

Building Tomorrow's Cities Today: Smart Technologies, Green Infrastructure, and Inclusive Governance for Sustainable Urban Development

¹Sujatha Gundeboiyna ²Tanzeer Ahmad Dar ³Sudhakar Kota

¹Professor, Department of Chemistry, Audisankara (Deemed to be University), Gudur-524101, A.P, India

²Department of Chemistry, Audisankara (Deemed to be University), Gudur-524101, A.P, India

³Assistant Professor, Department of Chemistry, Narayana Engineering College, Nellore-524002, A.P, India

Corresponding author: sujathavenkat1999@gmail.com

DOI: <https://doi.org/10.5281/zenodo.23120746>

ABSTRACT

The key spatial development of the twenty-first century is urbanization. The United Nations predicts that about seven out of ten people will live in cities by 2050, with the majority of this growth focused in the Global South. Currently, over half of humanity resides in cities. Urban areas are both the main causes of environmental change and the most promising places for climate solutions because, despite making up a small portion of the planet's land area, they consume the majority of global energy and resources and produce the majority of greenhouse gas emissions. In international policy studies, the assessment looks at twelve interrelated areas: smart grids and urban energy transitions; electrified and sustainable transport; green and blue infrastructure and natural solutions; Urban heat island mitigation and climate adaptation; smart waste management and the circular economy; energy-efficient and sustainable buildings; smart urban water management; digital twins and data-driven planning; smart governance, equity, and citizen participation; data privacy, cybersecurity, and artificial intelligence ethics; disaster risk reduction and urban resilience; and tracking advancements toward Sustainable Development Goal 11. Evidence from these domains consistently shows a tension: while technological innovation is developing quickly and producing quantifiable improvements in efficiency, monitoring, and service delivery, the social, institutional, and governance aspects of sustainability are still lagging, especially in low- and middle-income nations where urbanisation pressure is highest. Instead of assuming intelligence and sustainability as inevitably interchangeable, the research concludes that truly sustainable urban development necessitates the intentional integration of technological, ecological, and social-equity factors under unified governance frameworks. It concludes with a research and policy agenda that prioritizes stronger city-level monitoring systems, inclusive digital governance, climate-just infrastructure investment, and interoperability.

Keywords: sustainable urban development; smart cities; green infrastructure; urban resilience; climate adaptation; circular economy; smart governance; digital twins; Sustainable development Goal 11; urban sustainability indicators



Graphical Abstract



1.1.11. Introduction

Part of the twenty-first century's story is the story of cities. Less than one-third of human inhabitability in the cities was observed in 1950, whereas close to 68 per cent of humanity, about six billion people are living in the cities by the middle of this century (Sustainable smart city and Sustainable Development Goals review, 2025; UN-Habitat, 2024). This demographic shift is putting new and unprecedented demands on cities' housing, transport, energy, water, and waste systems just as they are being called on to decarbonize, adapt to more extreme climate risks, and responsibly manage new digital technologies. Although urban facilities cover a small portion of the Earth's surface, cities are responsible for a high proportion of global energy use and GHGs emissions, and the future course of urban growth will to a large extent drive both the global effort to realize climate and sustainability targets and the resulting environmental impacts.

Researchers and practitioners have a body of parallel intellectual and policy programmes concerning the future of the city. There are two parallel intellectual and policy streams that have formed researchers' and practitioners' thinking about the urban future. The first one is the sustainability tradition which was formalized at the city scale in Sustainable Development Goal 11: Sustainable and inclusive, safe, resilient cities and human settlements (Redclift, 2005; UN DESA, 2026). The latter is the "smart city" tradition, beginning in early 2010s, where scientists brought together information ICTs with urban infrastructure, hampered by a lack of cross-sectoral collaboration, with the aim of creating an "IoT-enabled city" that will be more efficient, more responsive, and make cities more liveable by using sensors, data analysis, AI, and connected devices (Caragliu et al., 2011; Batty et al., 2012). These two traditions are complementary, at least even competing signs of smart technology have been promoted and studied as solutions for sustainability goals, ranging from optimized energy systems to intelligent waste picking. But there are many points in this equivalence that deserve critical interrogation, as shown by a new critical scholarship. However, the concept of "smart city" has been overlooked when it comes to ecological integrity and social equity; and, as of yet, there is little evidence that cities claiming to be 'smart' are more sustainable when it comes to outcome measures (Shang et al., 2022; Frontiers integrated review, 2025).

The focal question of this review is where and how smart technologies are actually promoting sustainable urban development and, conversely, where they are not, and what scope and limits of governance, equity and institutional conditions is responsible for that? The review does not follow a chronological structure, rather it spans from more technical areas of the energy sector, the mobility sector, green infrastructure and water, to the more recent and important aspects of the digital sector (of the urban digital twin and data governance), and the social and institutional sector (of citizen participation, privacy, resilience and measurement). Such a structure demonstrates the evolution of scholarship on the subject of the smart city: at first the focus of the research was techno-centric, and later, after 2023, it has become clear that the issue of the smart city is dealt with from a number of perspectives including aforementioned governance, equity, ethics, and Global South (Chen et al., 2022; Luo & Huang, 2024; social sustainability Global South review, 2025).

The rest of the review is organized in the remaining plan. The Methodology for Reviewing is described in Section 2, in Section 3, a conceptual framework defining smart urbanism and sustainable urban development, and sketching out the pillars that link the two, is built up. The thematic review is contained in 12 domains in Section 4. Section 5 is an aggregation of cross-cutting challenges, which are common to domains. Future research directions are outlined in Section 6 and distilled policy implications in Section 7 before a conclusion in Section 8.

2. Review Methodology

This review does not follow a systematic review from scratch methodology, but a narrative-integrative review that is guided by recent systematic and bibliometric reviews in the field. The idea behind this is that there are lots of systematic reviews and bibliometric analysis done to the smart and sustainable cities literature so far that focus on individual and specific sub-domains (such as urban digital twining, smart grid, green infrastructure, or waste management), and the crux one needs now is to get a unified, coherent and cross-cutting of the various sub-domains out of the literature and bring them together in a unified collection, some kind of a synthesis. The literature was identified by the systematic search of academic databases and publisher platforms, including platforms such as



ScienceDirect, MDPI journals (e.g., Smart Cities, Sustainability), Springer Nature, Frontiers, MDPI data preprints, and arXiv preprints, encompassing the last three years of publications since 2023 up to 2026 and then by some earlier works where they continue to form the central reference point of a concept. Systematic reviews, meta-analyses and bibliometric studies with clear methodologies (including those that followed PRISMA reporting guidelines) were given a higher priority, as were authoritative international reports from the UN Statistics Division, OECD, the UN Habitat and the UNDP and UNDRR. The review brings together conclusions from over eighty different sources from the engineering, urban planning, public administration, environmental science and information systems literature. The literature on smart and sustainable cities is vast, rapidly expanding and unevenly distributed geographically; at this time, there is still a literature gap with materials on smart and sustainable cities from the Global South in particular; this review is therefore consciously endeavoured to highlight literature available for Smart and Sustainable cities from the Global South where appropriate.

3. Conceptual Framework: From Smart Cities to Sustainable Urban Development

Specific definitions are important in this context since the terms 'smart city' and 'sustainable city' are often used interchangeably, though they are two very different (but not mutually exclusive) concepts. When defining a smart city, it is best considered as a locality that combines information and communication technologies, sensors and data analysis for the efficient provision of urban services and for better urban decision-making processes (Caragliu et al., 2011). In contrast a sustainable city is defined as being one where multiple generations fulfil its economic, social, and environmental goals (Redclift, 2005) as the Brundtland formulation has since been adopted and meant for SDG 11. Looking more contemporary and instead of just technology, a smart and sustainable city should be a healthy system of systems creating a net positive environmental impact with the infusion of social, human and environmental capital (Frontiers integrated review, 2025). This formulation comes in handy as it points to the fact that technology is an enabling but not a guaranteeing factor in outcome of sustainability.

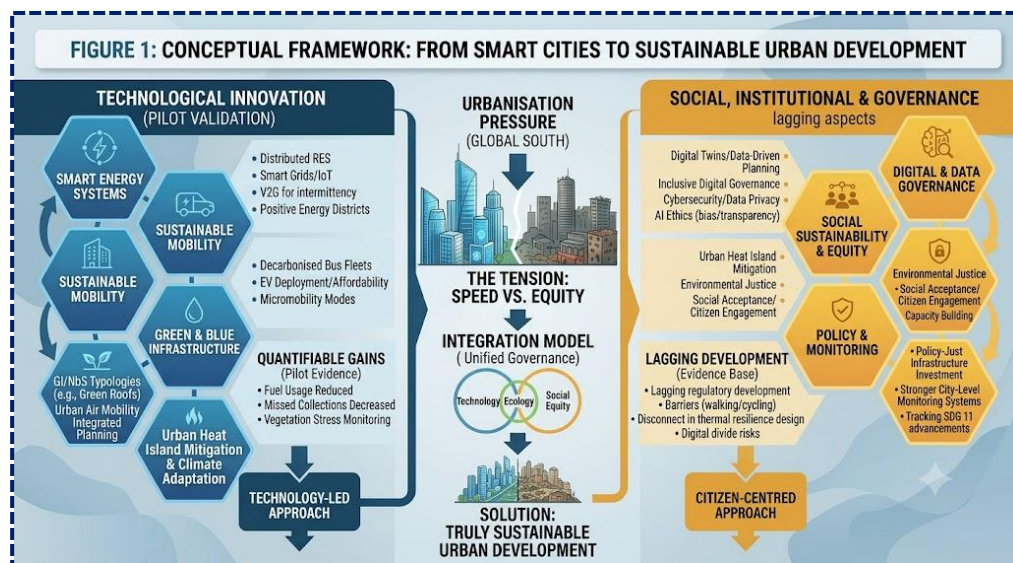
The four- or six-pillar approach has been widely used to analyze the literature. One of the influential schemes has separated the smart city strategies into four pillars such as environment, society, governance, and economy a stance that the authors make in favor of making all four work together to ensure that investments in smart cities translate into sustainable development gains (Sustainable development strategies for smart cities review, 2024). A parallel, more specific systematic review of 524 bibliographic records found six interrelated domains that are

observed across the resilient, smart and sustainable city literature, both in the field of economy, people and society, mobility, natural environment, energy/waste, and governance (Nor Shrgdin, et al., 2025). These come together on one central idea: for any and every technical solution whether it is an optimized traffic signal network, an ecologically acceptable rooftop solar array or a smart water meter purely technical solutions in each of these fields do not bring sustainability value in their own right; they need to be part of a governance system that also engages with distributional equity as well as institutional capacity and long-term ecological integrity.

The Smart Renewable Energy System (Smart RES; integration study, 2025) is another interesting concept found in the urban energy-climate planning literature, which explicitly combines energy and climate planning on both district and building levels, and views decarbonization and digitalization as a unified problem, rather than two independent streams. The highly imbricated and socio-technological formulation of energy, mobility, water and waste systems is a recurring theme in the following reviewed domains: From the domain of energy, to being plans as socio-technological instead of as a sector of infrastructure planning; from the domain of mobility to cities that rely on water resources plans and infrastructure investments; from the domain of water to urban waste plans and investments; and from the domain of waste to socio-technological systems for urban waste planning and investments (also referred to as the "social-ecological-technological systems" formulation of urban ecosystem services research (McPhearson et al., 2025)).

Two other conceptual differences are found throughout this review. There is first a technology-led versus citizen-centred distinction, with the former typically located in the top-down implementation of technologies such as sensors and platforms, while the latter, with elements such as participatory design, algorithmic transparency and co-

production of urban services with the citizens (Rethinking the smart city review, 2025, Kummitha, 2025). Second, the existence of a specific disaster-oriented versus capability-oriented understanding of urban resilience, the former being geared towards the ability of urban systems and institutions to withstand and recover from discrete disaster events, and the latter towards their ability to develop the underlying adaptive capacity of the urban system and institutions over time (Governmental climate governance discourse study, 2026). The first and the second difference is important because they determine which are deemed to be indicators of success and therefore whose goals are represented by a particular "smart" or "sustainable" intervention.



4. Thematic Review

4.1 Urban Energy Systems and the Renewable Transition

Urban energy systems are considered as a first order priority for sustainable development and estimated at 75-80% of total global energy consumption and greenhouse gas emissions (Smart Grids in the Context of Smart Cities review, 2025). However according to a large bibliometric study of over 9,300 papers on smart cities and urban energy planning, only a few research areas have been extensively explored, and technology efforts are consistently stronger than those to integrate building energy use, urban design and planning, transportation and mobility, and even the modernization of the electric grid, and policy and regulatory frameworks (Smart Cities and Urban Energy Planning: An Advanced Review, 2024). This asymmetry, the rapid change in technological development coupled to the delayed regulatory and institutional development, is amongst the most common across the smart and sustainable cities literature, and recurs in the water, waste, mobility, and digital twin spaces outlined below.

At the technology level, significant changes have been documented in the field of integrating distributed renewable generation, with a particular focus on photovoltaics, wind, and in specific cases geothermal and biofuels, into urban energy systems via the implementation of smart grids, in which an internet-of-energy architecture is used to balance energy supply and demand in real-time (Sustainable Urban Energy: Integrating Smart Grids into Smart Cities, 2020; Gill et al., 2024). As EVs become more widely adopted, the decades-long argument for them as a de-carbonising transport component is becoming more than obvious, as vehicle-to-grid systems become a daunting asset to deal with renewable intermittency: particularly when vehicles are parked, with stored energy being fed back to the grid during peak periods and being recharged when there is a surplus (Gill et al, 2024). Eight of those eleven implementation gaps were more or less common in urban smart grid, but eleven solutions were found to be persistent across the different contexts investigated: they represent either interoperability issues, financing models, workforce difficulties, inactive solutions, or challenges in the existing grid architecture. Smart Grid and Smart Cities Smart Grids in the Context of Smart Cities review (2025) outlines a possibly exhaustive portfolio of sixteen smart grid solutions that were



developed for urban use during the systematic gap analysis. Later architecture-first reviews advance this thinking and consider the new generation of decentralized, smart energy grids, powered by artificial intelligence, to be poorly suited to the multi-actor coordination that they're now calling for (Electrical Grid Architectures for Smart Cities review, 2026).

Positive energy districts, neighborhoods or buildings which generate renewable energy at least as much as what they consume over an annual cycle are starting to become a key implementation unit between building-scale and city-scale energy planning, although systematic reviews indicate that there is still a need for more regulation, financing, and social acceptance issues to be resolved before positive energy districts scale much longer than the underlying technology (Urban energy transition in smart cities review 2025). Moving to the municipal to district level, comparative case analysis of European cities like Strasbourg and Aarhus shows how ESCP can be put into practice with operational tools, integrated simulation tools and the technical expertise of individuals, as well as how the social acceptance of the transition, and/or coherent institutional structures, are as important as the technical modeling capacity (Smart Renewable Energy System integration study, 2025).

4.2 Sustainable and Smart Mobility

One of the most obvious aspects of urban sustainability transition particularly concerns transport decarbonisation. The deployment of electric vehicles has been rapidly gaining momentum worldwide; it is estimated that by the end of 2025, the global fleet stood at approximately 85 million EVs (up from 64 million a year ago); that B tabulation had a share of about three-quarters of the market; and since then, EV numbers are projected to grow further to reach over 145 million by 2030 (A Positive Outlook for Sustainable Mobility, 2025). Delivers examples of how quickly change is happening at the market leading edge: In Norway, almost 96 per cent of all new cars registered in 2025 were electric vehicles, compared to 89 per cent in 2024 (Mapfre sustainable mobility outlook, 2026). Despite this, current studies on EVs warn of the need to address the issue of affordability and equity; the design of the subsidy can significantly influence the uptake of electric vehicle benefits, such as reduction of local emissions (Stefaniec et al., 2025).

In addition to electric cars, the mobility literature highlights multimodal decarbonization, such as the aspiration to have a 100% clean-energy bus fleet by 2040 in Singapore and efforts to increase charging infrastructure, while also observing that increased autonomy and sharing of mobility services are becoming a common feature of the mobility landscape (Brears, 2024; A Positive Outlook for Sustainable Mobility, 2025). The systematic review revealed ongoing barriers to walking and the use of cycling such as extreme temperatures, air pollution and poor infrastructure

in cities that are struggling with environmental conditions and cited a range of interventions from shaded pedestrian walking lanes to integrated multi modal trip planning (Wismadi et al., 2025). Building on that, a study on the potential of using big data and Artificial Intelligence in urban mobility systems found that predictive analytics and adaptive traffic management have the potential to significantly improve urban mobility management, provided that the data governance capabilities are in place, a critical challenge that many localities face (Yusuf et al., 2025).

The studies on the sustainability and safety characteristics of emerging modes like urban air mobility (excitably vertical take-off and landing aircraft) and micromobility devices (electric scooters) are still in a preliminary and exploratory phase compared to the existing body of literature related to ground based electric vehicle studies (Urban Air Mobility review, 2025). However, a comprehensive review of electric vehicles and sustainable urban mobility in the Middle East and North Africa reveals that many systems of mobility transition pathways cannot be transferred untouched from high-income to low-income urban contexts and highlights the importance of adjusting regulation, charging infrastructure siting and battery-swapping innovations to regional-specific barriers such as limited grid capacity and extreme heat (comprehensive EV and SUMP review in MENA, 2026).

4.3 Green and Blue Infrastructure and Nature-Based Solutions

Enhancing and working with nature to mitigate urban climate challenges is emerging as a key part of urban adaptation strategies, and Natural Based Solutions or NbS is defined by the IUCN as solutions that leverage and enhance nature to resolve societal problems. (Urban NbS scoping review, 2025). A systematic review conducted by grouping 749 initially retrieved publications into 84 articles that met inclusion criteria showed that the type of intervention is only



a small part of the solution; that data-driven planning, stakeholder efforts and data on sufficient long-term resourcing are key to successful NbS implementation for urban climate resilience; and that NbS offer considerable potential for optimizing urban climate resilience in their capacity (NbS for urban climate resilience review, 2025). A parallel systematic review and bibliometric analysis of ninety peer-reviewed papers published in the last decade (2014–2024) also identified fragmented methodology as a significant challenge for the effective incorporation of NbS in GI planning and financial, technical, social and political challenges as key barriers to uptake despite current strong evidence for the ecological benefits. (Nature-Based Solutions in Urban Green Infrastructure systematic review, 2025).

Empirical case studies are provided to demonstrate the possibilities and variation of implementation models. Green corridors and vertical greenery have helped deliver measurable benefits in terms of cooling and biodiversity advantage in Singapore (City in Nature strategy), with more than 80,000 trees planted in Cardiff as part of its One Planet Strategy, and green roofs have had a noticeable impact in the creation of climate resilient neighbourhoods to reduce the risk of flooding and enhance liveability in Copenhagen (International experts urban greening report, 2025). A dedicated review of what they call 'green infrastructure typologies' mapped specific interventions to climate regulating services, including flood prevention and thermal regulation, identifying a matrix to normalize temperature and decision support to planners selecting interventions based on local hazard profiles (Green infrastructure for urban climate mitigation and adaptation, 2025). Urban climate adaptation literature emphasizes the urgent need for adaptation measures to remain sustainable over time. Complementing this, biodiversity-based research focuses on the pragmatic synergies between ecological connectivity and provision and dense urban development, arguing that a range of adaptation management approaches is required instead of a one-size-fits-all design approach to climate adaptation (Frontiers Review urban green infrastructure for biodiversity, 2024).

Furthermore, a rapidly emerging body of work identifies NbS as public-health infrastructure, and shows how parks, street trees and blue-green corridors all offer more than just environmental services; there are studies documenting the multiple public-health benefits of investing in NbS as a multi-sectoral public good, rather than an environmental amenity (Urban nature-based solutions public-health scoping review, 2025). The use of digital monitoring tools on top of traditional green infrastructure is also on the rise, as governance research about Internet-of-Things (IoT) for green space management in Campobasso, Italy, shows, an example of which is a direct application in the Field of Irrigation Systems (2025), which sees digital tools used to manage the state of vegetation and to implement proactive maintenance actions to counteract stress (Urban Green Governance IoT study, 2025).

4.4 Urban Heat Islands and Climate Adaptation

The UHI phenomenon is one of the most widely studied urban climate hazards both because of its demonstrable human health impacts and its range of potential urban mitigation options. Results from a systematic quantitative literature review show that across all strategies for adaptation to higher temperatures, green, blue and grey infrastructure all offer significant basic mitigation of heat intensity at a low cost, but grey infrastructure can also be even more cost and resource effective at times than green infrastructure, especially taking into account ongoing maintenance costs (A Review of Adaptation Strategies to Increased Urban Temperatures, 2025). Ubiquitous quantifiable case evidence exists, for example in Singapore which has documented 2–3 degree Celsius reduction in maximum temperatures with the introduction of a green roof, and another example is the cooling effects the urban forest creates when paired with a blue-green roof and water features in Philadelphia, which was documented at approximately 2–5 degree Celsius.

Environmental justice has been important in urban heat research, with a systematic review of the literature that urban heat exposure and vulnerability across income and racial/ethnic lines in cities, and co-occurrence analysis of the literature has been a consistent finding across all U.S. cities (Urban heat vulnerability and mitigation in U.S. cities review, 2026). The need for context-sensitive rather than one size fits all heat governance is reflected in a critical review of urban heat island management strategies, in which unintended trade-offs and conflicts can be created such as by balancing reflective roofing strategies (which reduce the indoor heat, but also increase the glare and heat reflection at the pedestrian level) with vegetative cooling (which needs water resources that are in limited supply in the same places where cooling is most required and critical for heat governance) (Critical reflections on urban heat



island strategies, 2024). However, moving from hazard diagnosis to meaningful, thermally resilient urban design in order to move and sustain the implementation of urban heat island policy requires institutional capacity that is hard to build and sustain, because it flows through the reorientation of local decision-making processes. Even when the basic urban science of the hazard is robust, there can be a disconnect between the translation of urban heat island science and the development of meaningful urban design that is put to use, as evidenced in a policy implementation study conducted cross-city that diagonalized the process of institutionalizing urban HAs by examining the path from urban heat island science to meaningful action (Lau et al., 2025).

At a larger scale, several critical reviews of urban planning approaches towards climate change adaptation and mitigation highlight that there is significant disconnect between the implementation of urban plans and the monitoring of outcome of their implementation after they are adopted, with many empirical plans still being more aspirational than actual (Aboagye & Sharifi, 2024). The evidence from the vast literature on climate governance overall also suggests that public pressure brought by citizen engagement via digital channels and civic engagement contributes to strengthening local government's formal capacities to clamp down on climate policies as opposed to replacing them (governmental climate governance discourse study, 2026).

4.5 Circular Economy and Smart Waste Management

While it is estimated the cities account for about half of waste generation, only approximately 19 per cent of municipal solid waste (MSW) is recycled globally, and many cities lack proper systems for collecting and processing waste materials (circular economy and digitalization in MSW review 2026). This constitutes the conceptual promise versus the reality gap between the circular economy, and the resulting significant, and increasingly vast, literature on smart-waste management. The research concept of Internet-of-Things (IoT) smart bins, dynamic route optimization, and waste generation prediction has become well started; although most available evidence is still from pilot projects, real-time monitoring and optimization algorithms have demonstrably decreased fuel usage, missed collections, and overflow situations during these validation stages (2025: Internet-of-Things (IoT) smart bins for waste management in smart cities: A review from the published literature on IoT applications from 2018 to 2024).

The applications of Artificial Intelligence aren't limited to optimizing logistics, but also encompass materials recovery and circular economy design of value chains. A review of the applications of AI in the field of waste management frames the technology as a part of the shift towards a "zero waste circular economy" favoring decisions whether to recycle, reuse or reduce the waste stream, such as through machine learning models identifying the variables that

affect waste stream composition, for instance, in energy recovery programmes such as biogas generation from organic waste (Artificial intelligence for waste management in smart cities review, 2023). The Internet of Things (IoT) has become a significant sub-domain of this as digital instruments come to be the enablers of the Internet of Things or smart cities sector's own circularity: The systematic literature review on smart cities and electrical and electronic waste management has shown that information security, interoperability, and cost are the top three barriers to expanding the sector's circular recover/reuse of valuable materials from discarded electronics, despite the sector's growth in electronics (Souza et al., 2025).

The European Union Waste Framework Directive (2030) ambition of 60 per cent municipal solid waste recycling and preparation for reuse, and additional measures such as separate bio-waste collection requirements, which were introduced at the end of 2023, are examples of how EU legislation can help drive up the uptake of the circular economy in cities, although implementation is delayed in some members states who have not yet done so (circular economy and digitalization in MSW review, 2026). While circular economy policies and practices can certainly be measured and managed through technical solutions, there are also governance considerations to take into account from a circular city perspective, as it is not just a technical waste management challenge but one that is relational, spatial and digital, requiring greater synergy between the two strategies: circular economy policy and digital economy strategy (Anttiroiko, 2023).

4.6 Sustainable and Energy-Efficient Buildings

The built environment is a key domain for sustainable urban development solutions since buildings occupy a



significant proportion of EUR urban energy use and embodied carbon. According to market data, green building material markets and green building technologies are growing rapidly, with global green building technology and material markets worth approximately 377 billion USD in 2024 and anticipated to grow in the future despite recent disruptions in supply chains, and increased policy support for implementing net-zero retrofit rates, including the EU's expanded initiative of the Renovation wave (Sustainable Construction Driving Green Building Growth, 2026). Energy-efficient HVL, renewable technologies for energy generation on site (solar, wind, and geothermal), and more recently, artificial intelligence for building automation that learns occupancy to optimize energy use and consumption in real time (technical review of the use of AI in green buildings, 2021; Modern Energy Sources for Sustainable Buildings review, 2025) dominate the field of technical reviews of green building technologies.

Additionally, there is a parallel research path exploring novel materials and construction technology, such as self-healing concrete, mycelium-based insulation and transparent photovoltaic glazing, and modular approach, which includes minimizing construction material wastage and expediting project schedules (Green Building Technologies 2025 guide; Sustainable building trends report, 2025). Internet-of-Things (IoT) based building management systems which are inter-connected sensors, devices and networks are being adopted as a core component of many new commercial buildings, contributing to energy savings, as well as fault detection and optimizing the comfort of occupants (Special Review on Sustainable building trends 2025). Despite this, the sector is not yet at a point to achieve equitable penetration — industry surveys suggest that although most construction professionals know about some Green methods, building to deep decarbonization, as opposed to new construction, is still a “more capital-intensive endeavor” that takes “more time” (Green Building Practices 2025 guide).

4.7 Smart Urban Water Management

Climate change effects on the distribution of water have increased with water scarcity, ageing water distribution systems make urban water system an important target for digitalization. A representative study of how artificial intelligence and Internet-of-things architectures are applied to urban water distribution systems in Spain resulted in up to a 96.6 percent reduction in water wastage using dynamic, real-time optimization, as compared with the traditional static optimization methods (Leveraging Urban Water Distribution Systems, 2025). Wider evaluations of ‘smart water city’ concepts document the proliferation of urban water infrastructure applications driven by network-based technologies, which range from smart water tanks and meters to smart leak detection and advanced monitoring and analytics for both drinking water, storm-water and wastewater systems, but warn that technological deployment remains a significant step ahead of the needed communication-technology coordination and institutional integration to achieve system-wide benefits (Towards a smart water city review, 2021).

Results from multi-criteria decision making (MCDM) research for the water management (WM) aspects of smart cities showed that the selection of water management strategies has its highest priority based on factors of effectiveness and risk management, with the lowest priority for energy intensive desalination; rainwater harvesting, greywater recycling and reuse are rated medium, with regard to the overall priority for water management strategies (Optimal Water Management Strategies study, 2023). Some case-study examples provide evidence of the actual outcomes from water management practices integrating AI and IoT systems in Barcelona and Singapore, which have achieved tangible water savings and strengthen water distribution networks' efficiency and resilience in facing climate and population increase risks (AI and IoT in smart water management review, 2024). Meanwhile, studies on the life cycle effects of smart water meter deployment warn that the water and energy savings that smart water systems offer must be balanced by the water, energy and embodied software and electricity costs of digitalization including the costs of producing electronic water meters, energy consumption needed to power the data centres, and the replacement cycle of smart water meters.

4.8 Digital Twins and Data-Driven Urban Planning

Over the last five years, dynamic virtual replicas of physical cities systems, urban digital twins, have come a long way from research concepts to municipal implementation, characterized by the integration of real-time data streams for supporting simulation, monitoring, and decision-making. Interest has paralleled the growth of scholarly activity too, as a systematic review of innovation in urban DTs has been observed an increasing number of papers on urban DTs



published since 2020, appearing at significant volume in 2023 after a “spatially distributed” amount of papers in the years that preceded it (Review of Urban Digital Twins Integration study, 2024). Examples for cities include the city model developed for urban planning decisions in Zurich (Schrotter & Hürzeler, 2020); the “Virtual Singapore” platform that helps resolve transport and resilience issues in Singapore (AI-Driven data governance for smart cities study, 2025); and Vienna’s geo-centric digital twin infrastructure (Towards Civic Digital Twins study, 2024) - citing Lehner & Dorffner.

Although this trend is occurring, systematic reviews have consistently revealed that there is a significant mismatch between the goals set for the urban digital twin and the impact that these can have on the actual decision-making process and planned results. A systematic literature review points to the lack of considering the socio-technical complexity of digital twin implementation, suggesting an “Augmented Urban Planning” research agenda that enables digital twin adoption to go beyond just a data engineering problem and involve stakeholders and institutional processes in the construction and use of digital twins (What Have Urban Digital Twins Contributed study, 2025). However, despite the ongoing advancement of the technical frontier by edge-cloud, 3D immersive visualization, generative artificial intelligence, and blockchain integration, a related systematic review that included 64 peer-reviewed studies based on the PRISMA methodology found that interoperability challenges remain with respect to the integration of different urban data systems into a coherent and efficient Smart City ecosystem, and that there is limited empirical evidence of digital twins providing the city-scale operational benefits and flexibility envisioned. IoT, AI and Digital Twins in Smart cities systematic review, 2025.

An example of the promise as well as fragmentation of the current digital twin landscape is the sector-specific review, digital twins in urban water networks (Pedersen et al., 2021), which is a very separate undertaking from the digital twin for the smart-grid and transportation systems (Jafari et al., 2023), or the digital twin for intelligent traffic intersection management (Digital Twins for Intelligent Intersections review, 2025). A more comprehensive bibliometric analysis of over 4,200 studies related to Digital Twins in the field of Smart Cities also revealed that the research is largely constrained within different technical sub-levels, instead of a city-wide digital twin architecture (El-Agamy et al., cited in Digital Twins for Intelligent Intersections review, 2025). This is because the environmental, equity-based benefits that can be leveraged by use of digital twins, optimized emissions reduction, more efficient operation of infrastructure and emergency response rely on cross-sectoral integration of data that only a few of the current digital twin deployments have integrated together (Digital twin technology in smart cities review, 2025).

4.9 Explore the importance of smart governance, citizen involvement, and equity

The literature on governance spells out why those institutional lags are important for sustainability outcomes, since the technical domains explored above demonstrate that change in the technical areas can actually be swift while institutions lag behind. Smart governance (SGO) with a focus on the integration of digital technologies into institutional decision-making processes in the field of urban governance has been acknowledged as one of the key factors for sustainable urban development, however, it relies on a set of actors, digital technologies and enablers that are unevenly distributed between urban systems (Understanding Smart Governance of Sustainable Cities review, 2025). Comparative case evidence shows a range of governance models: Medellín, Colombia, is often cited as an example of human-centered governance that has improved social resilience through participatory approaches, and, Aarhus, Denmark, has pursued a more technocratic collaborative governance model, with the combined efforts of smart sensors, IoT infrastructure, and green energy systems leading towards carbon neutrality (Understanding Smart Governance of Sustainable Cities review 2025).

But, a more critical literature is emerging, warning that digital governance devices do not necessarily lead to venues that are more inclusive or equitable. The analysis of the Smart City Governance literature conducted by bibliometric analysis showed that the awareness of social sustainability aspects was still comparatively low, while the knowledge of aspects related to technology and environment were still highly dominant in smart city research (Social sustainability smart cities Global South study, 2025). The structural, economic and governance barriers have been cited as still affecting progress towards SDG 11, in particular in the context of global south, suggesting for example the need to be more creative in governance reform at the local level, rather than attempting direct implementation of



high-income derived smart city models (Oguntona et al., cited in Social sustainability smart cities Global South study, 2025). A systematic review of Citizens Engagement barriers in the field of smart city governance organized these barriers into four categories, namely: technologic barriers, access and inclusivity barriers, information and awareness gaps, bureaucratic and policy barriers, stating that the need to overcome these barriers is a prerequisite for smart city investment to have a tangible impact on inclusivity and responsiveness of smart city governance (Rethinking the smart city review, 2025).

Specifically for the Global South, the scale of the equity challenge shines through: By 2025, estimates by the United Nations suggest that almost 1.1 billion people lived in slum or informal settlements, a number that is expected to grow to 2 billion over the next 30 years, with the vast majority concentrated in the developing world. (United Nations - Smart Governance and the Equity Imperative in South Asia study, 2026) However, much of the growth happening is not in these 'big urban center's as demonstrated by the majority of the literature in smart city discourses, but rather in small and intermediate cities and towns, where critical scholars posit governance capacity is weak and smart infrastructure investment has not yet taken place, which while undoubtedly contributing to a growing urban population, do so while worsening urban poverty and inequality (Smart Governance and the Equity Imperative in South Asia study, 2026). Evidence collected through case research in intermediate cities in Ecuador also reflects how poor inter-sectoral coordination, disconnected planning responsibilities and limited citizen engagement hinder effective outcomes for implementation of good municipal policies, and how low-level participation of planners, urban practitioners and citizens helps fuel skepticism of smart city initiatives in African cities (Rethinking urban governance in the global South study, 2025; Smart cities in Africa systematic review, 2026). A related critical literature describes an "AI urban exclusion cycle" in the implementation of smart cities in the Global South, in which data-driven government and grounded surveillance-based infrastructures are introduced into cities characterized by informality and colonial urban planning history norms, which, instead of alleviating spatial and social inequality, can exacerbate it (The AI Urban Exclusion Cycle study, 2026).

Meanwhile, AI for good governance research is on an optimistic trajectory, providing examples of genuine innovations with participatory digital tools: smart city algorithm registers in Barcelona and Helsinki for instance, which allow to audit automated municipal decision making processes; Vienna's digital-rights charter; Seoul's data-release protocols that address 'differential-privacy'; or the algorithmic accountability regime for cities in New York City (AI-Driven data governance for smart cities study, 2025). The general picture that emerges from governance literature is one of a high degree of variation: "smart governance" can be a strong enabler of inclusive, sustainable urban development but can only be achieved if it is clearly designed to promote citizens' participation and institutional capacity building, not if it is only predetermined by smart technology deployments.

4.10 Data Privacy, Cyber security, and Artificial Intelligence Ethics

The same sensor networks, data platforms, AI systems capable of smart and efficient urban services that also raise major privacy, security and ethics concerns, are a growing topic in recent literature. A systematic review of 145 scientific sources on AI, data privacy and ethics in smart cities revealed that the body of evidence was geographically biased, with case studies being under-represented in Central Asia, Africa and Latin America and making it difficult to generalize the governance recommendations originating mainly from North America, Europe and East Asia, based on the available evidence (Data Privacy and Ethical Governance in AI-Enabled Smart Cities review, 2025). A systematic literature review on data privacy and security in smart cities was performed implementing PRISMA methodology, revealing that the main problems presented are scalability, interoperability, regulatory issues, and the complexity of the implementation of real-time threat detection, where, although many of the techniques implemented are based on encryption and access control, their flexibility isn't sufficient for the dynamic and decentralized data architectures in smart cities (synthetic literature review on data privacy and security in smart cities, 2025).

Some technology areas provide clear examples of such risk vectors: AI-supported public-safety surveillance systems are subject to potential hacking attacks that could trigger privacy violations and misuse of captured data; the Internet-of-Thing-enabled energy systems has its own unique "attack surfaces" (A thorough examination of smart city applications study, 2023). Themes of common risks there found across the literature are the digital divide, the lack of



inclusiveness in the design of digital services, the presence of such deep discrepancies in public acceptance of the practices of data collection that it is impossible to know which is which, the general worry about privacy and cybersecurity risks, and an overall critique of technocratic forms of governance which are designed as services and data providers for citizens (Social smart city research review, 2025). These worries are compounded by the emerging areas of interest in connections beyond smart city deployments, increased sensing density and algorithmic decision-making that pose new privacy, equity and governance concerns for next generation 6G-enabled smart cities infrastructure as examined in a study commissioned by the AIOE entitled Navigating Ethical Challenges in 6G-Enabled Smart Cities study (2025).

To tackle these threats, policy regimes have started to create and formalize ethical and privacy-protective recommendations tailor-made for the urban realm, such as the European Commission's Ethics Guidelines for Trustworthy Artificial Intelligence, the International Electrotechnical Commission's smart city privacy and security best-practice guidelines, or UN-Habitat's human-centric approach to digital urban governance (AI-Driven data governance for smart cities study, 2025; Impact of Data Security and Privacy Concerns study, 2024). However, provision of such frameworks is deemed to be effective strongly relying on local adoption and enforcement capacity, with significant differences in regional and municipal institutional maturity (Impact of Data Security and Privacy Concerns study 2024).

4.11 Disaster Risk Reduction and Urban Resilience

Energy systems in cities represent one of the most important fields for sustainable development (Smart Grids in the Context of Smart Cities review, 2025): they are estimated to be responsible for 75-80 percent of world energy consumption and the very same is expected for energy consumption-related greenhouse gas emissions. According to a more in-depth bibliometric study of over 9,300 publications on smart cities and urban energy planning, the research has tended to focus on the five themes of building-scale energy use, integration of smart cities and urban design in planning, smart transportation infrastructure and mobility, smart power network modernization, and smart policy and regulation (Smart Cities and Urban Energy Planning: An Advanced Review, 2024), with progress in the first four themes consistently outpacing the development in the fifth. This asymmetric has been a key and consistent theme in all the smart and sustainable cities literature that can be reiterated in the water, waste, mobility, and digital twin fields mentioned below.

Advances in the integration of distributed renewable energy at the technology level have been demonstrated, particularly in the context of PV, wind, and, in some cases, geothermal and biofuels (Sustainable Urban Energy: Integrating Smart Grids into Smart Cities, 2020; Gill et al., 2024). Electric vehicles are now increasingly presented not just as a decarbonisation weapon, but a weapon that can help balance the grid: vehicle-to-grid approaches enable the use of 'Idle' EVs to 'catch', store, then 'return' to the grid electricity generated from renewables at peak periods, when consumption exceeds supply (Gill et al., 2024). While various potential solutions for smart grid in cities had been identified, a full list of sixteen solutions was identified, as well as a list of eleven that could be generalized as persistent implementation gaps that would span interoperability standards, financing models and workforce capacity (Smart Grids in the Context of Smart Cities review, 2025). More recent architecture-first reviews take this one step further and adopt a broader view of the new generation of AI-powered, decentralized urban electrical grids, suggesting that legacy power systems, built for a single-time, single-actor grid and passive response, are ill-equipped to address the new challenges of multi-actor coordination needed for an AI-powered, decentralized grid (Electrical Grid Architectures for Smart Cities review, 2026).

Positive energy districts, neighbourhoods or districts (which meaning an annual cycle to produce as much or more renewable energy as consumed) has become widely cited as a critical implementation unit between the building and the city scales of energy transition actions whilst some of the key scaling challenges emanate from policy and regulatory, financing and social acceptance difficulties that have been noted in some systematic reviews of the subject (Urban energy transition in smart cities review, 2025). Strandjberg and Aarhus have served as case examples for Europe in the operationalization of energy/cluster of cities-energy-climate planning at the municipal and/or district level (Smart Renewable Energy System integration study, 2025), aiming to demonstrate that while technical



modelling and simulation skills are important, they are not the determining drivers for success in energy-climate planning and transitions on the local level.

4.12 Measuring Progress: SDG 11 and Urban Sustainability Indicators

Good measurement is a prerequisite for good accountability for sustainable urban development, as Sustainable Development Goal 11 contains the most comprehensive global framework for monitoring city-level SDG 11 development under ten targets and sixteen indicators that cover issues of housing, access to transport, land use, participatory planning, protection of cultural and natural heritage, disaster resilience, access to air quality, and public space (The Sustainable Development Goal tracker of SDG 11, data from Our World in Data, 2023). The latest official monitoring figures show a true mixed picture. On the bright side, Europe and Northern America (in addition to Australia and New Zealand) have collection coverage above 98 per cent, while Eastern and South-Eastern Asia and sub-Saharan Africa considerably lag behind at 65 and 63 per cent respectively, with the need for more coordinated investments in collection infrastructure and the support of policy closing the basic service gaps (UN Statistics Division SDG 11 report 2025). The proportion of the urban population which has easy access to open public spaces has actually decreased from 48.0 per cent to 45.9 per cent in the timeframe between 2020 and 2025, pointing towards worsening conditions on this less encouraging sign of urban quality of life, according to a dataset of 414 cities across 126 countries (UN DESA Goal 11 report, 2026).

There are still recurring issues in methodological work linking global indicators to policy-relevant guidance for local implementation in SDG 11 measurement. A study developed an SDG 11 local implementation framework for municipalities in Japan applied principal component analysis and structural equation modelling to examine the roles played by a set of indicators, such as associations between higher degrees of urbanisation and better quality of life and better fiscal capacity of municipalities, which supports government decision making for investing on which areas to focus, but may not be applicable to regions with less developed fiscal institutions (Study to develop an SDG 11 local implementation framework for municipalities, Japan, 2022). The Research provided by the municipalities using alternative, established, indicator frameworks (such as the Mapping and Assessment of Ecosystems and their Services scheme, and the Knowledge and Learning Mechanism on Biodiversity and Ecosystem Services framework, and the Smart City Performance Measurement Framework, CITY keys) showed that these indicators do not consistently map onto all of the SDG 11 sub-objectives, and that municipalities should carefully consider which indicators to use or perhaps opt for a mix of indicators, intentionally selecting those that represent the sub-goals that are most relevant to their specific city. (Public-pages Frontiers SDG 11 alignment study, 2018)

A more widely used cross-national benchmarking tool is the Sustainable Development Report series, which has been released by the Sustainable Development Solutions Network every year, and which rates country-level performance on SDG 11 alongside other SDGs and provides a basis for comparison of the financial gaps that need to be addressed to achieve SDG 2030 targets (Sachs et al., 2025). The underlying nuance is provided in regional monitoring reports: "Although Asia-Pacific fares well overall, SDG 11 reporting illustrates where some indicators have seen backsliding since 2000, such as increases in absolute numbers in slums, progress on slum upgrading and decreasing exposure to disasters, reflecting the fact that aggregate regional urbanization and economic development does not automatically correspond to better sustainability outcomes at the indicator level (SDG11 Sustainable Cities and Communities Asia pacific report, 2025).

5. Cross-Cutting Challenges

Many of the issues discussed in the above twelve thematic domains appear repeatedly in the different domains, indicating that they are not a set of sectoral problems but a set of structural issues in the field of smart and sustainable urban development. First, as far as energy planning goes, technological innovation consistently outpaces regulatory and policy development, as mentioned by Smart Cities and Urban Energy Planning: An Advanced Review (2024); for digital twins, the technical but not open-ended capabilities are lagging behind regulations and policy, with What Have Urban Digital Twins Contributed? study (2025); and waste management engagements reveal that although technical capacity is winning a race, it is not yet able to keep up with city-wide operational deployment, as mentioned by IoT-Enabled Waste Management in Smart Cities: review (2025). It suggests that in addition to ongoing technological



research and development, long-term financial investment should be continued in the field of building institutional capacity and expanding and strengthening the skills of municipal personnel to close implementation gaps.

Secondly, interoperability is a special and recurring technical challenge. Interoperability is recognized as one of the eleven persistent challenges for smart grid deployment (Smart Grid review of Smart Grids in the Context of Smart Cities, 2025); data-integration and system-interoperability as central obstacles to the achievement of smart city-wide benefits (IoT, Data, AI, and Digital Twins in smart cities systematic review, 2025); and interoperability as a factor that harms the effectiveness of otherwise solid security measures (systematic review on the requirements for data privacy and security within smart cities, 2025). But since most domain-specific digital infrastructure is acquired independently (sector-by-sector, as a rule from several suppliers adhering to different sets of data standards), failures of interoperability add up, and in practice, fully-integrated, cross-sectoral smart city governance is difficult.

Third, the very basis of the research is geographically biased, which hampers the generalizability of many smart and sustainable cities findings. Even some of those that are related to urban areas in Africa explicitly mention the lack of case studies in the region that will be experiencing the highest growth in urban populations over the next decades (e.g. Data Privacy and Ethical Governance in AI-Enabled Smart Cities review, 2025; Nor Shahrudin et al., 2025). This poses a risk of applying governance mechanisms, technical standards and best practice recommendations geared predominantly to Northern American, European and East Asian experience to Southern, Global South cities that have institutional, informal-settlement and socio-spatial contexts very different from those in which those mechanisms and standards were developed (Smart Governance and the Equity Imperative in South Asia study, 2026; The AI Urban Exclusion Cycle study, 2026).

Fourth, there was a lack of equity or distributional research in most of the areas examined, relative to technical and environmental research. The underlying focus of the literature on governance of smart cities has been confirmed by bibliometric analysis: the literature is predominantly dominated by technical and environmental issues, with limited attention paid to social equity issues (Social sustainability smart cities Global South study, 2025), a trend which is also reflected in studies on urban heat, for which social vulnerability studies, not dealing with urban heat per se, and focusing on social equity are only now gaining weight in the literature, and in the mobility literature, where it is still a topic of controversy how to introduce and sustain social equity aspects related to EV subsidies. (Urban heat vulnerability and mitigation in U.S. cities review, 2026) (Stefanec et al., 2025).

Fifth, sustainability accounting for the digital infrastructure, embodied carbon, e-waste and energy use is not included in the assessment of smart city technologies that are predominantly promoted based on their services' operational efficiency. This is specifically mentioned by life-cycle assessment (LCA) research on smart water meters, which identifies the environmental costs of digitalization as part of the business case of smart water meters (How sustainable is digitalization in urban water infrastructure study, 2025), a detail that is often overlooked from the business case of smart city technology. This is a huge gap in the existing sustainability assessment practice when specific sensor, communication or computing infrastructure imagine digital twins, smart grid and AI-driven governance systems.

6. Future Research Directions

Based on the cross cutting challenges outlined above, there are specific research priorities that are particularly pressing. Evaluation evidence from almost all of the domains evaluated depicts primarily pilot-project reporting, or technical studies on feasibility, rather than any long term evaluation of the outcomes of smart city interventions and their impact on sustainability, as embodied in emissions reductions, resource saving or equity impacts over multi-year periods. Second, the lack of research explicitly designed with a focus on Global South urban contexts, dealing with informality, resource-constrained institutional capacity and rapid population growth in small and intermediate sized cities, rather than megacities, is considered a priority gap as the majority of urban population growth will likely take place in these contexts in the future (Smart Governance and the Equity Imperative in South Asia study, 2026). Third, there is a need for dedicated research into integrated, cross-sectoral architectures of digital twins and data governance, explicitly linking energy, water, waste, mobility and green infrastructure data systems that has been proposed within the digital twin literature for the socio-technical research agenda "Augmented Urban Planning"



(What Have Urban Digital Twins Contributed study 2025). Fourth, there is a need to develop sustainability life cycle accounting frameworks specifically for urban digital infra, which will account for the "embodied environmental costs" of sensor, communication infrastructure and computing units to enable decisions for adoptions of smart city tech to be made based on operational efficiency or 'real' net environmental costs. Finally, comparative institutional research that explores the mechanism behind cities that are able to turn smart governance tools into real participatory and equity-oriented results (like Medellín) into what leads others (like much of the Global South's smart city cases) to technocratic, exclusionary ones (as reported in critical scholarship on Global South smart urbanism) would yield and disseminate institutional design principles that go beyond mere 'technical best practices'.

7. Policy Implications

The evidence compiled in this review suggests some implications for urban planners and urban policy makers. The use of "smart" and "sustainable" should not be synonymous and planning and procurement choices for smart city investments should be based only if such an investment will bring social equity and environmental integrity as an explicit measurable benefit rather than an operational efficiency. In other contexts, there is a consistent finding that as technology implementation gets traction faster than institutional and/or regulatory development, it would seem that municipal governments should build institutional capacity, such as interoperable data governance standards, train staff and build engagement infrastructure not after, but while ongoing technology procurement. Interoperability failures cascade through sectors, and should be a central part of cities and national governments' digital infrastructure planning and investment priorities from the start of smart city initiatives, not after investment in and implementation of sector-specific digital infrastructures has taken place. To achieve sustainability without amplifying the benefits for already privileged urban populations, policy instruments can target specific population-specific equity challenges, such as introducing means-tested EV subsidies, an electric vehicle reversing charging framework, heat-vulnerability-based green infrastructure placement, and participatory budgeting mechanisms for smart governance platforms. To conclude, with increased Africa, Latin American and some Asian underrepresentation in current evidence base, despite these regions as vital in current and future urban growth, international development finance institutions and research funders must focus on context-specific pilot programmes and research in these areas instead of continued funding of Global North smart city adaptation models for the Global South.

8. Conclusion

In the last 10 years, the combination of smart digital technologies and sustainability concerns has produced a reactive scope and vision of urban innovation that is truly transformative, first with renewable-integrated smart grids, AI-optimized water networks, and nature-based climate adaptation and, more recently, ever-growing and complex urban digital twins. But, there is an important and consistent message in the recent literature reviewed here: technologically sophisticated does not equal to sustainable, equitable, or resilient urban outcomes. The same is true for the energy system, mobility system, smart and green infrastructure, water management, waste management, the built environment, digital twin solutions, governance, privacy, and resilience? In all of these fields, new technologies are advancing faster than the institutional capacity, interoperability standards, equity protection, and evidence base needed from the Global South to lead the way in their deployment and management in ways that bring better sustainability benefits for all city dwellers? In the next few decades, as over two thirds of humanity moves to cities and the city's institutional framework lacks sufficient preparation to meet the vital needs of these growing populations, the question for the rest of the century will be whether this change in urban life will be a story of truly sustainable development or of growing inequality and technologically mediated development. Smartness needs to be recognized as one of the tools needed to enable a transition in the direction of truly inclusive, safe, resilient, and sustainable cities, the whole larger purpose for which Sustainable Development Goal 11 was conceived.

Credit authorship contribution statement

Sujatha Gundeboiyna: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Tanzeer Ahmad Dar:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Formal analysis. **Sudhakar Kota:** Writing – review & editing, Writing – original draft, Supervision. **Acknowledgement**



The authors are grateful to Department of chemistry, Audisankara (Deemed to be University) for providing good environment for the research.

References

1. Aboagye, P. D., & Sharifi, A. (2024). Urban climate adaptation and mitigation action plans: A critical review. *Renewable and Sustainable Energy Reviews*, 189, 113886. <https://doi.org/10.1016/j.rser.2023.113886>[†]
2. Almulhim, A. I. (2026). The AI Urban Exclusion Cycle: Smart urbanism and inequality in the Global South. *Frontiers in Sustainable Cities*, 8. <https://doi.org/10.3389/frsc.2026.1955093>
3. AI-IoT-graph synergy for smart waste management: A scalable framework for predictive, resilient, and sustainable urban systems. (2025). *Frontiers in Sustainability*. <https://doi.org/10.3389/frsus.2025.1675021>
4. Alnaser, A. A., Maxi, M., & Elmousalami, H. (2024). AI-powered digital twins and Internet of Things for smart cities and sustainable building environment. *Applied Sciences*, 14(24), Article 12056. <https://doi.org/10.3390/app142412056>
5. Analyzing sustainable urban development through smart and sustainable cities: An integrated review. (2025). *Frontiers in Sustainable Cities*. <https://doi.org/10.3389/frsc.2025.1685716>
6. Anttiroiko, A.-V. (2023). Smart circular cities: Governing the relationality, spatiality, and digitality in the promotion of circular economy in an urban region. *Sustainability*, 15(17), 12680. <https://doi.org/10.3390/su151712680>
7. Fang, B., Yu, J., Chen, Z., Osman, A. I., Farghali, M., Ihara, I., Hamza, E. H., Rooney, D. W., & Yap, P.-S. (2023). Artificial intelligence for waste management in smart cities: A review. *Environmental Chemistry Letters*, 21, 1959–1989. <https://doi.org/10.1007/s10311-023-01604-3>
8. **Bibri, S. E. (2021)**. Data-driven smart sustainable cities of the future: Urban computing and intelligence for strategic, short-term, and joined-up planning. *Computational Urban Science*, DOI: 10.1007/s43762-021-00008-9
9. Gu, Q., Sing, M. C. P., Jefferies, M., & Kanjanabootra, S. (2025). Bridging the gap between smart cities and sustainability: Current practices and future trends. *Cities*, 159, 105799. <https://doi.org/10.1016/j.cities.2025.105799>
10. Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). *Smart cities in Europe*. *Journal of Urban Technology*, 18(2), 65–82. DOI: 10.1080/10630732.2011.601117
11. Chen, T., Gil-García, J. R., & Gascó-Hernández, M. (2022). *Understanding social sustainability for smart cities: The importance of inclusion, equity, and citizen participation as both inputs and long-term outcomes*. *Journal of Smart Cities and Society*, 1(2), 135–148. DOI: 10.3233/SCS-210123
12. “A review on circular economy and digitalization in the organic municipal solid waste sector”, published in *Resources, Conservation and Recycling*, 234, 109069. DOI: 10.1016/j.resconrec.2026.109069
13. Barakat, S., Güven, A. F., Abdelaziz, A. Y., & Samy, M. M. (2026). *A comprehensive review of electric vehicles and sustainable urban mobility in the Middle East and North Africa*. *Renewable and Sustainable Energy Reviews*, 225, 116154. DOI: 10.1016/j.rser.2025.116154
14. *Critical reflections on strategies for mitigating and adapting to urban heat islands*. (2024). *Journal of Sustainable Urbanism*. <https://doi.org/10.1080/19463138.2024.2350205>
15. Turgimbayev, A., Ayaulym, S., Issayeva, V., Zhetpissov, Z., & colleagues. (2025). *Data privacy and ethical governance in AI-enabled smart cities: A systematic review*. *Research Methods and Tools*. <https://doi.org/10.5281/zenodo.17660508> *Determinants and indicators of healthy, climate resilient cities: A scoping review*. (2025). *Cities & Health*. <https://doi.org/10.1080/23748834.2025.2558288>
16. Yessef, M., Hakam, Y., Tabaa, M., Alammam, M. M., & Elbarbary, Z. M. S. (2025). Digital twin technology in smart cities: A step toward intelligent urban management. *Energy Reports*, 14, 5539–5557.



<https://doi.org/10.1016/j.egy.2025.11.097>

17. *Digital twins for intelligent intersections: A literature review*. (2025). arXiv. <https://arxiv.org/abs/2510.05374>
18. *Electrical grid architectures for smart cities from digitalized power systems to AI-enabled urban energy ecosystems*. (2026). *Smart Cities*, 9(6), Article 96. <https://doi.org/10.3390/smartcities9060096>
19. Esfandi, S., et al. (2024). Smart cities and urban energy planning. *Encyclopedia*, MDPI. †
20. Yamasaki, K., & Yamada, T. (2022). A framework to assess the local implementation of Sustainable Development Goal 11. *Sustainable Cities and Society*, 84, 104002. <https://doi.org/10.1016/j.scs.2022.104002>
21. Gill, A., Ramachandran, T., Upadhyay, R., & Agarwal Gautam, A. (2024). Strategic grid integration of renewable using electric vehicles for smart cities stability. *E3S Web of Conferences*, 540, Article 10024. <https://doi.org/10.1051/e3sconf/202454010024>
22. Green building practices: Complete 2025 guide to sustainable construction. (2025).
23. Green building technologies: Complete 2025 guide to sustainable construction. (2025). Green infrastructure for urban climate mitigation and adaptation: Methods, strategies, and typology selection based on ecosystem services. (2025). *International Journal of Environmental Science and Technology*. <https://doi.org/10.1007/s13762-025-06754-1>
24. Hajibabaei, M., Oberascher, M., Shahangian, S. A., Gschösser, F., & Sitzenfrei, R. (2025). How sustainable is digitalization in urban water infrastructure? A life cycle assessment of the implementation of smart water meters. *AQUA – Water Infrastructure, Ecosystems and Society*, 74(10), 677–693. <https://doi.org/10.2166/aqua.2025.032>
25. Bedewy, S. F. (2024). The impact of data security and privacy concerns on the implementation of integrated systems in smart cities. In *Smart Cities – Foundations and Perspectives*. IntechOpen. <https://doi.org/10.5772/intechopen.115076>
26. International experts lead calls to embed nature in city infrastructure for better health and climate resilience. (2025). ScienceDaily. (Citing *Frontiers in Sustainable Cities*, 7). <https://doi.org/10.3389/frsc.2025.1595280>
27. IoT, AI, and digital twins in smart cities: A systematic review for a thematic mapping and research agenda. (2025). *Smart Cities*, 8(5), Article 175. <https://doi.org/10.3390/smartcities8050175>
28. Alaoui, M. L. T., Belhiah, M., & Ziti, S. (2025). IoT-enabled waste management in smart cities: A systematic literature review. *International Journal of Advanced Computer Science and Applications*, 16(4), 131–138. DOI: 10.14569/IJACSA.2025.0160415
29. Jafari, M., Kavousi-Fard, A., Chen, T., & Karimi, M. (2023). *A review on digital twin technology in smart grid, transportation system and smart city: Challenges and future*. *IEEE Access*, 11, 17471–17484. DOI: 10.1109/ACCESS.2023.3241588
30. Karimi, A., Mohammad, P., García-Martínez, A., Moreno-Rangel, D., Gachkar, D., & Gachkar, S. (2023). *New developments and future challenges in reducing and controlling heat island effect in urban areas*. *Environment, Development and Sustainability*, 25(10), 10485–10531. DOI: 10.1007/s10668-022-02530-0
31. Kummitha, R. K. R. (2025). Smart city governance: Assessing modes of active citizen engagement. *Regional Studies*. <https://doi.org/10.1080/00343404.2024.2399262>
32. Lau, K., Yuan, C., & Ng, E. (2025). Urban heat island adaptation and mitigation in practice: Lessons from policy implementation in five cities. *Philosophical Transactions of the Royal Society A*, 383(2308), Article 20240581. <https://doi.org/10.1098/rsta.2024.0581>
33. Leveraging urban water distribution systems with smart sensors for sustainable cities DOI: 10.3390/s24227223, 2024 article in *Sensors*, 24(22), 722333.
34. Luo, X., & Huang, R. (2024). *How to achieve sustainable development of smart city: A comprehensive bibliometric analysis*. DOI: 10.1007/s10098-024-02945-5



35. Maatallah, R., Abdessamad, A., & Khatori, Y. (2026). *Smart cities in Africa: A systematic literature review of challenges and development strategies*. *City and Environment Interactions*, 30, 100365. DOI: 10.1016/j.cacint.2026.100365
36. MAPFRE (2026). *Keys for understanding the future of sustainable mobility*. This is a MAPFRE web article, published April 14, 2026, rather than a scholarly journal article.
37. Mhlanga, D. (2026). *Artificial Intelligence in smart cities: implications for urban governance in Africa*. *Frontiers in Sustainable Cities*, 8, 1835768. DOI: 10.3389/frsc.2026.1835768
38. *Modern energy sources for sustainable buildings: Innovations and energy efficiency in green construction*. (2025). *Energies*, 18(5), Article 1121. <https://doi.org/10.3390/en18051121>
39. Mondal, P. (2024). AI and IoT in smart water management for urban sustainability. *Uncertainty Discourse and Applications*, 1(2), 151–157. <https://doi.org/10.48313/uda.v1i2.36>
40. *Nature-based solutions in urban green infrastructure: A systematic review of success factors and implementation challenges*. (2025). *Land*, 14(4), Article 818. <https://doi.org/10.3390/land14040818>
41. Mosisa, G. B., Bedadi, B., Dalle, G., & Tassie, N. (2025). Nature-based solutions for urban climate resilience: Implementation, contribution, and effectiveness. *Nature-Based Solutions*, 8, 100245. <https://doi.org/10.1016/j.nbsj.2025.100245>
42. *Nature-based solutions for urban sustainability*. (2025). *Proceedings of the National Academy of Sciences*, 122. <https://doi.org/10.1073/pnas.2315909122>
43. Rafique, S., Iqbal, S., Ali, D., & Khan, F. (2025). Navigating ethical challenges in 6G-enabled smart cities: Privacy, equity, and governance. *ICCK Transactions on Sensing, Communication, and Control*, 2(1), 48–65. <https://doi.org/10.62762/TSCC.2025.291581>
44. Peldon, D., Banihashemi, S., LeNguyen, K., & Derrible, S. (2024). Navigating urban complexity: The transformative role of digital twins in smart city development. *Sustainable Cities and Society*, 111, 105583. <https://doi.org/10.1016/j.scs.2024.105583>
45. Nor Shahrudin, N. S., et al. (2025). Sustainable, smart, and resilient city development: A systematic review. *Sustainable and Resilient Infrastructure*. <https://doi.org/10.1080/23789689.2025.2574256>
46. Oberascher, M. (2022). *Innovative concepts and applications for smart water cities: Towards integrated management of network-based urban water infrastructure* (Forum Umwelttechnik und Wasserbau, Vol. 32). Innsbruck University Press. DOI: 10.15203/99106-084-0
47. Olatunde, T. M., Okwandu, A. C., Akande, D. O., & Sikhakhane, Z. Q. (2024). *Review of energy-efficient HVAC technologies for sustainable buildings*. *International Journal of Science and Technology Research Archive*, 6(2), 012–020. DOI: 10.53771/ijstra.2024.6.2.0039
48. *Optimal water management strategies: Paving the way for sustainability in smart cities*. (2023). *Smart Cities*, 6(5), Article 128. <https://doi.org/10.3390/smartcities6050128>
49. Patil, M., Boraste, S., & Minde, P. (2022). A comprehensive review on emerging trends in smart green building technologies and sustainable materials. *Materials Today: Proceedings*, 65, 1813–1822. <https://doi.org/10.1016/j.matpr.2022.04.866>
50. Pedersen, A. N., Borup, M., Brink-Kjær, A., Christiansen, L. E., & Mikkelsen, P. S. (2021). Living and prototyping digital twins for urban water systems: Towards multi-purpose value creation using models and sensors. *Water*, 13(5), 592. <https://doi.org/10.3390/w13050592>
51. Redclift, M. (2005). Sustainable development (1987–2005): An oxymoron comes of age. *Sustainable Development*, 13(4), 212–227. <https://doi.org/10.1002/sd.281>



52. Kougias, C., & Papadakaki, M. (2026). Rethinking the 'smart city': From technology-led visions to citizen-centered governance—Barriers and pathways in digital urban initiatives. *Journal of Urban Affairs*, 48(5), 1581–1604. <https://doi.org/10.1080/07352166.2025.2502116>
53. Zambrano-Monserrate, M. A. (2025). Rethinking urban governance in the global South: Lessons from Ecuador's intermediate cities. *Urban Governance*, 5(4), 538–541. <https://doi.org/10.1016/j.ugi.2025.08.007>
54. A review of adaptation strategies to increased urban temperatures and heat island effect. (2025). *Discover Cities*. <https://doi.org/10.1007/s44327-025-00064-4>
55. A review of urban digital twins integration, challenges, and future directions in smart city development. (2024). *Sustainability*, 16(19), Article 8337. <https://doi.org/10.3390/su16198337>
56. A review of urban resilience to weather and climate extremes. (2025). *City and Built Environment*. <https://doi.org/10.1007/s44213-025-00063-6>
57. Sachs, J. D., Lafortune, G., Fuller, G., & Iablonski, G. (2025). *Financing sustainable development to 2030 and mid-century: Sustainable development report 2025*. SDN; Dublin University Press. <https://doi.org/10.25546/111909>
58. Schrotter, G., & Hürzeler, C. (2020). The digital twin of the city of Zurich for urban planning. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 88(1), 99–112. <https://doi.org/10.1007/s41064-020-00092-2>
59. Xu, H., Li, Y., Tan, Y., & Deng, N. (2021). A scientometric review of urban disaster resilience research. *International Journal of Environmental Research and Public Health*, 18(7), 3677. <https://doi.org/10.3390/ijerph18073677>
60. *SDG11 sustainable cities and communities: Asia-Pacific regional progress report*. (2025).
61. Wendling, L. A. (2018). Benchmarking nature-based solution and smart city assessment schemes against the Sustainable Development Goal indicator framework. *Frontiers in Environmental Science*, 6, 69. <https://doi.org/10.3389/fenvs.2018.00069>
62. Sharifi, A., & Yamagata, Y. (2016). Principles and criteria for assessing urban energy resilience: A literature review. *Renewable and Sustainable Energy Reviews*, 60, 1654–1677. <https://doi.org/10.1016/j.rser.2016.03.028>
63. Smart cities and urban energy planning: An advanced review of promises and challenges. (2024). *Smart Cities*, 7(1), Article 16. <https://doi.org/10.3390/smartcities7010016>
64. Smart cities and villages: Concept review and implementation perspectives in developing cities. (2024). arXiv. <https://arxiv.org/abs/2402.09284>
65. Smart governance and the equity imperative in South Asia: Promise, practice, and institutional contradictions. (2026). Springer Nature Link (book chapter). †
66. Smart grids in the context of smart cities: A literature review and gap analysis. (2025). *Energies*, 18(5), Article 1186. <https://doi.org/10.3390/en18051186>
67. de Larochelambert, T., Labaude, F., & Blond, N. (2026). Integration of a smart renewable energy system in sustainable and resilient urban energy-climate planning. In *Advances in Thermal Science and Energy II* (pp. 489–500). Springer, Cham. https://doi.org/10.1007/978-3-032-15368-5_46
68. Social smart city research: Interconnections between participatory governance, data privacy, artificial intelligence and ethical sustainable development. (2025). *Frontiers in Sustainable Cities*, <https://doi.org/10.3389/frsc.2024.1514040>
69. Sugandha, Freestone, R., & Favaro, P. (2025). Social sustainability, smart cities and the Global South: Learning from the Indian experience. *Cities*, 165, 106149. <https://doi.org/10.1016/j.cities.2025.106149>



70. Souza, D. S. F. D., Sehnem, S., Guarnieri, P., Nepomuceno, T. C. C., Taques, F. H., & Silva, L. C. E. (2025). Smart cities and electrical and electronic waste management: A review of challenges and opportunities. *Urbanization, Sustainability and Society*, 2(1), 284–309. <https://doi.org/10.1108/USS-08-2024-0051>
71. Stefaniec, A., Egan, R., Hosseini, K., & Caulfield, B. (2025). The challenge of making EVs just affordable enough: Assessing the impact of subsidies on equity and emission reduction in Ireland. *Research in Transportation Economics*, 109, 101495. <https://doi.org/10.1016/j.retrec.2024.101495>
72. Šulyová, D., & Kubina, M. (2022). Integrated water resources management in an urban concept: Results from water smart cities and water management institutions in Slovakia. *Entrepreneurship and Sustainability Issues*, 10(2), 294–319. [https://doi.org/10.9770/jesi.2022.10.2\(18\)](https://doi.org/10.9770/jesi.2022.10.2(18))
73. Cortés Ràfols, S. (2025, April 2). *Sustainable building trends: What will 2025 bring and how was 2024?* Zero Consulting,
74. *Sustainable construction driving green building growth*. (2026). Expert Market Research.
75. Shao, J., & Min, B. (2025). Sustainable development strategies for Smart Cities: Review and development framework. *Cities*, 158, 105663. <https://doi.org/10.1016/j.cities.2024.105663>
76. *Sustainable smart city and Sustainable Development Goals (SDGs): A review*. (2025). *Regional Sustainability*, 6(1), 100193. <https://doi.org/10.1016/j.regsus.2025.100193>
77. Karduri, R. K. R., & Ananth, C. (2020). Sustainable urban energy: Integrating smart grids into smart cities. *International Journal of Advanced Research in Basic Engineering Sciences and Technology*, 6(2), 34–40. <https://doi.org/10.2139/ssrn.4637789>
78. *A systematic literature review on data privacy and security techniques in smart cities: Trends, gaps, and future directions*. (2025). *Computing*. <https://doi.org/10.1007/s00607-025-01553-5>
79. Xia, L., Semirumi, D. T., & Rezaei, R. (2023). A thorough examination of smart city applications: Exploring challenges and solutions throughout the life cycle with emphasis on safeguarding citizen privacy. *Sustainable Cities and Society*, 98, 104771. <https://doi.org/10.1016/j.scs.2023.104771>
80. *Towards civic digital twins: Co-design the citizen-centric future of Bologna*. (2024). arXiv. <https://arxiv.org/abs/2412.06328>
81. Oberascher, M., Rauch, W., & Sitzenfrei, R. (2022). Towards a smart water city: A comprehensive review of applications, data requirements, and communication technologies for integrated management. *Sustainable Cities and Society*, 76, 103442. <https://doi.org/10.1016/j.scs.2021.103442>
82. UN-Habitat. (2024). *World cities report 2024: Cities and climate action*. United Nations Human Settlements Programme. <https://doi.org/10.18356/9789211065602>
83. UN Statistics Division. (2025). *SDG indicators report 2025: Goal 11*. <https://unstats.un.org/sdgs/report/2025/goal-11/>
84. UNDP. (2024). *Urban climate resilience*. UNDP Climate Change Adaptation Programme.
85. UNDRR. (2023). *Urban resilience*. United Nations Office for Disaster Risk Reduction.
86. *Understanding smart governance of sustainable cities: A review and multidimensional framework*. (2025). *Smart Cities*, 8(4), Article 113. <https://doi.org/10.3390/smartcities8040113>
87. *Urban air mobility: A review of recent advances in communication, management, and sustainability*. (2025). arXiv. <https://arxiv.org/abs/2510.18235>
88. *Urban green governance: IoT-driven management and enhancement of urban green spaces in Campobasso*. (2025). arXiv. <https://arxiv.org/abs/2507.12106>
89. *Urban green infrastructure: Bridging biodiversity conservation and sustainable urban development through adaptive management approach*. (2024). *Frontiers in Ecology and Evolution*, 12.



<https://doi.org/10.3389/fevo.2024.1440477>

90. Yuan, J., Antoszewski, P., Choryński, A., Gao, Y., Chai, J., & Kong, X. (2026). Urban Heat Island mitigation strategies: A comprehensive review of recent advances. *City and Environment Interactions*, 30, 100351. <https://doi.org/10.1016/j.cacint.2026.100351>
91. Hashemi, F., Meshkinkiya, M., Adib, M., & Khayatian, F. (2026). Urban heat, vulnerability, and mitigation in U.S. cities: A systematic review. *Sustainable Cities and Society: Advances*, 2(3), 100077. <https://doi.org/10.1016/j.scsadv.2026.100077>
92. Kalpakidis, D., Efthimiou, G., Skanavis, C., & Papadas, I. T. (2026). Urban nature-based solutions as public-health infrastructure: A scoping review of implemented interventions. *The Science of Nature*, 113, 90. <https://doi.org/10.1007/s00114-026-02139-7>
93. *Urban planning for disaster risk reduction and climate change adaptation: A review at the crossroads of research and practice.* (2025). *Sustainability*, 17(20), Article 9092. <https://doi.org/10.3390/su17209092>
94. *What have urban digital twins contributed to urban planning and decision making? From a systematic literature review toward a socio-technical research and development agenda.* (2025). *Smart Cities*, 8(1), Article 32. <https://doi.org/10.3390/smartcities8010032>
95. Wismadi, A., Frøyen, Y. K., & Rasheed, A. (2025). Sustainable active travel in environmentally challenging cities: A systematic review of barriers and strategies. *Sustainability*, 17(3), Article 1276. <https://doi.org/10.3390/su17031276>
96. Yusuf, O., Rasheed, A., & Lindseth, F. (2025). Leveraging big data and AI for sustainable urban mobility solutions. *Urban Science*, 9(8), Article 301. <https://doi.org/10.3390/urbansci9080301>