smart cities

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Review

Enhancing Urban Sustainability: Unravelling Carbon Footprint Reduction in Smart Cities through Modern Supply-Chain Measures

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Abstract: The worldwide Sustainable Development Goals (SDGs) for smart cities and communities focus significant attention on air quality and climate change. Technology and management can reduce fossil fuel dependence in smart cities' energy supply chains (SC). A sustainable smart city and reduced carbon emissions require coordinated technology and management with appropriate infrastructure. A systematic review of smart city SC management literature that reduces the carbon footprint (C.F) inspired this study. The study shows how each attribute reduces greenhouse gas (GHG) emissions. The Introduction highlights the subject matter and principal goal, which is to investigate how SC management strategies could assist smart cities in lowering their C.F. The Methods and Materials section provides a succinct description of the refining process in Systematic Reviews and Meta-Analyses in Scoping Reviews (PRISMA-ScR) relevant to C.F mitigation in smart city (SC) management. Significant works are described in the Results and Findings section, which exposes how smart cities and SC measurements reduce C.F. The Discussion section examines and scientifically debates the research findings. The Conclusion provides a scientific analysis based on the presented insights and features to enhance how policies must be coordinated to achieve the goal of this research study in a comprehensive way. Furthermore, it provides suggestions for practitioners and governments, and proposals for future research. The main contribution of this paper is conducting and proposing a framework for a better understanding of how the novel digital SCs, their components, and their management practices can help smart cities reduce their C.F.

Keywords: Sustainable Development Goals; carbon footprint; climate change; greenhouse gas; smart city; sustainable and digital supply chain

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1. Introduction

In today's cities, populations are growing due to uncontrolled migration, causing several problems. To address this issue, it is necessary to progress toward sustainability by reducing greenhouse gas (GHG) emissions and mitigating climate change by the United Nations' 2030 and 2050 targets [1].

In addition, the increasing number of people moving to cities has led to growth of urban areas, which has harmful consequences such as higher energy consumption, deforestation, and the extinction of plants and animals. In essence, cities are becoming a threat to our planet because they consume many natural resources [2].

Moreover, more than 80% of the global population lives in cities with high pollution levels that exceed the guidelines set by the World Health Organization (WHO) and, shockingly, every year, seven million people die due to air pollution and related health issues [2]. As a result, policymakers and academia have gradually realized that traditional management practices alone cannot meet the demands of modern societies, especially given the challenges posed by industrialization and the rise of new cities, and that new methods are required to address the problems that modern smart cities face [3].

On the other hand, the critical problem when developing "smart cities" is ensuring that they adhere to sustainability principles throughout the supply chain (SC) and society, while considering the well-being of present and future generations. In this regard, all services and products in smart cities must be supervised across the whole **SC** based on environmental concerns [4].

Furthermore, energy waste and environmental concerns influence how modern cities are planned, designed, and built [5]. Cities rely on technology, intelligent transportation, advanced construction systems, and complex control structures to become more efficient [6]. On the other hand, SC practices within cities, especially in the context of smart cities, are crucial for efficient resource management, logistics, and sustainability. The elements shaping smart cities include digital and sustainable SC operations, logistics and transportation within smart cities, inventory management and optimization, collaboration and partnership, and digital SC integration [7].

In this regard, and following the explanation linked to SC Management in smart cities, the main objective of this review article is to explore how SC management's modern practices can help smart cities reduce their carbon footprint (C.F). The research question (RQ) to address through the methodology described in Section 2 is "How have Modern SC Management (Digital and Sustainable) been working on C.F reduction initiatives in smart cities?".

The article examines various aspects of smart cities and identifies SC improvements that can significantly reduce emissions. This study aims to promote sustainability and economic growth in smart cities by finding ways to reduce C.F in SC.

Despite the growing interest in smart cities, most research still needs to pay attention to the role of SC practices in reducing emissions. Previous studies have focused on specific elements like transportation or energy systems, instead of the entire SC. This review addresses this "research gap" by examining SC strategies for emission reduction and sustainability in smart cities.

The "uniqueness and novelty" of this research lies in its focus on SC interventions to reduce emissions in smart cities. While smart cities are gaining popularity, there is still a need for more research on how SC measures can promote sustainability. This review paper contributes to the existing knowledge by identifying SC solutions that can reduce C.F in smart cities and understanding their economic impact. This study is a significant addition to smart cities and sustainability.

This review is intended for scholars and researchers in sustainability, SC management, and urban planning as "target audiences". It is also valuable for policymakers and practitioners in urban sustainable development, offering insights on operating more sustainably in smart cities by reducing emissions in SCs.

The following sections, starting with Methods and Materials, explain how materials were selected and refined for this research. Section 3, Results and Findings, explores the definitions of GHG and C.F; delves into the intricacies of smart cities and innovative SC management systems; and scrutinizes the components, responsibilities, and contributions of smart cities to reducing C.F. The Discussion section interprets the data and categorizes it. Finally, Section 5, the Conclusion, summarizes the work and provides recommendations for future research.

2. Methods and Materials

This research follows the method of a critical scoping review conducted based on the procedures for scoping reviews based on the PRISMA-ScR methodology [8]. This approach has been widely adopted in academic and research communities, contributing to a common language and promoting consistency in conducting and reporting scoping reviews.

Overall, the use of PRISMA-ScR methodology significantly contributes to promoting methodological rigor, transparency, and the quality of scoping reviews within various fields of research. It is commonly used in the humanities, social sciences, education, and healthcare fields, among others [9–12].

Furthermore, this study method includes a "cross-sectional descriptive scoping review" of pertinent materials, including publications, books, government websites, etc., which discuss minimizing C.F in smart cities across the smart or digital SC processes. The rationale of this research is to explore and identify the main concepts, components, and frameworks in smart cities, considering their implications and impact on C.F, CO_2 emissions, air pollution, GHG, and its mitigation around processes in modern SC management systems, contributing to the emission-reduction management science.

Figure 1 shows the phases of the method and protocol (identification, screening, and inclusion of relevant works based on the RQ), representing the selection process with a number progressively refined at each level, and are described above.

A. Searching databases, including Scopus and Web of Science, based on the combination of keywords "*smart city*" OR "*smart cities*" AND "*carbon footprint*" OR "*carbon dioxide*" OR "*GHG*". The research study's primary emphasis was on "SC", but the authors chose to concentrate on SC in the refinement as there were not enough resources available on the mentioned database when "supply chain" was included as a required term in the initial research phase. The first identification criteria described the records removed before the screening due to being duplicated, marked as ineligible, and a lack of availability. The last 15 years were considered (2008–2023) and all subject discipline areas were included.

B. The results were refined further based on criteria such as the use of the English language, the kind of publications (conference papers, articles, books, book chapters, reports, and reviews), and the manner of access (open access due to availability).

C. Then, the next phase was reducing the vast quantity of results by concentrating on "SC" components in the title, abstract, and keywords, and phrases of "smart city", "carbon dioxide", "greenhouse gas", "smart cities", "gas emission", "carbon footprint", "CO_2 emission", "air pollution", and "carbon dioxide emission" in the abstract, title, or keywords, so as to address the primary topic of the study project.

D. Applying the next eligibility refinement based on a deep screening of the abstract and keywords, focusing eligibility on the following concepts of "*mitigation carbon footprint*" in "*smart cities*" and "*supply chain*" or "*digital supply chain*" or "*smart supply chain processes*". This stage of eligibility criteria and refinement aims for a thorough and deep reading of the abstract, as well as screening articles, in order to reduce the vast amount of results by focusing on the main scope of this research, that is, the rationale previously presented in this section and all records containing "*SC management and C.F-reduction initiatives in smart cities*".

E. Finally, the selection and eligible review process yielded 55 results by deeply reading the 94 papers filtered from the previous step. During this in-depth reading and analysis process, the eligibility criteria considered whether a record took part or not in this research, only if its main contribution in the discipline and theory science of carbon-reduction management was practical and organizational. In other words, a record was only selected if, in terms of methods and innovations, it presented solutions to problems related to SCs within smart cities, considering the main difficulties and implications around C.F, CO_2 emissions, air pollution, GHG mitigation, and global warming potential (GWP).

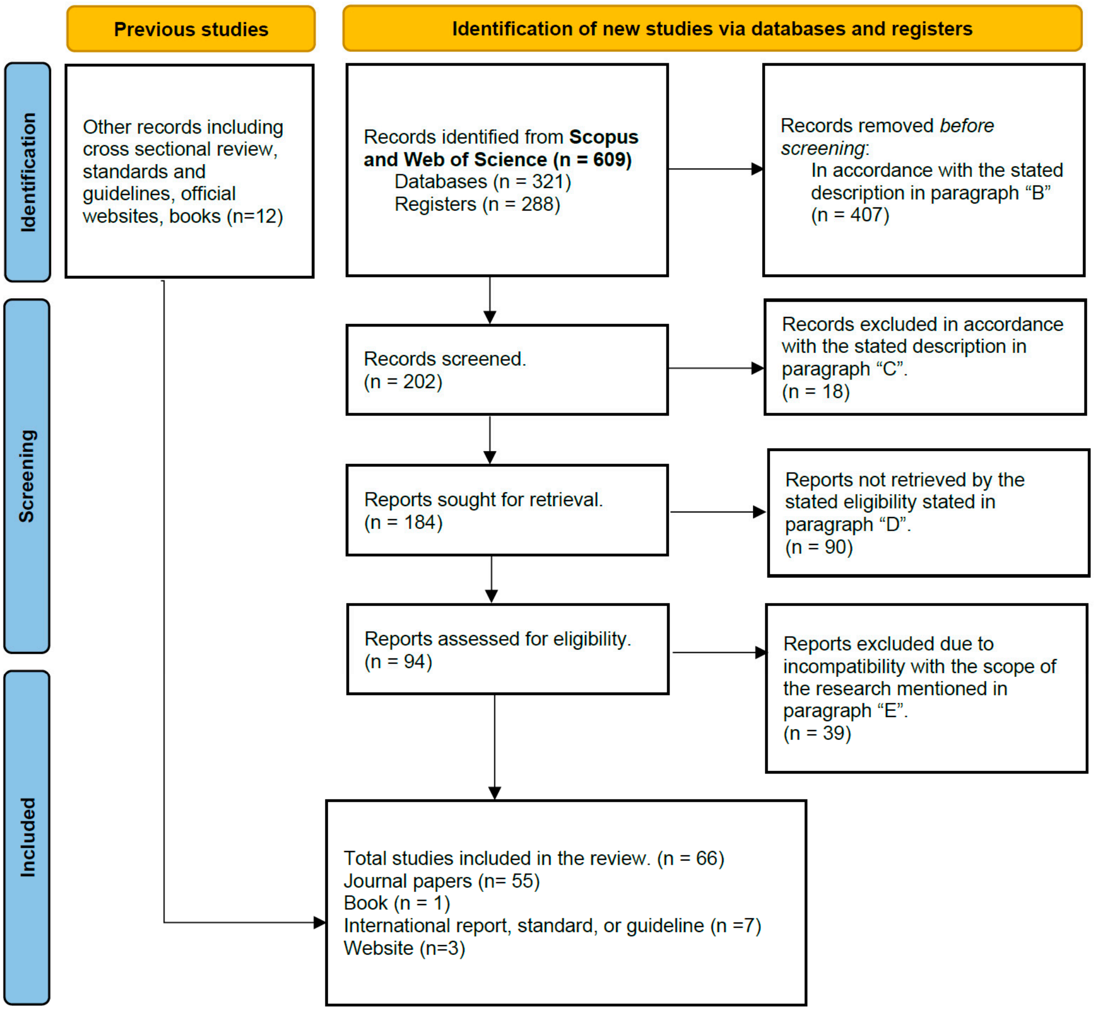

Figure 1. PRISMA scoping review methodology research and refinements.

Based on the refinement and selection process in Figure 1, 66 sources in total were studied, comprising 55 journal articles and conference proceeding papers. One book, seven extra official websites with pertinent information in the work study, and four internationally approved reports and guidelines were included.

The data acquired from the literature were classified and annotated in the following section based on the research scope.

3. Literature Review

Based on the literature review developed for RQ in this research study, a classification of the literature was created by looking over pertinent works. Four primary categories were used to organize the literature classification in the research context generally: (i) case studies, (ii) modelling, (iii) frameworks, and (iv) literature reviews. Each category contributed in a certain way to the comprehension and analysis of the problem being studied.

Case of studies—For a specific smart city or subset of it, case studies examining the implementation of SC solutions to reduce GHG emissions in the real world were used. These studies contextualized strategy challenges, successes, and failures. They usually detailed the techniques, data collection methods, and results. Case studies provided insight into the problems and reality of implementing SC-emission-reduction methods. Table 1 shows 16 works of literature on smart city SC-emission-reduction case studies.

Table 1. Literature review research works.

No	Major Them	Authors	Research Category
1	Moving toward intelligent, greener cities and utilizing pollution information for road traffic prediction.	N. Shahid et al. [2]	Case study
2	Urban household emissions and smart cities: An assessment of China's strategies for developing smart cities.	S. Wu [4]	Case study
3	A Survey of the Features, Structure, Difficulties, and Techniques of Smart Cities.	S. Pathak et al. [5]	Literature review
4	An evaluation of increased greenhouse global warming and its possible impact on specific species in southeast Australia	R. Brereton et al. [13]	Case study
5	Carbon footprinting: Continue to define methodologies.	D. Pandey et al. [14]	Literature review
6	An introduction to evaluating the urban C.F.	M. Lombardi et al. [15]	Literature review
7	Views on smart gas meters as a means of lowering carbon emissions in smart cities.	W. Hurst et al. [16]	Modelling
8	Thinking green: How intelligent technologies change how trash and distribution networks move across cities.	L. franchina et al. [17]	Framework
9	Measuring Urban C.F from Carbon Flows in the Global SC.	Y. Hu et al. [18]	Modelling
10	Do smart city policies contribute to a city's conservation?	T. Yigitcanlar [19]	Literature review
11	Analyzing two measurement multi-criterion approaches for smart city planning using real case studies.	B. Mattoni et al. [20]	Modelling
12	A thorough analysis of mitigation and adaptation and smart cities.	Huang-Lachmann et al. [21]	Literature review
13	Is smart energy a fantasy or a realism in smart cities? Data originating in Poland.	A. Lewandowska et al. [22]	Case study
14	Renewable energy implemented into the city for urban sustainability.	D. M. Kammen et al. [23]	Case study
15	Networks of city C.F.	G. Chen et al. [24]	Modelling
16	Smart city concepts with smart lights.	M. Castro et al. [25]	Framework
17	Using smart cities as a strategy to reduce carbon emissions transportation and promote sustainable transportation.	J. Zawieska et al. [26]	Case study
18	Volatility in strategy and economy for mitigating climate change: London smart city as an example.	G. Contreras et al. [27]	Case study
19	Wireless sensors on cars as part of a smart monitoring and control system for contamination smart cities.	M. S. Jamil et al. [28]	Modelling
20	Internet of Things-based intelligent trash can monitor and solid waste management system for smart cities.	T. Ali et al. [29]	Framework
21	Simulating the municipal solid waste management system's carbon cycle for urban metabolism.	C. Zhou et al. [30]	Modelling
22	An Internet of Things (IoT)-based smart cities infrastructure design implemented in a waste management situation.	P. Marques et al. [31]	Framework
23	An evaluation of smart water technologies for effective management of water resources.	A. D. Gupta et al. [32]	Literature review
24	Analysing urban water management techniques in Sub-Saharan cities: Opportunities and obstacles for the shift to green urban water management.	L. Herslund et al. [33]	Literature review
25	Shadow pricing as a means of reducing CO_2 emissions from drinking water treatment facilities.	Molinos-Senante et al. [34]	Modelling
26	Utilizing the convergence of Building information modelling and Geographic Information Systems to plan the necessary utility infrastructure for smart cities.	M. Marzouk et al. [35]	Framework
27	Urban transportation congestion might be alleviated with a smart city. China's smart city pilot program-based quasi-natural experimentation.	Y. Guo et al. [36]	Case study
28	Intelligent sustainable cities that are environmentally data-driven: used novel approaches to enhance energy efficiency, mitigate pollution, and optimize urban metabolism.	S. E. Bibri [37]	Literature review

Table 1. *Cont.*

No	Major Them	Authors	Research Category
29	A service for smart cities to monitor urban air pollution.	S. R. Garzon et al. [38]	Case study
30	Management of energy-efficient public lighting in urban areas.	D. Radulovic et al. [39]	Modelling
31	Intelligent city street lighting system energy efficiency optimization software.	R. Carli et al. [40]	Modelling
32	In the pursuit of green smart cities, the significance of urban vegetation and urban forestry.	Z. Uçar et al. [41]	Framework
33	Citizen participation in co-creating low-carbon smart cities: Insights from Nottingham City Council in the United Kingdom.	S. Preston et al. [42]	Case study
34	A China-based examination of how national policies assist the development of low-carbon cities.	Z. Y. Zhao et al. [43]	Literature review
35	Incorporating IoT into smart city C.F reduction for sustainable development.	P. Asopa et al. [44]	Case study
36	Safer, smarter, and more resilient cities.	N. Bansal et al. [45]	Framework
37	A comprehensive approach for evaluating the resilience of smart cities.	H. Khatibi et al. [46]	Framework
38	An overview of the literature on streets and street networks focusing on resilient urban forms.	A. Sharifi et al. [47]	Literature review
39	Comprehending CO_2 emissions from commuter trips: An analysis using the Technical University of Madrid as a case study.	N. Sobrino et al. [48]	Case study
40	The function of zero-energy constructions in European smart cities.	A. Kylili et al. [49]	Framework
41	What advantages do circular cities offer compared with circular development?	J. Williams et al. [50]	Case study
42	Tracking circular economy initiatives in Guiyang, China, regarding C.F associated with urban transition.	K. Fang et al. [51]	Case study
43	Carbon-emission reductions facilitated by the digital economy. Examination of 278 Chinese cities utilizing panel data.	Z. Yu et al. [52]	Case study
44	Energy conservation and CO_2-emission reduction as demonstrated by smart city development in China.	Q. Guo et al. [53]	Case study
45	Higher-resolution gridded data analysis of the temporal and spatial data. Aspects of energy-related CO_2 emissions in Shanghai, China, and determinant elements.	H. Zhu et al. [54]	Modelling
46	Co-beneficial urban cross-sector initiatives in China for carbon mitigation and local health.	A. Ramaswami et al. [55]	Modelling
47	An analysis of NB-IoT-based air pollution smart sensors LPWAN for Thailand smart cities 4.0.	S. Duangsuwan et al. [56]	Case study

The following section examines and simplifies the principal works and findings about GHG and C.F, unveiling relevant insights for practitioners, academics, governments, and all stakeholders.

Modelling—Modelling involves creating and using mathematical or computational models for complex systems like smart city SCs. Modelling allows researchers to assess the environmental impacts of SC methods like renewable energy, optimizing transportation, and improving waste management to reduce emissions. These models quantify an intervention's efficacy and cost-efficiency before implementation. Table 1 lists 11 relevant papers that employed modelling to express their thoughts. These papers used different methods to reduce smart city SC emissions.

Framework—Researchers used theoretical or conceptual structures called "frameworks" to organize their study problem perceptions. Frameworks could identify and evaluate smart city SC projects to reduce carbon emissions. These can help identify critical features, examine their relationships, and propose sustainable urban development and planning concepts. Smart city SCs include complex relationships and interdependencies that frameworks help understand. Table 1 summarizes recent research on the framework for lowering emissions in smart cities utilizing modern SC management systems.

Literature Review—Literature studies extensively survey and synthesize existing studies, theories, and concepts on the issue at hand—in this case, smart city pollution mitigation across the SC through modern and intelligent management. The literature studies aggregated and assessed scholarly works on smart city SC methods for GHG-emission reduction. This technique allowed researchers to assess the field, identify knowledge gaps, and build on previous research, which the authors of this study analyzed from this perspective. Literature reviews situated the current study in the larger scholarly discourse, provided a thorough and critical assessment of previous research, and laid the groundwork for future research. This literature review used nine studies, as shown in Table 1.

Table 1 classifies the literature by themes, genres, concepts, authors, and research categories. Data should reveal these motifs and literature's primary ideas.

4. Results and Findings

The following section discusses the conclusions and findings from examining the relevant PRISMA-ScR research works, constructs, definitions, data, and information. Sections 4.1–4.13 provides an entire narrative, summary, and literature synthesis. The findings outline the research study's motivation, principles, components, frameworks, and architectures.

4.1. Greenhouse Emissions and Carbon Footprint

One of the elements for the quick increase in global temperature is the "Enhanced Greenhouse Effect", or the greenhouse effect that nature has contributed to because of human-caused GHG emissions into the atmosphere. This influence may speed up negative results like climate change. Although not all GHGs have the same capacity to warm the atmosphere, this capacity depends on the radiative power they provide and how long, on average, their molecules stay in the atmosphere [13].

Any gas's "global warming potential" (GWP) refers to a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period relative to the emissions of 1 ton of carbon dioxide (CO_2). Consequently, one GWP unit equals one kilogram of carbon dioxide (CO_{2eq}) [57]. GHGs are an insulating blanket that warms the Earth by absorbing energy and limiting its escape into space. The warming of the Earth may be influenced in many ways by various GHGs. These gases vary from one another, primarily in terms of their capacity to absorb energy (known as "radiative efficiency") and the length of time they remain in the atmosphere (also known as their "lifetime") [58].

GWP was created to compare the effects of various gases on global warming. It calculates the energy that a ton of gas or regular CO_2 emissions will absorb over a certain period. The higher the GWP, the more gas warms the Earth than CO_2. By standardizing measurements, GWPs allow analysts to estimate gas emissions (e.g., to compile a national GHG inventor). They enable decision makers to evaluate emission-reduction prospects across industries and gases [59].

According to the US Environmental Protection Agency (US EPA), C.F measures all direct and indirect GHG emissions from an activity or product's life cycle [60]. This term covers goods, services, people, groups, governments, businesses, etc. All direct, internal, off-site, external, embodied, upstream, and downstream emissions must be included [14].

Governments and practitioners may use the C.F definition to answer research-related questions about smart cities. Although CO_2 is a part of GHGs, it is also essential to consider other compounds that contribute to greenhouse warming, such as SOx and NOx [60].

The most critical part of these air pollutants is C.F and, as studied by Lombardi et al., this is defined as "CO_2 and other GHG gases over the whole life cycle of a process or product", as follows, in Equation (1) [14]:

$$C.F = CO_2 + GHG \tag{1}$$

C.F is carbon footprint, CO_2 is carbon dioxide, and GHG is greenhouse gas.

However, due to data availability, many gases are either not carbon-based or are more challenging to assess. Methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases) may be readily grouped under this area. All of these gases need to be included in the "climate footprint", a comprehensive index of GHGs [14].

4.2. Carbon Footprint Reduction in Smart Cities across the Supply Chain

Cities and residential places are significantly more digitally and technologically advanced nowadays. The performance of outdated equipment and infrastructure is currently being updated, driven by data analytics [16]. Therefore, complex sociocultural developments are the outcome of technological developments. On the other hand, countries are starting to battle climate change and carefully monitor its environmental effects, so there is a well-recognized need to lower the environmental and climatic footprint, particularly C.F, in order to offer cleaner energy sources or more efficient energy services [61].

Furthermore, digital SC management, which is defined as "A type of SC management system that uses advanced technology and automated data analysis methods to optimize the flow of goods and services from suppliers to consumers", is used in place of traditional SC management to mitigate smart cities C.F [17].

A report by "Carbon Trust" titled "Carbon Footprints in the SC, the Next Step for Business" states how contemporary carbon management must be used across the whole SC, starting with raw materials and ending with the use and disposal of the final product or service. That is, the adoption of automated analysis techniques evolving the traditional SC to smart or digital SCs.

Figure 2 from the abovementioned report contrasts traditional and modern emission management strategies in SC [62]. The following paragraphs describe the relationship between smart cities and sustainable and digital SCs.

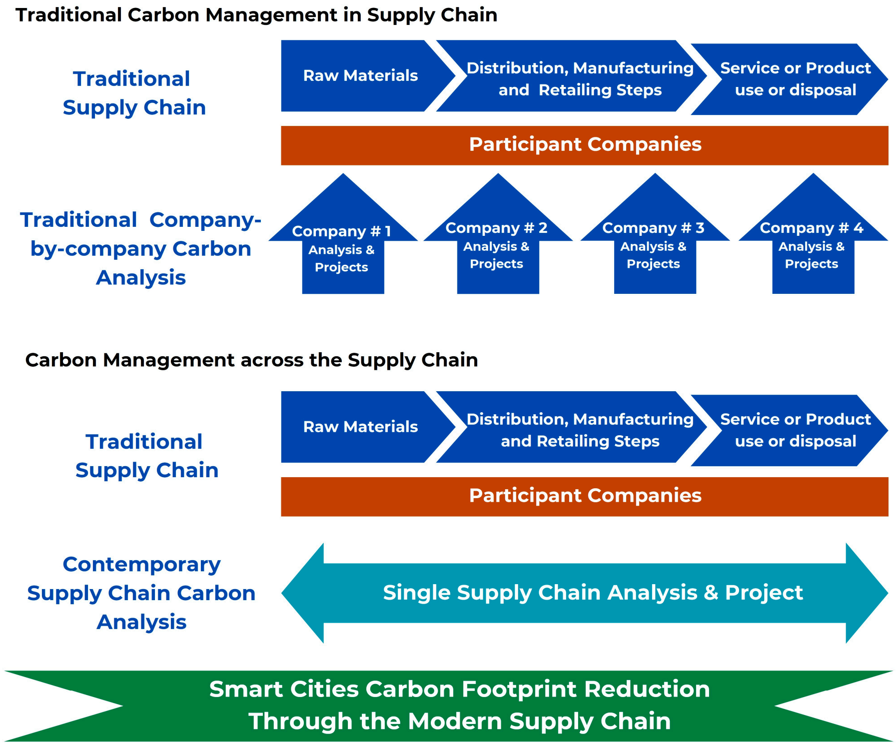

Figure 2. The comparison of traditional and contemporary methods of managing emissions across SC, based on [62].

Modern SC management and emission mitigation have particular applications in the era of mass customization and new technologies, as well as new structures such as last-mile delivery and other forms of smart logistics. Both smart city and modern SC management use inelegancy, innovative technology, and data-driven insights to improve efficiency and sustainability.

Furthermore, cutting-edge technologies, such as the Internet of Things (IoT), cloud computing, and artificial intelligence (AI), help smart cities collect and evaluate real-time data from traffic, energy, and waste management systems. This data allow SC managers to choose transportation routes, manage inventory, and predict demand. Traffic congestion data help SC managers optimize delivery routes and timetables, lowering transportation costs and emissions [16].

Consequently, technology integration in smart cities improves SC coordination and communication. Real-time product monitoring utilizing radio-frequency identification (RFID) or Global Positioning System (GPS) technology allows SC management to identify and fix delivery issues quickly. Smart cities enable smart warehouses that use automation, robots, and predictive analytics to manage inventory better and fulfil orders.

By integrating these technologies, SC managers may improve responsiveness, accuracy, and traceability, delivering items on time, reducing waste, and improving customer satisfaction. As smart cities and modern SC management have several synergies to enhance SC efficiency, accuracy, and sustainability, it is necessary to assess smart city components and analyse their emission-reduction effects.

During the Conference on Climate Change 2014, the International Panel on Climate Change (IPCC) examined the subject of C.F in detail and discovered that 27 cities with a population of over 10 million produced around 12.6% of the total air pollution in the world [5]. This highlights the need to research strategies for lowering C.F in smart and big cities [63].

On the other hand, using the elements shown in Figure 3, global and digital SC may aid in C.F mitigation in smart cities, according to a study by Yuanchao Hu et al. [18].

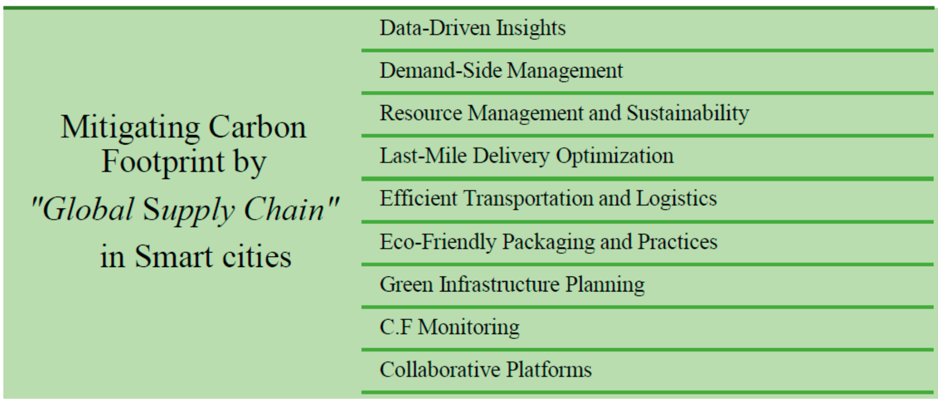

Figure 3. Global SC mitigation of C.F in smart cities, based on [18].

Utilizing all of the features shown in Figure 3, the most prevalent SC characteristics in smart cities might minimize the generation of C.F, aiding in the fight against climate change [18].

On the other hand, based on other studies, it was found that accurate estimation and analysis of C.F of cities could provide policymakers with more valuable information than the fundamental data of countries' C.F, which is presented in the dimensions of a country and can help them come up with better strategies [14].

Furthermore, a smart city also contains various components that all work together harmoniously to achieve sustainability; these will be covered in the following sections.

4.3. Smart Cities' Components and Performance Contribution in Emission Reduction

A smart city comprises many different things, such as advanced technology in infrastructure, transportation, energy, healthcare, communication, and governance (see Figure 4). These components may interact to form new ones, but must rely on each other to perform optimally and wisely. Each high-tech part works with IoT, ICTs, and other network infrastructures to reduce pollution and aid smart cities in their fight against climate change [5].

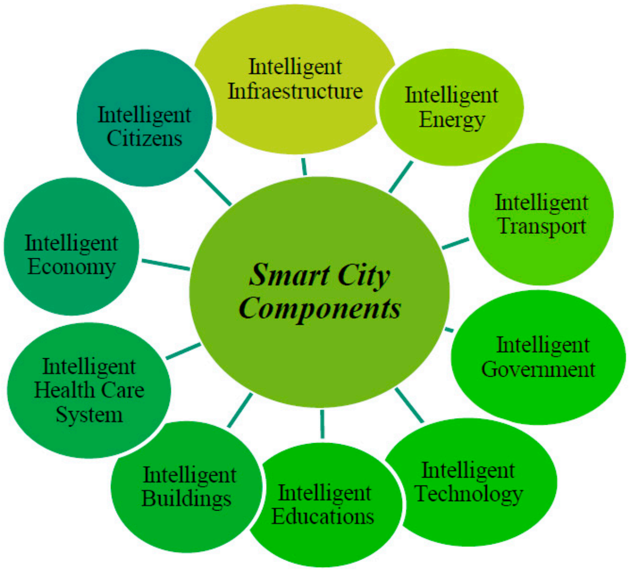

Figure 4. Components of smart cities, based on [5].

In addition, there are three distinct types of smart city criteria:

1. Attributes (such as sustainability, quality of life, urbanization, and smartness);
2. Themes (such as society, economics, environment, and governance);
3. Infrastructures (such as physical infrastructure and transport) [5].

The novelty of issues in the UN's Sustainable Development Goals, the conclusions of the climate change review, and the evaluation of the article by Yigitcanlar et al. led to the conclusion that more innovation and creativity must be used in the development of new technologies and in the search for methods to reduce CO_2 emissions [19].

Naturally, it should be kept in mind that each city should act in line with its distinctive traits, such as its climate, infrastructure, restrictions, and features, and that solutions should be appropriate for that city's and region's environment [64].

In contrast, the contributions proving that a smart city might reduce C.F rates are listed numerically in Figure 5 [20,21].

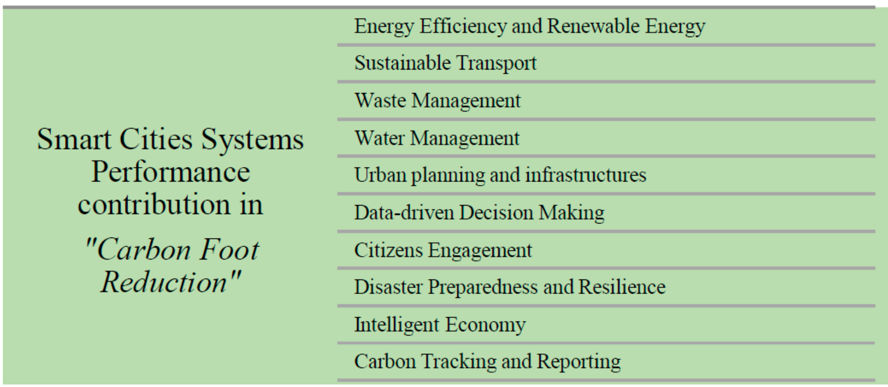

Figure 5. Smart cities' system performance when reducing C.F, based on [20,21].

As a result, there may be some extra categories and issues associated with each consequence of smart cities and their contribution to C.F reduction; each contribution has been briefly explored in the following sections with the assistance of some limited valuable examples.

4.4. Energy Efficiency and Renewable Energy

Smart cities may lower their C.F by using efficient and renewable energy, as shown by the components in Figure 6.

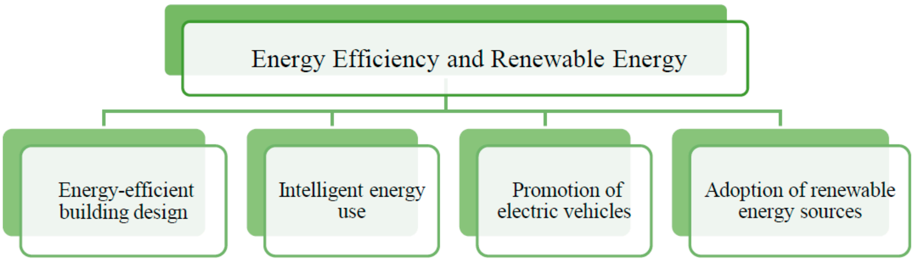

Figure 6. Components of energy efficiency and renewable energy to mitigate C.F in smart cities, based on [22].

These four elements could cooperate with other groups that impact pollution reduction, in addition to acting alone. By implementing "energy-efficient practices", smart cities can lower their energy usage. To maximize "intelligent energy use", energy management systems, smart meters, and smart grids are used. For "renewable energies", solar, wind, geothermal, and other energy sources can assist smart cities in lowering their dependency on fossil fuels to produce electricity. In smart cities, "electric vehicles (EVs)" contribute to a decrease in pollution emissions caused by transportation.

Their environmental benefits are increased by installing charging infrastructure powered by renewable energy. Building with "energy-efficient design and materials, insulation, and ventilation" may significantly reduce the built environment's C.F Utilizing occupancy sensors, smart lighting, and temperature control, buildings can use less energy. Furthermore, recycling, composting, and other environmentally sound waste management practices reduce GHG emissions from landfills. This involves encouraging recycling, enhanced waste processing, and sustainable waste disposal [23].

According to research by Guangwu Chen et al. in Australia, the country's five largest smart cities, including Brisbane, Adelaide, Sydney, Melbourne, and Perth alone, release more than half of the country's total carbon dioxide output [24].

This study's main results state the importance of C.F mitigation in industrial and smart cities. However, the vital point is the "city carbon map" method; the life cycle approach (LCA) has also been used to estimate all CO_2 emissions. In this way, C.F in a smart city can be expressed using Equation (2), as follows:

$$C.F = RTE + EEI + EEE \tag{2}$$

where RTE is the remaining territorial emission (all emissions inside the territory of a city), EEI is emission embodied import (all emissions due to activities in the city's hinterland resulting from globalization), and EEE is emission embodied export (all products and services exported from cities, leading to emissions).

This research shows that energy usage for power production was the most significant and challenging contributor to CO_2 emissions in these smart cities. Therefore, using new renewable energy to replace fossil fuels should obtain increased focus. Additionally, the government encourages the development and use of practical tools like the "Climate Change Tracker", which can be used to locate places with a high potential for emissions and then approve regulations to limit those emissions [24].

According to another research work by Castro et al., lighting consumes 19% of global power and produces 6% of GHGs. Smart cities that use IoT may help to prevent climate change by running lighter cities and buildings with fewer resources.

The Internet Protocol for Smart Objects (IPSO) alliance application may control smart city lights by employing chronological and astronomical scheduling, environmental and human behavior, concrete events programming, alarm conditions, and complex program logic or intelligent inference [25].

Intelligent control of a lighting management system contributes to sustainable architecture and lighting system designs, such as green energy environments, by allowing for remote monitoring and operation of the entire system to achieve an efficient operating mode, while preserving appropriate behavior based on physical-world interactions and reducing energy consumption.

The authors demonstrated that clever lighting control might help smart cities endure climate change. This article has examined the impact of lighting power use and the need for greater control. This research is a crucial case study for managing energy consumption, using renewable energy sources and intelligent urban design [25].

4.5. Sustainable Transport

A smart city's second way to reduce C.F is by providing shrewd and environmentally friendly mobility and transport. This group may reduce emissions by carrying out the actions shown in Figure 7 [26]:

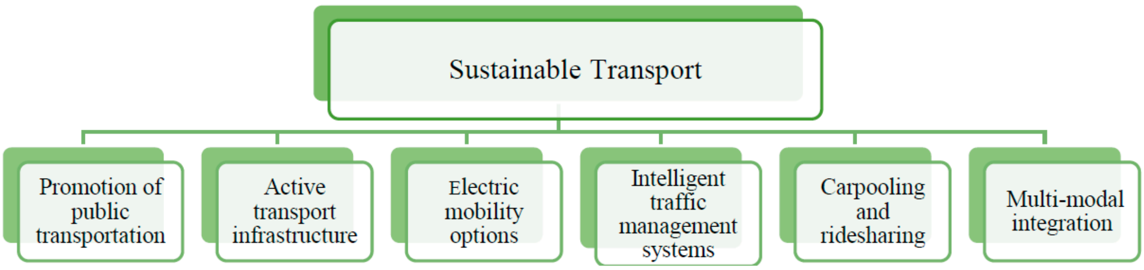

Figure 7. Sustainable transport components to reduce C.F in smart cities, based on [26].

"Public transportation" use declined as it increased. Carbon emissions from "electric vehicles (EVs)" were drastically reduced. "Active transport infrastructure" was promoted in smart cities with a convenient and safe walking and cycling infrastructure. "Carpooling and ridesharing" increase vehicle occupancy, while reducing emissions.

Travel time and pollution decrease when traffic flow is optimized utilizing effective "intelligent traffic management technologies". Sustainable mobility is promoted through easing integration and communication across "multi-model integration of transportation". This comprehensive plan provides locals access to simple, environmentally friendly car options [27].

In the research, the University of South Florida and the Islamia University of Bahawalpur examined how well intelligent transportation and intelligent governance performed in concert [28]. It proposes a new technique for gathering data utilizing wireless sensor networks (WSNs), which comprise tiny, inexpensive, and autonomous nodes that can be monitored from fixed nodes across the city.

The structure of wireless sensor networks is shown in Figure 8. The workings of a WSN system are shown in the following:

(A) Communication part;
(B) Memory region;
(C) Sensor node.

All of the steps were taken from the same work study.

The proposal incorporates IoT and long-term evolution mobile (LTE-M) modules, which are practical, cost-efficient solutions for machine-to-machine (M2M) devices. It is possible to monitor air quality throughout a smart city using both fixed and mobile nodes to comprehend the concept of air pollution and develop a strategy to reduce C.F. This example can help understand the role of sustainable and intelligent transportation infrastructure in smart cities and its role in reducing emissions and, as a result, C.F [28].

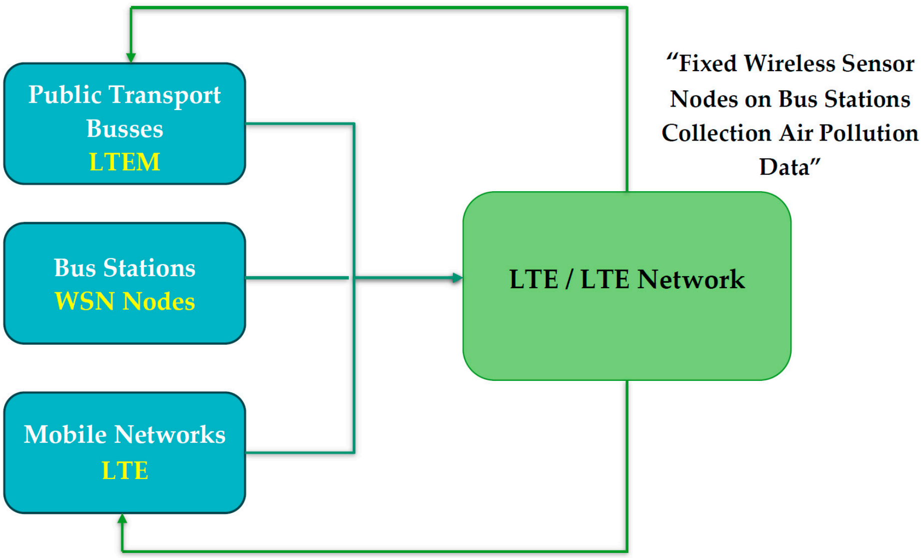

Figure 8. WSN working method, based on [28].

4.6. Waste Management

Waste management is one of the most crucial functions of smart cities, and studies have argued that it might significantly reduce the quantity of C.F in such cities. According to Figure 9, the following variables are impacted by waste management [29]:

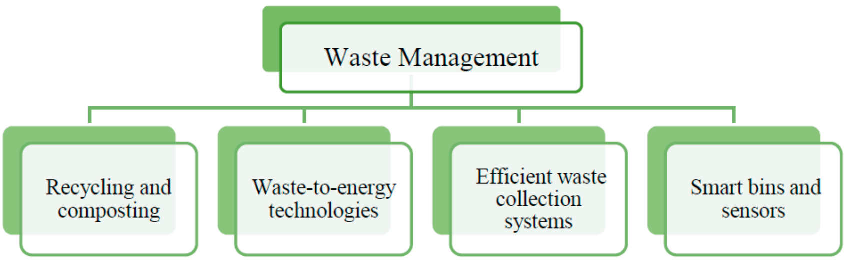

Figure 9. Waste management components to reduce C.F in smart cities, based on [29].

Additionally, several other elements, such as intelligent economies, public awareness, and education, may be included under this heading; however, the writers attempted to place them in other headings owing to the interconnectedness of the categories.

A viable "composting and recycling system" has the potential to reduce garbage and pollution. Cities may minimize their GHG emissions, mainly methane, by composting organic waste and using "waste-to-energy systems". An effective garbage collection system may include sensors, Global Positioning System (GPS) monitoring, and other similar technologies to optimize trash collection routes and guarantee that trucks use the most direct routes. "Smart bins and sensors" can track garbage to better schedule pick-ups [30].

In research by Marques et al. on the use of IoT-based garbage cans, indoor and outdoor scenarios were specified, and the case of the study was utterly dependent on four layers [64]:

1. Physical objects;
2. Communication;
3. Cloud platform;
4. Services.

The premise was entirely dependent on internet-based technologies; at the same time, the end outcome of IoT-based smart cities' infrastructure architecture could manage up to 3902 garbage bins simultaneously as urbanization increases (in the research case study), correctly separating organic and recyclable waste in both indoor and outdoor scenarios, with low response times, and providing a good user experience. This results in a Social Satisfaction Indicator, an environmentally friendly system, and air pollution mitigation consequences, and can be a helpful example for literature on intelligent and sustainable waste management in smart cities [65].

4.7. Water Management

Another element that might affect C.F mitigation in smart cities is water management. The following implications of water management on C.F mitigation in a smart city are shown in Figure 10 [32]:

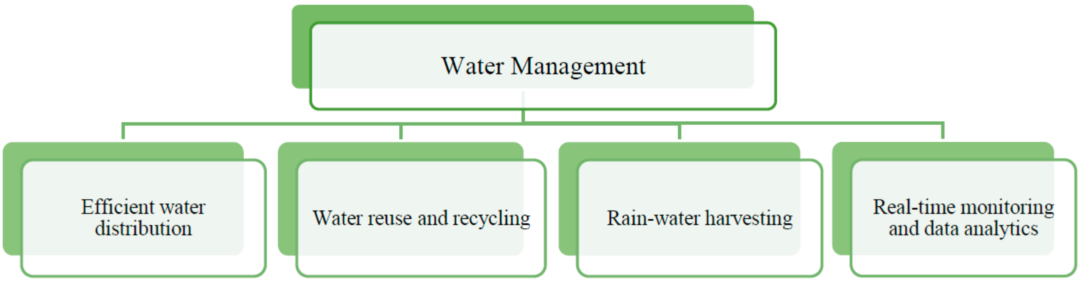

Figure 10. Water management components to reduce C.F in smart cities, based on [32].

Utilizing intelligent "efficient water distribution" systems may decrease water leaks and losses, save energy needed to pump water, and, hence, lower C.F. Implementing wastewater treatment systems through "water reuse and recycling" may lessen the requirement for freshwater extraction, as well as minimize energy use and emissions. Encouragement of "rainwater collecting" and storage will decrease the need for treated water.

Water networks that use intelligent sensors and "real-time monitoring systems" may provide information on water use, leakage, and quality. With this knowledge, proactive efforts may be made to reduce energy use, water waste, and related carbon emissions [33].

Molinos-Senante et al. conducted research on lowering CO_2 emissions from drinking-water treatment plants. Based on this research, determining the CO_2 "shadow price" is essential for addressing environmental policy issues. Given that the shadow price is considered the marginal abatement cost, it may be used to determine the initial market price for CO_2 emissions and the carbon tax rates. This study computed the shadow price of CO_2 for the first time for a sample of drinking water treatment plants (DWTPs) to help with this concern [34].

From a policy perspective, the economic value of the negative externalities related energy consumption may be seen in the shadow price of CO_2 emissions from DWTPs. The water regulator should incentivize water businesses to promote energy-saving measures to achieve this goal.

Water firms will gain from the reduction in DWTPs' C.F by having cheaper energy costs. The authors conclude by stating that there is a chance of reducing the C.F of smart cities with large populations that need drinking water by considering taxes on the energy use of drinking water companies, and this research work can be used as an example of intelligent and sustainable water management in smart cities [34].

4.8. Urban Planning and Infrastructure

Urban planning and infrastructure are crucial for reducing C.F in smart cities, and in this section, Figure 11 shows a numerical representation of those factors [26]:

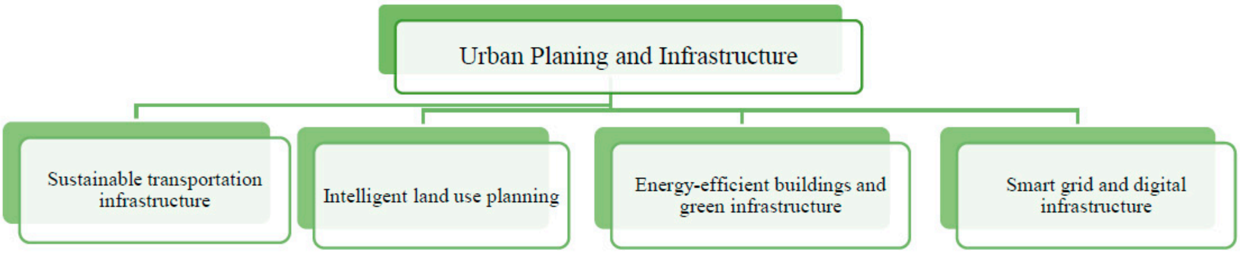

Figure 11. Urban planning and infrastructure components to reduce C.F in smart cities, based on [26].

Sustainable urban design that promotes "intelligent land-use planning" leads to improved accessibility, optimized commuting, and user-friendliness for disabled individuals. The problem of sustainable mobility in smart cities may also be related to the need to create a well-connected and "sustainable transportation infrastructure" and, consequently, less mobility and less emissions [35].

However, putting in place a "smart grid and digital infrastructure system" makes it possible to monitor energy production, distribution, supply, and consumption effectively. This, as well as using renewable energy sources, reduces energy waste and lower carbon dioxide emissions through "energy-efficient buildings and green infrastructure" [36].

In 2016, the National Research Foundation of Korea (NRF) and Balasubramaniam et al. released the Analysis of Intelligent Transportation Systems for a Sustainable Environment in Smart Cities. By stopping the carbon emissions caused by reducing traffic density, transportation officials may slow down climate change. "Intelligent" and "sustainable" have been the main topics of Internet of Vehicles (IoV) transportation research. The term "transportation system" has been replaced by the term "intelligent transportation system" due to substantial advancements in transportation technology (ITS) [2].

To reduce accidents and traffic congestion and make driving safe and pleasurable for drivers and passengers, IoV collects and shares vehicle, road infrastructure, and user data. These data are processed to manage automobiles properly. Motorized transportation has improved; however, transportation sustainability is crucial and challenging. Sustainable transportation requires environmentally friendly transportation and good planning to maintain road traffic safety. Sustainable transportation can reduce carbon emissions and help stop climate change, (worldwide government goal) [2].

This study suggests an autonomous intelligent or smart car with IoT-based management, weather- and road-surface-assistance technologies, and sustainability. The weather and road-surface accident data analysis report might minimize automobile accidents. The next-generation transportation sector will include autonomous taxis and other automobiles; thus, their judicious use will enhance transportation. This futuristic concept will result in transportation becoming simpler, more innovative, safer, and more sustainable, but it will take years to develop. This research could also show how urban planning and infrastructure, as parts of the SC for smart cities, might work together to mitigate C.F.

4.9. Data-Driven Decision Making

"Data-driven decision making" is another component that considerably lowers C.F in smart cities. Here are four elements that illustrate its effect [19]:

I. Real-time monitoring and analysis.

Real-time monitoring of the energy utilized by different smart city components is made feasible through data-driven decision making. By analysing this information, city authorities may receive more information about areas with high emissions and make informed decisions to reduce them [37].

II. Predictive modelling and optimization.

Data analytics may predict future energy use using predictive modelling techniques. This allows city planners to maximize resources and infrastructure effectively, decreasing emissions through less energy usage [37].

III. Interventions for behavioral change.

Data-driven decision making enables the identification of behavioral trends among city dwellers. By analysing these trends, city planners may create targeted interventions and campaigns to encourage sustainable behavior. These treatments may use green technologies, thus reducing their C.F [37].

IV. Smart infrastructure management.

Effective smart infrastructure management is facilitated by data-driven decision making. Reducing C.F may be achieved more effectively using data to manage and maintain infrastructure [37].

"Optimizing the Energy Use in Cities with a Smart Decision Support System (OPTIMUS)" is a project carried out in Europe and it is sponsored by the European Union Seventh Framework Program (FP7/2007–2013) [2].

The Smart City Energy Assessment Framework (SCEAF) sub-framework is implemented by this web-based tool, which provides energy managers a platform to evaluate the city's performance as a whole or the performance of individual buildings in terms of energy optimization, CO_2 emissions reduction, and energy cost minimization. This system may be a fantastic illustration of "data-driven decision making" and may also be categorized under "urban planning and infrastructure", "energy efficiency", and other concepts [2].

The suggested technique is valuable as it combines management with energy efficiency by leveraging data from several disciplinary fields. The proposed framework has been used in some notable buildings, including (A) Savona's "Colombo-Pertini School" in Italy (6092 m^2), (B) Sant Cugat's "Sant Cugat Town Hall" in Spain (8593 m^2), (C) Sant Cugat's "Sant Cugat Theatre" in Spain (4150 m^2), and (D) Zaanstad's "Zaanstad Town Hall" in the Netherlands (18,531 m^2) [2].

A project undertaken in partnership with the Unitec Institute of Technology and the National Institute of Water and Atmospheric Research (NIWA) in New Zealand and conducted in the city of Rangiora examined the role of developing a database and an intelligent system to identify locations with high C.F. It demonstrated how collaboration between an intelligent government and intelligent citizens to monitor air quality could lead to preventing entering a high C.F area [2]. Figure 12 depicts how this mechanism, called "Airtify", works.

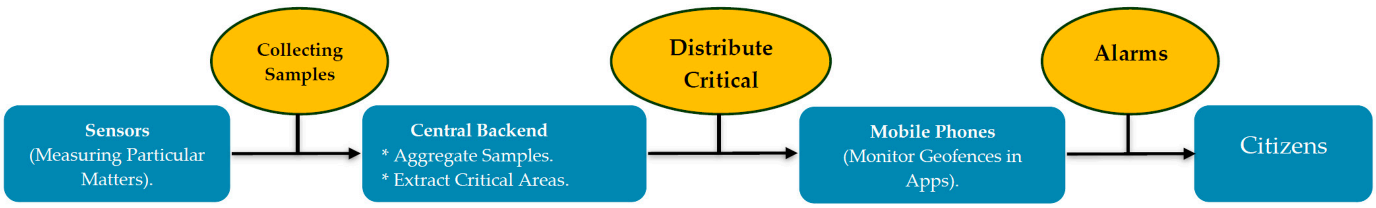

Figure 12. "Airtify" network processing chain and citizens' feedback to provide controls for smart cities' continuous improvement, based on [2].

Figure 12 depicts the four components' access to the internet and an intranet network, which can transmit data about sensor emissions, as well as to the people, starting with the sensors and ending with the backend, mobile devices, and, finally, citizens. Finally, smart citizens can be alerted to minimize emissions by forecasts via "Airtify". Customers may obtain this data online by utilizing relevant smartphone apps and fixed sensors in critical locations exposed to ambient particulate matter concentrations. Additionally, these clients reduce emissions by promoting a moral culture [2].

Airtify adapts to the grid size and updates its frequency based on the particulate matter sensor dispersion, density, and sampling frequency in metropolitan environments.

Further research with different urban features is needed to improve the performance of this system and exceed the current limitations so that citizens are not only end users. Then, the government can use system information to force residents to reduce emissions. Airtify demonstrates the advantages of merging urban air quality sensors with citizen-centric location-based services for environmentally conscientious smart city residents [2].

In addition, one of the causes of the public sector's excessive CO_2 emissions is energy supply for streetlights; thus, utilizing sensors to enhance their working hours might be a vital step towards optimizing energy consumption and reducing pollution. R. Carli et al. in Bari (southern Italy) and Radulovic et al. in Rijeka (Croatia) conducted two more research works on optimization tools for energy-efficient control of street lighting systems in smart cities using the same premise and approach.

According to these studies, combining intelligent governance with intelligent energy may be vital to developing a sustainable smart city if timely decisions and correct rules are implemented [39,40].

Research by Ucar et al. looked at how new internet-connected technologies like IoT and international communication technology (ICT) may reduce C.F in smart cities. To manage and optimize energy use and boost the effectiveness of infrastructure, transportation, healthcare, and other services, they are regarded as an IoT component in smart cities. The use of ICT and IoT, on the other hand, is likely to assist forestry in cities by enhancing quality of life, which is one of the goals of smart green cities, by employing several observations [41].

In a different study by Shahid et al., a framework using an ensemble regression model that included four stages of "data gathering", "processing", "comparative analysis", and a "regression model" was presented as an illustration of a real-world applications. This study can be a valuable example of real-time data transfer and decisions made based on this data.

This study shows how an intelligent government may utilize the considerable data gathered in a smart city to issue inventive legislation or make wise decisions. The data are taken from the research paper previously stated. This picture demonstrates the value of a smart city's infrastructure and other components, such as urban planning and sustainability, which are covered in the section below [2].

The use of sensors and decision-based data receiving makes these studies ideal candidates for energy-efficiency factors and excellent instances of data-driven decision making.

4.10. Citizens Engagements

In addition to technological solutions, intelligent residents may play a significant role in reducing the risk of C.F in smart cities. They can help smart cities reduce emissions through the factors listed in Figure 13 [42]:

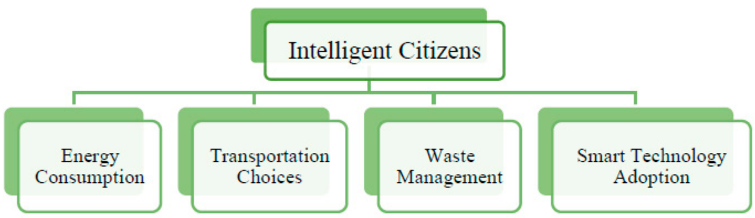

Figure 13. Intelligent citizens' main features to reduce C.F in smart cities, based on [42]. Citizens can embrace intelligent home technology such as intelligent thermostats, energy-efficient lighting, and automated systems that optimize energy use. The numbers in Figure 14 pertain to energy use, transportation options, and trash management. These decrease C.F individually and contribute to the smart city infrastructure's overall carbon-reduction goals [22,30,36,43].

It should be noted, however, that the characteristics listed in Figure 13 can only exist with the backing and development of intelligent and circular economies from shrewd governments. On the other hand, it has been determined that intelligence must begin with the most fundamental aspects of human life, such as employing intelligent devices in homes, relating IoT's function in smart cities, and evaluating the impact of utilizing technical resources that an intelligent government can assist with.

The 2020 US EPA report states that electricity manufacturing accounts for 28% of commercial and 12% of residential carbon emissions worldwide. As a result, intelligent citizens can significantly impact emissions, and their behavior is crucial for reducing C.F [65]. Although it has been reported that homes with an IoT system and sensors to keep their temperature at the ideal level emit 22.4% less carbon in managing the home's temperature than homes without this system, this difference is not statistically significant [44].

The challenge of producing and deploying these sensors in residences, which could play a vital role in urban planning, however, comes with cost considerations and cultural factors; these factors should be addressed by forward-thinking governments who embrace cultural development and intelligent solutions [16].

4.11. Disaster Preparedness and Resilience

One of the other essential requirements for a smart city is "disaster preparedness and resilience", which both aim for smartness and sustainability. This standard may help smart cities reduce C.F and reduce emissions in three different ways, as detailed below:

I. Efficient resource allocation.

Smart cities can deploy resources more efficiently by prioritizing disaster preparedness and resilience. Networks for better waste management, transportation, and energy distribution are included. When disasters occur, these well-organized systems are better equipped to handle disruptions, decreasing the need for energy-intensive recovery efforts and lowering emissions [45].

II. Renewable energy integration.

Building a resilient infrastructure often involves incorporating renewable energy sources like solar and wind power. These sources might provide dependable energy alternatives if regular power networks fail during disasters. Utilizing renewable energy more often reduces C.F, lowering reliance on fossil fuels and GHG emissions [46].

III. Integrated urban planning.

Integrated urban planning entails developing surroundings and infrastructure that can withstand shocks and natural disasters, which are highly valued in smart communities resilient to catastrophes. This approach may lead to more concentrated urban expansion, reducing the need for urban sprawl and lengthy commutes. As a result, residents travel reduced distances, lowering transportation emissions [50].

Another research work regarding the significance of disaster planning and resilience, by Sobrino et al. conducted at the Polytechnic University of Madrid (UPM), found that CO_2 emissions by attendants, employees, students, tourists, etc., could predict how effective the government is at lowering CO_2 emissions [48].

This study quantifies and categorizes commuter carbon emissions to schools based on the commuter group, campus, age, and gender. It was found that 16% of personal car computers accounted for over 50% of daily CO_2 emissions. Thus, municipal and UPM authorities could implement incentive, punitive, and cultural policies such as improving campus public transportation accessibility and infrastructure for all campuses, including those in inconvenient locations, resulting in increased frequency of use and better connections to other modes and smaller and more mobile vehicles in order to take preventive measures using intelligent management and other intelligent components [48].

Another study, "Smart Energy Regions" in Europe, looked at construction rules for zero energy buildings (ZEBs), which are crucial to smart cities, and the relevance of ZEBs in intelligent energy regions. Intelligent governments provide these guidelines to reduce thoughtful building energy consumption and C.F [50].

Environmental design, building practices, renewable energy sources, technical building system labelling, and intelligent energy management in smart cities are all priorities for

ZEBs. They improve energy efficiency, conservation, and renewable energy generation in smart cities [49].

This study argues that intelligent cities need energy-efficient smart buildings. Reducing GHG emissions by following current and applicable regulations, such as the European Strategic Energy Technology Plan, which started in 2010 and is implemented via European Industrial Initiatives, or the zero energy standards in European countries, can be achieved as follows [49]:

- Wind initiative;
- Solar Europe is photovoltaic and concentrated solar electricity;
- Electricity Grid Initiative;
- CTS Initiative;
- Sustainable Nuclear Initiative;
- Industrial Bioenergy Initiative;
- The Smart Cities and Communities Initiative;
- JTI on fuel cells and hydrogen.

Furthermore, it encompasses transportation, energy, heating, and cooling. This study provides an outstanding example of "integrated urban planning", a "disaster preparedness and resilience" component.

4.12. Intelligent Economy Systems

Another crucial aspect influencing C.F reduction in smart cities is the implementation of intelligent and circular economies, which may considerably impact emission reduction. This factor may play its part by using the components shown in Figure 14 [50]:

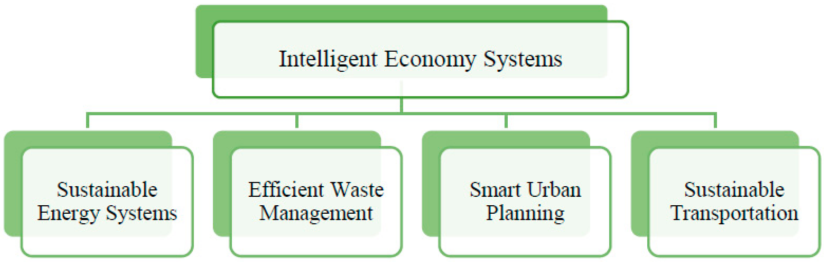

Figure 14. Intelligent economy components in smart cities affecting C.F reduction, based on [50].

Circular and intelligent economies prioritize using renewable energy sources, energy-efficient technologies, and smart grid systems to optimize energy production and consumption. They also strive to decrease waste while enhancing resource recovery by recycling and reuse [51].

What is more, circular and intelligent economies support the sustainable transportation methods already mentioned. Additionally, they emphasize the previously mentioned green and sustainable urban development practices, which may impact emissions reduction [52].

In research by Q. Guo et al. in 231 Chinese cities, the impact of smart city development on emission reduction, energy saving, and the interaction between them was examined. Moreover, in smart city construction, energy efficiency reduced the CO_2 emissions per person by 18.42 logarithmic percentage points. The benefits of smart city development, which lowers per capita CO_2 emissions by increasing energy efficiency, are most remarkable in cities with higher administrative levels, neutral technological growth and green innovation, and advanced industrial structures [53].

Above all, in smart cities, intelligent governance and intelligent economics are linearly coupled. This suggests that technological and environmental advances are more prevalent in economically smarter communities. The Chinese government implemented these actions between 2011 and 2021, as examined in the study above [53].

A detailed case study in China showed that energy savings should be the foundation for emissions reduction. According to the mediation effect, 63% of the benefits of building smart cities for reducing carbon emissions come from energy saving. Therefore, a wise government must prioritize making cities smarter and improving their "green" building practices [53]. This comprehensive study demonstrates how all of the above elements work together to achieve sustainability, reducing energy use.

4.13. Carbon Tracking and Reporting Systems

Finally, a smart city must include carbon monitoring and reporting systems, which could play a significant role in C.F mitigation. As illustrated in Figure 15, these systems can influence emissions reductions in the following ways [54]:

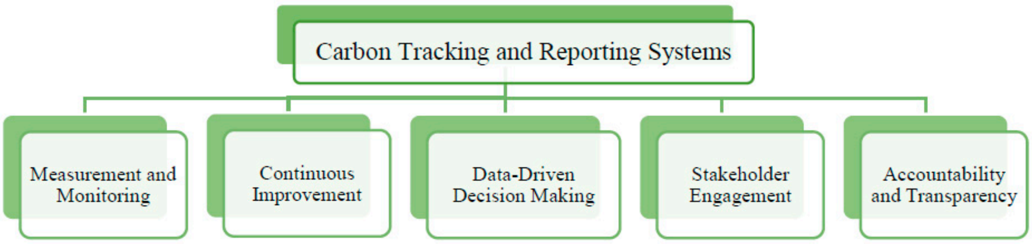

Figure 15. Carbon tracking and reporting systems components affecting C.F in smart cities, based on [54].

Systems for monitoring and reporting carbon emissions "detect and monitor" emissions from various sources. Cities may utilize C.F quantification to identify areas with high emissions and implement targeted reduction strategies as "data-driven decision making". These procedures promote "transparency" and "accountability", and cities may demonstrate their sustainability by accurately collecting and disclosing data on emissions [54].

By enticing individuals and organizations to adopt sustainable practices and reduce emissions, these systems track progress, analyze strategy effectiveness, and promote "continual improvement" and "stakeholder engagement" in emission-reduction programs [55].

Duangsuwan et al. researched the carbon tracking and monitoring systems in Bangkok, Thailand, using automobile sensors. By constructing an intelligent system consisting of automotive sensors and databases and coupling these systems to simple software in drivers' smartphones, urban management agents can provide accurate data on CO_2 emissions for further action. This is called a low-power wide area network (LPWAN). It could be used to create an integrated database for managing and reducing C.F emissions [56].

Another study, by Shahid et al., discussed a model of an intelligent approach to identifying areas with a high volume of pollutant emissions, which is one of the new issues raised in using traffic information in the urban management system for the use of innovation in smart cities and following these innovations. This system can control and monitor traffic lights. The proposed technology can operate well in high-traffic regions and smart cities, lowering C.F. All of the regions with the most traffic congestion are designated high-potential CO_2 emission zones. It then directs traffic to other routes and strives to reduce traffic density significantly before attempting to cut transit time for cars in the city by managing traffic [2]. The research of Shahid et al. can serve as a valuable example of integrating various aspects and components of a smart city that collaborate to minimize C.F.

Figure 16 illustrates the link between smart city traffic management and sustainability. The figure proposes three factors interacting in the smart city, describing an ideal system focusing on reducing traffic and, as an effect, reducing C.F to achieve the basic principles of sustainability.

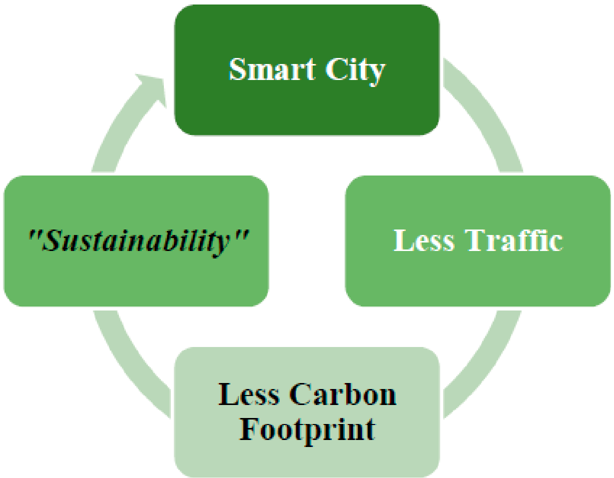

Figure 16. Sustainability loop through intelligent traffic management.

Finally, it can be stated that the following factors contribute to smart cities' contributions to reduce GHG emissions, which in turn helps to mitigate their C.F throughout the entire SC: "energy efficiency and renewable energy, sustainable transport, waste management, urban planning, and infrastructures, decision making driven by data, citizens' engagement, preparedness and resilience for disasters, intelligent economy, and carbon tracking and reporting". While each can be further subdivided, some have a critical impact on different categories due to their emerging and close contributions through SC to improve conditions for citizens and the governing city alongside the important issue of sustainability. For example, given the importance of mobility in today's world, the issue of intelligent and sustainable transportation can have a significant impact on all of the mentioned contributions, and the same issue can also be applied to citizens and the intelligent and circular economy.

Based on the findings and outcomes of this chapter, the writers attempted a scientific debate in the next chapter.

5. Discussion

Introducing smart cities has created new potential and challenges for reducing emissions. C.F in smart cities is a significant issue, especially given the risks of climate change. This review paper studied numerous **SC** strategies that can lower C.F in smart cities. It also discussed how smart cities can help reduce C.F by possessing several components. This discussion aimed to interpret the information provided in the article and to share the author's opinions on the subject.

The article's starting point was a definition of C.F and GHG emissions. Knowing C.F is essential because it provides an overview of the GHGs that cause climate change. Sea level rise, air pollution, and water shortage are all detrimental effects of GHG emissions. The steps required to lower C.F at different phases can be determined by studying the GHG emissions produced by goods or services.

Making decisions in the context of smart cities requires considering long-term C.F effects. As a result, reducing C.F requires adopting SC strategies such as renewable energy sourcing, green manufacturing, and sustainable transportation networks. These actions support the development of resilient and sustainable urban ecosystems while lowering emissions.

The research study emphasized the different features that set apart smart cities. These elements include citizen engagement, intelligent and circular economy, disaster preparedness and resilience, waste management, sustainable transportation, waste tracking and reporting, waste management, sustainable waste management, urban planning, and infrastructure.

Their ability to minimize GHG emissions makes these components important. The replacement of internal combustion engines with electric or hydrogen fuel-cell alternatives reduces transportation emissions. Lighting, cooling, and heating systems that use less energy assistance keep residential and commercial buildings comfortable. Waste management can reuse or recycle and reduce emissions in landfills. Renewable energy helps minimize emissions through energy-efficient urban planning and infrastructure.

Data-driven decision making can help smart cities reduce pollution emissions. Data analysis helps identify GHG emission hotspots, track reduction targets, and identify trends for decision making. This includes real-time data analysis, machine learning to optimize energy production and distribution, and data-driven mobility solutions that cut emissions.

Reducing pollution emissions also requires citizen engagement to empower residents to own their C.F engagement and can be achieved through education, awareness initiatives, and reduction incentives. For instance, smart city bike-sharing systems cut car use and emissions.

Based on the results of this analytical research study, implementing **SC** measures in smart cities is essential for lowering C.F While the elements of smart cities offer numerous chances to cut emissions, their relative importance in doing so varies. To approach urban development sustainability, it is crucial to consider the SC and its components. By implementing these strategies, metropolitan areas can become more resilient, sustainable, and have lower emissions while fostering sustainable economic growth.

6. Conclusions

This study's "main finding" is that smart-city-emission reduction is a worldwide priority. Smart cities are crucial for reducing C.F and fighting climate change. This inquiry revealed numerous critical findings and suggestions that help explain this complicated challenge, including a link to modern SC management.

Hybrid smart city components are needed to achieve the Sustainable Development Goals (SDGs) and reduce air pollution. The collaboration includes government, business, and resident sectors and modern SC management, including digitization and sustainability. SC must be optimized using a circular economy and intelligent management to decrease waste, energy consumption, and emissions from product transportation and distribution.

Furthermore, even though smart cities have a wealth of creative solutions, like intelligent transportation systems, green buildings, renewable energy sources, and smart grids, these tactics must be used holistically, including modern SC management. By implementing sustainable transportation choices, cutting unnecessary inventory, and guaranteeing efficient logistics, a well-optimized SC may drastically lower emissions.

This research emphasizes the need for intelligent governance in SC management. Smart cities must make smart decisions and implement educated policies to monitor air pollution, measure environmental contaminants, quantify C.F, and optimize SC operations. Sustainable approaches and green logistics should be used in modern SC management to reduce carbon emissions.

Although this research offers insightful information on the difficulties and potential of reducing emissions in smart cities, it is crucial to recognize key "limitations" impacting the study's breadth and depth.

First, smart city and SC management technology and policy development are dynamic, creating difficulty. This study used data until 2023, and rapid technological and policy changes may affect these findings in the future. To overcome this constraint, future research should examine how new technology and legislation affect smart city C.F-reduction methods, particularly SC management.

Additionally, the replicable and scalable nature of smart city projects warrants more study. The focus has been on the conceptual and strategic elements of GHG-emission reduction, resulting in a reduction in C.F in smart cities with SC management. Smart city case studies should analyze how modern SC management assists with success.

Future studies should focus on SC management. Numerous intriguing research avenues have emerged from this study's results and limitations. These topics need advanced knowledge and practical strategies for sustainable urban development, concentrating on smart city contrition and SC management in C.F reduction.

Further research should examine how smart cities might reduce C.F by incorporating modern SC management. This includes logistics optimization, transportation-emission reduction, and green SC strategies.

Conversely, digital technologies examine the effects of data analytics, blockchain, and IoT on SC management in smart cities. These technologies could increase the sustainability, efficiency, and transparency of SC, and future research should take these factors into account.

Furthermore, future research should create and deploy sustainability measures for smart city SC management. These indicators may assess the SC's environmental effect and inform decision making.

Additionally, future studies should examine stakeholder collaboration. They should investigate how governments, companies, and communities can cooperate to improve SC operations and decrease carbon impact. Studying effective public−private SC sustainability collaborations is significant.

Finally, regarding SC resilience, research should examine how smart city SC management can adapt and increase resilience to climate change and other shocks by assessing risks and implementing measures to maintain essential supply networks.

In conclusion, this study emphasizes the need to reduce emissions in smart cities via modern SC management. The optimization of SC operations is crucial for this effort, along with collaboration, comprehensive strategy, and informed governance. This study has limits, but the authors hope that further research on the subjects above will assist in creating more sustainable and resilient urban futures where modern SC management reduces GHG emissions and promotes environmental sustainability. Bridging these research gaps may help build smart cities that are technologically sophisticated, ecologically sustainable, and habitable—improving the future for everybody.

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Abbreviations

GWP	Global warming potential
RQ	Research question
PRISMA-ScR	Systematic reviews and meta-analyses in scoping review
ICT	Information and communication technology
WHO	World Health Organization
GHG	Greenhouse gas
C.F	Carbon footprint
SDGs	Sustainable Development Goals

SC	Supply chain
US EPA	United States Environmental Protection Agency
IPCC	International Panel on Climate Change
IoT	Internet of Things
EV	Electric vehicle
LCA	Life cycle approach
IPSO	Internet Protocol for Smart Objects Alliance
WSN	Wireless sensor network
LTE-M	Long-term evolution mobile
M2M	Machine-to-machine
GPS	Global Positioning System
DWTP	Drinking water treatment plant
NRF	National Research Foundation of Korea
IoV	Internet of vehicles
ITS	Intelligent transportation system
SCEAF	Smart City Energy Assessment Framework
NIWA	National Institute of Water and Atmospheric Research
UPM	Polytechnic University of Madrid
ZEB	Zero energy building
LPWAN	Low-power wide area network

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