization on the loss of pervious land cover including UTC to mitigate that impact by a revised policy and guidelines. It incites a valid discourse on the environmental implications of development decisions in historic districts, which—under the Secretary of the Interior's Standards (NPS, 2018), could results in a loss of UTC and pervious land cover and thus increases LST. The Secretary of the Interior's Standards strictly mandate that all added structures need to conform with the size, shape, massing, and alignment of existing buildings in their respective blocks/or the immediate-contextual blocks. Thus, measuring the magnitude of land cover changes of in Dignowity Hill and other districts is vital to the preservation and is an attempt to answer the question of whether the national and local guidelines have contributed to the loss of UTC and pervious land cover by not incorporating them in its standards? How could this loss be quantified in an endeavor to be mitigated?

I. The **AUTOMATION** tool utilized in this chapter is a feature-extraction method using OBIA tools on fine spatial resolution (0.5 m) of both Orthoimagery (NAIP and TOP data) and LiDAR point cloud. Using eCognition Developer 9.1 (Trimble, 2018), a programming process was developed to segment and classify land cover of Dignowity Hill, as shown in Fig. 13.1. Detect the locations and to quantify the change—in square foot—in pervious land cover. The output classes were used to calculate the percent loss of pervious land cover including UTC, which is a warning to climate change as it increases urban heat island (UHI) effect in and around the urban center of a city. The proposed automation tool builds on Mogelgaard et al. (2018) research discussed five key factors as the core components of adaptation strategies. One of these factors was defined as information and tools. The four other factors include leadership, coordination mechanisms, policy frameworks, and supportive financial processes. Mogelgaard et al. (2018) also argued that these tools can help accelerate the commitment to implementation.

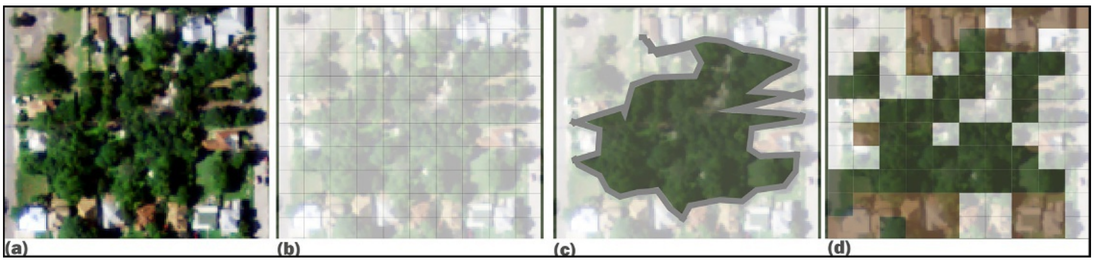

FIG. 13.1 (A) Sample block located in DHHD; (B) pixel-based segmentation; (C) visual interpretation of UTC; and (D) classification of the image elements with *green* (gray in the print version) representing UTC and *brown* (dark gray in the print version) representing impervious land cover. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

13.2.2 Geography and prominence of the Dignowity Hill district

Dignowity Hill historic district, one of the 31 historic districts in the City of San Antonio, Texas (City of San Antonio (COSA), Office of Historic Preservation (OHP), 2018), is located on the East site of the city center. The district, which occupies 539 acres of land, has buildings dated back to c.1877 through 1940 from various and well-crafted authentic architectural styles ranging from Folk Victorian to Queen Anne to Craftsmen. Because of its proximity and morphology, the neighborhood offers an open view to the city's downtown and thus has become an attractive housing market. In 2014, the district, shown in Fig. 13.2, was allocated resources for economic development due to its location within the federally designated East-Side Promise Zone (ESPZ). The COSA has since encouraged both commercial and residential development, and thus such changes in the district's built, natural, and economic characteristics emerged and were accelerated since 2014. Whether it is a new—or an expansion of existing—structure or a rear-detached—addition, in the USA, a development of historic property, site, and landmark are critical and need to abide by the Secretary of the Interior's Standards for the Treatment of Historic Properties (NPS, 2018).

Where LiDAR data are used for studying land cover maps, the derived height information and intensity information are often combined with imagery. According to Hellesen and Matikainen (2013) OBIA is an orthodox method for researchers who combine LiDAR data and imagery classification of urban environment as well as open land landscapes.

Satellite systems offer a myriad of types and formats of the Earth surface data and represent a credible source for acquiring most recent information on the conditions and coverage of the surface. Such information, which could be retrieved from the satellite image is a thematic map, mostly covering a large area. However, change detection maps are also increasingly becoming more popular. The most important aspect of assessing the accuracy of satellite-data thematic information is how efficient the procedures used to classify satellite images (Veljanovski, Kanjir, & Oštir, 2011).

13.2.3 Data and proposed workflow

The workflow for detecting the changes in land cover in Dignowity Hill from 2010 to 2015 is shown in Fig. 13.3 and is followed by Table 13.1, which identifies the sources and specifications of the satellite imagery and other data formats used in this analysis. Data shown in Table 13.1 include NAIP and TOP imagery and Stratmap/LiDAR data for the study area were downloaded from Texas Natural Resources Information System (TNRIS, 2018) portal, and vector data (i.e., historic districts and city boundaries, expressways) were obtained from COSA GIS portal. It is worth noticing that the classification of ground-level land cover cannot be precisely determined from a leaf-on imagery, which is normally captured during spring season, and thus, this paper used imagery with leaf off for land cover segmentation and leaf on for distinguishing ground cover from UTC. Use of LiDAR data also helps to incorporate the height of features within the image in the classification process, which helps separate UTS from surrounding shrubs and lawns.

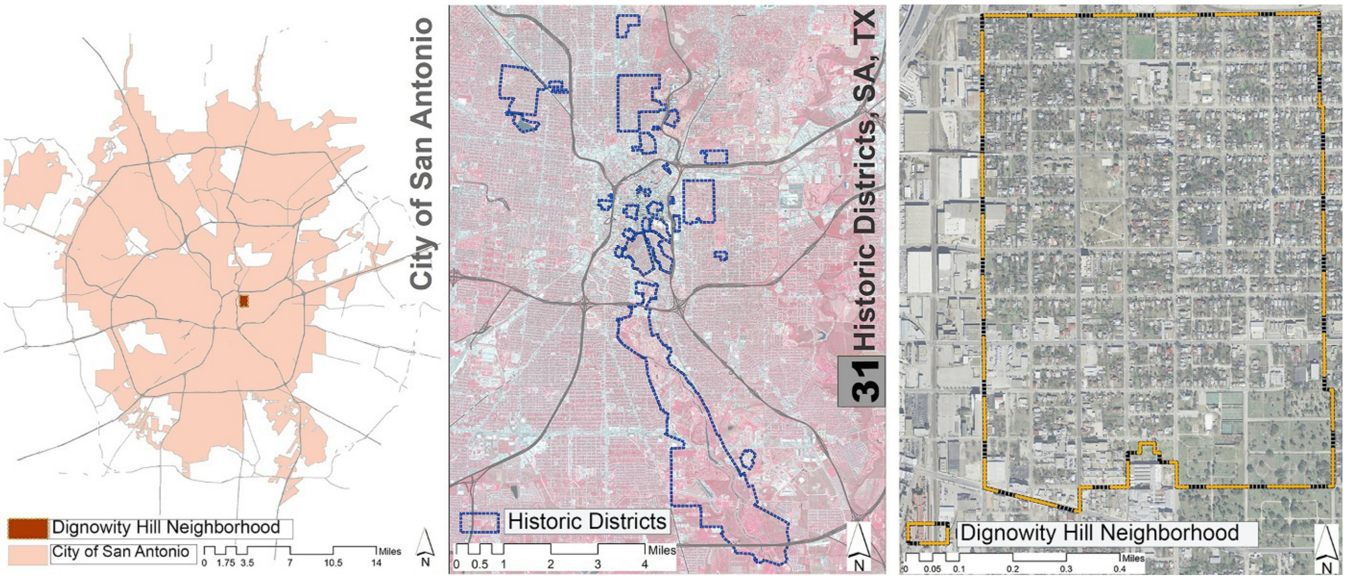

FIG. 13.2 Maps of San Antonio showing (A) the city boundary; (B) the 31 historic districts; and (C) Dignowity Hill.

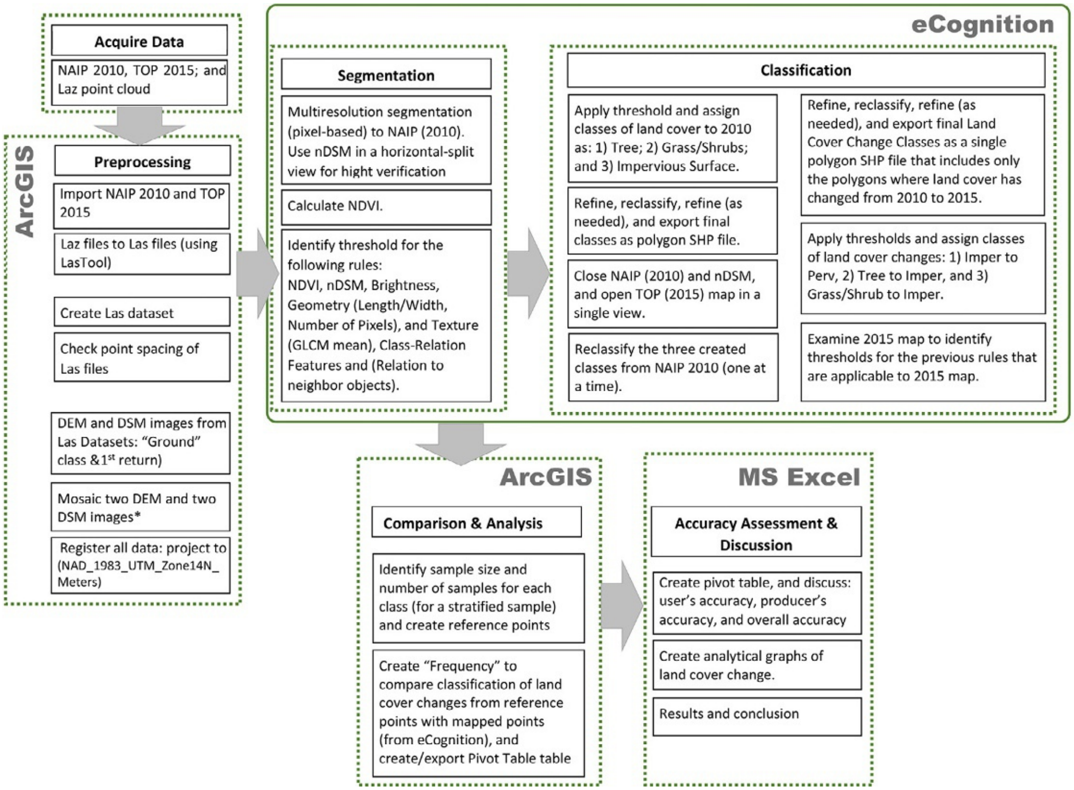

FIG. 13.3 Workflow for mapping and calculating changes in land covers in Dignowity Hill.

13.2.4 Data preprocessing and conversions

Satellite data often require preprocessing prior to analysis to account for several environmental and technical factors including sensor, solar, atmospheric, and topographic effects (Campell & Wynne, 2011). The research in this area though shows that there are inconsistent terminologies on preprocessing that challenge the process itself, its time, and method (Krauß, 2015; Young et al., 2017). In this paper, preprocessing was limited to the following steps, which adopts Krauß's (2015) approach to generate digital surface and terrain models which, in addition to the digital terrain model, altogether provide the height as a helpful feature in the segmentation process.

- Conversion to change data format to be compatible with ArcMap. This includes a Laz to Las conversion of point cloud data;
- Co-registration to align all data to the same datum using the same projection;
- Correction, adjustment, and clipping to interpolate values of pixels with missed data and to limit project boundary to the necessary area;
- Creation of a digital elevation model DEM) using ArcMap;
- Creation of a digital terrain model (DTM) using ArcMap; and

TABLE 13.1 Remote sensing data specifications and sources for this paper.

	Remote sensing data		
Features	**National agriculture imagery program (NAIP)**	**Texas orthoimagery program (TOP)**	**Stratmap (LiDAR point cloud data)**
Sensor	Leica ADS80	Leica ADS100	N/A
Flight dates	5/2/2010 during leaf-on season	Between October 2014 to August 2015; mostly during leaf-off season	2010
Format	Compressed JPEG 2000 (JP2)	Compressed JPEG 2000 (JP2)	LAZ
Tested absolute horizontal accuracy	Orthoimagery rectified to a horizontal accuracy of within ±5 m of reference digital ortho quarter quads (DOQQ's) from the National Digital Ortho Program (NDOP)	ASPRS class 1, accuracy 95%, confidence 2.45 m	N/A
Spectral resolution	4-Bands (R,G,B,NIR)	4-Bands (R,G,B,NIR)	N/A
Spatial resolution	1 m	0.5 m	0.5 m
Radiometric resolution	8 bit	8 bit	N/A
Orthorectified	Yes	Yes	N/A
Source	National agriculture imagery program (NAIP)	Texas orthoimagery program (TOP)	Texas natural resource information system (TNRIS)
Projection	UTM Zone 14	UTM Zone 14	UTM Zone 14
Horizontal datum	NAD 1983	NAD 1983	NAD 1983
Horizontal units	Meter	Meter	Meter
Source	National agriculture imagery program (NAIP)	Texas orthoimagery program (TOP)	Texas natural resource information system (TNRIS)

- Creation of a digital surface model (DSM) from LiDAR data.

Data preprocessing was conducted using ArcMap 10.5.1 (Environmental System Research Institute (ESRI), 2017), and the "Void Fill Method" was used to fill the missed pixel values, which is caused by the sensor's missed data. Normalized digital surface model (nDSM), which calculates features; net height in an image was calculated in using Eq. (13.1). Baseline NAIP imagery of 2010 with leaf-on, calculated digital models (DEM, DSM, DTM, and nods'), and TOP imagery of 2015 with leaf-off were uploaded to cognition Developer 9.1 (Trimble, 2018).

$$\mathrm{nDSM} = \mathrm{DSM} - \mathrm{DTM} \tag{13.1}$$

13.2.5 Features extraction using eCognition 9.2

Satellite imagery and aerial photographs are common method to provide different data on the Earth surface, and they offer a breadth of information on the configuration of land cover, urban landscape, and plants species on that surface. The key factor in the accuracy of information retrieved from satellite imagery lies in method used to classify each imagery, which is a process aims to distinguish different elements (geographical objects and phenomena) on the Earth surface (Veljanovski et al., 2011). There are two types of images classification methods, manual and digital (automatic). Both types utilize elements of image interpretation (EII) and expert's knowledge of the scene to define classes as explained by Campell and Wynne's (2011). This is processed through spectral and/or geometric, texture, context, temporal information along with clustering pixels into classes. In this paper, digital object-based classification tool was utilized since it is advantageous over other methods and its inclusion of the benefits of both visual interpretation and pixel-based classification.

Segmentation

On eCogniton, the following segmentation of the DHHD imagery was conducted:

- An initial pixel-based multiresolution segmentation of NAIP 2010 imagery. Because NAIP map was acquired during leaf-on season, this resulted in an intensive mature trees canopies that overlapped most of the buildings and pervious land cover, and thus use of nDSM for classification based on height as a threshold helped separate tree canopies from ground cover and buildings.
- All created classes were re-segmented as object-based image, and the segmented objects were utilized to classify land cover of 2015 TOP imagery. nDSM was not available for 2015, and therefore normalized difference vegetation index (NDVI) was calculated and applied to distinguish impervious land cover from pervious/vegetated land cover. NDVI, which is a value used to detect vegetated/nonvegetated surfaces and to identify different plant species, is based on spectral characteristics of surfaces, and was calculated in eCognition using Eq. (13.2).

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{Red})/(\mathrm{NIR} + \mathrm{Red}) \tag{13.2}$$

Classification

- Following segmentation of 2010 and 2015 imagery, each imagery was examined to develop different thresholds and was then classified. This was followed by multiple steps re-classify and re-segment the baseline imagery, NAIP 2010. Final classes were named as Tree10, Grass, and Imper and then exported—as vector polygons—to ArcMap for analysis.
- The three created classes were re-segmented using object-based multiresolution segmentation, and a classification was performed to TOP 2015 imagery. The following rules and thresholds were used in the classification, reclassification, and refining process.

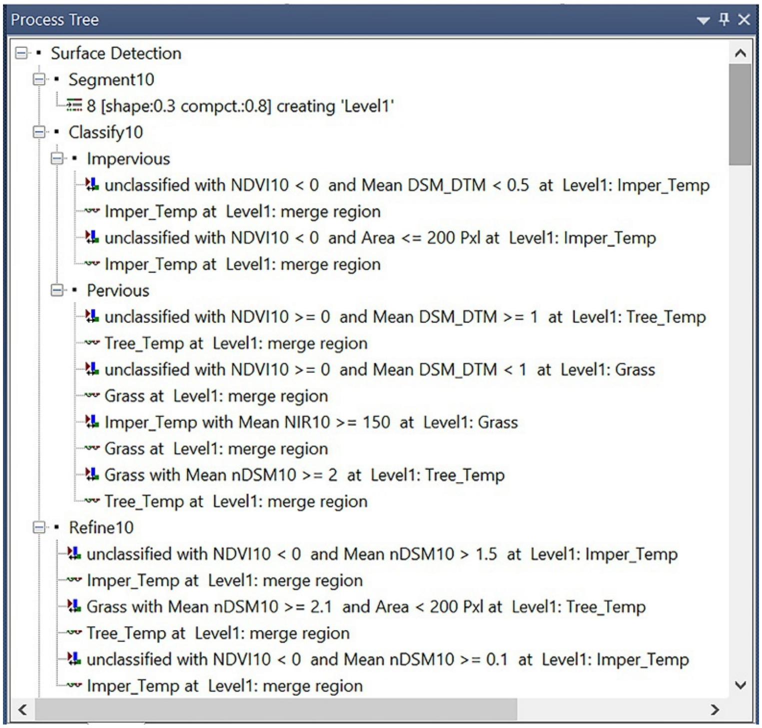

FIG. 13.4 Segmentation parameters and classification thresholds for baseline NAIP 2010 imagery.

- Rules used in classification encompasses height, brightness, shape, geometry, and NDVI, and thresholds of baseline 2010 imagery and target year imagery of 2015 are shown in Figs. 13.4 and 13.5, respectively.

Mapped classes of land cover change

Three final classes representing the change of land cover were generated on eCognition are results of all land cover changes were exported as a single shape file for further analysis on ArcMap.

- Tree10_Imper15: Tree Canopies in 2010, changed to impervious land cover in 2015, as shown in the sample block in Fig. 13.6.
- Grass10_Imper15: Grass/shrubs in 2010, changed to impervious land cover in 2015.
- Imper10_Perv15: Impervious in 2010, changed to pervious land cover in 2015.

13.2.6 Accuracy assessment

With the advanced digital satellite remote sensing techniques, it became necessary to perform an accuracy assessment. Accuracy assessment is measured using a stratified sample

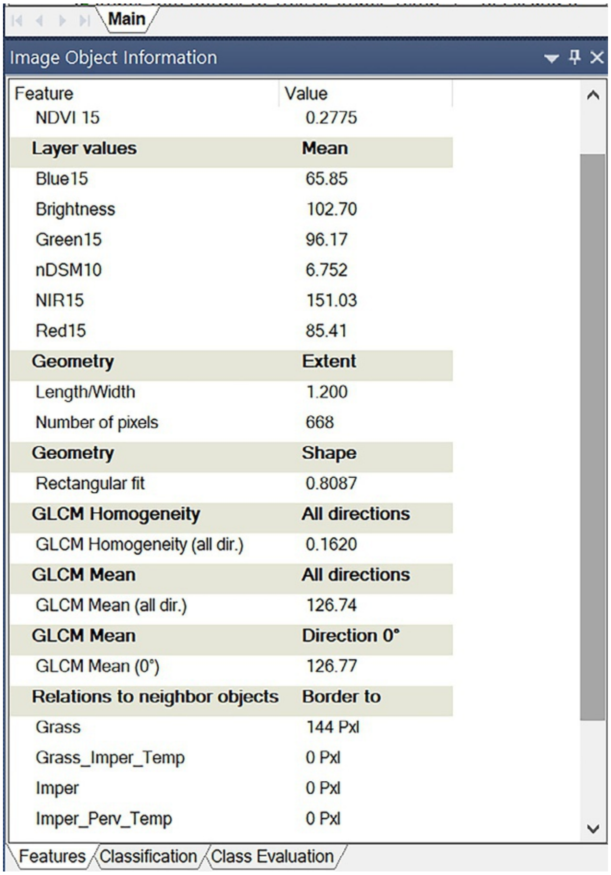

FIG. 13.5 Features used in detecting land cover change in eCognition platform (*right*).

created in ArcMap by applying random points in each layer that represent a single feature class resulted from eCognition output. Using spatial analysis tools, 300 points were created in the three classes of land cover change layers, shown in Table 13.2, and were allocated using stratified sample method, which uses each layer's area the weight by which the number of points were assigned. Tabulation processing in ArcMap 10.5.1 (Environmental System Research Institute (ESRI), 2017) was used to create a Frequency Table 13.3 and an error matric—a Microsoft excel (MS Office, 2016) Pivot Table—was used to calculate OBIA's overall accuracy.

13.3 Results and discussion

13.3.1 Baseline year's land cover analysis (2010)

Exported from eCognition, the following is the result of segmentation and classification of NAIP 2010 map, which was used as the base map for data analysis. The segmentation

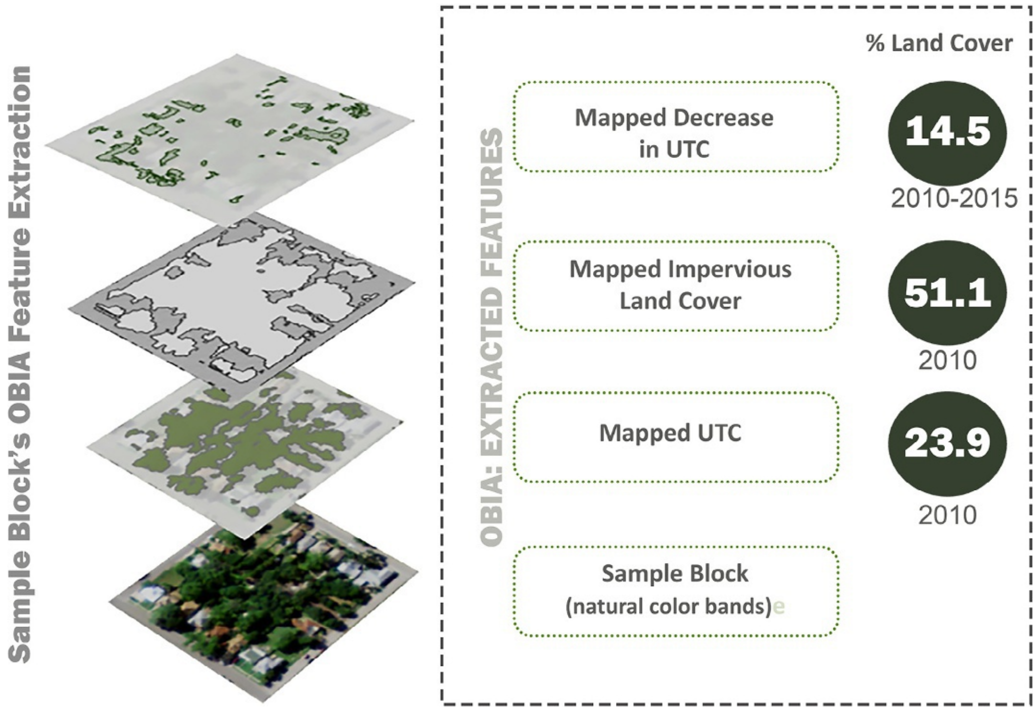

FIG. 13.6 (*Left*) Sample block showing extracted features using OBIA from NAIP 2010 imagery; (*center*) mapped extracted features; and (*right*) the percent of mapped feature area and changes in UTC land cover between 2010 and 2015.

TABLE 13.2 Number of points per each stratified sample for each class of land cover change.

Land cover change (by class)	Area (SQM)	Weight (%)	Sample (number of points)
rass10 to Imper15	35,391.19	14.5	44
Imper10 to Perv15	115,809.43	47.4	142
Tree10 to Imper15	93,238.60	38.1	114
Total	244,439.22	100	**300**[a]

[a] *8 out of 300 reference points were showing a no-change in land cover, and therefore, these points were removed from the total sample size. The total finalized sample were only 292 (see Table 13.3 for final reference points).*

TABLE 13.3 Error matrix of land cover change detection (2010–15).

	Reference data				
Mapped points (eCognition)	**GRASS_IMPER**	**IMPER_PERV**	**TREE_IMPER**	**Total**	**User's accuracy**
GRASS_IMPER[a]	33	2	9	44	75.0%
IMPER_PERV[b]	17	113	8	138	81.9%
TREE_IMPER[c]	18	3	89	110	80.9%
Total	68	118	106	292	
Producer's accuracy	48.5%	95.8%	84.0%		

[a] *Grass/Shrubs detected (in 2010); changed to Impervious Surface (in 2015).*
[b] *Impervious Surface detected (in 2010); changed to Pervious Surface including Trees and/or Grass/Shrubs (in 2015).*
[c] *Tree Canopy detected (in 2010); changed to Impervious Surface (in 2015).*

distinguished three classes of land cover: (1) UTC (named as Tree2010); (2) grass and low shrubs (named as Grass2010); and (3) pavement, curb side, asphalt, buildings, etc. (named as Impervious2010). An analysis of the total area (in m^2) and percentage of land cover is also provided below. The areas of land cover detected for each class represented the following land cover classes:

- 24% classified as Tree2010, representing UTC;
- 51% classified as impervious2010, representing sidewalks, buildings, and roads;
- 25% Grass 2010, which is classified as either grass or low shrubs; and
- 1% unclassified.

13.3.2 Change in land cover from baseline year (2010) to target year (2015)

The classes of land cover change from 2010 to 2015 were exported from eCognition as a single polygon layer, and ArcMap tabulation was used to calculate the changes in each land cover class. The calculation yielded the following results:

- The overall change in all three land cover classes including trees, grass/shrubs, and impervious comprised a total of 1,581,259 m^2 (391 acre), which is a 15.5% of the total land cover detected in 2010. Most of the change (52.6%) was in the pervious land cover, with 38.1% UTC and 14.5% grass area that have changed to impervious land cover (see Figs. 13.7 and 13.8). This indicates that despite the strict regulations on form, style, density, and conformity, the existing guidelines does not target resilient land cover changes, resulting in unmeasured and alarming loss in pervious land cover.
- Table 13.4 shows approximately a total of 61 acres (245,000 m^2 or 17% of the neighborhood total area) of net change in land cover from one class to another was detected.
- Table 13.4 also shows that from 2010 to 2015, land cover changed by an average of 15.5% with the highest change detected in the UTC class, which has changed to impervious land cover. This area alone occupied more than 377,000 m^2 (93 acres). However, the new development may have brought more landscape and tree canopies around new properties or adjacent streets, yet the newly planted trees and vegetation is less than the overall loss in pervious cover including old mature trees.

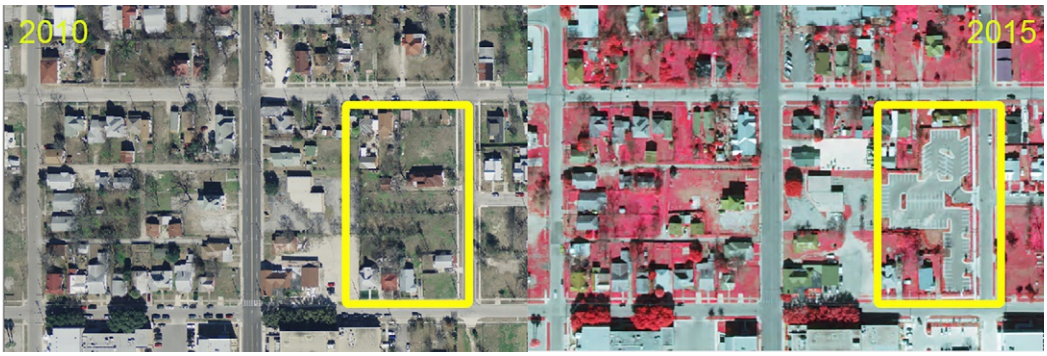

FIG. 13.7 Sample block shows pervious to impervious land cover change (2010–15) in Dignowity Hill.

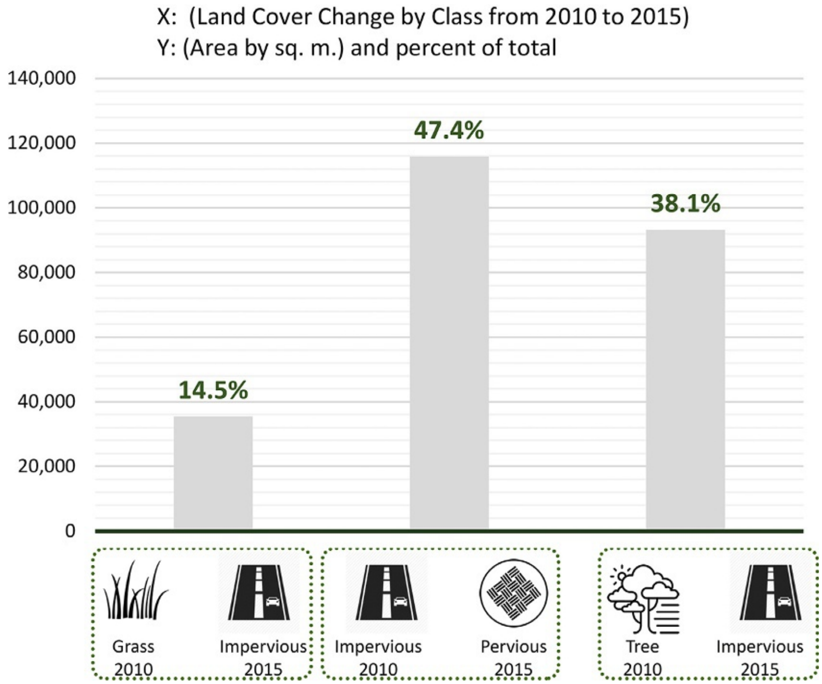

FIG. 13.8 Area (in m^2) and its percent of total change in land cover categorized by class from 2010 to 2015 in Dignowity Hill.

TABLE 13.4 Area and percent change in land cover classes and estimated change relative to the total area detected in 2010 (the baseline year).

Changes of land cover	Area (m^2)	Percentage (%)	2010	Percent change (2010–15) (%)
Grass10_Imper15	35,391	14.5	395,468	8.9
Imper10_Perv15	115,809	47.4	808,332	14.3
Tree10_Imper15	93,239	38.1	377,459	24.7
Total	244,439	100	1,581,259	15.5

- This apparent increase in pervious land cover accounted for 14.3% (from 2010 to 2015). Despite the challenges in data processing, the error matrix showed an overall accuracy of 80.5%.

13.4 Conclusions and implications of adaptation policy

Many tools exist to support the effort of studying climate change impact on land cover and land use; yet, integrating the results of these tools into mainstreamed policies and robust action plans has been slow on the ground (Mogelgaard et al., 2018). Mainstreaming requires an assessment of several strategies that could help to reduce those risks (OECD, 2009; Runhaar, Wilk, Persson, Uittenbroek, & Wamsler, 2017) and offers concrete recommendations and adjustments to existing activities to reduce vulnerability and increase adaptability (Huxtable & Yen, 2009). The research discussed in this chapter provides a replicable model that the local municipalities could use to assess the changes and risk of land cover and LUCs on the neighborhood level. With the automation process of object-based image analysis (OBIA), the methodology utilized eCognition to compare areas of land cover in several satellite imagery to assess the extent of land cover change between 2010 and 2015 in Dignowity Hill.

Additional feature extraction rules and thresholds should be integrated in the programming within eCognition to enhance the overall accuracy, and thus the calculation of total land cover change. The study alerts for the need to compare the loss and added vegetated land cover and to track the trees by their location, specimen, and size. Such a comparison should build on the findings of this paper and by replicating this automated neighborhood-level model, such as ModelBuilder, to assess and compare neighborhoods' resilience and implications on climate change.

The study offered a systematic, replicable, and iterative approach to analyze and visualize urban complex districts and neighborhoods, which could be replicated in other neighborhoods. The results could be integrated in a mainstream process for adaptation policy. Mainstreaming, which takes place at various administrative levels, from national to regional and local levels, is an opportunity to guide an iterative and versatile process of integration and adjustments based on the assessment of outcomes. It is also driven by stakeholders' input from a wide range of governmental and nongovernmental entities (Olhoff & Schaer, 2010; UNDP and UNEP, 2011).

One of the replicability precautions researchers should consider is the need to extend the use of texture and shape in defining the parameters of eCognition rules in order to refine objects classification and achieve higher accuracy. The results of this paper highlight the environmental implications of development as a missing component of historic areas guidelines and national standards overseen by the Secretary of the Interior (NPS, 2018). The paper offers an insight on the ways to integrate a policy governing municipalities tree ordinance and pervious land cover when making decisions on new development and expansion of existing structures to mitigate the loss of UTC. The paper also highlights the advantages of OBIA's feature extraction using eCognition rule set and its versatility and feasibility to be applicable to other districts and communities across San Antonio. For instance, goal #13, climate action, of the United Nations sustainable development goals (SDGs) is precisely tailored to climate adaptation and mitigation, yet other targets and their indicators across several SDGs refer to the need to prepare for climate impacts (Northrop, Biru, Lima, Bouye, & Song, 2016). Thus, governments have committed to integrating adaptation considerations into development plans and sectoral strategies within the national climate change plans linked to the Paris Agreement (UNFCCC, 2016). This integration can take the form of mainstreaming climate change policies and actions, a process that implies a cultural shift within institutions and government units, so that consideration of climate risks and strategies becomes embedded part of regulation, review process, and everyday decision-making (Parry & Taylor, 2012). Mainstreaming adaptation focuses on integrating climate change adaptation into sectoral policies and plans. Smart methods such as object extraction discussed in this chapter offer a reliable and effective tool that could easily be incorporated in mainstreaming climate-adaptation response decisions within the early planning process by cities and regions. The automation process provides a versatile and geography-tailored model for assessing changes in vegetative land cover, which could be replicated on other geographies within the city or the region, and thus provides an effective climate action adaptation and proactive sustainable planning decisions.

Mogelgaard et al. (2018) recommended direct path to implementation and visibility could be achieved by adopting the method proposed in this paper. With the availability of citywide orthoimagery and LiDAR data, replicating the method developed in this paper is attainable so that policymakers and planners, who recognize the need to integrate climate change adaptation into broader development objectives Mogelgaard et al. (2018) could incorporate this tool on San Antonio neighborhoods.

Appendix: Notes on the methodology caveats

- The challenge of materials and forms used throughout the district was the availability of metal roofs. When directly facing the sun, the NDVI value of the shiny portion of the roof. To overcome this discrepancy, "brightness value" was used since it was a record high that was easy to re-classify.
- Due to the complexity and density of urban areas, particularly in older neighborhoods, which are populated by dense and large tree foliage, isolating tree canopy with high accuracy requires classifying tree canopies based on geometry (shape) in addition to NDVI. However, due to interconnected foliage and manmade structures, UTC separation with high accuracy may not be attainable.
- In the historic districts that are in transition such as the case study discussed in this chapter, portions of narrow sidewalks might be totally covered with weeds, especially due to irregular or absence of site maintenance. As such, there might be an error of omission/or of commission where weeds may be detected/and classified as grass, which may have increased the percent of areas of impervious 2010 to pervious 2015 land cover change.

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CHAPTER

14

Smart transformation in Iran, a step toward adaptation and reduction of climate change

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14.1 Introduction

One of the primary causes of global climate change is rapid urbanization. Carbon dioxide emissions, the greenhouse effect, heat islands, and global warming all increased due to the industrial revolution and the rapid development of city activities. They are intertwining and becoming increasingly fierce, striking the Earth and causing a slew of problems, creating a vicious cycle impeding the development of the progressive malignant city (Deng, Zhao, & Zhou, 2017).

The world's population is now over 7.8 billion people. About 54% of the world's population lives in cities, and this trend is expected to continue through 2050, reaching 66%. In other words, cities now house half of the world's population, and cities in the global south will account for 95% of population growth over the next 90 years. This is in stark contrast to previous centuries. Only 3% of the world's population lived in cities until 1800, and less than 15% lived in cities by 1900. Urbanization and its benefits may have drawbacks, such as income disparities between urban and rural areas. Urbanization and economic transformation necessitate the consideration of integrated development and equity. The Industrial Revolution and the rise of the capitalist economy, which first appeared in Western countries and then in developing countries, are widely considered to be direct causes of urbanization. The growth of urbanization has been fueled by factors such as distance from industrial centers, roads, commercial centers. Cities have also served as incubators for new ideas and growth. Other positive factors in the urbanization process include culture, economy, employment rate, and household income (Mansoorian, Khazaei, Shariat Panahi, & Moshfegh, 2015).

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After World War II, developing countries experienced unprecedented levels of urbanization. The end of colonialism in developing countries and the attempt at industrial growth in developed countries spawned a new movement known as modernization. Rapid urbanization and exogenous industrialization were only a few of the negative manifestations of modernization that global south cities experienced during the rapid transformation. Iran's and other developing countries' historical experiences show changes in lifestyle, rural-to-urban migration, and economic transformation from primary to secondary and tertiary sectors. Many rural residents relocated to urban areas as a result of these changes. This claim is supported by the experience of land reform in Iran in the 1960s. The national policy of prioritizing cities over rural areas resulted in an urban population increase. Meanwhile, marginalization, worn-out texture, traffic, urban sprawl, illegal constructions, air and noise pollution, land and housing exchange, parasitic growth of the city economy, urban income instability, water supply crisis, and other environmental crises arose. A historical examination of these issues leads us to conclude that environmental issues have had significant externalities. They have had a big impact on people's lives and come with many health and management costs for cities. Population growth, rapid urbanization, increased car dependency, deregulated industrialization, and mass livestock production have all contributed to these environmental externalities, raising serious concerns about our long-term well-being and even citizens' existence (Priscila Trindade et al., 2017).

Iran is a Middle Eastern country with a population of about 82 million people, or about 1.07% of the world's population, and ranks as the world's 18th most populous country. Water scarcity, soil erosion, energy, air pollution, and biodiversity loss are five major environmental issues facing Iran. In comparison to the increase in national production, the rising trend in energy consumption has increased energy use, indicating a decrease in productivity (Shayestehfard, 2013). However, the main issue that large cities face is environmental issues such as air pollution. It has been suggested that technological advancements and innovation can help to mitigate the negative effects of climate change (Ferreiraa, Fernando, & Ferreirabc, 2020).

The lack of appropriate responses to environmental challenges has exacerbated the situation. We are facing a climate change crisis that directly threatens human life. The only way out is to alter one's lifestyle, business, leisure, and mobility. Traditional agriculture and submerged cultivation are no longer viable options for increasing land productivity. It is no longer possible to consider the industrial value chain without Big Data, real-time analysis, and energy storage. Buildings, energy, transportation, the economy, agriculture, health, education, and governance are all sectors that will not develop unless fundamental changes are made. As Thomas Cohen's paradigm shift demonstrates, smart transformation is required to address emerging urban and regional crises. Without a doubt, smart city solutions are a way to address climate change and find an appropriate solution is to maximize the use of technology and implement smart transformations.

14.2 Smart city and smart transformation

The third millennium has been dubbed the "urban millennium" because the world's urban population surpassed 50% for the first time in 2007. The increased rate of contemporary urbanization triggered the second wave of urbanization. The pace of urbanization accelerated at the beginning of the third millennium, which is the era of information technology in various fields of urban life and is known as the third wave of urbanization.

The unprecedented rate of urbanization and the pressing need to address the challenges that come with it have compelled governments to seek the best solutions possible. Solutions should address sustainable development, education, energy, the environment, safety, and public services. Some argue that a "Smart Transformation" is needed to achieve these goals. In other words, one strategy for pursuing sustainable urban development is "smart urban development" (Razavizadeh & Mofidi, 2018).

According to research, cities face complex and broad challenges that can only be addressed in a systematic manner. Massive urban population growth has created chaos and conditions that have thrown cities off balance and made sustainability impossible to achieve using current urban management and development methods. As a result, urban planners worldwide are attempting to develop development models for 21st-century cities that meet today's new demands and expectations. It is capable of dealing with a wide range of urban issues, including pandemics and health emergencies.

One of the new concepts to address the current challenges of cities in urban planning is the need for smart urban transformation and smart city development, which has received a lot of attention in recent years. By combining real-world and virtual-world capabilities to address urban challenges, the smart city has opened up new avenues in urban planning.

Many major cities around the world, including Seoul, South Korea, New York, Tokyo, Shanghai, Singapore, Amsterdam, the Netherlands, and Dubai, United Arab Emirates, have launched smart city initiatives to address existing challenges. Given the volume of innovation, smart city solutions are more likely to be implemented faster in developing countries and to become the dominant urban development strategy. Smart appears to be a catch-all term for "sustainable," "livable," "safe," "green," and "connected." In other words, the smart city is the ultimate goal that will allow all of these objectives to be realized.

Smart cities make use of information and communication technology (ICT) to give cities a competitive advantage (Caragliu, Del Bo, & Nijkamp, 2011). It is a conceptual model that uses human, collective, and technological capital to achieve urban development (Angelidou, 2014). As a result, the term "smart city" refers to a broad concept that includes several subthemes such as smart urbanism, smart economy, sustainable and smart environment, smart technology, smart energy, smart mobility, and smart health (Cocchia, 2014; Gudes, Kendall, Yigitcanlar, Pathak, & Baum, 2010; Lara, Costa, Furlani, & Yigitcanlar, 2016).

In contrast, the recent expansion and continuation of rapid and dramatic technological advances have provided an unprecedented opportunity to develop smart tools to achieve sustainable development goals. In other words, technological, infrastructure, service, and inclusive management system advancements have aided the transition to smarter, more sustainable cities (Yigitcanlar & Lee, 2014).

In this regard, one of the emerging components of the urban system that has had a significant impact on its structures and functions is the introduction of smart systems and technology, which introduces a new concept called the smart city in the management literature. In the past 2 decades, smart cities have emerged as new urban ecosystems that combine digital technologies, knowledge, and assets to improve residents' responsiveness, the quality of urban services, and the attractiveness of cities.

As a result of the technological revolution and its application in cities, smart cities have greatly improved. The application of big data, cloud computing, and other cutting-edge technology in urban planning has resulted in significant changes in urban governance methods and models and increased city efficiency. To create a triple button lines planning system, smart cities use remote sensing cloud technology to integrate spatial data, geological information, and climate data. In smart city planning, data intelligence is used to improve the city's management capacity in dealing with climate change.

The concept of the smart city is gaining traction as new technologies, particularly ICT, advance in order to achieve more efficient and sustainable cities. It makes it possible for communities to address social and economic issues in a more secure manner. This advancement in information and communication technology has made it possible to take a more holistic approach to urban issues. It can be used to improve the efficiency of the urban system, as well as to enable people to create, build, try, and experiment with new things in order to improve their quality of life. It should be noted that, while the terms "smart city" and "technology" are frequently used interchangeably, as are terms like "electronic city" and "information city," a comprehensive, integrated, and multidisciplinary approach is required. In other words, a smart city necessitates a smart society that makes informed and mutually agreeable decisions about how to use technology as a catalyst to meet its business and social needs.

The smart city, according to experts, managers, and urban planners, is an important and effective government strategy for addressing crises and challenges caused by population growth and urbanization in large cities. In the modern era, smart city development necessitates the best use of economic and social capacities to improve citizens' quality of life, socioeconomic development, and resource management (Eghbali, 2018). Using information and communication technology to become smarter and more efficient in resource utilization can result in cost and energy savings, improved service delivery, a higher quality of life, and a smaller environmental footprint (Ramaswamy & Madakam, 2013).

The smart city concept is still in its early stages; it is a new concept with a meta-instrumental perspective as well as short- and long-term perspectives that, if realized, will improve citizens' lives and make urban management easier. A smart city, from this perspective, is one that is based on urban needs that are best met. To respond to environmental issues, the capacity to tolerate the environment in different conditions has different answers. The melting of the polar ice caps and their impact on the hot water flow of the Gulf Stream will strain the ocean's entire food chain, including humanity. One of the simplest steps toward smart transformation and mitigating the effects of climate change is to reduce the use of nonrenewable energy sources such as fossil fuels and replace them with new energy.

14.3 Climate change and environmental problems in Iran

The expansion of industries and factories and deforestation and environmental degradation have resulted in an increase in natural disasters and greenhouse gas emissions around the world in recent decades. This negative consequence has resulted in significant changes in the planet's climate, such as severe droughts, floods, and other extreme events in various parts of the world have increased significantly in recent years (Abbasi, Babaian, Malbusi, Asmari, & Mokhtari, 2012).

Evidence such as rising average temperatures in the country, declining rainfall, and increasing frequency and severity of severe environmental events such as floods and droughts in the country indicate the increasing effects of global warming and climate change, according to studies by the National Center for Climate Change. According to numerous studies, Iran is more vulnerable to climate change than the global average. The study also demonstrates that the effects of climate change will differ across the globe. Global warming will have the greatest economic impact on the Middle East and North Africa, while European and North American countries will suffer the least. The increasing frequency of severe environmental events in Iran, such as heatwaves on extremely hot days in the southeast and extremely cold days in the northwest, is signs of climate change.

Climate change has resulted in a 40% increase in torrential rains across the country, as well as dry days in Iran's western and southeastern regions. Climate change has manifested itself in Iran, with spring floods in 2018 and frequent floods in 2019. Although a definitive argument for the role of global warming in the local environment cannot be made, the occurrence of drought and dust storms in Iran and the region can be considered tangible effects of rising ground temperatures and decreasing rainfall. Reduced rainfall in the country has also resulted in reduced surface runoff in the spring and reduced hydropower generation capacity. Furthermore, soil erosion and poor vegetation rangelands are two of the country's effects of global warming. Reduced rainfall and local water resources have resulted in social issues such as economic consequences in rural areas, an increase in rural-to-suburban migration, and the negative social and economic consequences of marginalization and the loss of rural capital.

According to the Iranian Housing Foundation of Islamic Revolution's Deputy Minister of Rural Development, according to the 2016 census, 30,000 villages in Iran are uninhabited, implying that 30,000 dynamic, productive sources have been removed from the country's economic cycle, and thousands of laborers have relocated to cities. The severe decline of groundwater aquifers and the destruction of Qanats, the barrenness of land due to livestock overgrazing, the severe livelihoods dependence on water and soil resources, and the lack of alternatives are the most important reasons for these unwanted migrations. Khuzestan is a prime example of migration as a result of environmental neglect (Hajian Hossein Abadi & Khavarian-Garmsir, 2022; Khavarian-Garmsir, Pourahmad, Hataminejad, & Farhoodi, 2019). According to Khuzestan Province's Director-General of Environmental Protection, the people of Khuzestan have been migrating out of the province in recent years. The main cause of this trend is an increase in dust and a decrease in water quality. Agricultural lands in Sistan and Baluchestan, Isfahan, and other provinces have been deserted, forcing farmers to migrate. Immigration has posed a challenge to the provinces of destination. The spread of drought and its consequences in some parts of Iran, as well as the availability of water and green space in the northern provinces, has increased the population of Golestan and Mazandaran provinces in recent years.

Migration is an expensive process that can be triggered by a variety of factors. The most common features are economic opportunities, civil and international conflicts, religious and ethnic clashes, and climate change (UNEP, 2012). Climate-induced migration has gotten more attention in recent years as policy debates around the world have been sparked by the importance of understanding the impacts of climate change and the consequences of stable migration flows. Human migration was identified as the most significant impact of climate change in one of the first studies, which was done for an Intergovernmental Panel on Climate

Change assessment report (IPCC, 1990). Following this, the International Organization for Migration (IOM, 1992) expressed concern about the dramatic increase in mass displacements, and the likelihood of a significant increase in forced migration flows as a result of climate change rendering many settlements in various parts of the world uninhabitable. However, the number of natural disasters has more than doubled since then: according to reports from the Internal Displacement Monitoring Centre (IDMC) and the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), more than 20 million people were displaced by sudden onset of climate-related natural disasters and extreme weather events in 2008, compared to 4.6 million people displaced by conflict and violence over the same period—some of which, incisively, were displaced by natural disasters (OCHA-IDMC, 2009). According to projections, the number of people displaced as a result of climate change will more than double by 2050, to an estimated 200 million people (Gemenne, Brücker, & Ionesco, 2012).

While major abrupt displacements caused by severe and abrupt changes in climate conditions are widely reported and discussed, the impact of steady changes in climate, which have long been known to induce gradual and slow migration flows by affecting the habitability of living environments, receives less attention (Meerow & Mitchell, 2017). This type of displacement, on the other hand, is likely to have serious long-term socio-economic and environmental consequences. There are numerous examples of how this type of migration can result in a vicious cycle of civil conflict and poverty associated with urban overcrowding and rural desertification.

Despite the fact that the effects of climate change are likely to be felt globally, certain regions and countries will inevitably be hit harder. Because of their low geographical altitude, some regions are more vulnerable to climate change, as are the less developed and developing countries, which have the weak infrastructure and are unable to respond quickly (IPCC, 1997). For example, MENA (the Middle East and North Africa region) is considered to be highly vulnerable to climate change in the coming decades due to its high level of water scarcity and the fact that a significant source of its inhabitants' livelihood is directly and inflexibly reliant on more traditional water-dependent agriculture. Given the magnitude and importance of the issues, it is surprising that so few statistical studies of the phenomenon attempt to quantify the impact of climate change on migration flow and predict the impact of gradual climate change, particularly in more vulnerable regions like the Middle East and North Africa.

The following are the physical geography characteristics that predispose Iran to climate change consequences: More than 80% of the country is arid or semi-arid, with around 20% of the land covered in desert, and only 9% of the country's 1.648 million km^2 is forested (Iran's National Climate Change Office, NCCO, 2010). In 1996, the proportions of arable and agricultural land were 10.1% and 39.2%, respectively, but by 2011 they had dropped to 9.3% and 28.5%. Parts of the country have a severe lack of rainfall when compared to global averages; from 1996 to 2011, the annual average precipitation was 203 mm, compared to 1121 mm globally. Iran is one of the most water-stressed countries, according to the World Resources Institute (Luo, Young, & Peig, 2015), and projections show that a 3 °C increase in temperature would reduce Iran's crop yields by 30%. (WRI, 2013). Climate change, according to Gohari et al. (2013), will likely result in significant reductions in Iran's four major crops—wheat, barley, rice, and corn—over the next 3 decades. In the western parts of the country, there have already been multiple episodes of unprecedented sand storms, and some of the country's major rivers and lakes have dried up or are receding. Fig. 14.1 depicts the proportion of the population living in rural areas in each province. Fig. 14.2 shows that areas with a higher proportion of rural people are more likely to experience a precipitation drop. It was created as part of a collaborative project between NCCO and the United Nations Development Program.

While environmental concerns may become one of the most important factors influencing internal migration decisions, internal migration is not a new phenomenon. When the country underwent fundamental changes following the discovery of major oil fields over a century ago, there was a major episode of internal migration. As a result of the resulting economic growth, major cities became economic hubs, resulting in the first major waves of rural-to-urban migration. The late Shah of Iran's major Land Reform Act of 1963, as well as the OPEC-induced oil boom of the early 1970s, boosted this pattern (Taleb & Anbari, 2005), albeit for different reasons. Finally, the 1979 revolution, followed by the Iran-Iraq war from 1980 to 1988, significantly impacted migration patterns. As a result, 71% of the 75 million people in 2011 (SCI, 2011) lived in urban areas, and this number is expected to rise to 80% by 2050 (Mahmoudian & Ghassemi-Ardahaee, 2014). According to demographic data, 1 million people per year have moved within the country's borders on average over the past 3 decades.

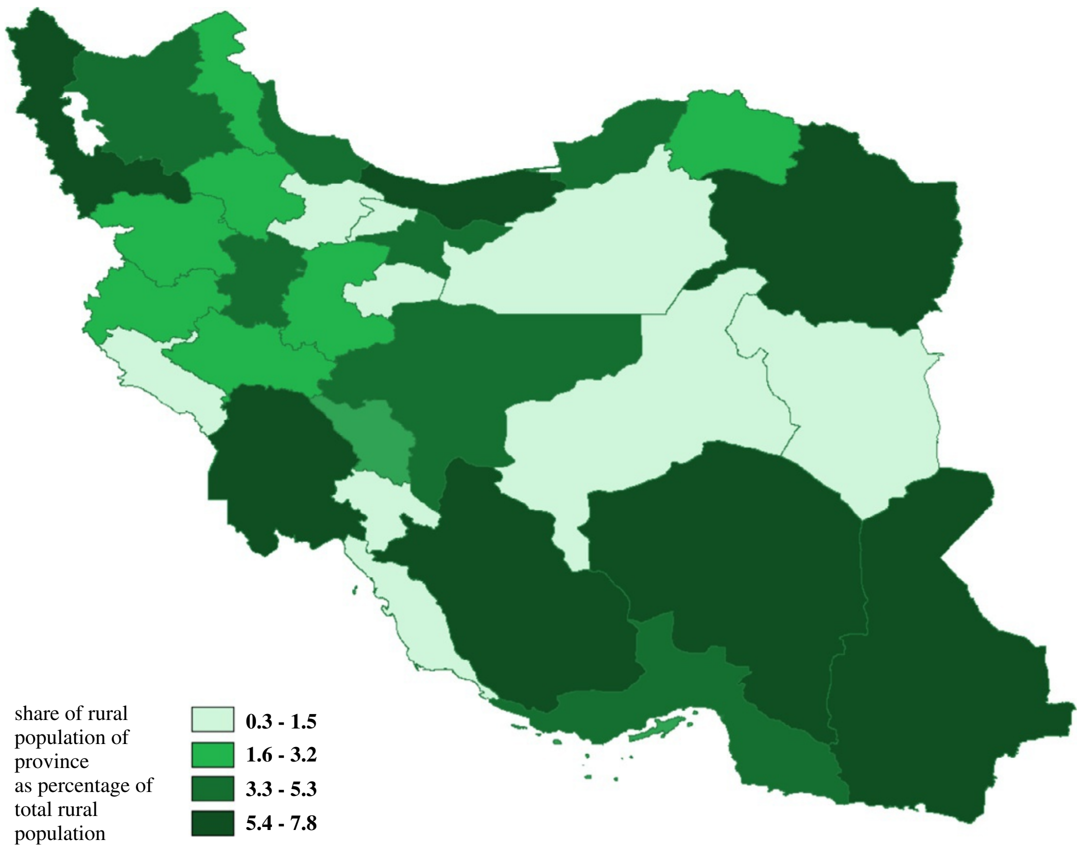

FIG. 14.1 Province-level rural population in Iran (Shiva & Molana, 2018).

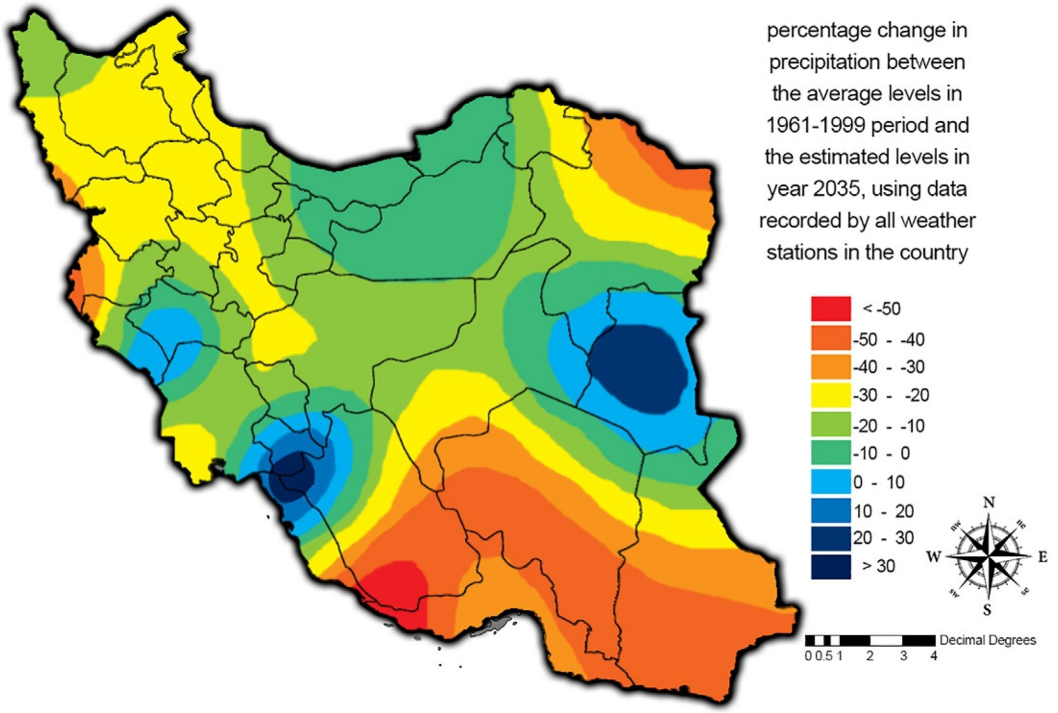

FIG. 14.2 Projection of change in precipitation levels (NCCO, 2015).

Between 1996 and 2011, the rural population decreased by 5%, and the total number of rural villages in the country decreased 9.

The Middle Eastern countries, particularly Iran, are very concerned about climate change. Iran will see a 2.6-degree increase in average temperature and a 35% decrease in precipitation over the next decade, compared to other Middle Eastern countries. Iran's high greenhouse gas emissions are a result of significant oil and gas production, as well as rapid urbanization. Mansouri et al. investigated issues related to climate change on a global, regional, and national scale in a study published in 2019. Annual temperature increases and greenhouse gas emissions were considered for this purpose. In Iran, changes in meteorological characteristics like surface temperature, total precipitation, and longwave radiation were also studied. The findings revealed an unusual decrease in precipitation events, as well as increased radiation and temperature characteristics, confirming the effects of global warming/climate change (Mansouri Daneshvar, Ebrahimi, & Nejadsoleymani, 2019).

The findings of studies conducted in Iran, including those conducted in Marvdasht, show that climate change significantly impacts the agricultural sector. According to Khoshakhlagh and colleagues' research, the rate of wheat harvest in Marvdasht city decreased by 3.38% in the 2007–08 water year compared to the previous year due to drought. Farmers who used river or canal surface water, according to Mohsenpour and Zibaei, experienced a sharp drop in expected income as a result of the drought, owing to their reduced access to water. Furthermore, research conducted in this city reveals that farmers have not adapted to the effects of climate change. For example, Qareli conducted a study in the area below the Doroudzan Dam, claiming that the value of water has increased as a result of the droughts, and that farmers' cultivation patterns are not optimal and that they are not working efficiently. Forouzani also conducted a study on farmers in Marvdasht, concluding that the farmers studied are lacking in human, technological, financial, and social capacities to make the best use of available water resources (Azizi Khalkheili, Zamani, & Karami, 2016).

Climate change is a web of interconnections. This chain begins with development activities, particularly fossil fuel consumption, and has a number of consequences. The amount of greenhouse gas emissions, their control, and their consequences, such as global warming, settlement submergence, storms, floods, and droughts, have all been studied so far. These events appear to be leading to homelessness and displacement and large-scale migration, statelessness, unemployment, poverty, and insecurity. Hundreds of millions of people have been affected by climate change, but many are unaware that they are victims. Between 2000 and 2004, 98% of the estimated 262 million people affected by climate change lived in developing countries (Khoshmanesh, Pourhashemi, Soltanieh, & Hermidas Bavand, 2015).

14.3.1 The Most important effects and consequences of climate change on global security and human rights

Creating war and conflict

Climate change might have a greater negative security impact in areas where there are currently armed conflicts, such as East and Central Africa, the Middle East, and Central and East Asia.

Bangladesh, which was militarily and politically controlled by Pakistan's western region, was struck by a devastating tornado in 1970. And then there was the conflict, which culminated in Bangladesh's independence from Pakistan in 1971.

Threat of water and food resources

One of the most significant effects of global warming is a decrease in agricultural production and, as a result, water availability and increased competition for grain.

Unprecedented heat and drought in India, the United States, and Canada reduced grain production by 89 million tons in 2002, reducing global grain production by 89 million tons.

Impact on the spread of poverty

The situation in Darfur, Sudan, is an undeniable example of the struggle for survival and destructive poverty that began in the 1980s with the catastrophic drought and continues to this day.

Long-term climate change appears to have resulted in less rain in Sudan, and much of Africa, particularly in Sub-Saharan Africa, where rain is life and drought is death.

Impact on internal and external migration

Global warming's most disastrous consequence is migration. Natural disasters have unexpectedly increased in number, affecting 231 million people per year on average, with climate change-related disasters accounting for 98% of all disasters.

Climate-related wars and conflicts drove 42 million people to migrate in 2008. According to the Norwegian Rescue Association, natural disasters caused by climate change forced 20 million people to flee their homes in 2008.

Impact on geographical and political borders

The melting of the Arctic ice will open the Northwest Passage as an international shipping route, and access to rich resources, including oil, will spark debate over the waterway's governance and ecological dimensions.

The conflict is intensifying as several countries draft political and legal bills for submission to the judiciary and assert claims over various regions of the region.

Threat to human health and the spread of infectious and dangerous diseases

According to the World Health Organization, 150,000 people died in 2000 as a result of climate change's effects. Additionally, there are reports of 300,000 deaths in 2003 due to an increase in malaria. According to projections, that number could reach half a million per year by 2030 (Khoshmanesh et al., 2015).

14.3.2 Reasons for the inefficiency of climate change management in Iran

Weaknesses in compliance with the principles governing air protection

A. Air pollution control laws should create an accurate and comprehensive list of pollutants and subject them to prohibitions, phase-outs, or emission restrictions. However, the list of air pollutants included in the laws enacted in this area is insufficient. These laws do not use the mechanism of prohibiting or phasing out the release of hazardous and replaceable pollutants. Also, due to time constraints, the rules for controlling released pollutants and how to manage them, such as the need to create natural and artificial wells, and the rules for emissions, have not been institutionalized (Deputy of Infrastructure Research and Production Affairs, 2017).

B. Pollutant emission standards for each production unit have not been developed at the national (national emission standard for each specific type of pollutant) and local levels (depending on the type of production unit and its product).

C. Pollution control regulations should be codified at the national and local levels with a control approach tailored to the region's specific conditions. This method has been heavily considered in adopting this category of regulations. The regulations governing local control, on the other hand, apply to seven major cities in Iran, particularly Tehran. Special regulations governing local air pollution control have not been adopted in vehicle pollution and other local areas, such as industrial and agricultural areas.

D. Although some polluting gases are subject to controlled and reduced regulations, particularly in the case of industries, the methods for compensating for this reduction by polluting sources and the use of alternative materials to maintain the level of production are not included in these regulations. Some units meet certain requirements, such as lowering the emission of certain materials. During production, certain standards must be followed, such as filter installation, waste disposal in a specific manner, and the use of healthy fuels like gas. At the same time, the financial and technical costs of adhering to these standards are not covered. As a result, it will impose additional costs on industry and the economy, which is incompatible with the principle of sustainable development unless modification methods such as charging emissions for certain gases or phasing out emissions, emissions taxes, technical assistance, and economic incentives to use healthier production methods are implemented.

Failure to adopt a cross-sectoral approach

A. Energy
B. Transport
C. Industry
D. Agriculture
E. Economy
F. Health
G. Education and information
H. Administrative organization

In terms of expertise and the complexities of air pollution and its interconnections with other fields, organizational empowerment entails establishing various units and training specialized human resources to combat air pollution. The provision of interministerial and cross-sectoral units to coordinate these measures is a basic requirement in the next stage. The Air Pollution Investigation Office of Iran's Ministry of Environment is the country's only specialized governmental organization in charge of air pollution control. However, no steps have been taken to establish cooperation between ministerial units. It has always been difficult to take coordinated measures, formulate joint executive plans, and put them into action. Training specialized human resources in the field of air pollution control can help strengthen these organizations in ways that the relevant institutions have not considered before.

Poor performance guarantee

The use of performance guarantees for enforcing the rules and legal provisions in the approved regulations in this field has been based on three axes of criminal punishment: imprisonment, fines, and the prohibition of the polluting unit's continued operation. Despite the fact that these regulations are relatively comprehensive and cover a wide range of polluting activities, they have not proven to be effective.

Need to regulate and control

To develop and strengthen legal mechanisms to combat air pollution, a comprehensive and coordinated approach to regulation, effective control, and close monitoring is required.

Weak infrastructure and moving toward smart transformation

In the third millennium, a shift in the approach to urban planning is a fundamental principle. In this regard, Iran, as one of the cradles of urban civilization, requires a shift in mindset and a new approach to problem solving. This has begun in recent years, but progress has been slow. However, moving toward smart transformation and achieving a smart city, which will be discussed later in this chapter, is one of the requirements for responding to climate change in the world in general and Iran in particular.

14.4 Moving toward smart transformation in Iran and the status of smart transformation

With the global smart city transformation and developments in planning, research on smart meteorological services has become a hot topic. The unprecedented rate of urban growth and its attendant challenges compelled urban management systems to seek optimal solutions capable of addressing all aspects of urbanism, such as sustainable development, education, energy, environment, safety, and public services. These solutions were labeled as "smart" as information and communication technologies advanced. The concept of "smart city" is introduced to achieve efficient and sustainable cities that can face all different urban challenges in terms of their cultural, environmental, economic, and logical context.

Iran has begun the infrastructure development required to develop smart and innovative solutions tailored to the Persian urban context. It attempts to establish "smart transformation" as a process for implementing ICT technologies and infrastructure to meet local urban challenges. Tehran (the capital), Mashhad, Tabriz, Arak, Tehran, Qom, Isfahan, Shiraz, Kish Island, Urmia, and other Iranian cities have joined the process.

Numerous governmental and nongovernmental organizations are tasked with tracking the smart transformation process. Among them, the following are suggestions:

- Ministry of Information and Communications Technology of Iran (Information Technology Organization of Iran)
- Ministry of Interior
- Iran Ministry of Roads & Urban Development
- Ministry of Economic Affairs and Finance
- Vice-Presidency for Science and Technology
- Supreme Council of Provinces
- Iran Chamber of Commerce, Industries, Mines and Agriculture (ICCIMA)
- Law Enforcement Force of the Islamic Republic of Iran
- Department of Environment
- ICT guild organization of Iran
- And all cities' councils

Aside from developing ICT infrastructure, several projects and initiatives have been established to address the major challenges confronting Iran's metropolises in the areas of transportation, housing, pollution, and urban services. It should be noted that because Iranian cities have different urban climates, social and cultural contexts, and economic situations, local solutions and initiatives that can meet geographic specificities are still in the works, but significant progress has been made in the development of the infrastructure debate. Some of the successful infrastructure developments and initiatives are listed below.

14.4.1 Smart transformation in Iran

Information related to smart transformation in different cities is presented in Tables 14.1–14.4.

To date, notable progress has been made in implementing smart transformation for Iranian cities with unique local characteristics to implement new technologies to address local challenges. It is important to note that smart transportation is a multistep process that is unique to each city's urban culture.

TABLE 14.1 Tehran.

Status	Actions
+8200 km	Fiber-optic network
Done	Tehran Urban Observatory
Done	Smart Tehran Center
Done	Smart parking
Done	Electronic Municipality
Done	Electronic tolls
Done	Development of urban innovation centers
2019	Tehran and the Smart Tehran (STP) program were selected as one of the six finalists selected for the 2019 Smart City World Award in the City Award
2020	Special Mention Award in the WeGO Awards (Mobility Field)
From 2017	Smart city conference and exhibition
Done	Municipal video conferencing system
Done	Municipal telecommuting system
Done	Smart green space irrigation system
Done	The integrated electronic government interaction system
Done	Citizenship and providing smart building permitting services
Done	Bus Finder System
Done	My Tehran smart system

What is “Smart Transformation?” is the crucial question. A fundamental change in the performance of a service, business, or organization on a village, city, region, country, or other scale is referred to as smart transformation. New technologies like ICT infrastructure, artificial intelligence, IoT, cloud computing, virtual reality, augmented reality, data analysis, and online applications and services are not the only way to achieve smart transformation. Rather, it employs them deftly in the face of adversity and requires smart citizens who recognize the importance of smart technologies and are able to use them on a daily basis. It is also important to note that smart transformation must take into account the social, economic, cultural, and environmental contexts.

Extreme urbanization and its effects on living space, the economy, and the political system are among the most significant challenges facing cities and organizations in developing countries like Iran. New technologies may provide new ways to address these issues. Integrated urban management is a serious challenge for Iran’s administrative system and bureaucracy, along with other urban issues.

Thus, identity crises (housing costs, distorted identity structures of neighborhoods, and social context), functional crises (including urban management challenges with high

TABLE 14.2 Mashhad.

Status	Actions
+130 point	Wireless network
+150 km fiber-optic network to connect 24 main points of the municipality	Fiber-optic network
Done	Setting up Mashhad Computer Center
Done	Organizing Telecommunication Towers
+150 pcs	Physical server activation
+360 pcs	Virtual server activation
Done	Electronic municipality
Done	Electronic tolls
Done	Development of urban innovation centers
2020	Silver Award in the WeGO Awards (Sustainable City Field)
From 2012	Smart city conference and exhibition
Done	My City smart system

TABLE 14.3 Ahvaz.

Status	Actions
+80 km length to connect +13 main points of the municipality	Fiberoptic network
Done	Optical fiber development plan
Done	Providing municipal service on the fiberoptic platform
+23 km at a speed of 80 mb/s	Development of home internet service (VDSL)
Done	Video surveillance systems
Done	Building smart management
Done	Smart parking
Done	Distance learning
Done	Electronic municipality
Done	Electronic tolls

TABLE 14.4 Yazd.

Status	Actions
+3000 km	Fiberoptic network
220 g	Input bandwidth capacity
96 g	The peak of bandwidth consumed by operators
18,000 GB/s	The core capacity of the national information network
4500 GB/s	International communication capacity
Done	National Center for Information Exchange
Done	E-government services
Done	NB-IoT network
Done	Municipal video conferencing system
Done	Municipal telecommuting system
Done	Smart green space irrigation system
Done	The integrated electronic government interaction system
Done	Citizenship and providing smart building permitting services
Done	Bus finder system
Done	My Yazd smart system

population mentioned economic challenges for citizens), transportation and service crises, environmental crises, and other crises are the most significant urban management challenges in Iran as a result of urbanization.

As a result, to effectively address cities' environmental, economic, social participation, and preservation, systematic urban management is the most basic need. It could be in the fields of development management, participatory management, knowledge management, indigenousness, development control, and smart growth. To deal with the introverted and decentralized structure with minimal interinstitutional partnership and low citizen participation, a transformation in the structure of urban management is needed. It is capable of meeting smart city management standards as well as the structural and fundamental changes that are required. Because these structural changes in developed countries have occurred over time as a continuous process, a comprehensive understanding of smart urban management necessitates the development of a step-by-step procedure. "Smart Transformation of Urban Management," the current study, explains this process.

Reviewing and evaluating actions taken in Iran in the context of smart city and smart urban management, particularly in leading cities such as Mashhad, Isfahan, and Tehran, reveal that urban management's effort and intention have solely focused on implementing new technologies in the urban management system. However, the measures taken could be limited to achieving electronic urban management and basic smart service delivery using apps and technology.

Smart and integrated strategies, policies and laws, master plans and projects, guiding and integrating actions, and integrating services and partnerships are the four categories in which smart urban management principles are summarized. Having a holistic approach to urban development strategies, policies, programs, and plans, as well as formulating integrated economic, social, cultural, and environmental goals in relation to the novel smart cites criteria, is at the forefront of achieving smart urban management in Iran. To achieve these objectives, researchers must examine the economic, social, cultural, and environmental effects of urban systems. It necessitates fundamental and intelligent changes in theories, organization, planning, and urban management.

Because of Iran's current urban management system, a complete transformation is required to spread smartness across all layers, dimensions, and urban management processes in an integrated and coordinated manner, which is referred to as "Smart Transformation of Urban Management" in this study. To achieve smart management for Iranian cities, the smart urban management transformation employs new technologies and innovations as a tool. With the maximum use of technology and online services, smart transformation in the structure of urban management will not be accomplished. Rather, smart city management is a multifaceted process that encompasses all aspects of city management (including processes, services, urban interventions, policy making, etc.).

Due to the need to adopt smart technologies, increase productivity, and learn from successful global experiences, changing the structure and fundamental approach to urban management in Iran is an obvious necessity. The use of global experiences in Iran's various cultural and social contexts is the most important factor in the structural plans' uncertainty and management changes. The following are the challenges that urban management faces in its transition to smart urban management.

- The lack of comprehensive and integrated strategies and policies is the first and most pressing problem.
- The introduction of new technologies into the urban management system may result in incompatibilities between the old and new systems. The cost of integrating new programs and software with traditional and older models is high (new hardware and software and the cost of training human resources).
- Another major challenge for smart urban management is the lack of existing technical infrastructure due to sanctions to keep up with new changes. To keep up with the information and communication technology age changes, technical, and scientific training programs are required, as is keeping all groups current.
- The use of advanced technologies adds to the complexity and uncertainty of the situation, and it may be incompatible with the current cultural system. As a result, the localization and formulation of urban management structure and performance should be based solely on successful global examples and designed and planned in the context of society's cultural context.
- A mechanism to control the commitment and loyalty of stakeholders and the private and public sectors of production and industry to the principles and objectives of operations and strategies is needed in a participatory urban management system with a large number of factors, effective groups, and citizens.

14.4.2 Custodian of Iran's smart cities

When the concept of smart city and smart transformation became popular in Iran in recent years, the lack of standards, technical, and implementation systems highlighted the need for a smart city institute to guide Iranian cities toward smart city realization. In January 2020, Iran's Smart City Research Center was established in collaboration with the University of Tehran. With the steps it has taken over the years, this research aims to address the majority of these issues and become Iran's smart city model.

The Smart City Research Center of Iran was established after numerous studies and needed assessments in various organizational, urban, and national dimensions, as well as collaboration with the University of Tehran, to meet some of Iran's research, study, and executive needs in the field of smart cities and other related fields.

One of the Smart City Research Center of Iran's goals and measures is to improve citizens' quality of life and, as a result, livability, which is not unrelated to environmental concerns.

The Iranian Smart City Research Center decided at the end of 2020 to use crowdsourcing and rely on collective wisdom and participation to find better solutions for smart transformation in Iran. As a result, it proposed the establishment of a National Smart City Committee in Iran to facilitate collaboration among stakeholders and key players in the smart city field in Iran, compile a national smart city document, and serve as the primary custodian of the smart city in Iran. The Islamic Consultative Assembly, Ministry of Interior, Ministry of Roads and Urban Development, Ministry of Economy and Finance, Supreme Council of Provinces, Metropolitan Council, Vice-Presidency for Science and Technology, ICT Guild organization, and other stakeholders and influential people made up this committee, which was formed in collaboration with the Ministry of Communications and Information Technology (Information Technology Organization of Iran).

The following are the tasks and missions of the National Smart City Committee:

- Organizing, monitoring, and observing the country's integrated smart city development system with the help of agencies involved in urban management, economics, and information and communication technology, while taking into account the roles of municipalities, the government, the private sector, and society.
- Approve technical, implementation, and financial frameworks for providing smart city services and collaborating and interacting with government and public organizations, the private sector, and emerging innovative groups in the country, as well as monitoring their activities, such as the scope of services, how to share data, how to compensate for services, and how to renew and terminate relevant licenses.
- Ensure that the various public, private, and citizen sectors involved in smart city issues are coordinated and coherent.
- Collaboration and oversight of the development of strategic and legal documents in the smart city's specialized areas.
- Establishing and pursuing short-term plans to implement pilot projects in the areas of smart cities and smart transformation.
- Examining, advising, and cooperating in the field of credit for smart-related projects in Iran.
- Examining cost-effective financing models and investment plans for smart city projects in Iran.

- Approval and grant of smart city standards to all types of applicants for use in cities (including hardware and software).
- Establishing tariffs for municipalities' revenue share from smart city equipment.
- Approval of the working groups of the Committee Secretariat's.

14.5 Conclusion

As previously stated, human life underwent gradual changes until the 18th century, when the Industrial Revolution began. Despite the traditional pattern of using the environment and the ability of the environment to recover, communities did not face environmental crises due to their small population. Perhaps the experience of the late-18th-century Industrial Revolution, with its rise in industrial production capacity, and then the late-19th-century Second Industrial Revolution, with its increasing development of machines and the invention of electricity, introduced a man to a new mode of mass production. As depicted in the vision of industrial cities in the early decades of the Industrial Revolution in cities such as Manchester (England), the situation was pitiful. The global effort in our report on our common future was a wake-up call for humanity's future. Brundtland's efforts at the United Nations World Commission on Environment and Development, which the Rio Conference followed, aimed to find a long-term solution to the environment. However, in the second half of the 20th century, the Third Industrial Revolution and the advent of the age of telecommunications and digitalization painted a picture of a bright future. The emergence of the fourth space, as described by Castells, in the fourth industrial revolution, with concepts like cloud computing, artificial intelligence (AI), deep learning, machine learning (ML), augmented reality (AR), virtual reality (VR), and other disruptive or transformative innovations, signaled the beginning of a new era of smart cities.

The current urbanization trend suggests that, in order to avoid catastrophic climate change, technologies, or smart cities, should be used in the following areas:

1. Bio-jets and hydrogen planes are examples of aerospace industries.
2. Industry sector: Carbon capture technologies will reduce carbon dioxide emissions by more than 30% by 2050.
3. Advanced biofuels production; artificial photosynthesis or the use of algae for bioethanol production is discussed in this section, which can save 1.5 tons of CO_2 per ton of algae oil used.
4. Energy conservation. Thermal cycle, wind energy, gas, lithium-ion batteries, REDOX batteries, and high-temperature, sodium-based batteries are some of the new technologies that can be used in this field.
5. Technologies that help to cut down on harmful emissions (www.oecd.org).

To combat climate change, smart city planning should start with four main elements. To begin, energy conservation and emission reduction should be prioritized in order to mitigate climate change, effectively regulate the use of energy sources and the supply side, reduce greenhouse gas emissions, increase urban greening, and increase urban carbon sequestration capacity.

Second, city planning's scientific capacity and predictability should be increased to cope with extreme weather events such as sea-level rise, heat, cold, drought, flood, typhoon, dust storms, and other types of weather disasters.

Finally, cities must develop intelligent meteorological public cloud platforms for disaster prevention, mitigation, and climate change adaptation planning. There is a need for society and the general public to have access to a comprehensive set of weather information services.

Fourth, smart city technology must be fully utilized, a big weather data "incubator" must be built, smart induction must be implemented, climate change and development must be monitored, and urban planning optimization and dynamic adjustment must be fed back.

At the same time, the COVID-19 pandemic taught us practical steps to take in the face of climate change. Since the Kyoto Protocol, global greenhouse gas emissions, particularly carbon dioxide, have increased, ocean temperatures have risen, arctic ice has melted, heatwaves have become more intense, and rising sea levels have put near-sea levels and river delta settlements in jeopardy. Human health is directly affected by climate change through events such as heatwaves, floods, storms, and indirectly through infectious disease transmission, freshwater availability, and changes in the food supply chain (Campbell-Lendrum et al., 2007). Three directions of action and measures in how cities and societies responded to the COVID-19 pandemic stand out as lessons for addressing climate change and mitigating its risks: (a) restrictions and rules for using and planning cities, (b) digital means and smart city solutions, and (c) research, technology, and innovation (Kakderi, Komninos, Panori, & Oikonomaki, 2021).

The process of smart cities development is long, perhaps as depicted in the 2067 film of a green future with smart cities; a positive view of smart transformation in various fields as a way out is today's cities' challenge.

Finally, the city as an open system comprises three major components: the natural environment, the built environment, and people. The relationships between these three elements indicate the urban arena's stability. It will be challenging to disrupt these relationships. Meanwhile, people are looking for a new way to create a utopia in which new tools and smart transformation are the only ways to achieve excellence.

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CHAPTER

15

Technological solutions for adaptation with Iran's water resources crisis

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15.1 Introduction

The human environment in the 21st century faces challenges and opportunities that the earth as a human habitation has never seen before. Globalization, urbanization, spatial and social imbalances, climate change, and environmental challenges such as wetland drying, droughts, floods and subsidence, and land commodification are among these issues (Pike, Rodríguez-Pose, & Tomaney, 2016). Increased population and demand for natural resources create competition among populations to meet their requirements and place a premium on resource conservation and rational use (Ashoori, Bagheri, Allahyari, & Al-Rimawi, 2016). Among these resources, water is the most vital for agricultural output and food security. Due to severe water scarcity in regions like the Middle East, it is critical to manage and plan for this resource properly (Gholamrezai & Sepahvand, 2017).

Iran is located in the Middle East, which is the largest region in the world in terms of water resources constraints (Khodarahimi & Deghani, 2012). Iran receives an average annual rainfall of only approximately 250 mm, less than one-third of the global average (Motiee, Salamat, & Bean, 2012). Evaporation consumes over 70% of this partial precipitation (Lehane, 2014). Aridity covers 65% of the country, whereas semi-aridity covers 20% (Madani, 2014; Zargan & Waez-Mousavi, 2016). In Iran, annual renewable water resources are less than 1700 cubic meters per person, much lower than the world average (7000 m^3). The vital point is that this is all available water, which in part may be unsuitable for drinking, irrigation, or industries' uses since heavy metals, toxic compounds, nitrate, and salinization contaminate Iran's surface and groundwater (Ghadimi, Ghomi, & Hajati, 2013; Mirzavand & Bagheri, 2020; Mirzavand, Ghasemieh, Sadatinejad, & Bagheri, 2020).

In Iran, surface waters such as Lake Urmia, Lake Bakhtegan, and Lake Gavkhoni are severely depleted of water due to decreased rainfall, increased evaporation, and harmful

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human activities like diversion of rivers, dam construction, unlimited surface water abstraction, and loss of vegetation (Kalirad, Malekian, & Motamedvaziri, 2013; Khatibi & Arjjumend, 2019). The results of Mirzavand and Bagheri's, (2020) research pointed to the issues of (a) an absence of land use planning, (b) poor management and a desire for growth, (c) political allocation of water, (d) inefficient water price, and (e) farmers' incapacity to utilize irrigation systems. In another study, Madani, Agha Kouchak, and Mirchi (2016) identified root issues such as rapid population growth, inadequate spatial distribution, inefficient agriculture, mismanagement, and thirst for development.

Sustainability of water resources requires more focus on reducing demand in favor of a better balance of supply and demand to slow down the inevitable reduction of water resources and the destruction of the water environment. As demand in many countries will outpace supply and population growth, water scarcity will inevitably be worsened unless broader adaptation measures are implemented to limit the demand (O'Connell, 2017). The deployment of adaptation technologies is widely described as the process of reducing a natural or human system's susceptibility to the effects of climate change or increasing its resistance to those effects (UNEP, 2017). Adaptation typically refers to adjusting the behavior and features of a system to better deal with the possible negative repercussions of climate change or embracing potential opportunities. Adaptation to climate change has been considered an essential response strategy to reduce vulnerability and increase resilience in sectors such as water, agriculture, energy, and the environment (Gohari, Mirchi, & Madani, 2017).

Technologies have always been beneficial, providing the conditions for the world to remain habitable for human beings while addressing issues such as the water crisis and adaptation to climate change. We can point to new technologies as a way of addressing environmental challenges and crises. These technologies provide avenues for managing water resources and consumption, converting saline water into drinking water, utilizing atmospheric moisture and converting it into water, and updating agricultural exploitation systems in order to obtain more water with less water consumption.

Implementing these technologies is especially critical in countries such as Iran, which are located in the desert belt of the earth and have long been faced with water crises due to the particular characteristics of their climate. Iranians have had previous breakthroughs, such as qanats, with the purpose of ensuring the sustainable use of water resources and have been able to cope with the water crisis for years utilizing these methods. Nevertheless, in recent decades, due to the unbalanced development that has taken place, water resources in Iran have faced a severe crisis and become a significant challenge for policymakers. With this introduction, this chapter of the book deals with the extent of the water crisis in Iran and the technological solutions that have been proposed to solve these water-related challenges. The information presented in this chapter is based on library studies and semi-structured interviews that the authors had with the experts and government officials related to water management and governance. Specifically, the interviewees had responsibilities and specializations in groundwater management, land subsidence, agriculture, dust, climate change, climatology, and land use planning. The results show that despite the criticality of the water issue in Iran, experts and policymakers still hope to solve the challenges by changing the policy process, adopting policies appropriate to the country's water conditions, and the use of appropriate technologies.

15.2 Iran's climate change and water resource issues

Climate change is an umbrella that includes various environmental phenomena that threaten the very fabric of modern society. It is a multifaceted phenomenon that inevitably leads to an increase or decrease in temperature from the ideal state to the extreme (Wasif, 2018). The roots of climate change are embedded in how a society chooses to develop its habitable environment. Lack of planning in such cases has led to water scarcity or what is more commonly known as the "water crisis." Global climate change is causing an increase in water cycle variety, diminishing the predictability of water availability and demand, impacting water quality, intensifying water shortages, and jeopardizing global sustainable development. These issues disproportionately impact poor and vulnerable people and are exacerbated by variables such as population expansion, uncontrolled migration, land-use change, diminished soil health, rapid groundwater extraction, widespread ecological degradation, and biodiversity loss (UN Water, 2019).

Global warming due to greenhouse gas emissions is likely to change the Earth's climate. Due to the greenhouse effect, increasing the amount of energy trapped on the ground can accelerate water transfer processes in the climate system. Hydrological studies predict that intensification of the water cycle due to global warming will cause significant changes in rainfall patterns and intensity. These changes may increase severe weather events such as droughts, floods, and hurricanes. In addition, scientists predict that higher temperatures will cause large-scale melting of snow and ice stores and help raise sea levels. These changes may impact different groups' access to water (Ruettinger, Morin, Houdret, & Taenzler, 2011). Due to the Middle East's water shortage and the critical role of water in agriculture, industry, and daily life, governments that do not maintain a balance between water supply and demand would suffer political and social difficulties. This problem is compounded in the Middle East, which has a history of political battles over water (Gürsoy & Jacques, 2014). Scientists warn of severe water shortages and desertification in the future. They have stated that access to water will decrease by almost 50% by 2050 (Bucknall, 2007). Significant climate change has been observed in Iran, with an arid and semi-arid climate. Iran has encountered several calamities as a result of management issues, ranging from the decreasing of a substantial number of lakes and rivers to land subsidence, flooding, and drought. Lake Urmia, the biggest lake in the Middle East and one of the largest lakes in the world, has shrunk significantly and may dry up altogether in 6–9 years, depending on the present circumstances. Hamoon Lake in eastern Iran, Parishan and Shadegan Lakes in southern Iran, and the Zayanderud River in central Iran are likewise threatened with extinction as a result of climate change and mismanagement (Vaghefi et al., 2019). Water shortage in Iran has been considered one of the limiting factors of sustainable development. It is predicted that Iran will be one of the countries that will face absolute water shortage by 2025 (Zargan & Waez-Mousavi, 2016).

In recent decades, water-related issues such as water scarcity and pollution, the damage caused by floods, and droughts in various parts of the world, especially in developing countries, have increased. Increasing population growth, increasing urbanization, uncontrolled expansion of industries, and development of agricultural lands in arid and semi-arid regions of the world have increased the need for clean water and, as a result, water harvesting. In addition, the increasing human involvement in the ecological potential of the environment and the issue of climate change have placed increasing pressures on the quantity and quality of limited water resources. Due to the particular geography of Iran and the predominance of semi-arid climate in most of its areas, pressure on water resources has shown its effects in various ways, including the increased vulnerability of urban and rural settlements to floods (more than 3500 floods in the last 20 years in the country with average damage of 400 billion rials per flood and more than 450 cities and 8650 villages at the risk of floods with a population of 55 million people), drying, pollution (due to agricultural, industrial, and urban pollutants) and reduction of water entering the wetlands, lower quality of water resources, expansion of dust hotspots, and increase of subsidence (more than 90% of plains of the country are prone to this phenomenon).

The world's average annual rainfall is 813 mm, but the Middle East and Iran receive 217 and 228 mm, respectively, less than one-third of the global average. The study of water consumption by main sectors shows that in most parts of the world, except continental Europe and the United States, the agricultural sector has the largest share of water consumption. Iran's share of the world's freshwater resources is lower than other regions. While Iran has 1% of the world's population, its share of freshwater resources is only 0.3%. The UN Commission on Sustainable Development has introduced the percentage of withdrawals from each country's renewable water resources as an index for measuring the water crisis. According to this index, the Middle East with a coefficient of 55% (Mohammadjani & Yazdanian, 2014) and Iran with a coefficient of 89.9% (in the long run, for a period of 15 years leading to 2016, it is about 97%) are facing severe water crisis (SPRI, 2020).

As a result of droughts and climate change, the total amount of renewable water in the country has fallen from a long-term average of 130 billion cubic meters to 89 billion cubic meters (average of the last 10 years ending in 2017). In other words, compared to the long-term average, the amount of renewable water in the country in the years leading up to 2017 has decreased by about 32%, which is a very significant decline. By 2017, about 135 billion cubic meters of static groundwater resources had been lost. Considering the total static reserves of groundwater resources in the country, which is a figure of about 500 billion cubic meters, it can be stated that, unfortunately, about a quarter of the static reserves of groundwater resources have been destroyed (The Research Centre of Iran's Parliament, 2017).

In the decade of 2005–15, the amount of rainfall in the country has decreased by about 9.7% compared to the long-term average, and consequently, the volume of surface flow in the same period has decreased by about 27.5% (SPRI, 2020). It is noteworthy that the decrease in rainfall was due to drought and climate change, but the decrease in surface runoff was due to upstream harvests. In the past 15 years, one of the reasons that the country's dam reservoirs have been filled with water up to half has been the improper upstream water withdrawal (The Research Centre of Iran's Parliament, 2017).

Currently, in many cities of Iran, the water supply faces many challenges. Table 15.1 shows the population and number of cities under water stress in recent years. Annual changes in rainfall, measures taken by the National Water and Wastewater Company to manage water demand and consumption, increase water supply and transmission capacity, and improve drinking water quality have reduced the population exposed to water stress in recent years. Nevertheless, despite the significant rainfall in 2018–19, the urban population under water

TABLE 15.1 Number of cities and population exposed to water stress in the country in recent years.

Number of cities exposed to water stress	Number of people exposed to water stress (mil)	Year
233	28.6	2019
336	35.1	2018
289	35.0	2017
301	35.6	2016
547	50.7	2015

From SPRI (2020). Designing prototypal environmental projects according to Iran's Macropolicies for Resilient Economy, Tehran, Iran. [in Persian].

stress is still significant, indicating the significant vulnerability of urban water supply systems in arid regions of the country.

In 2017, about 91 million hectares of watersheds (55.5% of the total area) were prone to flooding. These areas produce more than 22 million cubic meters of direct and fast water per year, intensifying erosion and destructive floods (Agricultural Statistics, 2017). The devastating floods in Golestan, Lorestan, and Khuzestan provinces at the beginning of 1998, the increase in flood events in all parts of the country, and the associated economic and social damages, raised concerns about how to deal with the causes of floods and how to compensate. In recent years, in addition to causing heavy financial losses and endangering economic activities, floods have had a very negative impact on the psychological state of vulnerable communities and their level of satisfaction with the government.

Subsidence is another environmental crisis in Iran. One of the consequences of this phenomenon is the condensation of sediment particles that make up the aquifer, which is, unfortunately, a non-return procedure. The result is a loss of capacity and water transfer in the aquifer even after water supply. For this reason, subsidence is interpreted as aquifer death. All the technical shreds of evidence and proofs show that the main reason for the crisis of land subsidence is the destruction of the country's aquifers due to the improper abstraction of groundwater resources. According to the Iranian Ministry of Energy, 420 plains out of 609 are among the Prohibited Operating Zones. Many of them are among the largest and most developed economic and social centers of the country. Of the remaining 190 plains, 150 lack aquifers; this means that less than 10% of the country's plains are still in equilibrium, and more than 90% of them are out of equilibrium in which the presence of succulent granular layers is not expected, i.e., they are prone to subsidence. Given the average drop of 55 cm in the country's aquifers, it can be expected that subsidence in the country is an expanding phenomenon.

According to studies, subsidence has occurred primarily due to the decline of groundwater caused by the industrial revolution. Table 15.2 shows the extent of subsidence in Iran's two largest cities (Tehran and Mashhad), which accounted for a quarter of the population and 40% of the Iranian economy. Studies show that in 2004, the settling rate was 16 cm per year, but

TABLE 15.2 Rate of recent global subsidence in various locations.

Measurement method	Period	Rate (mm/year)	Location
Global positioning system	1993–2003	111	Aguascalientes Valley, Mexico
Differential interferometry	1995–2001	23	Anthemountas Basin, Northern Greece
Differential interferometry	2006–2009	230	Bandung, Indonesia
Leveling	2006	30	Bangkok, Thailand
Differential interferometry	2003–2009	115	Beijing City, China
Differential interferometry	2002–2006	40	Bologna, Italy
Differential interferometry	2003–2009	70	Coachella Valley, California, USA
Differential interferometry	2004–2008	20	Datong, China
Differential interferometry	1992–2006	23	Gioia Tauro plain, Italy
Leveling	2002–2008	65	Guangrao, Yellow River Delta, China
Differential interferometry	1996–1998	40	Houston–Galveston, Texas, USA
Global positioning system	1997–2010	220	Jakarta, Indonesia
Differential interferometry	2003–2005	280–300	Mashhad Valley, Iran
Differential interferometry	2002–2007	380	Mexico City, Mexico
Differential interferometry	2008–2009	35	Murcia, Spain
Global positioning system	2006–2009	100	Quetta Valley, Pakistan
Leveling	1994	160	Saga Plain, Japan
Global positioning system	2007–2009	130	Semarang, Indonesia
Differential interferometry	2004–2008	205–250	Tehran Basin, Iran
Differential interferometry	1995–2001	45	Thessaloniki plain, Northern Greece
Leveling	2007–2010	30–40	Tianjin, China
?	1977–1988	40	Tokyo, Japan
Differential interferometry	2003–2008	90	Toluca Valley, Mexico
Differential interferometry	2007–2011	184	West of Villa De Arista, Mexico
Leveling	2002–2007	100	Yunlin, Taiwan
Differential interferometry	2007–2011	128	Zamora, Mexico

From Shiri, M., & Razavi, B. S. (2017). Comparison of land subsidence in Iran and other countries, the second conference on engineering geology and environment in Mashhad, Ferdowsi University of Mashhad.

from 2004 to 2012, the settling rate reached 20.7 cm per year due to the tripling of water abstraction. Studies conducted in Iran show an uncontrolled increase in groundwater exploitation alongside the droughts of the past 2 decades. The world's somewhat controlling and decreasing trend and the noticeable increasing trend of Iran are highly contrasting. High groundwater per capita means the country is highly dependent on groundwater resources.

15.3 Research methodology

The present study was methodologically descriptive analytical and applied in nature. The present qualitative exploratory research used in-depth interviews in order to obtain useful and reliable research data up to a theoretical saturation point. The study's sampled population (interviewees) included middle managers of relevant organizations and researchers and faculty members related to the research topic. Since qualitative research methods do not use probabilistic sampling methods, the purposive sampling method was used. The interviews continued until the theoretical saturation was reached, which resulted in 30 interviews in total. Interview scripts were then analyzed using the content analysis method.

Water challenges were identified based on the literature review and interviews with relevant experts, which were then divided into three groups: (a) environmental challenges in which man's activities do not have much impact on creating these challenges, (b) governance or institutional challenges whose main causes are the laws that man imposes on the surrounding nature, and (c) economic and social consequences of environmental challenges. Table 15.3 illustrates this categorization in detail.

TABLE 15.3 The most important environmental and institutional challenges related to water.

	Type of challenge			
Field	**Governmental or institutional**	**Environmental**	**Economic or social**	**The most important challenges**
Wetlands				Increasing trend of wetland drying
				Decreasing water quality of wetlands due to the spread of nutritional phenomenon (eutrophication)
				Increasing number of non-native and harmful species in wetlands
				Habitat shrinkage
				Increasing salinity of wetlands
				Decreasing habitat capacity of wetlands
				Severe reduction of natural production capacity and economic support capacity of wetlands
Dust				Lack of necessary standards and instructions to provide practical solutions to deal with dusts
				Continuity of drought and limited water resources in arid and semi-arid ecosystems; increase in intensity and scope of domestic and foreign dust hotspots
				Lack of assessment of economic and social damages of dusts

Continued

TABLE 15.3 The most important environmental and institutional challenges related to water—cont'd

Field	Type of challenge: Governmental or institutional	Environmental	Economic or social	The most important challenges
				Structural and institutional coordination failure between related organizations and ministries
				Lack of international funding to deal with dust, especially for border hotspots
				Difficulties in predicting, monitoring, and informing people of sandstorms
Land subsidence				Lack of interorganizational coordination for water management issues and subsidence
				Improper management of water resources in all stages of identification, exploitation, implementation, and monitoring
				Improper harvesting and digging of wells in critical areas
				Ignoring the risk of subsidence in development projects
				Lack of knowledge of the volume and quality of water resources; lack of national online monitoring system
				Inefficient agriculture that is unsuited for the available water resources
Water scarcity				Unbalanced distribution of economic and social activities considering the water resources
				Increase in the socio-economic vulnerability of the country to floods due to uncontrolled land use change
				Imbalance between the share of provinces in achieving agricultural self-sufficiency and the amount of water available in each province
				Not observing water rights of rivers and wetlands
				Unbalanced distribution of water budget between supply and demand sides
				Inadequacy of budgets for water consumption management projects considering their effectiveness in reducing evapotranspiration and pollution of water resources
				Lack of attention to underground water rehabilitation plans and restoration projects

TABLE 15.3 The most important environmental and institutional challenges related to water—cont'd

Field	Type of challenge: Governmental or institutional	Environmental	Economic or social	The most important challenges
				Missing the opportunity to control water exports and to import virtual water
				Lack of a national water audit system
				Weakness of legal and executive mechanisms for standardization of water equipment used in buildings
				Excessive non-drinking use of drinking water
Sea				Increasing microbial pollution of the sea water due to urban and rural wastewater entering it
				Failure to comply with environmental requirements in construction and development activities in coastal areas
				Drying of the sea as a result of coastal development activities and the destruction of coastal habitats
				Development of tourism, industrial, urban activities in coastal areas regardless of territorial development potentials
Climate change				Lack of governmental organizations and agencies' understanding of the issue of climate change despite the laws passed on
				Absence of legal, technical and executive infrastructure necessary for public–private partnership
				The country's high vulnerability due to the consequences of climate change
				Severe drop in surface runoff and thus high harvesting of groundwater to compensate for that
				Lack of the technologies needed to reduce greenhouse gas emissions
				Continuous and prolonged droughts

Based on the interviews, seven critical challenges were identified for the wetlands, out of which six were related to environmental challenges and one to governance. Unfortunately, many wetlands in the country are currently in poor condition. The director of the Wetland Ecosystems Office of the Iranian Department of Environment considers the most important factor contributing to the unfavorable situation of the wetlands to be improper management of water consumption in various fields of agriculture, industry, and drinking. The most crucial challenge for wetlands is water competition, and since wetlands are usually located at the base of the watersheds, they are defeated in this competition. Six out of Iran's 20 wetlands, which are registered under the Ramsar Convention, have been exposed to ecological change, and as a result, they have been included in *Montreux* Record. This record contains "Shurgol, Yadegarloo, and Dargah Sangi," "Anzali Wetland Complex," "Shadegan, Khoralamieh, and Khormousi," "Neyriz and Komijan," "Southern End of Hamoon Pozak," and "Hamoon Saberi and Hamoun Helmand" wetlands.

One of the environmental challenges of Iran is the dust out of storms. In addition to dust particles, storms contain dry particles suspended in the air caused by industrial pollutants, forest fires, desertification, vehicle traffic, and the destruction of the earth by human activities. These storms pose a serious threat to human communities and the environment due to their long transmission paths. Because of Iran's location in the desert belt and the arid and semiarid climate of the Middle East, the issue of dust storms is inevitable. Still, the intensification of this environmental phenomenon in recent years, especially in Iran's western and central regions, could be for natural and human reasons. In addition to moving surface soil particles such as humus, clay, and soil salts, storms also cause air pollution, respiratory problems, and reduced visibility. Recent years have shown an increase in the frequency of this phenomenon in the provinces of Ilam, Khuzestan, Kermanshah, and Kurdistan.

Another major challenge is the problem of land subsidence, which was identified to be all a matter of governance. Groundwater supplies in Iran have been under severe strain for 4 decades, and these resources have been depleted. The loss of groundwater supplies has created an artificial drought in several sections of the nation, resulting in land subsidence. Land subsidence, which is one of the less-considered challenges in the country and mostly due to the improper management of water resources, will cause heavy damages. In some areas, a record of 10–30 cm of land subsidence have been reported per year. According to the Secretary-General of the Flood Control and Aquifer Management Office of the Forests and Rangelands Management Organization, unfortunately, the subsidence rate in Iran is very high, and the important plains of the country are facing a negative water balance. On the other hand, illegal water activities have created challenging conditions in 67% of the country's aquifers and made critical aquifers with subsidence rates of more than 35 cm forbidden.

The challenges of water scarcity have been identified via 11 components, 10 of which were related to governance issues. The damage caused by water shortage is more than the damage caused by other environmental hazards such as floods, earthquakes, or storms. The adverse effects of the water crisis are gradually emerging in various sectors of agriculture, economics, health, international relations, and the environment. If the necessary measures are not taken to deal with the adverse effects of the water crisis, this crisis will turn into war and tension, which will then have irreparable impacts. The Deputy Minister of Human Environment of the Iranian Department of Environment has argued that the silo approach, bad governance, and irrational policies are the major contributors to Iran's water crisis: "people cannot be expected to reform their habits and behaviors unless the water management system begins to reform on its own and the water, agriculture, and environment sectors are coordinated."

The environmental challenges related to the seas have been identified as three governance issues and one environmental issue. According to the Deputy Minister of Marine

Environment of the Iranian Department of Environment, due to bordering three seas, namely the Persian Gulf, Oman Sea, and the Caspian Sea, with a coastline of more than 5800 km, free trade-industrial and special economic zones of the country in the southern coasts have an excellent capacity for sustainable maritime development. However, there exist various challenges for these zones, including overfishing, drastic reduction of aquatic stocks, entry of non-native invasive species, reproduction and breeding of non-native aquatic species, destruction of beaches and islands, destruction of sensitive habitats, smuggling of endangered species, and entry of various wastes especially plastic ones into the sea.

The Caspian Sea, for example, is the largest utterly closed water area in the world that is not naturally connected to any ocean. This feature makes the sea more vulnerable to environmental problems. Another characteristic of the Caspian Sea is that the water level of the Caspian Sea is lower than that of the oceans. The environmental effects of the rising Caspian Sea water level are:

1. Destroying residential, commercial, and administrative units along the coasts and submerging agricultural lands;
2. Malfunction of the waste management system and surface water;
3. Entry of surface pollution of the coasts into the sea and the intensification of microbial pollution of coastal waters;
4. Increasing the number of nutrients in coastal water and reproducing destructive marine fish;
5. Changing the environmental conditions of the coasts and thus threatening the coastal habitats;
6. The entry of saline water into the coastal wetlands and the salinization of the coastal and agricultural lands; and
7. Increasing the rate of coastal land erosion.

Climate change has been acknowledged as a key concern in the realm of water resource management. This study identified climate change challenges via six components that, like most the other challenges, were mostly governance issues. Disturbance of the climate system due to the increase of greenhouse gases warrants investigating the effect of climate change on hydrological parameters such as evaporation and transpiration. Climate change can have dramatic effects on water resources and freshwater ecology. Due to rising concentrations of greenhouse gases, especially carbon dioxide, global climate change is expected to cause changes in precipitation regime, wind speed, solar radiation, and surface temperature. Changes in the hydrological cycle are one of the consequences of global warming that significantly affect on water and soil resources and change runoff, sediment, and soil erosion in the basin. Taking appropriate measures to reduce vulnerability requires assessing the impact of climate change and the effectiveness of adaptation options.

As can be noticed from the challenges presented in Table 15.3, most of the country's water challenges go back to the overexploitation of water reserves. Natural events, such as drought and flood, have exacerbated this situation and intensified the human settlements' vulnerabilities. This gap, which has not been seriously and practically taken by the society as well as the government into consideration, has finally manifested itself in the form of land subsidence, intensification of dust, floods, drying of wetlands, evacuation of villages, and destruction of ecosystems. Such conditions have necessitated the adoption of a comprehensive approach that can define the sustainable distribution of water under the capabilities and needs of the territory. Designing water activities in the context of a spatial development approach is a perspective that can offer such a capability. The application of spatial development planning in the face of environmental changes can be classified into two areas of adaptation and mitigation, which is summarized as follows:

a. To adapt to environmental changes:
- Zoning adaptable activities for each region;
- Designing a resilient infrastructure system for each region;
- Providing green and blue infrastructures for flood mitigation and water recycling; and
- Establishing rules and regulations for resilient construction in each region.

b. In order to reduce the effects of environmental changes:
- Creating a settlement system in balance with the ecological capacity;
- Zoning and determining land use based on ecological capabilities;
- Establishing rules and regulations for green/sustainable construction in each region; and
- Designing green/low-carbon transportation systems.

15.4 Technological solutions

Scientific and technological advances have rapidly had far-reaching and dramatic effects on all aspects of human life and countries' economic, social, cultural, and environmental relations. With the formation of the green revolution and the consequent introduction of technology into the agricultural sector, exploitation systems underwent fundamental changes, and concerns related to food security in proportion to population growth were relatively well addressed. However, agricultural technologies were mainly used in more developed countries, and in this regard, imbalances arose between countries. In association with environmental crises, technology is now ready to help find solutions and reduce the burden of problems. Among the technological tools that can help ecological balance, one can point to the development of technologies related to salt treatment and desalination, electrodialysis, production of microfilters and ultrafilters of water treatment, new thermal methods in water desalination, application of remote sensing technology to manage groundwater resources, utilization of aeroponic and hydroponic greenhouses as methods of cultivation that consume water less than one-tenth of outdoor cultivation with higher quality, and various systems of water distribution management in farms. According to the survey and interviews with water and environmental experts, the following technologies are of high priority for use in Iran.

15.4.1 Water extraction from air humidity and rainwater

Iran is composed of different ecosystems and climates and thus requires different technologies and innovations—commensurate with the local capacity—for these diverse climates and water issues. One of the technologies proposed by experts—only for the southern and coastal regions of the country due to their high volume of air humidity—is the technology of extracting water from the atmosphere by Warka Water. Warka Water tower can provide drinking water in problematic urban and rural areas (Sangita Mishra, 2018). The Italian company Architecture and Vision, the designer of Warka Water, has announced the largest towers of Warka Water at 10 m weighing 60 kg, capable of producing about 100 L of water per day. As it has been said, due to the high humidity in Iran's southern regions, this technology will help supply drinking water to the residents of these regions.

15.4.2 Intelligent volumetric water meters combined with water consumption management systems

A smart water meter is a typical water meter connected to a data logger. This technology allows continuous monitoring of water consumption. Features of smart water meters are (1) water leak warnings for quick repair planning; (2) checking consumption and payment bill online; (3) the capacity to regulate the amount of water that enters the system; and (4) ability to automate water rationing. These meters are equipped with shock sensors, temperature sensors, meter lid opening, and magnetic field. They have industrial and domestic applications and can measure and control water wells and agricultural uses (Sonderlund & Smith, 2014). Due to the lack of water management in Iran's agricultural sector and the greatest water consumption in this sector, this tool can assist in managing consumption in this area.

Metering systems can measure the amount of water in and out of houses and warn urban users in case of excessive consumption. This system can notify users of water leaks or other accidents by measuring consumption or automatically notifying water relief centers to prevent damage. It is based on sensors, smart meters, artificial intelligence, and digital technology (Fuentes and Mauricio, 2020). Deployment of such systems is a high priority considering that the per capita consumption of drinking water is about 200–220 L per day in Iran, about 70–80 L higher than that of the world.

15.4.3 Remote sensing systems to manage groundwater and measure soil subsidence

Until 2 decades ago, the only ground subsidence detection tool was the ground observation method with GPS satellite positioning and leveling systems, which were very time consuming and expensive, limited to a series of specific points, and impossible to identify the subsidence area. Today, remote sensing technology and radar satellite imagery are efficient and cost-effective tools for monitoring land subsidence with very high accuracy for large areas. These images are taken periodically. The subsidence rate and the areas affected can be monitored with an accuracy of less than 1 cm based on the time series of these images. Given the critical situation of Iran's groundwater resources and subsidence in recent decades, the production of land deformation maps such as subsidence maps and groundwater maps is inevitable for the initial zoning of high-risk areas.

15.4.4 Hydroponic greenhouse cultivation

Persistent droughts in Iran, as well as the indiscriminate use of water resources in the agricultural sector, have compelled policymakers to make changes to the agricultural exploitation system. One of the developments in recent years has been greenhouse cultivation that requires to be more inclusive, both geographically and socially. Iran's unique geography (with many hours of sunlight), cheap and readily available energy, cheap labor, and, most importantly, the existence of a stable international market (Russia in the north and Persian Gulf countries in the south) create ideal conditions for the development of greenhouse cultivation.

Hydroponics is the cultivation of plants in nutrient solutions without using soil recommended for crops such as tomatoes, cucumbers, peppers, lettuce, and in general for fast-growing plants. The Netherlands, Spain, Japan, New Zealand, Morocco, the United Kingdom, Turkey, and the United States are the leading countries in this method (Lakhiar, Gao, Syed, Chandio, & Buttar, 2018). Hydroponic greenhouses have many advantages over earthen greenhouses, including the following:

- There are no pollution or soil toxins in the hydroponic method since the soil is not used and water pollution is reduced;
- The quantity and quality of products are higher such that using this method in an area of 4000 m^2, cucumber production is four times, tomato production is 12 times, lettuce production is two times, and cabbage production is 1.5 times of similar products cultivated in soil;
- In hydroponic cultivation, the nutrient solution is liquid and can be easily controlled, and only nutrients that have been reduced can be added to the solution. However, this is impossible for cultivation in soil.
- Hydroponic cultivation can be used where the soil is unsuitable or suffers from some diseases; and
- It does not need plowing, irrigation, soil pest, and weed control, and its water consumption is lower than soil greenhouse cultivation. For example, to produce 1 kg of tomatoes in a normal greenhouse, 30 L of water are needed, while a hydroponic greenhouse requires about 17 L.

15.4.5 Flood warning technologies and intelligent systems

Intelligent systems with sensors to collect data such as the water level of rivers, lakes, and water storage tanks (dams) and other weather data such as wind speed, air pressure, and rainfall can help humans combat floods. Data centers store flood data from the past 2 decades and analyze it in case of danger by using artificial intelligence technology to issue warnings and take preventive measures to control the flood. This system can significantly reduce losses with appropriate decision-making power in certain situations (Sakib & Ane, 2016). Due to the climatic characteristics of Iran, floods hit urban and rural settlements every year and cause irreparable human and financial damage. According to the experts, the development of these systems can significantly reduce flood damage and losses.

15.4.6 Seawater desalination technologies

The most common water desalination methods are thermal, membrane, and hybrid processes. According to the interviewed experts, considering the existence of several power plants, long beaches in the country's southern regions, and the benefits of the hybrid method, it is recommended for Iran to follow the hybrid method. Its advantages are

1) Ensuring water production in cases where it is impossible to use the thermal process due to the out-of-circuit part of the power plant. In these cases, membrane methods can be used to produce water;

TABLE 15.4 High priority technologies to solve environmental crises in Iran.

Rank	Expert rating (1–10)	Application	Technology
2	9	Producing drinking water from air humidity	Warka Water
1	9.5	Managing water consumption in the domestic and agricultural sectors	Intelligent volume meters and consumption control systems
4	8	Monitoring the subsidence rate and the areas affected by subsidence with less than 1 cm accuracy	Remote sensing and subsidence management systems
2	9	Managing water consumption in agriculture sector (reducing water consumption by up to 10%) and increasing agricultural production (10–15 times)	Hydroponic greenhouse cultivation
3	8.5	Preparing citizens to deal with the risk of flooding and reduce its destructive effects	Flood warning technologies and intelligent systems
1	9.5	Producing drinking water from renewable water sources	Hybrid seawater desalination

From Research findings.

2) Significant reduction of additives in thermal processes due to the possibility of combining water produced from the membrane process with water produced from the thermal process;
3) Lower temperature of water and effluent produced in the hybrid method than the thermal method; and
4) Utilizing excess network electricity for the membrane process when water is needed.

In Iran, the hybrid method has been used for water desalination for several years, and thus of a good experience. The development of this technology in the southern and coastal areas of the country, i.e., the areas with long beaches, can reduce the problem of freshwater supply.

Although the above technologies (Table 15.4) are of priority to be developed and deployed in Iran, other technologies can lessen the water crisis and mitigate the negative effects of climate change on water resources. In particular, the authors may name laser technology for detecting atmospheric currents and water vapor, software and web services for climate data dissemination, industrial wastewater treatment with plasma technology, use of renewable technologies for water desalination, as well as technologies based on quantitative modeling and climate change prediction or artificial intelligence and computing.

15.5 Summary

Challenges created in Iran's urban and rural settlements related to the water crisis and climate change are generally categorized into two super challenges: (1) incompatibility of the country's economic development model with the environmental developments and (2) incompatibility of the country's governance model with the environmental changes.

According to the experts, the current development model of Iran is not commensurate with the capacity and environmental capabilities of the country. In this regard, policymakers and decision-makers see two ways in front of them: first, to reduce their pressure on nature, which is practically impossible due to the population growth and increasing demand; and second, to increase the level of productivity in water consumption across all sectors through institutional changes. Technology is only one ingredient of the solution. The results showed that considering the climatic conditions of Iran, high priority technologies that can alleviate this crisis are those related to (1) accessing new sustainable water sources such as desalination of seawater and conversion of air's moisture into the water, (2) information management and status warnings such as the use of remote sensing systems in water management, groundwater, weather forecasting systems, and flood warning systems, and (3) improving water productivity such as the development of greenhouse cultivation in agriculture or smart water consumption control technology in the domestic sector.

However, the use of technology has several risks in resolving the water resources crisis. One of them is the incompatibility of technology with the economic and cultural structure of regions and countries. Technology's most apparent economic risk is due to the lack of political support, high maintenance and operation costs, and depreciation, which is widely observed in developing countries such as Iran. On the other hand, the use of technology may not necessarily reduce water consumption because the saved water may be used, for example, to rather develop the area under agriculture.

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CHAPTER

16

The way forward for data-driven and climate-resilient cities

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16.1 Contributions of smart solutions and technologies to climate change adaptation and mitigation

Efforts to deal with climate change have been on two fronts: mitigation and adaptation (Laukkonen et al., 2009; Pachauri et al., 2014). The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "the process of adjusting to real or expected climate and its impacts" in human and environmental systems. Mitigation was also defined as "a human intervention to reduce the sources or improve the sinks of greenhouse gases (GHGs)" (Pachauri et al., 2014).

The main thrust of this volume was to build on the existing knowledge of the potential and/or actual contributions of smart city solutions and technologies to climate change adaptation and mitigation. While a vast body of research exists on smart cities, their applications, and their societal contributions, knowledge on contributions to urban climate change adaptation, and mitigation are relatively limited. In this regard, the research reported in this volume is essential for raising awareness about actions that need to be taken for effective climate change adaptation and mitigation in cities through integration of smart cities and technologies.

Throughout the volume, it was demonstrated that smart solutions and technologies can provide multiple benefits for climate change adaptation across multiple sectors, including, water, energy, waste, buildings, transportation, and governance. Indeed, smart solutions can enhance adaptation capacities through, for example, facilitating better prediction abilities

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and early warning systems. Such solutions can be utilized for a more effective response against multiple climate-induced hazards and stressors like urban floods and extreme heat in cities.

Smart solutions and technologies can also be utilized for more effective climate change mitigation efforts in cities. Big Data analytics and major smart solutions and techniques for data analysis such as machine learning, random forest, and neural networks can be used to optimize the operation of energy systems, optimize the consumers' energy consumption patterns, and better integrate renewable energy technologies. In turn, this will contribute to climate change mitigation.

In the remainder of this chapter, we will discuss why integrated approaches are needed for effective climate change adaptation and mitigation and what issues should be considered for mainstreaming data-driven smart cities.

16.2 Integrated approaches for maximizing mitigation-adaptation co-benefits and minimizing trade-offs

Many argue that climate change action plans established by cities have failed to make a balance between mitigation and adaptation efforts and that adaptation plans have less progressed (Sharifi, 2021). The increased emphasis on mitigation is generally based on the argument that increasing the concentration of GNGs in the atmosphere can make adaptation measures unsafe, costly, and ineffective because increasing GNGs can be associated with an increase in the frequency and intensity of extreme climatic events (such as hurricanes, extreme temperature events, rising sea levels, and extreme precipitation). However, contrary to this argument, it has been correctly pointed out that climate change is unavoidable due to historical emissions and that mitigation measures have thus far been ineffective, necessitating a greater focus on adaptation (Ayers & Huq, 2009; Janetos, 2020). Despite the IPCC's emphasis on the significance of addressing adaptation and mitigation together, climate change action plans have historically tended to be focused in one direction (Ayers & Huq, 2009). However, climate change policies may elicit reactions due to their many temporal and spatial complexities and dynamics. As a result, there is a need for a paradigm change away from a compartmentalized approach to mitigation and adaptation (Sharifi, 2021).

Many studies have focused on compact urban development and its conjunction with land use mix, building, and water measures in terms of co-benefits (Caparros-Midwood, Dawson, & Barr, 2019; Yang & Goodrich, 2014). Compact urban development and integrated land use can increase the accessibility and connection of urban districts, which could significantly reduce per capita transport demand and energy consumption (Khavarian-Garmsir, Sharifi, & Moradpour, 2021). Compact urban development can also save energy by reducing dwelling size and the thermal efficiency that shared walls provide (Pierer & Creutzig, 2019). Another set of co-benefits occurs in the water sector, as water use is lower in densely populated urban areas and can be considered part of community adaptation efforts to address water scarcity. Furthermore, the contribution of compact city development in reducing extreme thermal events has been acknowledged. Overall, the compact urban form can help with the efficient use of water and energy resources and the mitigation and adaptation to climate change (Sharifi, 2021).

Transportation is another section that has mainly been the focus of climate change mitigation policies. Multimodal public transportation, transportation-oriented development (TOD), crowd pricing, and parking demand management are examples of transportation policies that have been used separately to reduce emissions (Khavarian-Garmsir, Sharifi, & Hajian Hossein Abadi, 2021). However, these actions have interactions that may influence communities' coping and adaptation abilities. Smart city solutions, such as electrification and shared transportation, minimize greenhouse gas emissions while enhancing adaptive ability through cost savings, economic resilience, and increased energy-saving capacity (Dulal, 2017; He et al., 2019; Sharifi, 2021).

Building-related measures have also received much attention. Among the initiatives having co-benefits are smart, green, and energy-efficient buildings. These measures can contribute to energy resilience by increasing energy production alternatives. Furthermore, smart and green buildings can increase energy efficiency, resulting in cost savings, less strain on energy systems, and improved thermal comfort. Measures related to climate change mitigation and adaptation through waste management have also co-benefits as measures such as composting, waste energy utilization, and landfill gas recovery can reduce greenhouse gas emissions (Grafakos, Trigg, Landauer, Chelleri, & Dhakal, 2019; Laukkonen et al., 2009; Sharifi, 2021).

There are also synergies for energy systems in decentralizing and distributing energy source systems. Energy-related smart city technologies boost productivity while lowering greenhouse gas emissions. The combination of energy and water can have significant implications for mitigation and adaptation. Decentralized energy systems based on renewable energy, for example, can assist in alleviating pressure on water resources in water-stressed areas and help communities cope with water scarcity (Grafakos et al., 2019; Sharifi, 2021; Sugar, Kennedy, & Hoornweg, 2013).

Green infrastructure has been identified as a key strategy for climate change mitigation and adaptation. It contributes to climate change mitigation through carbon sequestration and cooling effects that reduce energy use indirectly. They can also improve adaptive capacity by increasing microclimate, air quality, and thermal comfort. As a result, there is less reliance on air conditioning, resulting in greater energy resilience. Green infrastructures also promote public health and economic resilience, which can help society cope with and adapt to climate change. Furthermore, the role of green infrastructure in dealing with environmental disasters such as floods and water scarcity has been acknowledged (Capolongo et al., 2018; Coutts, Beringer, & Tapper, 2010; Sharifi, 2021).

Sharifi (2021) emphasizes that the cumulative effect of mitigation and adaptation strategies is higher than their separate deployment. He discovered several synergies between climate change mitigation and adaptation strategies. The transportation, building, green infrastructure, urban design, land use, water, and energy sectors have a significant synergy potential. Measures relating to urban design, land use, and transportation have a high potential for synergy. They can be used both directly and indirectly to reduce and adapt to climate change. Furthermore, urban vegetation policies can be linked with construction regulations, energy systems, water management, and risk zoning. When combined with flood management strategies, efforts performed in the building sector can help mitigate the effects of climate change (Sharifi, 2021).

Along with co-benefits and synergies, the literature reveals that adaptation and mitigation measures may involve trade-offs and conflicts. Energy, land use, transportation, water, building, green infrastructure, waste, and policy, as Sharifi (2020) notes, are major sectors that may include trade-offs. Efforts to reduce GHG emissions may limit adaptive capacity in a variety of ways, including increased vulnerability to the UHI effect and floods, as well as magnifying negative health outcomes. However, the most often occurring trade-offs associated with mitigation initiatives are in the area of equity. In other words, mitigation initiatives may indirectly affect the adaptive capacity of poor and disadvantaged populations in some circumstances by reducing the cost of urban services and diminishing livelihood possibilities, among other things. As a result, equity problems should be given full consideration in mitigation efforts. When attempting to improve adaption, trade-offs may occur. It was discussed that such efforts could increase Gas (GHG) emissions based on a variety of factors, including the requirement for important physiological reconfiguration, which increases embodied emission levels, increased energy demand for infrastructure construction and maintenance, increased energy demand for air conditioning, and decreased efficiency associated with the use of redundant and/or energy intensive technologies (Sharifi, 2020).

16.3 Policy and planning considerations for mainstreaming data-driven smart cities

Climate change, pandemics, resource depletion, and environmental degradation are among the issues that have put the sustainability and productivity of smart cities in jeopardy. Addressing these complex and multifaceted problems necessitates developing and implementing novel solutions based on smart and transdisciplinary technologies. IoT and Big Data technologies are smart city solutions based on Information and Communication Technologies (ICT) created to address current challenges better and pave the way for achieving sustainability, prosperity, justice, and equality (Bibri & Krogstie, 2020). This smart data-driven city establishes a city-wide data system that monitors cities holistically and collects real-time data from sectors such as traffic, transportation, energy, and markets in order to offer the necessary knowledge about upcoming issues (Bibri, 2019).

Planning and policy issues related to climate change that should be considered for mainstreaming smart cities include comprehensiveness, stakeholder participation, context-sensitivity, strategic needs, uncertainty management, internal relations, temporal change, and flexibility and feasibility. To comply with the comprehensiveness criterion, smart city solutions have been suggested to provide multiple economic, social, environmental, and institutional co-benefits. As a result, the emphasis should be on information and communication technologies and their application to achieving economic success, fairness, and social cohesion while simultaneously cutting greenhouse gas emissions and minimizing the effects of climate change (Caird & Hallett, 2019). Another idea for planning is stakeholder involvement. This refers to the engagement of stakeholders in order to promote transparency and a feeling of ownership, as well as to share information and resources, respond quickly, and prevent top-down planning in climate-affected smart cities. Collaboration among actors strengthens their ability for adaptation and enables the development of innovative carbon-reduction strategies. Furthermore, people will become more educated, and their creativity will be increased by their participation in decision-making processes and the adoption of sensible measures to address climate change. This way, they can generate innovative ideas for adaptation and mitigation through a synergistic approaches (Ahvenniemi, Huovila, Pinto-Seppä, & Airaksinen, 2017; Fernandez-Anez, Velazquez, Perez-Prada, & Monzón, 2020; Sharifi, 2019).

Each city has its own unique geography, culture, economy, and challenges. The effects of climate change have not always been the same for all cities. As a result, communication technology development should be tailored to the demands and challenges of local communities (Fernandez-Anez et al., 2020). Under a serious water scarcity scenario, for example, the implementation of information and communication technologies and tools should be related to smart water management systems, whereas in a flooded region, the installation of early warning systems is required. As a result, it is impossible to take a single development model for all cities based on the one size fits all approach (Manville et al., 2014; Sharifi, 2019).

Additionally, connecting smart city instruments with strategic goals is a planning endeavor that aims to increase long-term rationality in planning, which can help ensure the long-term viability of smart city plans. By recognizing strategic imperatives, planners can make more informed technology decisions to address climate change (Kourtit & Nijkamp, 2018). As a result, an examination of a city's strategic issues and requirements can give valuable insight into the strategic directions of smart cities in the era of climate change. However, it should be highlighted that long-term planning attempts have always been hampered by the complexity and ambiguity inherent in forecasting the future. Planners must understand that cities are dynamic and always changing. As a result, smart cities must revisit strategic goals over time, and targets and needs must be updated on a regular basis. Furthermore, in the face of climate change, flexible evaluation tools are required to constantly update and adjust the targets and priorities of smart cities (Brorström, Argento, Grossi, Thomasson, & Almqvist, 2018; Sharifi, 2019).

Another planning guideline is to avoid oversimplifying urban systems. Cities are classified as systems of systems, with various feedback loops in which subsystems interact. For instance, climate change has a simultaneous effect on energy and water supplies. Meanwhile, the water and energy sectors are so interdependent that any shifts in one's direction may result in changes in the other. As a result, climate change has a cyclic effect on a city's numerous systems. Hence, information technology cannot be used to tackle a system's problems in isolation without taking into account parallel systems (Debnath, Chin, Haque, & Yuen, 2014; Sharifi, 2019).

Finally, not every city has the financial and technical resources to adopt information and communication technologies and smart solutions. Therefore, securing funding sources for the effective implementation of smart city projects is essential. Simultaneously, efforts are required to develop technical and managerial capabilities. Planners and city managers must also occasionally report outcomes of developing information and communication technologies. Such outcomes must be presented in various formats and to a range of audiences to maximize impact (Sharifi, 2019; Simpson, 2017).

At the end, we hope that various stakeholders will find this volume insightful and informative for the transition toward climate-resilient urban planning and design. We hope that this work will inspire more theoretical and empirical research on the contributions of smart cities and technologies to climate change adaptation and mitigation in the future.

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Index

Note: Page numbers followed by *f* indicate figures and *t* indicate tables.

J

K

L

T

U

URBAN CLIMATE ADAPTATION AND MITIGATION

AYYOOB SHARIFI AND AMIR REZA KHAVARIAN-GARMSIR

Discusses smart city solutions for resilience and climate change mitigation and adaptation

Uniquely focused on the contributions smart cities can make to climate change resilience, *Urban Climate Adaptation and Mitigation* offers evidence-based scientific solutions for improving cities' abilities to prepare for, recover from, and adapt to global climate-related events. Beginning with the observation of global environmental change, this book explores what sustainable smart projects are, how they are adopted and evaluated, and how they can address climate change challenges. It brings together a wide variety of disciplines such as planning, transportation, and waste management to address issues related to climate change adaptation and mitigation in cities.In general, many social science researchers lack cohesive, broad-based literature knowledge; *Urban Climate Adaptation and Mitigation* bridges this gap and informs different types of stakeholders on how they can enhance their preparation abilities to enable real-time responses and actions. Therefore, it is a valuable reference for researchers, professors, graduate students, city planners, and policy makers.

Application-focused throughout, this book explores the complexities of urban systems and subsystems to support researchers, planners, and decision makers in their efforts toward developing more climate-resilient smart cities.

Key Features

- Provides a structured in-depth analysis of smart city cases from around the world
- Introduces evidence-based toolkits and frameworks for assessing actual and/or potential contributions of smart city solutions to climate resilience
- Includes state-of-the-art literature review and glossary

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