Sustainable Cities and Society 75 (2021) 103278

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

# What makes a city 'smart' in the Anthropocene? A critical review of smart cities under climate change

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ARTICLE INFO

*Keywords:*
Smart cities
Climate change
Critical infrastructure
Urban resilience
Sustainable development

ABSTRACT

In recent years, smart cities have grown in popularity, both in research and in practice. The focus of smart city studies and policy initiatives has historically been on technology, particularly how information and communication technology can be leveraged to improve city functions. This focus has begun to shift towards sustainability, with many researchers calling for the development of smart, sustainable cities, which can aid efforts of climate change mitigation and adaptation. The connection between smart cities and climate change, however, is not clear. In this review article, we aim to synthesize the recent literature surrounding smart cities and climate change, and to discuss the benefits (or costs) of smart cities with regard to climate change mitigation and adaptation efforts. In particular, we focus on five key aspects of urban resilience to climate change: infrastructure, public health and well-being, accessibility and equity, sustainable systems, and governance. The literature reveals a higher level of emphasis on infrastructure resilience to climate change than the other categories. Moreover, the research areas differ in the level of connection between smart city initiatives and climate change adaptation and mitigation efforts. For example, within the critical infrastructure research area, studies on smart energy systems focus on climate change mitigation, particularly reducing emissions, while studies on smart water systems emphasize adaptation to future floods and droughts. Going beyond the aforementioned research areas, we discuss the role of big data in smart cities, including the benefits and challenges associated with collecting large amounts of data from smart technology, as well as the techniques needed to analyze such data. Finally, we highlight future directions that we believe the research on smart cities needs to focus on, based on the results from our literature review. These include infrastructure and disaster resilience, public health and social equity, and sustainability.

## 1. Introduction

The World Bank has projected that nearly 70% of the world's population will live in cities by 2050 (The World Bank, 2010). This rapid urbanization is occurring simultaneously with climate change, both of which are increasing the stress on the cyber-physical infrastructure within cities, as well as the services provided by these systems. These unprecedented challenges have led scholars, policymakers, and practitioners to call for new paradigms in urban planning and management, including the concept of smart cities.

The concept of smart cities, as a research topic and policy framework, has risen in popularity in recent years. Yet, there is no agreed upon definition of what makes a city 'smart'. In fact, the definitions range from purely technological to more holistic views grounded in sustainability (Albino et al., 2015). These different definitions can be traced to various schools of thought surrounding smart cities. For example, a number of studies consider technology to be the determinant of 'smartness', particularly when implemented to facilitate automation and data-driven decision-making (Belissent and Frederic, 2013; Nam and Pardo, 2011). Conversely, other studies have posited that social and human capital are key elements in defining smartness, relating the concept to social cohesion and networks, education and economics within urban spaces (Caragliu et al., 2011; Storper and Scott, 2009). Finally, there is a growing body of work that emphasizes sustainability

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https://doi.org/10.1016/j.scs.2021.103278
Received 13 January 2021; Received in revised form 29 July 2021; Accepted 14 August 2021
Available online 21 August 2021

as a primary tenet of smart cities (Ahvenniemi et al., 2017; Chourabi et al., 2012; Fitzgerald, 2010).

In practice, smart cities are often lauded as a means to transform urban areas into modern cities while contributing to sustainability goals. However, there is a need to consider the broader impacts of smart cities, including those to the environment, infrastructure, public health, accessibility, and equity, as well as the implications of generating and using 'big data' for decision-making. Given the challenges posed by climate change and the increasing popularity of smart cities, it is important to integrate these areas of research.

The purpose of this study is to synthesize the recent literature surrounding smart cities and climate change and to discuss the benefits (or costs) of smart cities, with regard to future climate change mitigation and adaptation. While smart cities have been discussed as a potential path towards climate change adaptation and mitigation, the literature related to the environmental and social impacts of smart cities under climate change is nascent and there are not, to our knowledge, any critical reviews on the subject. In this review, we aim to fill this gap by focusing on the role of smart cities on key aspects of urban environments in the Anthropocene, including critical infrastructure, public health, accessibility and equity, sustainability, and governance. These thematic areas are not only important within the smart city literature, but also critical to climate change adaptation and mitigation efforts.

In the following sections, we first discuss the various definitions and conceptualizations of smart cities. Next, we describe the methodology used to conduct the critical literature review. Then, we focus on the results of the literature review on smart cities and climate change, as it relates to (i) infrastructure; (ii) public health and well-being; (iii) accessibility and equity; (iv) sustainable systems; and (v) governance. Finally, we briefly discuss the role of big data and recommend future directions of research on smart cities and climate change.

## 2. Smart city definitions

There is a lack of consensus on the definition and conceptualization of smart cities, as evidenced by Table 1, which lists several common definitions. Despite having originated over 20 years ago, the scientific community is still grappling with defining what it means for a city to be smart (Neirotti et al., 2014). Much like the concept of resilience, smart cities are conceptualized differently based on the field of research, as well as the purpose of building a given smart city. For example, a smart city conceptualized by technology alone may not account for the environmental and social impacts of climate change. Conversely, a smart city initiative based in environmental sustainability and social well-being might have more in common with climate change adaptation and mitigation policies. Moreover, the country in which a given smart city initiative is being implemented will affect the conceptualization of a smart city (e.g., smart cities in middle income countries will be conceptualized differently than those in high income countries) (Neirotti et al., 2014). This makes determining a universal definition difficult.

Despite the lack of a universal definition of smart city, most scholars agree that information and communication technologies (ICT) are a pillar of smart cities (Albino et al., 2015; Batty et al., 2012; Bibri and Krogstie, 2017b; Meijer and Bolívar, 2016; Neirotti et al., 2014). In fact, there are a number of instances in the literature in which technology is the *only* requirement for a smart city. For example, Batty et al. (2012) defined a smart city as a city that has integrated ICT with 'traditional' infrastructure (e.g., energy and water systems). Using this definition, smart cities emphasize technology rather than social capital or sustainability, which may impact climate change adaptation and mitigation efforts, particularly if the smart technology that is implemented is not sustainable. Similarly, Nam and Pardo (2011) focused on the ability of smart cities to use technology to collect data that can then be used to improve various aspects of the city, as well as make decisions and respond to disasters. Kitchin (2014) defined a smart city as having an extensive network of sensors and capabilities to harness big data analytics, with the ultimate goal of improving city functions. Furthermore, Marsal-Llacuna et al. (2015) focused their definition on the application of ICT to collect data and ultimately improve urban performance. While access to ICT for large-scale data collection and analytics is an important aspect of smart cities, it is not a sufficient criteria for enhancing city functions. In fact, a singular focus on technology and disregarding other key elements such as social, economic, and human capital or sustainability can paint an incomplete picture of smart cities.

**Table 1**
Select definitions of smart cities within the literature.

| Authors | Definition/Conceptualization |
|---|---|
| Giffinger et al. (2007) | a smart city has several characteristics: smart economy (competitiveness), smart people (social and human capital), smart governance (participation), smart mobility (transportation and ICT), smart environment (natural resources), and smart living (quality of life) |
| Caragliu et al. (2011) | a city which invests in "human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" |
| Deakin and Al Waer (2011) | a city that works with the community to implement ICT that ultimately improves the quality of life for the community |
| Nam and Pardo (2011) | a city that "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" |
| Batty et al. (2012) | a city in which "ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies" |
| Kitchin (2014) | a city which has an extensive network of sensors and is capable of harnessing big data analytics to improve the function of the city |
| Neirotti et al. (2014) | a smart city should "optimise the use and exploitation of both tangible (e.g. transport infrastructures, energy distribution networks, natural resources) and intangible assets (e.g. human capital, intellectual capital of companies, and organisational capital in public administration bodies)" |
| Angelidou (2015) | a city that takes a 'humane' approach to integrate technology throughout the city, with a goal to advance human and social capital |
| Marsal-Llacuna et al. (2015) | a city which improves "urban performance by using data, information and information technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration amongst different economic actors and to encourage innovative business models in both the private and public sectors" |
| Ahvenniemi et al. (2017) | smart cities use technology to enable sustainable development |

A number of definitions of smart cities go beyond sensor networks and large-scale data collection and analytics to describe the economic and social aspects of smart cities. For example, in a European report about smart cities, Giffinger et al. (2007) outlined six key characteristics of smart cities: smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. These characteristics encompass the competitiveness of the city within a regional or global market (smart economy), as well as community participation, social/-human capital, and quality of life (smart governance, smart people, and smart living) Giffinger et al. (2007). Additionally, Giffinger et al. (2007) highlighted the need for accessible, available, and sustainable transportation and ICT infrastructure, as well as environmental protection and sustainable resource use. The sentiment of integrating smart cities and sustainability has been echoed by a number of recent articles (Ahvenniemi et al., 2017; Bibri and Krogstie, 2017a; 2017b). This growing trend of smart, sustainable cities indicates a shift towards a more integrated view of smart cities and what it means to be 'smart' in the Anthropocene. It is likely that these new smart, sustainable cities will be more closely tied with climate change adaptation and mitigation efforts. Moreover, initiatives based in both technology and sustainability may be more prepared to account for and ultimately limit the environmental and social impacts of climate change, as well as any unforeseen impacts of smart cities themselves.

Finally, there are a number of definitions that are primarily focused on the integration of ICT and social capital. Caragliu et al. (2011) defined smart cities as cities which integrate social (and human) capital with ICT to improve quality of life and encourage economic growth. Similarly, Deakin and Al Waer (2011) focused on community participation and argue that a city is smart when it works with the community to implement ICT that ultimately improves their quality of life. Angelidou (2015) took an analogous approach, arguing that smart cities are those that adopt human-centric approaches to integrating technology throughout the city, with a goal of advancing human and social capital. Finally, Neirotti et al. (2014) defined smart cities as cities which work to integrate the tangible (i.e., infrastructure systems) and intangible (i.e., human and social capital) assets of the city. This integration of physical and social systems will be critical for climate change adaptation and mitigation, which ultimately involves preparing our physical infrastructure for higher temperatures and more extreme weather, while also protecting people and building adaptive capacity.

The aforementioned definitions (summarized in Table 1) primarily focus on defining 'smartness' with respect to technology, sustainability, or social/economic capital. While none of these definitions directly mention climate change mitigation and adaptation, several of them can be applied to this area. For example, Giffinger et al. (2007) considered the sustainable use of natural resources to be paramount to smart cities. The protection of natural resources is also crucial to many climate change adaptation efforts, such as those related to water conservation in drought-prone areas. Nam and Pardo (2011) also defined smart cities with an emphasis on natural resources. Specifically, they discussed the use of technology to conserve energy and improve water and air quality (Nam and Pardo, 2011). Finally, Ahvenniemi et al. (2017) directly connected smart cities with sustainable development, of which climate change mitigation and adaptation play a major role. Going forward, we will focus on the relationship between climate change and smart cities, which will cover not only the technological aspect of smart cities, but also the social and environmental aspects.

## 3. Literature review methodology

Following a well-documented guide for developing literature review protocols (Model Systems Knowledge Translation Center, 2021), the critical literature review was conducted in four main steps: (i) online database search based on keywords and selection criteria; (ii) further refinement based on keywords; (iii) abstract screening; and (iv) full text review, which are outlined in Fig. 1. The first step involved using the Web of Science online database (Web of Science Group, 2021) to search for literature.

Initially, the keyword 'smart city' was used to find articles, which were then further refined using the keyword 'climate change'. As our aim was to synthesize the recently published literature, the articles were also refined based on several selection criteria, including article type, language, and publication year. Specifically, articles were kept if they were peer-reviewed, written in English, and published between 2010 and 2020. The initial search resulted in 8517 articles on smart cities (i.e., using the keyword 'smart city'). However, only a subset of these articles (i.e., 280 articles) covered the nexus of smart cities and climate change (i.e., searching both 'smart city' and 'climate change').

The third step involved screening the abstracts of this subset. Specifically, we reviewed the abstracts for the 280 articles and removed those that did not have smart cities as a primary focus. For example, there were a number of articles that were included in keyword search in step 2, but within the abstract, the authors only discussed smart cities as a potential avenue for *future* work, rather than the main focus of the article. Given that the goal of this paper was to synthesize the recent progress on smart cities and climate change, these less relevant articles were removed, resulting in 126 articles remaining after step 3.

The final step was a full text review. Following the same criteria as the abstract screening, each of the 126 articles were read in detail and any that were not directly focused on smart cities or technology were removed from consideration. This ultimately resulted in 74 peer-reviewed articles that focused primarily on smart cities and climate change. These articles varied by research category, journal, and year, as discussed below.

### 3.1. Classification of articles

Within the selected articles, there was a wide variety of topical domains and journals considered. This is due to, in part, the multidisciplinary nature of smart city research. Below we will discuss the classification of the articles, as well as some trends in the publication history.

#### 3.1.1. Classification by research category

Within the Web of Science database, articles are classified by categories (Web of Science Group, 2021). By using CiteSpace, a widely-used tool for visualizing the body of literature on a subject (Chen, 2006), we were able to visualize the distribution of the articles selected for this study within these categories. The results of this classification are shown in Fig. 2, which depicts the major nodes and links between categories, as well as the research categories attached to those nodes. Based on the size of the text, it can be seen that the majority of studies on smart cities and climate change fall into the Environmental Sciences and Ecology category, with Environmental Studies and Engineering also being common. This indicates that while smart city research is often thought to primarily exist within the engineering domain, many studies focused on the climate aspect of smart cities is conducted within the environmental science domain.

#### 3.1.2. Classification by journal

The selected articles were published in 52 different journals, ranging in scope from sustainability to big data. Table 2 lists the nine journals

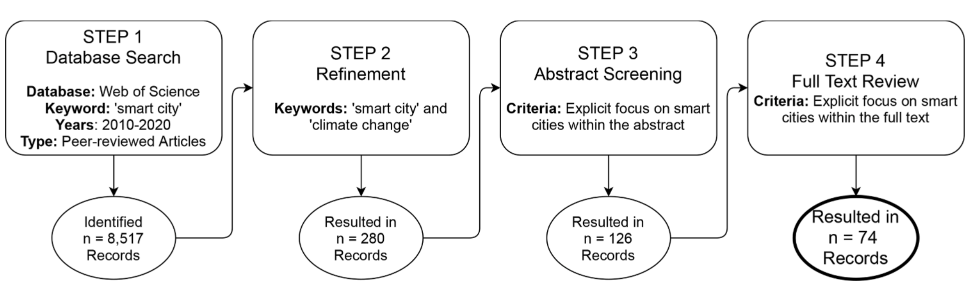


**Fig. 1.** Literature review methodology and resulting article count.


**Fig. 2.** A network of Web of Science categories, showing the classification of the final 74 research articles selected after the full text review (step 4). The larger the text, the higher the volume of papers in that category. The figure was generated using CiteSpace (Chen, 2006).

**Table 2**
Journals with more than one contribution to the critical literature review.

| Journal | Number of Papers |
|---|---|
| Sustainability | 6 |
| Journal of Land Use, Mobility and Environment | 4 |
| Sustainable Cities and Society | 2 |
| Land Use Policy | 2 |
| Energies | 2 |
| Technological Forecasting and Social Change | 2 |
| European Planning Studies | 2 |
| Journal of Cleaner Production | 2 |
| Environment and Planning A: Economy and Space | 2 |

from which there were more than one article selected. The most popular journal for work on smart cities and climate change was *Sustainability*, with five articles selected for the review. Other journals with significant contributions were *Journal of Land Use, Mobility and Environment* with four articles, as well as *Sustainable Cities and Society, Land Use Policy, Energies, Technological Forecasting and Social Change, European Planning Studies, Journal of Cleaner Production*, and *Environment and Planning A: Economy and Space*, which each had two.

#### *3.1.3. Classification by publication year*

The articles selected for this review were all published between 2010 and 2020. Given the pace of smart city research, this period was deemed to represent the current state the subject well. Figure 3 shows the distribution of articles within this time period. In particular, Fig. 3 demonstrates that the number of articles focused on smart cities and climate change has increased over the course of the decade.

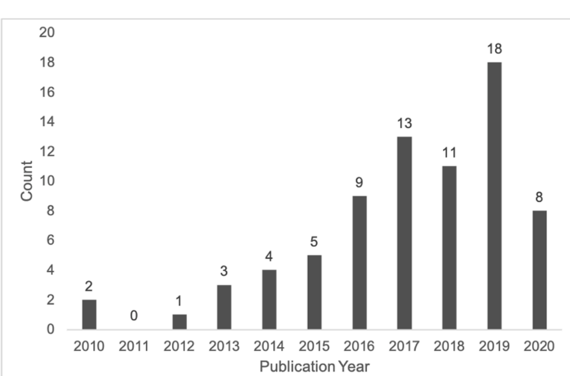


**Fig. 3.** Distribution of articles by publication year.

### *3.2. Classification by focus of the articles*

In general, the body of literature surrounding smart cities can be classified into two main areas of focus: (i) smart city frameworks, and (ii) smart city applications. In the former, articles tend to focus on how smart cities are conceptualized and designed, and policies implemented, often providing a more holistic view of the topic. Conversely, in the application-based literature, there is a focus on specific aspects of smart cities, such as the technology that is used to make a city 'smart'. In this review, articles of both types were included, although application-based articles were more prevalent. In particular, approximately 15% of the articles considered in this review were framework-focused, with the rest falling into the application category. Going forward, both types of article will be used to discuss the challenges and progress associated with smart cities and climate change.

## 4. Smart cities and climate change

The purpose of this review article is to assess the relationship between smart cities and climate change. In particular, we view cities as socio-technical-environmental systems (Brondizio et al., 2016; Elmqvist et al., 2021; Elsawah et al., 2020), in which climate change will not only impact various atmospheric processes, but also indirectly impact a number of critical urban services. Through this lens, we focus on five key areas: (i) infrastructure; (ii) public health and well-being; (iii) accessibility and equity; (iv) sustainable systems; and (v) governance. A summary of the articles included in each of these areas can be found in Table 3, which shows a subset of the final 74 articles.

### *4.1. Critical infrastructure in smart cities*

Critical infrastructure systems (US CISA, 2021) are under an increasing amount of stress due to the combined effects of infrastructure age, population growth, and climate change. In terms of climate impacts, recent work has shown that climate change is likely to increase the demand for water and electricity, which will in turn put pressure on the infrastructure systems (Kumar et al., 2020; Maia-Silva et al., 2020;

**Table 3**
Research area and classification of a selection of the articles considered in this study. These articles are those that are cited throughout Section 4, which included a subset of the final 74 articles. Note: I = infrastructure; PH/WB = public health/well-being; A/E = accessibility/equity; S = sustainability; and G = governance.

| Source | Research Area | | | | |
|---|---|---|---|---|---|
| | I | PH/WB | A/E | S | G |
| Dircke and Molenaar (2010) | x | | | | |
| Nijkamp and Kourtit (2013) | x | | | x | x |
| Dircke and Molenaar (2015) | x | | | | |
| Hayat (2016) | x | | | | |
| Sharma and Singh (2016) | x | | | | |
| Ogie et al. (2017) | x | | | | |
| Peng et al. (2017) | x | | | | |
| Sinha et al. (2017) | x | | | | |
| Alemi et al. (2018) | x | | | | |
| Garnett and Adams (2018) | x | | x | | |
| (2018) Hunter et al. (2018) | x | | x | | |
| Bragalli et al. (2019) | x | | | | |
| Contreras and Platania (2019) | x | | | | |
| Drysdale et al. (2019) | x | | | | |
| Kumar et al. (2019) | x | | | | x |
| Parks (2019) | x | | | x | |
| Zhu et al. (2019) | x | | | | |
| Froiz-Míguez et al. (2020) | x | | | | |
| Gonçalves et al. (2020) | x | | | | |
| Kaluarachchi (2020) | x | | | | |
| Ramsey et al. (2020) | x | | | | |
| Chourabi et al. (2012) | | x | | | |
| Tambo et al. (2016) | | x | | | |
| Butsch et al. (2017) | | x | x | | |
| Kumar Das (2017) | | x | | | x |
| Ricci and Mariano (2018) | | x | | | |
| de Amorim et al. (2019) | | x | | | |
| Kwon et al. (2019) | | x | | | |
| Pineda and Corburn (2020) | | x | x | | |
| Viitanen and Kingston (2014) | | | x | x | |
| de Jong et al. (2015) | | | x | x | |
| Yigitcanlar et al. (2018) | | | x | | |
| Papa et al. (2015) | | | | x | |
| White (2016) | | | | x | |
| Haarstad (2017) | | | | x | |
| Wendling et al. (2018) | | | | x | |
| Ipsen et al. (2019) | | | | x | |
| Ahvenniemi and Huovila (2020) | | | | x | |
| Galderisi (2014) | | | | | x |
| Yim et al. (2015) | | | | | x |
| Cavada et al. (2016) | | | | | x |
| Errigo (2018) | | | | | x |
| Moraci et al. (2018) | | | | | x |
| Berquier and Gibassier (2019) | | | | | x |
| Corsini et al. (2019) | | | | | x |
| Hall et al. (2019) | | | | | x |
| Levenda (2019) | | | | | x |
| Parks and Wallsten (2019) | | | | | x |

Mukherjee and Nateghi, 2019; Obringer et al., 2020). Moreover, climate change will alter the frequency and intensity of natural hazards, such as hurricanes and heatwaves, with significant implications for grid resilience (Alemazkoor et al., 2020; Alipour et al., 2019; Mukherjee et al., 2018; Raymond et al., 2019; Staid et al., 2014). Climate change mitigation and adaptation efforts must consider the impacts to these infrastructure systems to avoid potentially disastrous outcomes, such as water shortages or energy blackouts. Smart cities may provide solutions to some of these challenges. For example, adding real-time monitoring sensors or otherwise building up the information and communication technology (ICT) can improve the management of existing infrastructure (Kaluarachchi, 2020; Kumar et al., 2019). Smart cities also entail integrated cyber-physical systems, which may include self-monitoring or self-healing infrastructure (Liu et al., 2017). However, the framework-based smart city literature rarely includes discussions on climate change or the role it plays in exacerbating stress on infrastructure systems. In India for example, there is a nationwide focus on developing smart cities that can use technology to improve infrastructure, but there is little discussion on climate change or disaster resilience (UNISDR, 2009) with regard to infrastructure (Sharma and Singh, 2016). Similarly, in China, there appears to be a strong connection between 'smartness' and infrastructure, but not climate change (Zhu et al., 2019). There are, however, a number of applications that use smart technology to aid climate change mitigation and adaptation efforts in various infrastructure sectors, such as energy, water, and transportation systems. These applications are discussed in detail below.

#### 4.1.1. *Smart energy systems*

Smart energy systems are one of the core elements of smart city infrastructure (Hayat, 2016). In addition to real-time monitoring, these systems often include a smart grid that provides a mix of decentralized and centralized power systems. Smart energy systems also present a path towards climate change mitigation. For example, Hunter et al. (2018) discussed the benefits of using ICT to decarbonize the energy system. The authors argued that the increased efficiency of ICT-based smart energy systems combined with the ability to provide more specific consumption information will lead to reduced energy use, and thus, lower carbon footprints. Parks (2019) found that smart grids could help boost the integration of renewable energy sources, as well as improve efficiency. In a similar study, Drysdale et al. (2019) argued that technology alone does not make smart energy systems 'smart'. Instead, focusing on decarbonization and sustainability, in addition to the implementation of ICT are key requirements.

Improvements to efficiency and greater inclusion of renewable energy sources will aid current climate change mitigation efforts, demonstrating a benefit of implementing smart city applications within the energy sector. Another benefit of smart energy systems is resilience to disasters, such as hurricanes or heatwaves, which often negatively impact electricity generation technology. Recent research has shown that the decentralized nature of smart energy systems improves resilience by providing local electricity generation during disasters, such as hurricanes or storms, when centralized power plants are impacted (Hayat, 2016). The co-generation of electricity also reduces the load on the centralized generators, which could alleviate some of the stress put on the power system during heatwaves (Hayat, 2016). Given that climate change is likely to lead to more frequent disasters, such as heatwaves (Dosio et al., 2018), a crucial component of adaptation is lessening the impact on electricity generation technology. These studies demonstrate the progress that has been made within smart city applications to aid climate change mitigation and adaptation. In particular, smart energy systems remain a viable option to reduce carbon emissions not only due to their increased efficiency, load modulation, and higher integration of renewable, but also through offering a more decentralized resilience to climate-related disasters.

#### 4.1.2. *Smart water systems*

Smart water systems often serve two purposes: system monitoring (e.g., pipe leaks, end-user consumption, etc.) and flood preparation and mitigation. In terms of system monitoring, smart technology provides a means to detect pipe breaks and leaks, aiding the repair process and reducing water losses (Bragalli et al., 2019). Additionally, the system monitoring technology can aid urban water management efforts (Froiz-Míguez et al., 2020; Gonçalves et al., 2020; Ramsey et al., 2020), which will further climate change adaptation in drought-prone regions. In terms of flood mitigation, smart technology can be used to identify at-risk areas, as well as provide early warning to citizens. For example, Garnett and Adams (2018) identified areas within a city that were at-risk for stormwater flooding. Similarly, Ogie et al. (2017) developed a methodology to determine the optimal location of water level sensors around Jakarta (Indonesia) based on the infrastructure density, flood risk, and proximity to other sensors. Many cities rely on sensors to provide an early warning system to residents. For example, in the city of

Rotterdam (the Netherlands), the local government has implemented a number of sensors to monitor the city's preventative infrastructure (e.g., dikes), as well as the water levels outside of city (Dircke and Molenaar, 2010; 2015). A major impact of climate change will be the increased likelihood and severity of droughts and floods (Dai, 2011; Hirabayashi et al., 2013), which has prompted a number of climate change adaptation efforts to focus on smart water management. The current research on smart cities and water infrastructure demonstrates the progress towards building resilience to these climate-related disasters, as well as improving the water system as whole.

#### 4.1.3. Smart transportation systems

Transportation infrastructure is not only a key aspect of smart cities (Hayat, 2016), but also a critical area of focus in climate change mitigation efforts, given the sector's significant share of GHG emissions (Climate Change, 2014). Smart transportation technology ranges from monitoring systems of physical infrastructure to applications that improve the usability, sustainability and resilience of infrastructure. Following the devastating effects of several recent catastrophic events such as hurricanes Irene, Sandy and Harvey on the transportation infrastructure of major metropolitan areas in the U.S., there is a strong recent emphasis on climate resilience in terms of reducing emissions as well as preparing for disasters that may impact physical transportation infrastructure (North Jersey Transportation Planning Authority, 2021). This focus on climate resilience is becoming increasingly important as cities around the world face deadly floods that not only impact the above-ground infrastructure (i.e., roads), but also damage underground subway systems (Eddy, 2021; Shanahan and Wong, 2021; Tabuchi and Schwartz, 2021).

Nijkamp and Kourtit (2013) argued that a pillar of smart transportation is sustainability in addition to the reduction of the ecological footprint, congestion, and accidents. Moreover, one study found that in a holistic smart city initiative aimed at mitigating climate change, the transportation sector would see the most benefits in terms of $CO_2$ reductions (Contreras and Platania, 2019). Sinha et al. (2017) developed a framework to develop smart transportation infrastructure and policies that account for the effects of changing precipitation patterns, freeze-thaw cycles, and climate-related disasters, which may adversely affect transportation infrastructure. Considering these changes will be critical to improving the resilience of the transportation sector.

Beyond the physical infrastructure, smart transportation technology often focuses on reducing emissions by working to limit driving time. In particular, there have been several smart parking initiatives implemented around the world that aim to monitor parking availability in real-time to inform drivers. In theory, the initiatives reduce the time spent looking for parking, traffic congestion, and emissions. However, the results from such programs have been mixed. In a case study performed in San Francisco, for example, the authors reported a significant reduction in 'cruising time' spent looking for parking, which was associated with a reduction in emissions and congestion (Alemi et al., 2018). Conversely, in another case study performed in London, the authors found that although there was a potential to significantly reduce emissions, there was little awareness of the initiative among the citizens and thus, no reductions in congestion or emissions were recorded (Peng et al., 2017). While much progress has been made to improve the resilience of transportation infrastructure, there remains a significant challenge associated with citizen participation in programs that go beyond the physical infrastructure. Future efforts aimed at integrating smart transportation systems and climate change mitigation through emission reduction will need to focus on overcoming this challenge.

#### 4.1.4. Synthesis: critical infrastructure, smart cities, and climate change

While the literature, as discussed above, indicates several connections between smart cities and climate change adaptation and mitigation efforts, the connections are not always explicit. Specifically, the electricity and transportation sectors have well-known linkages to climate change (both the underlying causes, as well as aiding adaptation and mitigation efforts). Decarbonizing the current energy system, for instance, is one of the major mitigation solutions that is discussed on the world stage. It is also discussed extensively within the literature on smart energy systems (Drysdale et al., 2019; Hunter et al., 2018; Parks, 2019). Similarly, the emphasis on using smart transportation technology to reduce emissions (Alemi et al., 2018; Contreras and Platania, 2019; Nijkamp and Kourtit, 2013) directly aids climate change mitigation efforts. However, the connection between smart water systems and climate change adaptation and mitigation is less explicit. The literature on smart water systems tends to focus on improving flood resilience (Garnett and Adams, 2018; Ogie et al., 2017) or the management of water supply and distribution infrastructure (Froiz-Míguez et al., 2020; Gonçalves et al., 2020; Ramsey et al., 2020). These systems, though not directly related to climate change mitigation efforts, will help with adaptation as floods and droughts become more frequent and extreme (Dai, 2011; Hirabayashi et al., 2013).

In general, the smart city literature on critical infrastructure systems and climate change appear to place uneven emphasis on adaptation versus mitigation. For example, Smart energy and transportation infrastructure studies tend to lean more towards mitigation, focusing on reducing emissions through decarbonization or improving traffic patterns. Conversely, the smart water infrastructure studies tend to focus more on using smart technology to build resilience to floods and drought. In other words, smart water systems emphasize adapting to future conditions (i.e., floods and droughts), rather than working to mitigate the causes of those future conditions (i.e., climate change).

### 4.2. Public health and well-being in smart cities

An ongoing challenge within urban areas is improving public health and well-being, both of which are likely to be impacted by climate change (Thomas et al., 2014). For example, increased frequencies of heatwaves will lead to higher occurrence of heat stress (Thomas et al., 2014), particularly in cities, where the urban heat island effect already leads to higher probability of heat stress and related health issues (Krayenhoff et al., 2021). Additionally, climate change may lead to increased wildfires, loss of food (and subsequent increased food insecurity), and emerging diseases (Thomas et al., 2014), all of which pose issues for public health and well-being. Unfortunately, many smart city initiatives do not take public health or well-being into account. For example, as part of India's recent policy goal to create a number of smart cities around the country, there has been a focus on building more ICT. Less attention, however, has been given towards improving public health and well-being within these new smart cities (Butsch et al., 2017; Kumar Das, 2017). Ignoring public health and well-being may exacerbate existing inequities within cities and reduce the overall resilience to climate change and related disasters.

A number of recent smart city initiatives and research studies have focused on issues of public health and well-being. In Barcelona, Spain, for example, the smart city initiative has been branded as a 'public city' to emphasize the human dimension of the program. The public city, as defined by Barcelona, uses technology to improve public well-being and revitalize urban neighborhoods (Ricci and Mariano, 2018). Similarly, in China, smart technology has been employed to monitor air pollution levels in real-time and relay that information to citizens (Tambo et al., 2016). This additional data can help citizens take precautions to protect their health, but also provide information on the areas of the city that need attention (Tambo et al., 2016). Additionally, smart technology can be implemented to limit future public health crises. For example, heatwaves are likely to increase under climate change (Dosio et al., 2018), which will result in serious public health issues within urban areas particularly among the marginalized and vulnerable (elderly and children) communities (Sanchez-Guevara et al., 2019). In a recent study for example, Kwon et al. (2019) developed a framework that utilizes the data from sensors to determine the areas of the city that would benefit the most from thermal comfort improvements.

The studies summarized above demonstrate early steps towards integrating smart cities and public health, which is a relatively nascent field of research, with many applications focusing more on theoretical possibilities than physical implementations (Rocha et al., 2019). Nonetheless, challenges remain, particularly in terms of developing concrete solutions that enhance public health and well-being within smart cities, whether that be through improved air quality, disease control, or general health promotions (Rocha et al., 2019). Developing human-centric smart city initiatives, such as those discussed here, will be crucial in aiding cities in taking this area of research from theory to practice, and, ultimately, aid in limiting the impact of climate-related issues on public health and well-being.

#### 4.2.1. Synthesis: public health, well-being, and climate change

The literature on smart cities and public health/well-being is sparse, particularly with regard to climate change. There are, however, a few notable studies that demonstrate how smart city initiatives that focus on public health and well-being are related to climate change mitigation and adaptation efforts. For example, climate change will lead to higher temperatures and an increased likelihood of extreme heatwaves (Dosio et al., 2018), which is an issue of public health, particularly in marginalized communities. Smart city efforts that seek to identify areas facing extreme heat and improve thermal comfort (Kwon et al., 2019) also help build the adaptive capacity of the city in the face of future heat events. Additionally, while not directly related to climate change mitigation, the use of smart technology to monitor air pollution (Tambo et al., 2016) may help with greenhouse gas emission reduction in addition to improving air quality. Although this latter connection to mitigation was not explored in the reviewed literature, the link between climate change adaptation and public health/well-being was much more explicit. In general, improving various aspects of public health and well-being within cities will aid adaptation efforts to future climate change impacts such as heatwaves.

### 4.3. Accessibility and equity in smart cities

Accessibility and equity are core aspects of urban sustainability, particularly when it comes to climate change mitigation and adaptation (Bramley et al., 2009; Des Rosiers et al., 2017; Klinsky et al., 2017; Logan et al., 2019). It has been shown, for example, that vulnerable populations are not only more likely to face severe impacts from climate change and related disasters, but they are also often left out the decision-making processes for climate action (Klinsky et al., 2017). It is critical, therefore, to ensure equity and accessibility not only in climate policies but also in any smart city initiatives that seek to aid climate change mitigation and adaptation.

Given that a primary goal of many smart city initiatives is to improve the lives of citizens through technology, it is imperative to evaluate the actual impacts that these initiatives will have on accessibility and social equity. Many authors, however, have argued that smart cities don't consider social equity or the communities the initiatives propose to serve (de Jong et al., 2015; Pineda and Corburn, 2020; Yigitcanlar et al., 2018), and may even exacerbate existing divides within the city. As discussed by Butsch et al. (2017), smart city initiatives geared towards technology tend to only improve the lives of the affluent population. This deepening of the social divide in cities has consequences for environmental justice (Viitanen and Kingston, 2014), particularly with regard to the large environmental footprint of the production, implementation, and use of various smart technologies. Yigitcanlar et al. (2018) argued that this lack of consideration for social equity is caused by a lack of research on smart cities and community. The authors suggested that current smart city initiatives and applications do not consider the local residents; thus, they only create technology for the most affluent citizens (Yigitcanlar et al., 2018). Similarly, Hunter et al. (2018) called for equity to be included throughout the development and implementation of smart energy systems. Given that climate change is likely to impact urban residents disproportionately, building equity and accessibility is crucial for shrinking the climate gap. This presents a challenge for smart city research and applications, as there is currently a significant gap regarding equity and accessibility within the field.

#### 4.3.1. Synthesis: accessibility, equity, and climate change

Similar to the literature on public health and well-being, the connection between smart cities and accessibility/equity is limited. The studies reviewed here tended to focus on the lack of focus on accessibility and equity within smart city initiatives (Butsch et al., 2017; Viitanen and Kingston, 2014; Yigitcanlar et al., 2018). In particular, a few studies emphasized environmental justice (Hunter et al., 2018; Yigitcanlar et al., 2018), which is a topic that is gaining traction within the climate change adaptation and mitigation discussions. These studies show that while few initiatives are currently focusing on environmental justice, there is a broader discourse within the community that emphasizes building smart cities that are accessible and equitable for all citizens. In terms of climate change, improving accessibility and equity will aid adaptation processes, as well as ensuring that mitigation strategies do not place undue burden on any one group.

### 4.4. Smart, sustainable urban systems

Sustainable development (UN General Assembly, 1987) is another major research area aimed at improving cities and addressing the challenges of climate change. Urban sustainability is often intertwined with climate change mitigation and adaptation (Elmqvist et al., 2019). In the literature on smart cities, however, there is often a separation between being smart and being sustainable, even though the two concepts are not mutually exclusive. For example, in a review of the various terms used to describe cities, de Jong et al. (2015) found that smart cities are only distantly related to sustainable cities. In a similar study, Haarstad (2017) evaluated the recent increase in smart city discourse within the European Union. The author found that smart city initiatives and goals tended to focus on economic opportunities and innovation, rather than sustainability. There are similar separations between climate change adaptation plans and smart city initiatives. White (2016) argued that this disconnect is due to the scale of smart cities (i.e., local), which differs from the scale of climate change (i.e., global). However, smart city agendas do not necessarily conflict with sustainable development goals (Ahvenniemi and Huovila, 2020). For example, Wendling et al. (2018) compared a smart city assessment framework with the United Nations' 11th sustainable development goal—sustainable cities and communities (UN General Assembly, 2017). The authors found that the smart city assessment framework aligned well with some sustainable development goals, particularly those related to transportation and environmental impact, but did not align with the goals related to disaster preparation or housing (Wendling et al., 2018).

Although research has shown that smart city initiatives and research may not be completely contrary to sustainable development goals, there is a possibility that smart technology will cause environmental damage. In one study, (Viitanen and Kingston, 2014) argued that the increased use of ICT will lead to higher electricity consumption within cities. From a climate change mitigation perspective, the increased demand for energy could slow efforts to reduce emissions, particularly if the energy is generated through carbon-intensive means (Obringer et al., 2021). Moreover, the amount of electronic waste (e-waste) will increase, creating larger environmental footprints (Viitanen and Kingston, 2014). These environmental problems may not be felt by the urban residents themselves, rather the impacts are likely to affect people outside the city where the technology is produced and disposed. In this sense, the increased use of ICT may have implications for environmental justice, as well as climate change adaptation and mitigation. It is important to not only be aware that these issues may arise with increased smart city development, but also to evaluate the entire life cycle of new technologies before implementation. For example, Ipsen et al. (2019) used an urban metabolism approach to evaluate the performance of various smart technology programs in terms of carbon emissions. The authors found that smart energy grids, smart water infrastructure, and sensor-based waste collection successfully reduced the global warming potential and improved environmental performance, while technology such as smart windows and at-home graywater recycling decreased environmental performance (Ipsen et al., 2019). In other words, a smart window may dim itself to limit the amount of light that gets through, thus reducing the need for space-cooling and saving electricity. However, producing smart windows requires an immense amount of resources, making the entire production process more environmentally damaging than the benefits of using smart windows. As the world ramps up climate change mitigation and adaptation, sustainable development will become increasingly important. While smart city research shows promise in terms of achieving sustainable development goals, there remains a number a challenges associated with the environmental footprint of smart technology.

#### *4.4.1. Synthesis: Sustainable urban systems and climate change*

There is a growing trend in the literature that highlights smart, sustainable cities, as opposed to simply smart cities (Bibri and Krogstie, 2017b), which may indicate a shift towards smart cities emphasizing climate change adaptation and mitigation. Despite the idea of smart, sustainable cities gaining traction, however, smart cities and the technology used within smart cities may not be entirely sustainable (Ipsen et al., 2019; Viitanen and Kingston, 2014). If cities do not account for the full environmental impact of smart technology, it may be more difficult to reach climate change mitigation goals. This is particularly true if smart cities lead to higher resource consumption (i.e., electricity) without working towards climate mitigation and adaptation goals (i.e., decarbonizing the electric grid) (Obringer et al., 2021; Viitanen and Kingston, 2014).

A few studies reviewed here demonstrated the sustainability and climate change mitigation potential of smart cities and related technology (Ipsen et al., 2019; Wendling et al., 2018). In general, the studies on sustainability and smart cities are more closely related to climate change mitigation as opposed to adaptation. In other words, studies on smart, sustainable cities tends to focus on the improvement (or the exacerbation) of the conditions that are contributing to climate change (i.e., mitigation), rather than preparing for future climate change impacts (i.e., adaptation).

### *4.5. Governance in smart cities*

Both smart cities and climate change mitigation and adaptation efforts rely on various policy levers and forms of governance (Meijer and Bolívar, 2016). However, as discussed earlier, there is sometimes a disconnect between the governance of smart cities and the governance for climate change mitigation and adaptation (White, 2016). Regarding smart cities, Moraci et al. (2018) argued that planning is (or should be) the basis for any smart city initiative. Moreover, that planning should be tailored to local problems and focused on resilience (Moraci et al., 2018). Similarly, Yim et al. (2015) discussed the idea of a comprehensive master plan for smart city transitions. The authors presented a path towards creating these plans that integrate the economic, social, and environmental sectors (Yim et al., 2015). However, governance schemes geared towards smart cities do not always account for climate change mitigation and adaptation. For example, Galderisi (2014) discussed the separation of smart cities and climate change adaptation policies with the European Union. Similarly, Cavada et al. (2016) found that many cities have plans for climate change adaptation and mitigation, but they are rarely driven by the smart city agenda. The separation of these two major policy areas could result in inefficient implementation and missed opportunities for meaningful growth.

Another challenge in smart city governance is the lack of citizen participation. Several authors have argued that participation is necessary to reach smart city goals (Errigo, 2018; Nijkamp and Kourtit, 2013). However, in practice, smart city initiatives rarely include citizens, reducing the opportunities for participation (Corsini et al., 2019; Kumar Das, 2017). Berquier and Gibassier (2019) suggested this phenomenon was due to the fact that it is easier for cities to implement a top-down approach (i.e., the 'model city' paradigm) than a bottom-up approach (i.e., the 'good citizen' paradigm). In order to bridge this gap in participation, many authors have focused on smart grid technology, which is inherently linked to human behavior (Corsini et al., 2019; Levenda, 2019). Corsini et al. (2019), for example, suggested that smart microgrids (i.e., energy communities) can improve participation in the smart city initiatives, as well as integrate more renewable energy sources into the grid. Similarly, Hall et al. (2019) discussed the idea that smart grids can push electricity towards being more of a common good, with municipalities running their own grids with citizen participation. Encouraging citizen participation in smart city initiatives requires integration from multiple levels of government and, potentially, private industry. This need for integration has proven to be a problem for some cities. For example, Parks and Wallsten (2019) found that in Sweden, several plans for smart grids have been made, but regulations prevent citizens from connecting to the grid, limiting participation in the initiative. Similar to the smart transportation systems discussed in Section 4.1.3, participation is a challenge in smart cities.

#### *4.5.1. Synthesis: Governance and climate change*

The literature reviewed above highlight a lack of connection between the governance of smart city initiatives and the climate action plans of those same cities (Cavada et al., 2016; Galderisi, 2014). Given the number of connections in terms of the other key areas (i.e., infrastructure, public health/well-being, accessibility/equity, and sustainable urban systems), the lack of overlap in governance may indicate that a number of these mutually beneficial policies are not be being carried out efficiently, if they are being carried out at all. For example, smart water technology can be implemented to monitor water levels and provide early warning of floods (Ogie et al., 2017). If a city is implementing such a program without considering the climate change adaptation plans, the sensors may not be operationally suitable for future, more extreme floods. It is crucial that the governance of smart cities be connected to existing and future climate action plans. This will not only ensure that smart city initiatives account for future climate impacts, but also might help alleviate some of the sustainability issues discussed in Section 4.4.

## 5. The role of big data

A cornerstone of smart cities is the use of 'big data'[1], which is often obtained via sensors, live cameras and radar throughout smart cities (Al Nuaimi et al., 2015). The proliferation of big data and the associated computational techniques could improve understanding of climate change impacts, and benefit all the five key areas discussed above. For example, big data can help improve the efficiency of critical services, enhance the operation of infrastructure systems, and improve community resilience as well as citizens' quality of life (Al Nuaimi et al., 2015; Nateghi and Aven, 2021). Sinha et al. (2017) discussed using big data to monitor infrastructure and apply necessary policies to make improvements. In a study integrating infrastructure and governance, De Gennaro et al. (2016) suggested that data mining could be combined with governance to select optimal policies and locations for developing low-carbon transportation. These connections can be critical for

[1] Here, big data is used as an umbrella term that encompasses both the size of data that is often collected from smart city sensors *and* the technology used to analyze this data, including artificial intelligence, machine learning, and deep learning (Nateghi and Aven, 2021).

developing successful management policies in the face of climate change, as demonstrated by recent work on the water-energy nexus (Bartos and Chester, 2014; Obringer et al., 2019).

There are a number of challenges associated with the increased use of big data. As data grows larger, efficient infrastructure for data management and mining becomes a challenge from a management perspective (Sinha et al., 2017), not to mention the increase in energy use, which may lead to increased carbon emissions (Obringer et al., 2021). In this sense, sustainable computing is an important pillar of smart cities (Jeong and Park, 2020). Additionally, big data is often generated from different sources, which may have different structure and scales. A smart city initiative might, for example, generate microclimate data from sensors and satellite imagery, social data from twitter, and demographic data from the latest census. All of these data would need to be integrated and analyzed, which is a challenge, both computationally and in terms of management (Al Nuaimi et al., 2015). Surmounting these challenges often requires complex computational methods, which may not be available or accessible for many local governments (Sinha et al., 2017). Going beyond the challenges associated with using and analyzing big data, there are a number of vulnerabilities related to the digital nature of smart cities. As Hayat (2016) argued, the reliance on technology means that smart cities are especially vulnerable to cybersecurity threats. The author went on to argue that it is possible for a single disruption to shut down the whole city (Hayat, 2016). Finally, citizen privacy becomes an issue for smart cities, particularly when the technology is reliant on user data (i.e., smart grids) or the technology is owned by a private company (Viitanen and Kingston, 2014). This could also limit the ability to share data and resources between different government agencies (Al Nuaimi et al., 2015), potentially reducing the value of such connections. This represents a major challenge associated with big data and smart cities—how to make use of the data collected, while still respecting the privacy of citizens (Al Nuaimi et al., 2015).

In general, ICT and big data are considered to play a major role in smart city research (see Table 1 for definitions). There are several benefits to harnessing big data, from both research and practical perspectives. For example, smart grid data can be used to better understand the intricacies of energy demand (Parks, 2019), and further society's understanding of potential climate impacts on that sector. However, there are a number of challenges related to the proliferation of big data within smart cities, which need to be met in order to ensure high quality of life for citizens. Some of these challenges related to the data itself, such as the size, format, or required analytical techniques (Al Nuaimi et al., 2015; Nateghi and Aven, 2021; Sinha et al., 2017). Other challenges are related to system security (Hayat, 2016) and citizen privacy (Al Nuaimi et al., 2015; Viitanen and Kingston, 2014), both of which are of the upmost importance when developing smart city initiatives. Overall, the role of big data is critically important to the development of smart cities in the Anthropocene, both in terms of the benefits it can bring and the challenges it poses.

## 6. Future directions

Going forward, it is likely that smart cities will remain in the spotlight, while climate change adaptation and mitigation become increasingly important. As such, integrating these two areas could have a lasting impact in cities, in terms of quality of life as well as overall resilience to climate change and related disasters. Below, we highlight a few future directions for research on smart cities and climate change.

### *6.1. Smart cities, infrastructure, and disaster resilience*

A major aspect of climate change adaptation is ensuring resilience to climate disasters such as hurricanes, floods, sea level rise, storms, heatwaves, wildfires, and droughts. These disasters are becoming increasingly more frequent and expensive—the U.S. experienced 69 billion-dollar disasters from 2015 to 2019, 14 of which were in the last year (Smith, 2020). Smart cities have the potential to alleviate some of the stress caused by these disasters, especially in terms of the energy, water, and transportation infrastructure. It has been shown that droughts and heatwaves can push power generation facilities to the edge of available capacity, sometimes leading utilities to adopt 'reactive' stress-relieving measures, such as load shedding and rolling blackouts (Cronin et al., 2018; Gjorgiev and Sansavini, 2018). As Hayat (2016) discussed, the decentralized nature of smart grids could benefit the electricity generators by reducing the peak load during these disasters. Moreover, smart grids would allow citizens to maintain electricity via their local system in the event of a disruption at the centralized generator (Hayat, 2016), improving the resilience to hurricanes or similar disasters. Similarly, the increased adoption rates of electric vehicles can be leveraged to build disaster resilience (Rahimi and Davoudi, 2018; Tian and Talebizadehsardari, 2021). Smart grids could help accelerate the transition to electric vehicle integration. There is also an opportunity for smart transportation systems to better integrate electric and, in the future, autonomous vehicles. Finally, there has been a number of smart city initiatives aimed at improving water systems. Future work should continue to focus on these areas, while also building resilience to disasters. For example, there is an opportunity to integrate sensors throughout urban water distribution and supply systems to create early warning systems for droughts. Additionally, future work should account for interdependencies between various infrastructure systems. Research on the water-energy nexus is well-established (Newell et al., 2019; Newell and Ramaswami, 2020), but there is a need for further work on the impact of climate change on this nexus, particularly from the demand-side (Obringer et al., 2020). Smart cities offer a unique opportunity to obtain data from smart water and electricity meters, which would allow for more high-resolution studies of the nexus.

### *6.2. Smart cities, public health, and social equity*

Public health and social equity are critical challenges facing urban areas today, particularly with regard to climate change. For example, while increased heat stress will have a negative impact on the overall public health of a city/community, the marginalized and low income communities are often disproportionately impacted by heat stress (Nateghi, 2020; Sanchez-Guevara et al., 2019). Unfortunately, much of the research suggests that public health and equity are rarely taken into account when implementing smart city initiatives (Butsch et al., 2017; de Jong et al., 2015; Kumar Das, 2017; Pineda and Corburn, 2020; Yigitcanlar et al., 2018). However, work in this area has begun to increase. For example, Kwon et al. (2019) showed that smart cities can be designed for equitable thermal comfort. Going forward, these types of studies should be a focus within the research community, so as to inform policy makers as well as practitioners of both the issues associated with smart city initiatives and the solutions. For example, throughout the COVID-19 pandemic, contact tracing applications have been successful in containing local surges of the virus. Similar applications can be launched in the future to not only monitor disease outbreaks, but also localized air pollution, temperature, and public safety issues.

### *6.3. Smart cities and sustainability*

Smart cities are often differentiated from sustainable cities, both in research and practice (de Jong et al., 2015). However, as society begins to focus more closely on climate change mitigation and adaptation, environmental sustainability will become increasingly important. As such, smart cities ought to work towards integrating sustainability with the existing technology-based approaches. Nijkamp and Kourtit (2013) suggests that urban metabolism is a critical methodology for building sustainable smart cities. Through the implementation of urban metabolism, for example, researchers have determined the environmental footprint of smart cities and various forms of smart technology (Ipsen et al., 2019; Viitanen and Kingston, 2014). This is an area that requires additional study, especially as smart technology begins to be implemented in a number of applications, from water infrastructure to parking.

Future work should continue to focus on assessing the life cycle of smart technology, but also seek to consider cross-infrastructural integration using a systems approach. For example, while research on the life cycle of various smart grid technologies is ongoing, the large-scale impacts of smart grids on the overall electric power system is underexplored. Synergies between research in smart cities and energy economics is needed to better understand the impacts of smart grids on the energy market, as well as how those impacts will propagate through highly interconnected economic and infrastructure systems.

## 7. Conclusion

Over the past decade, smart cities have become increasingly popular, both in research and in practice. There has been little work integrating the technology-based smart city research with the work on climate change adaptation and mitigation, although the body of work is growing. This review sought to synthesize the recent literature surrounding smart cities and climate change and to discuss the benefits (or costs) of smart cities, with regard to future climate change mitigation and adaptation. We evaluated the challenges and opportunities within five key areas related to smart cities and climate change adaptation and mitigation: infrastructure, public health and well-being, accessibility and equity, sustainable urban systems, and governance. Across these areas, there have been a number of holistic frameworks created for implementing smart cities, as well as specific applications that can improve the function of the city and the quality of life for the citizens. Overall, there is still a significant focus on the technological aspect of smart cities, rather than social capital and environmental sustainability. This suggests a lack of community-focused smart city initiatives, which may lead to further social divides within cities.

In terms of climate action, we found uneven connections between smart cities and climate change adaptation versus mitigation. Specifically, we found that within the critical infrastructure research area, smart energy and transportation studies tended to emphasize mitigation (e.g., reducing emissions), while smart water systems research focused on adaptation (i.e., preparing for future floods and droughts). Similarly, studies on public health and well-being were more connected to adaptation (e.g., reducing heat stress). Within the literature on accessibility and equity, more emphasis is placed on the failings of smart city initiatives, rather than success stories. However, the focus on environmental justice aligns with both climate change adaptation and mitigation. In terms of smart, sustainable cities, the literature reviewed here was more directly connected to climate change mitigation, with a particular focus on how smart cities and technology may aid mitigation efforts or exacerbate the current situation. Finally, in the governance literature, there was very little connection between the smart city initiatives and the climate action plans of cities. This disconnect was discussed within a number of studies and may lead to inefficient management decisions that do not account for the long-term impacts of climate change.

In addition to this synthesis, we detailed future directions that can aid the integration of smart city research with a number of areas currently focused on climate change adaptation and mitigation. In particular, we emphasized the opportunity to use smart technology to better understand interdependent infrastructure, such as the water-energy nexus, as well as the need to take a systems-thinking approach to evaluating the sustainability of smart technology. By focusing on disaster resilience, social equity, and sustainability, researchers can help practitioners to build smart cities that not only aid climate change adaptation and mitigation efforts, but also create smart urban spaces that work for everyone.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

The authors would like to acknowledge support from NSF grants #1826161 & #1832688, as well as the National Socio-Environmental Synthesis Center (SESYNC) under funding received from the NSF grant #DBI-1639145. The authors would also like to acknowledge support from the Graduate School at Purdue University, the Bilsland Dissertation Fellowship, the Purdue University Center for the Environment, and the Purdue Climate Change Research Center.

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