resources

MDPI

Review

Waste Management in the Smart City: Current Practices and Future Directions

Danuta Szpilko [1,*], Antonio de la Torre Gallegos [2], Felix Jimenez Naharro [2], Agnieszka Rzepka [3] and Angelika Remiszewska [4]

1. International Department of Logistics and Service Engineering, Faculty of Engineering Management, Bialystok University of Technology, Wiejska 45A, 15-312 Bialystok, Poland
2. Departament of Financial Economics and Operations Management, Faculty of Economics and Business Sciences, University of Seville, Ramón y Cajal 1, 41018 Sevilla, Spain; atorre@us.es (A.d.l.T.G.); fjimenez@us.es (F.J.N.)
3. Department of Economics and Economic Management, Faculty of Management, Lublin University of Technology, Nadbystrzycka 38 D, 20-618 Lublin, Poland; a.rzepka@pollub.pl
4. Faculty of Engineering Management, Bialystok University of Technology, Wiejska 45A, 15-312 Bialystok, Poland; angelika.remiszewska.109326@student.pb.edu.pl

* Correspondence: d.szpilko@pb.edu.pl

Abstract: The discourse surrounding sustainability, particularly in the urban environment, has gained considerable momentum in recent years. The concept of a smart city epitomises the integration of innovative technological solutions with community-centred approaches, thereby laying the groundwork for a sustainable lifestyle. One of the crucial components of this integration is the effective and innovative management of waste. The aim of this article was to classify scientific research pertaining to waste management within the context of smart city issues, and to identify emerging directions for future research. A systematic literature review, based on a bibliometric analysis of articles included in the Scopus and Web of Science databases, was conducted for this study. The purpose of such a systematic review is to identify, integrate, and evaluate research on a selected topic, using clearly defined criteria. The research query included: TITLE-ABS-KEY (“smart city” AND (waste OR garbage OR trash OR rubbish)) in the case of Scopus, and TS = (“smart city” AND (waste OR garbage OR trash OR rubbish)) in the case of the Web of Science database. A total of 1768 publication records qualified for the analysis. This study presents an investigation into the current and forthcoming directions of waste management in smart cities, synthesising the latest advancements and methods. The findings outline specific future research directions encompassing technological advancement, special waste challenges, digitisation, energy recovery, transportation, community engagement, policy development, security, novel frameworks, economic and environmental impact assessment, and global implications. These insights reflect a multifaceted approach, advocating a technology-driven perspective that is integral to urban sustainability and quality of life. The study’s findings provide practical avenues for cities to enhance waste management through modern technologies, promoting efficient systems and contributing to sustainable urban living and the circular economy. The insights are vital for policymakers and industry leaders globally, supporting the creation of universal standards and policies, thereby fostering comprehensive waste management systems aligned with global sustainability objectives.

Keywords: smart city; waste management; smart bin; energy; living; transport; sustainability; internet of things; blockchain; machine learning

Citation: Szpilko, D.; de la Torre Gallegos, A.; Jimenez Naharro, F.; Rzepka, A.; Remiszewska, A. Waste Management in the Smart City: Current Practices and Future Directions. *Resources* **2023**, *12*, 115. https://doi.org/10.3390/resources12100115

Academic Editor: Eva Pongrácz

Received: 16 August 2023
Revised: 8 September 2023
Accepted: 19 September 2023
Published: 26 September 2023

1. Introduction

The concept of the smart city has become increasingly prevalent, especially in developing nations, as a prospective solution to the challenges triggered by the urbanisation process [1,2]. These cities necessitate the amalgamation of information and communication technology (ICT) and internet technologies to reshape their structure, including areas such as advanced infrastructure, transportation, environment, healthcare, governance, and more, all aimed at developing a sustainable ecosystem that minimises threats to urban life [3–6]. These novel frameworks consist of a convergence of ICT technologies, sustainability, and performance indicators in various sectors such as technical, social, and economic [7,8].

At the centre of these technological innovations, the internet of things (IoT) has emerged as a main driver in smart city initiatives globally. IoT-enabled systems catalyse the transformation of urban cities, fostering advancements in infrastructure, waste management, transportation, and the overall enhancement of human life. This transformation is further aided by advanced IoT communication technologies, enabling the fusion of various components to improve city administration and resident services [9]. IoT-enabled smart cities may bring extensive benefits in optimising public services such as transport, water management, smart buildings, healthcare, education, and more, with the potential to transform societies into smart communities [10–16]. One critical aspect where this convergence finds its application is waste management [17].

The impending increase in global population to 9.75 billion by 2050 (representing an increase of 22.5% from the 2022 population of 7.96 billion) [18] and the anticipated rise in worldwide waste production to 2.8 billion tonnes by 2050 [19] further necessitate the development of smart waste management. This increase, coupled with the potential doubling of waste generation every decade, introduces immense financial burdens related to collection, landfills, and recycling [20]. Research recommends utilising smart technologies to augment waste management systems [21–24]. However, the successful integration of these technologies necessitates citizen participation and behavioural changes, emphasising the role of city managers and policymakers in fostering awareness and engagement [25].

Smart waste management's complexity necessitates a comprehensive multi-criteria approach, involving data collection, analytics, route planning, optimisation, decision support, waste classification, and more [26]. A significant part of this complexity lies in the IoT-enabled services, which represent a departure from older technologies like geographical information systems [27] and routing and scheduling. IoT alone can facilitate true innovation in waste management [28]. The capabilities of smart waste management extend to improvements in energy efficiency, environmental safety, quality of life, and reduction in resource consumption [29].

Nevertheless, challenges persist, notably the lack of coordination between different data sources and an integrated data cloud that can be shared among various stakeholders [30]. Additional focus is required on social aspects, including citizens' environmental awareness and the further implementation of technologies in recycling, reverse logistics, and support of environmental regulations [31].

The integration of smart waste management within smart cities presents a promising avenue towards sustainable urbanisation. Leveraging IoT technologies, it offers significant contributions to energy efficiency, environmental protection, and improved quality of life. Continued research and development are essential, focusing on data integration, social considerations, and technological innovations.

The role of waste management within the smart city framework goes beyond its fundamental utility, mere rubbish disposal. Through the integration of state-of-the-art technologies and the adoption of data-driven methods, cities are charting a path towards sustainable development and increased quality of life [1,32–34]. As urban landscapes undergo transformation, the connection between smart solutions and waste management will unquestionably become more intricately intertwined, shaping the cities of the future. This represents a comprehensive approach to cultivating cleaner, more sustainable, and efficient urban environments.

Analyses of review articles in the realm of waste management have unveiled diverse avenues of research focus, spanning technological, sociological, geographical, and economic dimensions. The multifaceted nature of waste management research is reflected across the following categories: technological innovation in solid waste management [35,36];

electronic waste (e-waste) management [37–39]; medical and pandemic-related waste management [40,41]; waste-to-energy (WTE) technology [42]; zero-waste management [43]; municipal solid waste management [44–49]; construction and demolition waste [50–53]; circular economy [54–57]; global trends and analyses related to waste management [58,59]; behavioural and entrepreneurial aspects [60–62]; sustainable waste management [63]; and local waste management [64].

In order to highlight issues related to waste management in smart cities, the authors also analysed review articles closely related to this topic. The results of these analyses indicate a focus on:

- Technological foundations—most smart cities heavily rely on technology, with the internet of things (IoT) considered a pivotal component [1,65,66]. Beyond the IoT sphere, the literature also highlights the significance of other technologies such as big data analytics, cloud processing, and blockchain [67,68]. Additionally, the literature analysis encompasses topics like product lifecycle data collection, formulating innovative business models aimed at preventing waste generation, and sensor-equipped infrastructure for effective waste segregation and collection [30].
- Environmental issues and sustainable development—the literature emphasises that while technological innovations are essential, an equal emphasis on sustainability is vital. From this perspective, smart cities should not only be technologically advanced but should also promote sustainable development practices, especially in waste management [30,69].

Based on the analyses conducted, the following research gaps were identified:

- A lack of a holistic view on the topics of existing research concerning waste management in smart cities;
- Directions for future research in the area of waste management in smart cities are presented in a fragmented manner across various articles and typically relate only to the area researched within them.

In this paper, through the use of bibliometric analysis and systematic literature review, the authors comprehensively and succinctly present existing waste management practices in smart cities and identify areas requiring further research.

This publication will address the following questions:

- What research areas are included in scientific publications concerning waste management within the framework of a smart city?
- What should be the future research directions focused on the development of waste management in the context of smart cities?

The article is composed of five sections. The introduction provides fundamental information pertinent to waste management in smart cities. The second section elucidates the research method and tools applied, in addition to the material subject to analysis. The third part delineates the research findings related to areas encompassed within scientific publications on waste management within the context of a smart city. The fourth section offers a critical discussion of the results, segregated into three subsections that tackle matters of technology, living, and transportation. In this section, directions for future research regarding waste management in smart cities also are delineated. In the final section, conclusions and limitations of this study have been included.

2. Materials and Methods

The literature on waste in smart cities was examined using a bibliometric analysis approach. This method is frequently employed by researchers, particularly when first exploring a specific research topic. Given the vast number of publications available, it facilitates the identification, synthesis, analysis, and critical evaluation of their contents [70]. The results obtained provide insights into the main research directions, trends, and changes in the number of publications over a specific time period. Moreover, it enables the creation of rankings for the most productive authors, journals, research units, and countries within the field of research [71]. Bibliometric analysis is applicable to well-established research areas in the literature [72–75], as well as emerging ones [76,77]. Figure 1 illustrates the operationalisation of the process employed in this article using the bibliometric analysis method.

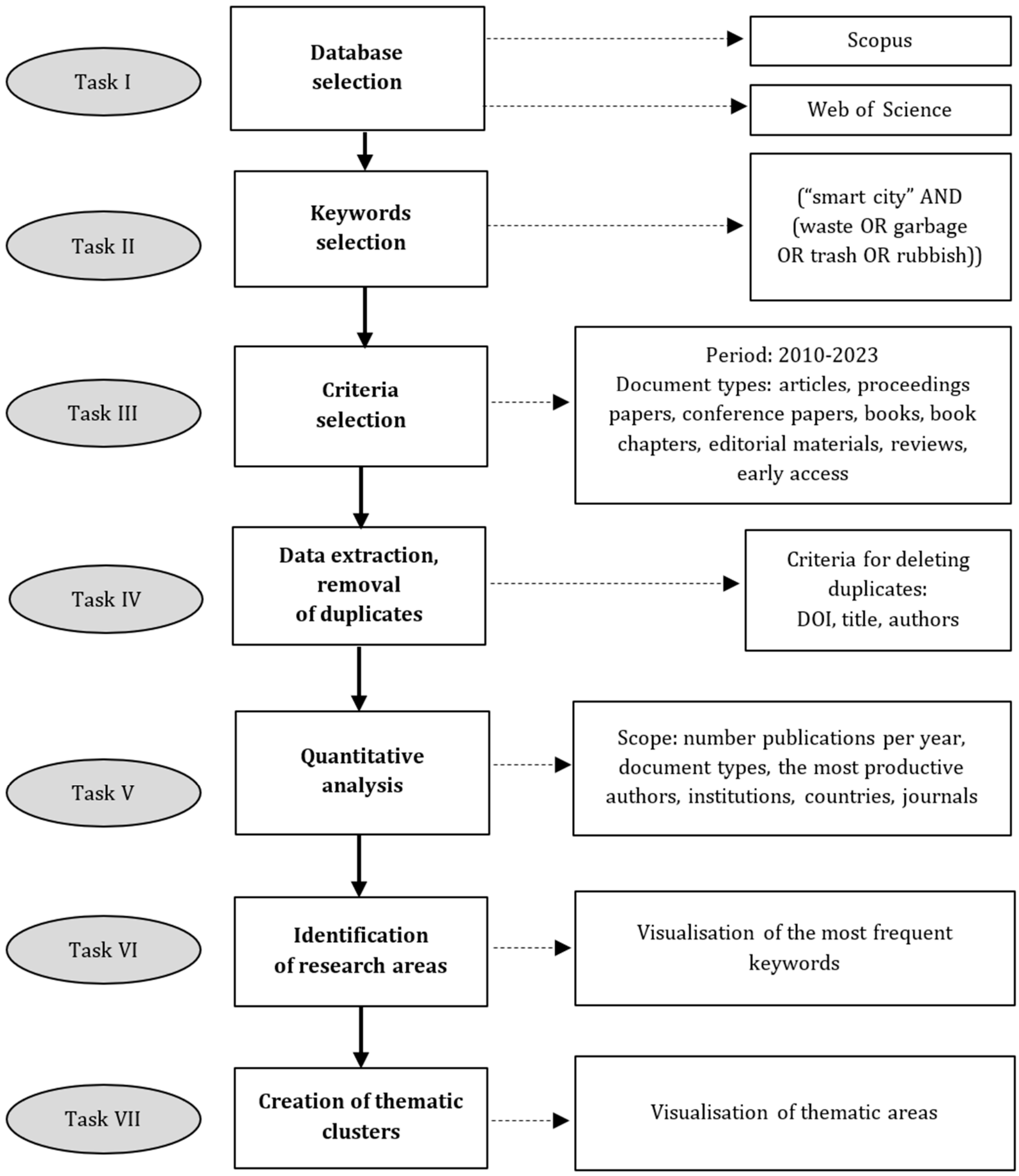

Figure 1. Research methodology. Source: authors' work.

The research process was conducted according to a methodology comprising seven tasks (Figure 1). In the initial phase of the study, the researchers opted for the Scopus and Web of Science bibliographic databases. The selection of these databases was motivated by their extensive availability and thematic coverage across various scientific disciplines. The bibliometric analysis began by focusing on publications that contained the specific terms 'smart city', 'waste', 'garbage', 'trash', 'rubbish'. In the first and second samples, the search encompassed publications with these phrases throughout the entire document, while the third and fourth samples included titles, abstracts, and keywords.

To refine the search, certain restriction criteria were applied. The search was limited to materials published between 2010 and 2023. For further analysis, articles, conference proceedings, books, book chapters, reviews, editorials, and early access publications were considered eligible. On the other hand, publication types such as retracted publications, notes, errata, and letters were excluded. The outcomes of the search are presented in Table 1.

Table 1. Search results.

Search Number	Stage	Web of Science	Scopus
1.	Research query	ALL = smart city AND waste	ALL (smart city AND waste)
	Number of all articles	1850	32,135
	Number of articles after inclusion criteria	1836	31,416
2.	Research query	ALL = "smart city" AND waste	ALL ("smart city" AND waste)
	Number of all articles	815	13,010
	Number of articles after inclusion criteria	815	12,911
3.	Research query	TS = "smart city" AND waste	TITLE-ABS-KEY ("smart city" AND waste)
	Number of all articles	881	1533
	Number of articles after inclusion criteria	881	1467
4.	Research query	TS = ("smart city" AND (waste OR garbage OR trash OR rubbish))	TITLE-ABS-KEY ("smart city" AND (waste OR garbage OR trash OR rubbish))
	Number of all articles	938	1657
	Number of articles after inclusion criteria	938	1582

Source: authors' work.

A search for the phrase 'smart city AND waste' across the range of papers in the first sample generated 32,135 records in Scopus and 1850 records in Web of Science. However, upon the initial analysis, it became evident that many of these publications were not directly relevant to the study area. The search in the second attempt, enclosing the keywords in quotation marks ("smart city" AND waste), also did not yield satisfactory results. As a result, a third attempt was made, restricting the search only to publications containing the specified phrase in their titles, abstracts, and keywords. The refined search produced 1533 records in Scopus and 881 in Web of Science.

Analysis of the collected records in all three search attempts provided extremely important information from the point of view of the study. It was noted that the record of the word 'waste' also appears in the form of the following alternative phrases: 'garbage', 'trash', 'rubbish'. A fourth search for the phrase ("smart city" AND (waste OR garbage OR trash OR rubbish)) across the range of papers in the first sample generated 1657 records in Scopus and 938 records in Web of Science. After applying the limiting criteria, 1582 records in Scopus and 938 in Web of Science were obtained. The search results are detailed in Table 1.

Full records in *.csv format were downloaded from each database, and these files were amalgamated into one, yielding a total of 2520 records. After the elimination of duplicates, a subset of 1768 records was selected for further analysis.

Based on the acquired dataset, various analyses were conducted to examine the number of publications within specific time periods and to identify the most productive authors, organisations, countries, and journals. The research also focused on pinpointing the most notable articles, particularly those with the highest frequency of citations. Furthermore, an exhaustive investigation of commonly recurring keywords was carried out, culminating in the creation of a map that depicts the co-occurrence of keywords associated with the application of waste in smart cities. The keyword co-occurrence map was created using VOSviewer software (version 1.6.19).

To ensure accuracy and relevance, an additional thesaurus file was prepared [78], which facilitated the elimination of duplicate terms with similar meanings (e.g., IoT and internet of things) or terms not pertinent to the study (e.g., article, research, review, state).

This file was developed on the basis of keyword analysis and a meticulous review of the publication collection. The outcome of this analysis enabled the identification of thematic areas.

3. Results

In the initial phase of the study, an analysis was conducted on the number of publications over the years and the types of publications in the area of waste in smart cities, using the Scopus and Web of Science databases.

Between 2017 and 2023, a significant number of publications on the subject of waste in smart cities emerged in both the Scopus (1582) and Web of Science (938) databases (Figure 2). Prior to this period, references to this topic were infrequent. The total number of citations for publications indexed in the Scopus database reached 17,268, while in Web of Science, it amounted to 14,052. There were 477 uncited publications in Scopus and 241 in Web of Science.

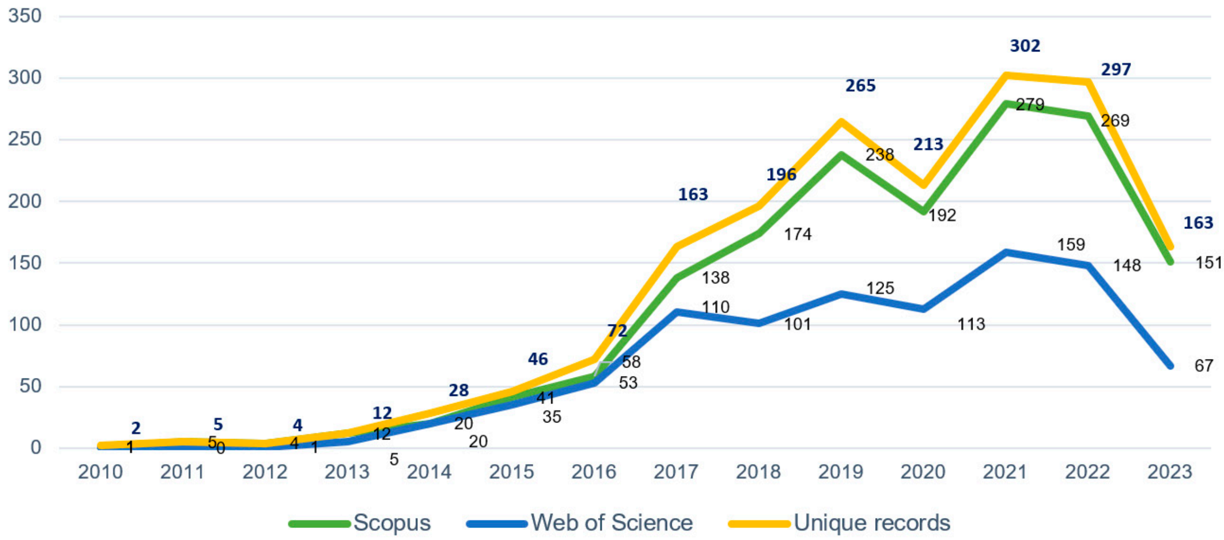

Figure 2. Publications in the field of waste management in smart cities in the Scopus and Web of Science databases (indexed from January 2010 to July 2023).

In both the Web of Science and Scopus databases, the majority of publications were articles (51.2% and 32.4%, respectively) and conference papers (42.2% and 53.1%). Reviews, editorials, and book chapters constituted a smaller portion. The distribution of publications by document type is depicted in Figure 3.

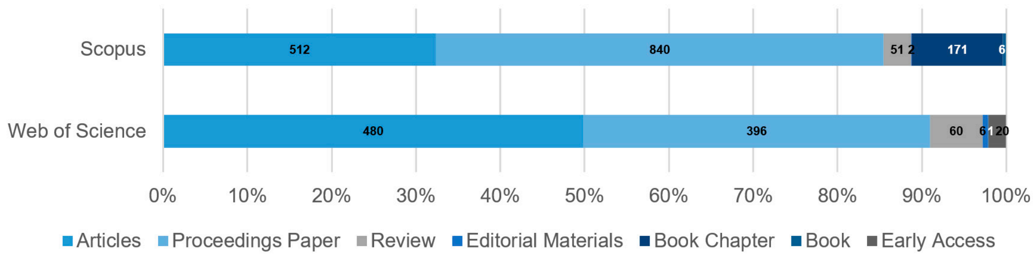

Figure 3. Types of publications in the field of waste management in smart cities, as indexed in the Scopus and Web of Science databases (January 2010 to July 2023).

Zaslavsky and Anagnostopoulos have been recognised as the most productive authors in this field, with 17 and 14 publications respectively. Their jointly referenced work, 'Challenges and Opportunities of Waste Management in IoT-Enabled Smart Cities: A Survey' from 2017, has gathered 195 citations in the Web of Science and 140 in Scopus.

Following them in terms of productivity are Medvedev with 9 publications, Nakazawa with 8, and Zafar with 7. Ratti has the distinction of having the highest average number of citations per publication in both databases, with counts of 71.2 in Scopus and 44.00 in the Web of Science. Ratti et al.'s most cited work, 'The Future of Waste Management in Smart and Sustainable Cities: A Review and Concept Paper' was published in *Waste Management* in 2018 and has been cited 225 times in Scopus and 174 times in the Web of Science. A detailed list of the most productive authors can be found in Table 2.

Table 2. The most productive authors, organisations, countries, and journals.

No.	Item	Publication [N]	[%]	Citation [Average]	
				Scopus	WoS
	Authors				
1.	Zaslavsky, A.	17	1.0	37.9	30.8
2.	Anagnostopoulos, T.	14	0.8	49.7	29.1
3.	Medvedev, A.	9	0.5	56.1	45.8
4.	Nakazawa, J.	8	0.5	9.5	8.6
5.	Zafar, N.A.	7	0.4	14.4	4.3
6.	Ratti, C.	6	0.3	71.2	44.0
7.	Toutouh, J.	6	0.3	9.2	7.2
8.	Sosunova, I.	6	0.3	5.5	4.8
9.	Fedchenkov, P.	6	0.3	28.5	4.3
10.	Chen, Y.	6	0.3	8.3	7.7
11.	Anjum, M.	6	0.3	4.0	1.8
	Countries				
1.	India	486	27.5	8.5	11.4
2.	China	153	8.7	12.1	22.8
3.	United States	112	6.3	25.3	33.3
4.	Italy	103	5.8	20.6	21.9
5.	Spain	73	4.1	11.6	17.8
6.	United Kingdom	63	3.6	29.3	33.7
7.	Australia	63	3.6	23.8	19.7
8.	Russia	58	3.3	19.1	19.3
9.	Indonesia	57	3.2	5.6	4.5
10.	Saudi Arabia	48	2.7	24.0	18.4
11.	Malaysia	47	2.7	21.4	22.0
	Organisations				
1.	Vellore Institute of Technology	24	1.4	14.3	19.8
2.	University of Information Technologies, Mechanics and Optics University ITMO	21	1.2	45.5	34.0
3.	National Institute of Technology Nit System	17	1.0	5.9	6.2
4.	Commonwealth Scientific and Industrial Research Organization	15	0.8	46.2	32.5
5.	K L Deemed to be University	14	0.8	8.1	N/A
6.	Amity University	13	0.7	2.1	0.5
7.	Lovely Professional University	12	0.7	8.4	8.1
8.	Massachusetts Institute of Technology	11	0.6	35.5	25.6
9.	Indian Institute of Technology System LIT System	11	0.6	8.0	8.6
10.	Instituto de Telecomunicações	10	0.6	45.2	N/A
11.	Politecnico di Bari	10	0.6	35.7	43.0
12.	Universitas Diponegoro	10	0.6	2.7	0.0
13.	Egyptian Knowledge Bank EKB	10	0.6	N/A	5.9

Table 2. *Cont.*

No.	Item	Publication [N]	[%]	Citation [Average]	
				Scopus	WoS
Journals					
1.	Lecture Notes in Computer Science including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	39	2.2	8.7	6.7
2.	Sustainability (Switzerland)	38	2.1	15.9	16.6
3.	IOP Conference Series Earth and Environmental Science	34	1.9	4.1	8.8
4.	Lecture Notes in Networks and Systems	30	1.7	0.6	0.8
5.	Advances in Intelligent Systems and Computing	27	1.5	3.8	4.0
6.	ACM International Conference Proceeding Series	24	1.4	1.3	N/A
7.	Sensors (Switzerland)	22	1.2	35.6	15.2
8.	E3s Web of Conferences	21	1.2	2.7	
9.	IEEE Access	20	1.1	28.8	25.0
10.	Sustainable Cities and Society	18	1.0	91.2	69.0
11.	Communications in Computer And Information Science	18	1.0	4.6	4.5
12.	Applied Sciences (Switzerland)	17	1.0	10.7	8.5

Note: [N]—number of publication, [%]—percentage of the total number of publication (1768), N/A—not applicable. Source: authors' work.

In terms of geographical origin, most of the publications hail from India (486), with China (153) and the United States (112) following behind. When examining affiliations of authors, Vellore Institute of Technology stands out as the institution responsible for the largest number of publications (24), with the University of Information Technologies, Mechanics and Optics (ITMO University) not far behind at 21, and the National Institute of Technology Nit System contributing 17. It is worth highlighting that works from the Commonwealth Scientific and Industrial Research Organization (cited 46.2 times on average in Scopus and 32.5 in WoS), ITMO (45.5 in Scopus, 34.0 in WoS), Politecnico di Bari (35.7 in Scopus, 43.0 in WoS), and Massachusetts Institute of Technology (35.5 in Scopus, 25.6 in WoS) are among the most frequently cited. These institutions show a remarkable average citation count in both the Scopus and Web of Science databases, setting them apart from other entities in the ranking.

Lecture Notes in Computer Science, including its subseries *Lecture Notes in Artificial Intelligence* and *Lecture Notes in Bioinformatics*, led the list of most productive journals with 39 publications. It was closely followed by *Sustainability*, which had 38 publications, and the *IOP Conference Series Earth and Environmental Science*, with 34 publications. In contrast, the journals boasting the highest average number of citations per article across different databases were *Sustainable Cities and Society* (with 91.2 citations in Scopus and 69.0 in WoS), *IEEE Access* (with 28.8 in Scopus and 25.0 in WoS), and *Sensors* (with 35.6 in Scopus and 15.2 in WoS) (Table 2).

Silva et al.'s 2018 [1] paper, titled 'Towards Sustainable Smart Cities: A Review of Trends, Architectures, Components, and Open Challenges in Smart Cities,' stands as the most cited work, garnering 838 citations in Scopus and 626 in the Web of Science. Subsequent to this were the 2010 piece by Harrison et al., 'Foundations for Smarter Cities,' and Yao et al.'s 2018 study, 'Deep Multi-View Spatial-Temporal Network for Taxi Demand Prediction.' While these articles were highly cited, their total citation counts in Scopus (784 and 631) and the Web of Science (588 and 569) were not as high as that of Silva et al.'s work.

The most highly cited papers were published in various journals and conference materials. Among the journals were *Sustainable Cities and Society*, *IBM Journal of Research and Development*, *IEEE Communications Magazine*, *International Journal of Information Management*, *Telematics and Informatics*, *Lecture Notes in Information Systems and Organisation*, *Journal of Systems and Software*, and *Journal of Cleaner Production*. Six of the most highly cited articles were published in 2017, 2018, and 2019, with exactly two in each year (Table 3).

Table 3. The most cited articles on waste management in the smart city area.

No.	Authors		Article Title	Journal	Citations [N]	
					Scopus	WoS
1.	Silva et al. (2018)	[1]	Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities	Sustainable Cities and Society	838	626
2.	Harrison et al. (2010)	[79]	Foundations for Smarter Cities	IBM Journal of Research and Development	784	588
3.	Yao et al. (2018)	[80]	Deep multi-view spatial-temporal network for taxi demand prediction	32nd AAAI Conference on Artificial Intelligence	631	569
4.	Mehmood et al. (2017)	[81]	Internet-of-things-based smart cities: Recent advances and challenges	IEEE Communications Magazine	423	328
5.	Ismagilova et al. (2019)	[82]	Smart cities: Advances in research-An information systems perspective	International Journal of Information Management	430	319
6.	Higon et al. (2017)	[83]	ICT and environmental sustainability: A global perspective	Telematics and Informatics	291	256
7.	Harrison and Donnelly (2011)	[84]	A theory of smart cities	55th Annual Meeting of the International Society for the Systems Sciences	271	N/A
8.	Benevolo et al. (2016)	[85]	Smart mobility in smart city action taxonomy, ICT intensity and public benefits	Lecture Notes in Information Systems and Organisation	247	181
9.	Piro et al. (2014)	[86]	Information centric services in Smart Cities	Journal of Systems and Software	239	171
10.	Nižetić et al. (2019)	[87]	Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management	Journal of Cleaner Production	220	192
11.	Esmaeilian et al. (2018)	[30]	The future of waste management in smart and sustainable cities: A review and concept paper	Waste Management	225	174

Note: [N]—number of citations, N/A—not applicable. Source: authors' work.

In the context of the bibliometric analysis, keywords recurrently associated with the subject of waste in the smart cities were extracted. The analytical process employed the use of VOSviewer software (version 1.6.19). The resulting collection consisted of 181 words or phrases that occurred a minimum of five times in the keywords of the 1768 articles examined. This collection included words synonymous with abbreviations or repetitions (for example, 'Internet of Things', 'internet-of-things', 'IoT', 'neural network', and 'neural networks'), as well as terms not intrinsically related to the central theme of analysis (such as 'article', 'analysis', 'scheme', 'model', 'knowledge', 'literature review'). A thesaurus file was curated and deployed to systematise the word set. Search keywords (e.g., 'smart city', 'smart cities', 'waste', 'garbage', 'rubbish', 'trash') were purposely excluded from this collection. The nomenclature of terms and abbreviations sharing similar meanings was standardised, and terms unrelated to the analysis performed were discarded. The refined collection included 94 keywords that appeared at least 5 times. The most prevalent terms and their interconnections are depicted in Figure 4.

In order to clearly present the obtained results, the co-occurrence map was reduced to 54 keywords strictly linked to the area under investigation. The limitation involved presenting only the keywords that appeared at least 10 times. Among the most frequent keywords related to waste in the context of a smart city are terms associated with technological aspects, such as the internet of things (451), waste management (229), sensor (103), machine learning (64), smart waste management (61), artificial intelligence (57), deep learning (57), wireless sensor networks (54), smart bins (52), waste collection (51), cloud computing (48), big data (46), LoRaWAN (42), blockchain (38), and GSM/GPRS (37).

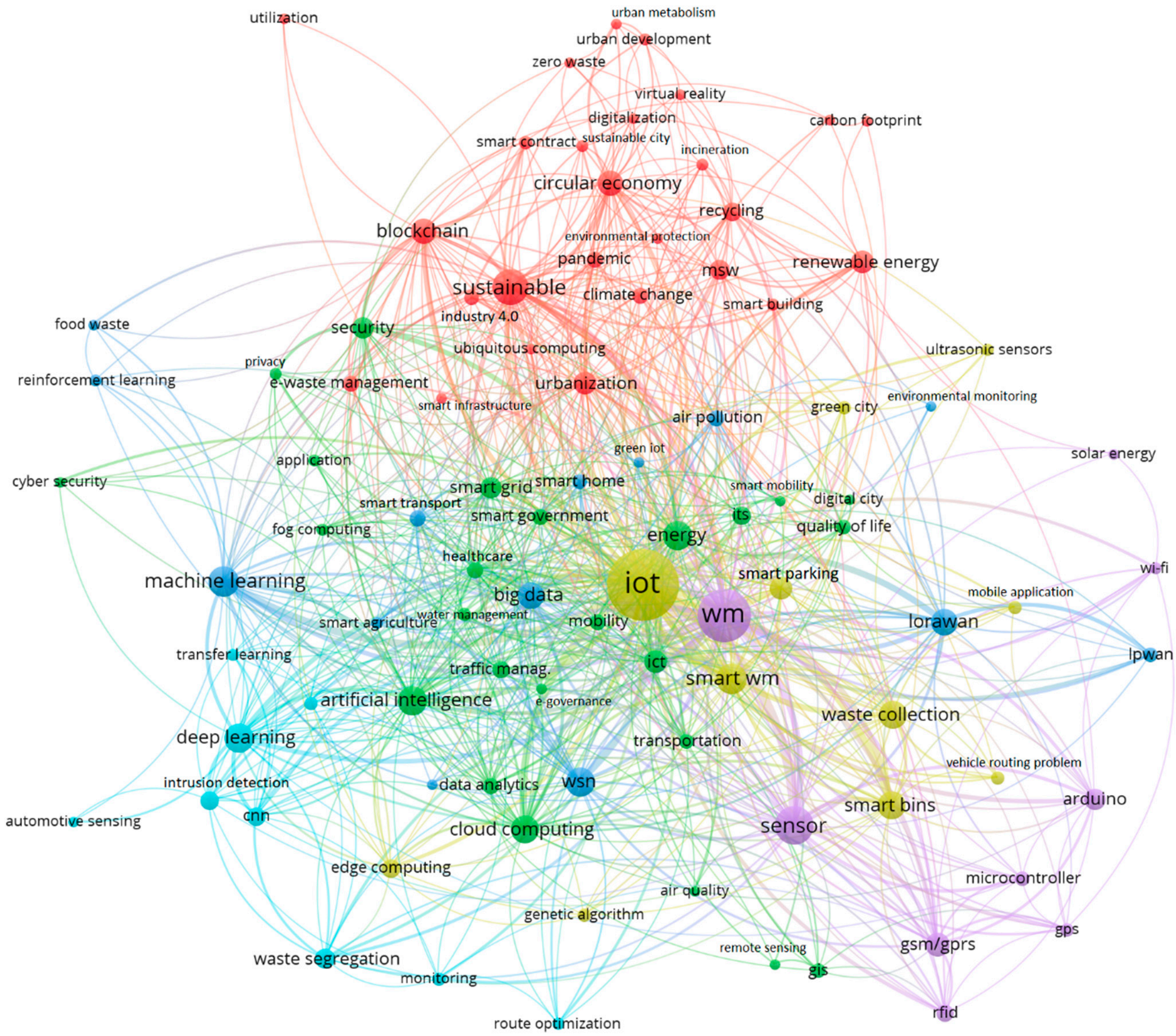

Figure 4. Key word co-occurrence map on the waste management in smart city. Source: authors' work using VOSviewer software (version 1.6.19).

These main terms are interconnected with waste and are closely linked with subareas identified in two clusters, encompassing issues related to waste within smart cities. Within these individual clusters, the most frequently appearing keywords were:

- Implications of waste on sustainability, urban living, and the environment—sustainable (91), energy (54), circular economy (39), renewable energy (32), urbanisation (31);
- Transportation in a smart waste management system—traffic management (16), smart transport (13), transportation (11).

The larger the circle in Figure 5, the more often a given keyword occurs. It should also be highlighted that these terms exhibit the most connections to other terms. A list of all key words from the 3 subareas is presented in Table 4.

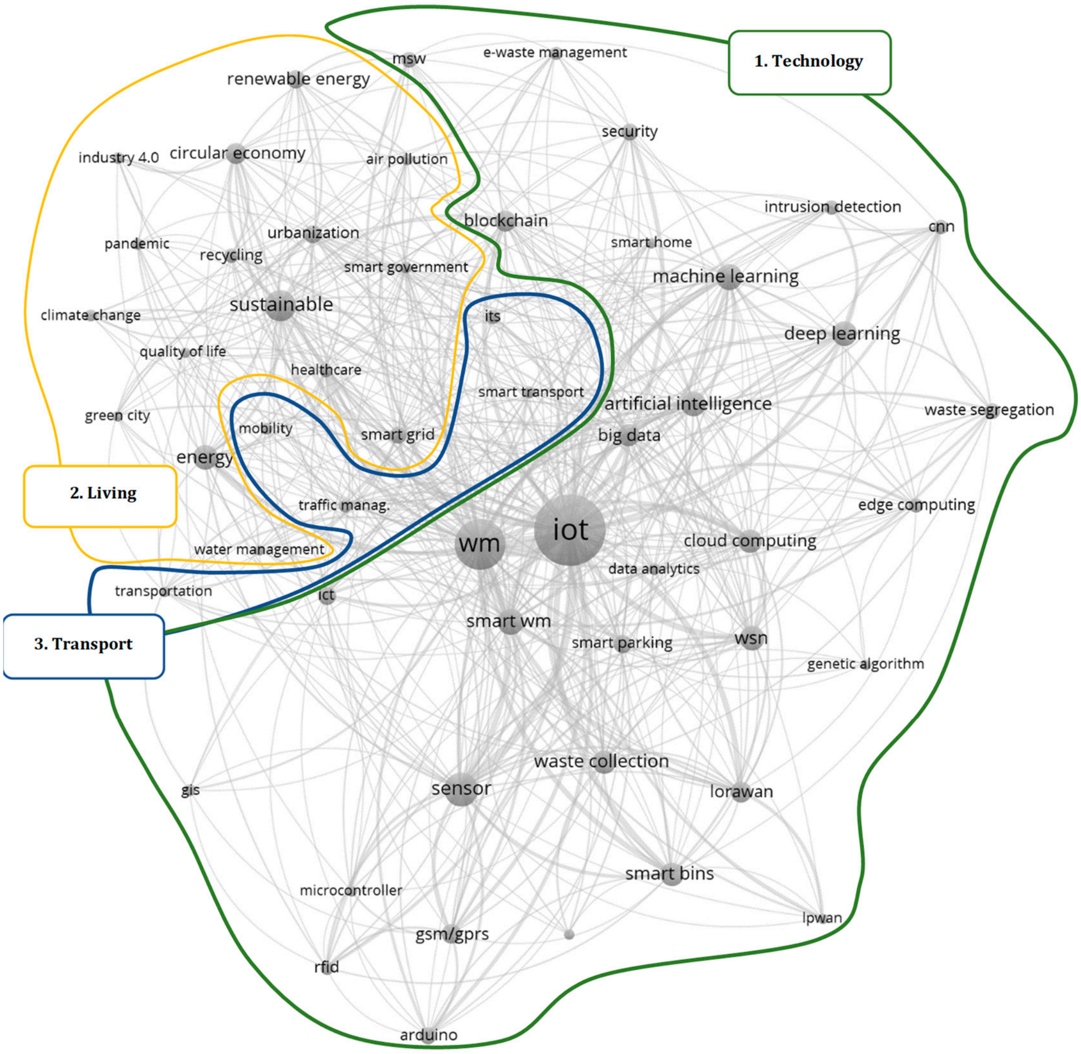

Figure 5. Thematic subareas on the waste management in the smart city. Source: authors' work using VOSviewer software.

Table 4. Subareas of waste management in the smart city research.

No.	Subareas Name	Key Words
1. Technology	Innovative technologies enhancing waste management in smart cities	waste management (WM), smart waste management, waste collection, waste segregation, municipal solid waste (MSW), internet of things (IoT), sensor, machine learning, artificial intelligence, deep learning, big data, data analytics, cloud computing, edge computing, radio-frequency identification (RFID), wireless sensor networks (WSN), LoRaWAN, LPWAN, GSM/GPRS, blockchain, information and communications technology (ICT), geographic information system, Arduino, microcontroller, genetic algorithm, convolutional neural network (CNN), e-waste management, recycling, smart bins
2. Living	Implications of waste on sustainability, urban living and the environment	sustainable, green city, urbanisation, air pollution, climate change, quality of life, healthcare, pandemic, energy, renewable energy, water management, security, intrusion detection, industry 4.0, circular economy
3. Transport	Transportation in smart waste management system	smart transport, mobility, traffic management, transportation, vehicle routing problem, smart home, smart government, smart grid, intelligent transport systems (ITS), smart parking

Source: authors' work.

The first area, 'Innovative technologies enhancing waste management in smart cities', scrutinises the application and integration of advanced technologies to elevate waste management within smart city infrastructures. It manifests an intersection of technology and environmental management, leveraging the capabilities of machine learning, artificial intelligence (AI), and cloud and edge computing, among others. Key terms such as internet of things (IoT), big data, sensor, geographic information system [27], blockchain and smart bins, to name a few, elucidate the technology-centric focus of this domain.

The second area, 'Implications of waste on sustainability, urban living, and the environment', critically assesses the multifaceted impacts of waste on sustainable development, urban living, and environmental health. It highlights the inextricable ties between waste management and quality of life, energy usage, circular economy, and environmental security. The essence of this theme is captured in keywords such as sustainable, green city, air pollution, renewable energy, and intrusion detection.

The third area, 'Transportation in smart waste management system', delves into the role of transportation within the context of waste management in smart cities. It brings into focus the synergistic relationship between smart transportation systems and effective waste management. Keywords such as smart transport, traffic management, vehicle routing problem, and intelligent transport systems (ITS) underline the logistical complexities inextricably tied to this theme.

4. Discussion

The study has unveiled three distinct research subareas related to waste management in smart cities: innovative technologies enhancing waste management (i), implications of waste on sustainability, urban living and the environment, (ii) and transportation in smart waste management systems (iii). Each of these subareas sheds light on different facets of waste management within the context of smart urban environments. Not only do they offer a comprehensive understanding of the subject, but they also reveal interconnections among them (Figure 6).

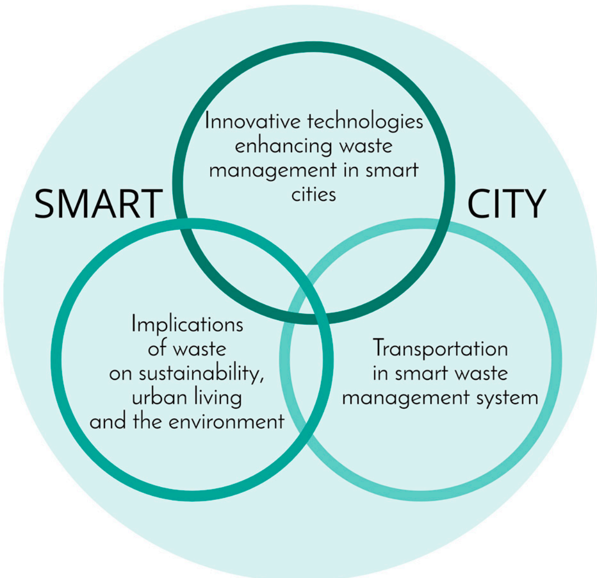

Figure 6. The relationships between thematic subareas on the waste management in the smart city. Source: authors' work using VistaCreate software.

In essence, despite the diversity in their primary focuses, these three subareas collectively shape a holistic and efficient waste management system for smart cities. Technological innovations underpin the tools essential for this system; sustainability implications set the goals to be achieved, and transportation logistics play a pivotal role in ensuring effective on-the-ground implementation. When synchronised, these facets contribute seamlessly to the broader vision of fostering a cleaner, greener, and more intelligent city.

4.1. Technologies Enhancing Waste Management in Smart Cities

As societies continue to grapple with rapid urbanisation and burgeoning populations, the management of waste becomes an increasingly pressing issue [3,66,88,89]. Modern technology has become a pivotal component in addressing the growing challenges of waste management in smart cities. This transformation has been catalysed by the increasing demand for efficient, eco-friendly, and sustainable waste management solutions. A key player in this movement is the internet of things, the use of which in waste management systems (WMS) has offered notable solutions to this pressing global issue [26,30,90].

The underpinning principle is the incorporation of smart devices and sensors throughout the urban landscape, tasked with monitoring and collecting data on waste generation and management. As a data-centric approach, this system empowers more efficacious management of waste collection and disposal, transportation logistics, and recycling efforts [26,91]. The comprehensive waste management system can utilise tracking and data-sharing technologies, all integrated into a central framework, thereby optimising waste lifecycle processes such as collection, recovery, and prevention [30].

One such recommendation is an IoT-based waste management system. This innovative system encompasses smart waste bins outfitted with sensors that monitor their fill levels, allowing for real-time waste management and analysis, revolutionising the way solid waste is managed in smart cities [24,92–94]. The data from these bins can then be wirelessly transmitted to a central hub, facilitating prompt waste collection and preventing overflow [23,24,89,95–101]. Sensors installed in these systems also measure the weight and level of waste inside the bin, communicating this information to waste management systems [23,24,102]. This technological amalgamation, with blockchain offering traceability, immutability, transparency, and audit features in a decentralised, trusted, and secure manner, is proving instrumental in enhancing waste management in smart cities [103].

Long-range wide area network (LoRaWAN) technology is another key enabling technology for IoT architectures. This technology can support different types of services under the smart waste management system, including smart bins and drop-off containers that interact with users, and video surveillance units [104] equipped with machine learning capabilities for detecting nearby fires [104].

Beyond mere collection of waste, IoT has also been instrumental in optimising waste collection routes. By utilising IoT-based devices and data analytics, optimal paths for waste collection can be determined, thereby minimising the total transportation cost and maximising efficiency [89,105].

Certain models even seek to maximise value recovery from waste, thereby not only optimising waste collection but also contributing to recycling efforts and the movement towards a more sustainable and circular economy [3,105].

Another prominent technological approach to waste management in smart cities involves machine learning. This can be seen in machine learning-based household waste management systems, which utilise techniques such as K-nearest neighbours (KNN) to generate alert messages based on different sensor values [106]. Similarly, innovative techniques like mobile edge computing and deep learning have been employed to automate street garbage information collection, using high-resolution cameras and faster region-convolutional neural networks (Faster R-CNN) for identification and counting of rubbish [107]. Automated machine learning-based waste recycling frameworks (AML-WRFs) utilise machine learning for the classification and separation of waste in mixed recycling applications, thereby enhancing the efficiency of waste separation. Coupled with real-time data on waste generation behaviour obtained from IoT-powered devices installed in waste containers, such approaches can significantly enhance waste management productivity in smart cities [108].

Machine learning techniques have also been applied to predict solid waste generation. Through a developed ensemble learning technique, authorities can accurately predict the weekly waste generation of households within urban cities. This assists in efficient planning of waste management processes, including collection, sorting, disposal, and recycling [106,109,110].

Big data analysis and geographic information systems [27] are being leveraged to optimise waste management in smart cities. Detailed mapping of waste generation and collection across the city, in conjunction with an analysis of the efficiency of collection routes, can illuminate areas of inefficiency and suggest potential improvements [111].

On the other hand, digital modelling and artificial neural network (ANN) applications have been employed to automatically sort and classify waste types according to recycling requirements. Such systems can enhance the efficiency and effectiveness of recycling in smart cities, thus accelerating progress towards a circular economy [112,113].

One significant challenge encountered by the waste management and recycling industry is the identification of waste materials prior to the separation process, which is often a costly endeavour. The emergence of smart waste management systems, such as recycle.io, aids in overcoming these challenges. This serverless IoT architecture can determine real-time types of source material violations prior to waste collection, thereby enabling identification and rectification of violations through awareness campaigns or issuance of fines [114].

Furthermore, geographical information system and remote sensing techniques can significantly enhance solid waste management in smart cities [115]. These approaches aid in the collection and transportation of waste from the generation stage to the dumping stage, reducing travel distances by more than half in some cases. Implementing optimal transfer station locations, considering factors like open land availability, access ease, and environmental requirements, also proves beneficial. The analysis of vegetation cover changes around dumping sites offers further insight into the environmental impact of waste management practices.

However, while the adoption of IoT and other modern technologies in waste management has shown immense promise, it is not without challenges. Identified barriers include operational costs, lack of standardisation and policy norms, privacy and security issues, and a general deficit in technical knowledge among policymakers [116]. Hence, the successful implementation of these technologies in waste management requires overcoming such adoption barriers, necessitating the development of standard policies and practices for the technology's usage. Future research directions could focus on the development of these policies, as well as the exploration of novel frameworks and business models for IoT-enabled waste management [30,116].

Modern technologies, particularly IoT, machine learning, mobile edge computing, blockchain technology, and LPWAN with LoRa, have brought about significant improvements in efficiency, cost-effectiveness, and environmental sustainability in waste management within smart cities. They have engendered more active participation and cooperation among stakeholders, including waste generators, collectors, city administration, and other industry players, thus signposting a more sustainable and eco-friendly future. While these technologies have shown significant promise in enhancing efficiency and reducing costs, the full potential of these innovations remains largely untapped, offering extensive opportunities for further research and innovation [66].

4.2. Implications of Waste for Sustainability, Urban Living, and the Environment

The critical intersection of sustainability, energy efficiency, and quality of life within the scope of smart city living is substantially influenced by the current approach to waste management, which remains a pivotal aspect of efficient urban functioning [30]. Smart cities offer promising opportunities to address environmental issues and amend deficiencies in existing waste management practices. Central to this effort is the development of an integrated waste management framework. This includes elements such as lifecycle data collection infrastructure, innovative business models that rely on this data to prevent waste generation, and intelligent, sensor-based facilities for efficient waste separation and collection [30]. Such a framework emphasises the link between waste management and the entire product lifecycle, ultimately promoting waste reduction and enhanced recovery.

The advent of industry 4.0 technologies has introduced new possibilities for waste management within smart cities. Simultaneously, the concept of a circular economy encourages the view of waste as a resource which, when integrated with technological advancements, cultivates a culture of reusability and recycling [117]. This approach aligns with the principles of a circular economy and assists in minimising waste production and maximising waste recovery [118]. Systems such as the automatic machine learning-based waste recycling framework (AMLWRF) and artificial neural network (ANN)-based systems enhance waste classification and separation for recycling, signifying the potential impact of machine learning on efficient waste management [108,112].

Special waste also has an important place in waste management. Electronic waste (e-waste) presents a distinct challenge within the waste management landscape due to the hazardous consequences of landfill disposal. Smart collection systems for household e-waste, employing level measurement sensors, could improve the efficiency of e-waste collection, thus enhancing urban sustainability [119,120]. Furthermore, certain waste types, like hazardous waste and used vehicle tyres, require special attention. Utilising ICT and IoT to manage these waste types can considerably mitigate their negative environmental and social impacts [121,122]. Similarly, recycling methods for car tyres should be prioritised and strengthened in the context of smart cities.

Waste management in smart cities extends beyond mere disposal. It encompasses conservation, recycling, and utilisation. For example, the production of geopolymer concrete [123] from waste materials like fly ash (FA) offers dual benefits: recycling waste and reducing raw material extraction, leading to reduced greenhouse gas emissions and increased energy efficiency [124]. Such strategies can significantly impact urban quality of life.

Digitising waste management systems can diminish the consumption of virgin materials and substantially reduce greenhouse gas emissions. These advantages highlight the transformative potential of digitalisation in moving towards a circular economy [125]. Future research should explore new technologies, business models, and policies to overcome challenges and realise the full potential of smart waste management [4].

Simultaneously, illegal dumping is a common issue within urban areas. Cognitive computing solutions are suggested to identify and alert authorities to any illegal rubbish dumping within the city. A potential solution could involve the use of cameras installed for traffic monitoring and surveillance to analyse pictures and videos and trigger an alarm to the municipality if necessary [126].

Energy recovery from waste is another avenue for sustainability and the transition towards a circular economy. Waste-to-energy (WTE) conversions are vital in waste disposal and can lead to both economic and environmental benefits. They offer a dual advantage: generating renewable energy and reducing landfill needs, thereby ensuring sustainable waste management [127–129]. When paired with machine learning, this technique can predict municipal solid waste quantities, enabling effective energy management [129].

However, despite these technological advancements, challenges persist. Key issues include the lack of adequate infrastructure, limited public participation and environmental awareness, technological gaps, and insufficient coordination among institutions [130]. The importance of community engagement in waste management is emphasised by Saeidi et al. [121], suggesting that simple, resource-friendly tools aimed at promoting household waste collection can have substantial potential, especially in the absence of a top-down city-level waste management policy. Frameworks like Living Labs and AI-driven systems contribute to successful project execution, enhancing efficiency and health protection [131,132]. It is also important to implement and promote the concept of zero waste [133,134] and to explore new ways to prevent excessive waste generation.

The escalating generation of waste and its management pose serious challenges to sustainability, especially in urban areas. By utilising emerging technologies and inventive models, smart cities can transform these challenges into opportunities for boosting energy efficiency and citizens' quality of life [135]. The potential of smart cities in waste management marks a crucial step towards a healthier, more sustainable urban future. This represents a paradigm shift from traditional methods, accentuating the essential role of technology in contemporary urban planning and public health strategy. Investment in smart waste management systems is supported by research and public agreement [136], underscoring this emerging field's importance within the broader framework of urban development and human well-being.

4.3. Transportation in Smart Waste Management System

In the drive towards developing sustainable smart cities, a vital element to consider is the system of waste management, particularly the transportation aspect of this process. Waste management in the modern era demands intricate interplay between waste collection, transportation, and sustainable urban planning [116,137,138]. The role of transportation in waste management within smart cities is entering a transformative phase, benefiting significantly from the integration of innovative technologies like the IoT, ITS, and AI.

The application of IoT in smart cities has been advocated as a potent solution to augment waste management systems, including waste transportation [116,137,139,140]. IoT's ability to provide real-time data about waste levels in containers helps in optimising collection routes and schedules, thereby enhancing efficiency [141,142]. This technology can also assist in curbing waste collection costs, conserving energy, and minimising environmental impacts associated with waste transportation.

Intelligent transportation systems, coupled with internet of things technologies, can revolutionise waste collection services within smart cities [91]. The incorporation of surveillance systems, RFIDs, sensors, cameras, and actuators into ITS significantly refines waste collection practices [88,143–145]. This combination facilitates high-quality services for citizens, enabling dynamic routing models driven by sensor data, and prioritising waste collection in areas where immediate collection is vital due to health or environmental risks.

Utilising IoT and vehicle routing problem (VRP) concepts fosters a more efficient waste management system [17,95,146,147]. Real-time monitoring of waste bin fill levels through IoT devices leads to more effective collection routes. Moreover, easy access to information on public waste bins via web or mobile applications for an informed citizenry substantially contributes to optimised waste management [148].

Long-range wide area network technologies enable smart waste management solutions, such as smart bins and drop-off containers equipped with sensors, to collect data regarding their status [104,149–152]. This integration aids in designing dynamic waste collection routes, decreasing operational costs, and curtailing environmental pollution.

Moreover, blending IoT technologies with GIS can revolutionise traditional methods, primarily through constant real-time monitoring of waste levels and the development of optimal routes for waste collection [115,148,153]. This integration considerably reduces travel distance and costs, promoting energy efficiency and emission reduction [88]. Additionally, smart city waste collection targets can be optimised using algorithms for optimal path planning, thereby minimising environmental and socioeconomic impacts [137].

A review of existing IoT-enabled solutions in smart city waste management reveals strengths and weaknesses, such as sensing accuracy, security, and range capabilities [154]. Future improvements could incorporate a novel smart city management system (SCMS) that blends IoT devices, ITS, and blockchain technology, enhancing both security and efficiency [90].

The integration of these technologies into city waste management systems is not merely vital but crucial in the global quest for sustainability and the creation of smart cities. The combination of sensor technologies, intelligent routing, and alerting systems for illegal dumping is paving the way for the sustainable deployment of these new technologies in real infrastructures. As nations grapple with unsustainable development and the increasing volume of waste generated, the importance of optimising waste collection planning in smart cities cannot be overstated. The transformation in waste management transportation underscores the essential role of technology in realising the potential of smart cities and emphasises the continuing need for innovative solutions.

The analyses undertaken have facilitated the identification of potential directions for future research:

- Technological advancement—industry 4.0, IoT, ITS, machine learning, and other technologies offer unprecedented opportunities for smart waste management. These technologies are fostering efficient waste separation, collection, transportation, and recycling, transforming waste into reusable resources. Further exploration is needed of how different technologies can be better integrated to create a unified waste management system. Research into cognitive computing solutions to address illegal dumping, energy recovery from waste, and predictive analytics for waste generation and energy management should be conducted.
- Special waste challenges—e-waste, and specific waste types like hazardous waste and used vehicle tyres, present unique challenges. Utilising emerging technologies to manage these waste types can considerably mitigate their environmental and social impacts, necessitating focused attention and strengthening recycling methods. Research should focus on creating more efficient collection and recycling systems for this specialised waste.
- Digitisation and circular economy—the digitalisation of waste management systems is vital for reducing the consumption of virgin materials and greenhouse gas emissions. Investigations into the transformative potential of digitalisation in advancing towards a circular economy should include the application of machine learning, IoT, and other technologies.
- Energy recovery and sustainable solutions—research should continue on waste-to-energy conversions, energy recovery from waste, and innovative solutions like geopolymer concrete from waste materials, as they signify a major impact on urban sustainability and energy efficiency.
- Transportation in waste management—the intricate interplay between waste collection, transportation, and sustainable urban planning is entering a transformative phase. Technologies like IoT, VRP, LoRaWAN, GIS, and algorithms for optimal path planning are revolutionising waste transportation, optimising collection routes, and minimising environmental impacts. Exploration of the integration of technologies like IoT, ITS, and blockchain to create more efficient, secure, and sustainable waste management transportation systems is needed.
- Community engagement and environmental awareness—despite promising advancements, challenges remain, including public participation, environmental awareness, technological gaps, and institutional coordination. Community engagement, simple tools, and frameworks like Living Labs and AI-driven systems can contribute to success. Investigations into mechanisms to enhance community participation and environmental awareness are necessary. Strategies that promote household waste collection and simple, resource-friendly tools may offer substantial potential.
- Policy development and standardisation—future research should focus on creating universal standards and policy norms to facilitate the smooth implementation and integration of IoT-enabled waste management systems. Research must also consider the regulatory and policy landscape to ensure alignment with technological advancements and to overcome institutional barriers.
- Security and privacy considerations—future improvements in IoT-enabled solutions should incorporate more robust security measures to protect data and the integrity of the waste management system. Research could delve into creating robust security measures to prevent any potential breaches in the increasingly interconnected waste management systems.

- Novel frameworks and business models—new frameworks and business models for waste management in smart cities can be explored, harnessing the power of existing and emerging technologies for a comprehensive, efficient, and sustainable waste management system.
- Waste prevention—as the global waste dilemma intensifies, it is vital that we explore new avenues of research within the realms of waste prevention and the 'zero waste' paradigm. While current methodologies are significant, they may fall short in addressing the complexities presented by rapidly changing consumer behaviours. In tandem with this, there is a growing need to delve into effective strategies for educating the public, ensuring a comprehensive understanding and proactive involvement in waste reduction initiatives.
- Economic and environmental impact assessment—comprehensive analyses of the economic feasibility and environmental impacts of technologies are necessary to evaluate the actual benefits and identify areas for improvement. Further studies are needed to understand the long-term environmental impacts of various waste management strategies, including waste-to-energy conversions and recycling practices.
- Global implications—the role of waste management in smart cities is pivotal not only within the urban landscape but also in the broader context of global sustainability. The insights drawn from this study offer a comprehensive perspective that can be adopted and adapted by various urban centres worldwide, aligning with the broader goals of sustainable development.

5. Conclusions

The study has mostly focused on identifying the current and future directions of research relating to waste management issues in smart cities. The transformation of waste management in smart cities entails a holistic approach that fuses technological advancements with community engagement, sustainability, and resilience [104,125,149,155]. The interplay of IoT devices, innovative methodologies, and human-centred strategies promises a pathway towards smarter and more sustainable urban living, reflecting the essence of socioeconomic development and citizen-centric governance. Continuous research is needed to address current challenges and build on the strengths of existing systems, ensuring the sustainability of our cities in an increasingly intricate world.

The application of modern technologies, notably the internet of things, machine learning, mobile edge computing, blockchain technology, and LoRaWAN, has become instrumental in revolutionising waste management in smart cities. These technologies enable a comprehensive approach to waste management, allowing for innovative strategies such as real-time monitoring, route optimisation, automated sorting and classification, and the effective prediction of waste generation trends. IoT technologies have been pivotal in creating a data-centric waste management system, offering actionable insights for efficient collection and disposal. Machine learning algorithms, coupled with high-resolution image processing, have facilitated the automation of waste identification and sorting, further promoting recycling efforts and a move towards a circular economy. Simultaneously, the application of geographic information systems and big data analytics has resulted in more precise mapping and tracking of waste generation, identifying inefficiencies and potential areas for improvement. The incorporation of blockchain has also contributed to increased transparency, traceability, and security in waste management processes. However, these innovations are not without challenges. Operational costs, a lack of standardisation and policy norms, privacy concerns, and technical knowledge deficits are among the barriers hindering the full utilisation of these technologies.

The multifaceted nature of waste management in smart cities demands a nuanced, technologically-driven approach that respects both environmental considerations and the quality of urban life. The current technological advancements and innovative strategies present an optimistic pathway towards a more efficient, cost-effective, and sustainable urban existence. Investment in research, technology, education, and policy development will be critical to fully realise these benefits, making waste management in smart cities an essential and compelling area for ongoing exploration by scientists, policymakers, and industry players alike. By focusing on the identified future research directions, a more holistic and responsive waste management system can be cultivated, aligning with the broader goals of sustainable development within smart cities.

The research conducted also has its limitations. The analysis of the systematic literature review was confined to articles indexed in the Scopus and Web of Science databases. While these are reputable sources, the exclusion of other relevant databases and grey literature may have overlooked significant research contributions, thereby limiting the comprehensiveness of the review. The research query was restricted to specific keywords such as 'smart city', along with 'waste', 'garbage', 'trash', or 'rubbish'. The choice of these keywords might exclude studies that utilise different terminology or explore related aspects of waste management in urban environments, thus potentially missing pertinent insights. The study, focusing on smart cities, primarily concentrated on technological advancements and the integration of modern methods, such as IoT, machine learning, and blockchain, in waste management within smart cities. It may not have extensively explored traditional and localised methods, potentially overlooking context-specific challenges and solutions.

Author Contributions: Conceptualization, D.S., A.d.l.T.G. and A.R. (Agnieszka Rzepka); methodology, D.S., A.d.l.T.G. and A.R. (Agnieszka Rzepka); software, D.S.; formal analysis, D.S.; investigation, D.S., A.d.l.T.G., F.J.N., A.R. (Agnieszka Rzepka) and A.R. (Angelika Remiszewska); resources, D.S., A.d.l.T.G., F.J.N., A.R. (Agnieszka Rzepka) and A.R. (Angelika Remiszewska); data curation, D.S.; writing—original draft preparation, D.S., A.d.l.T.G., F.J.N., A.R. (Agnieszka Rzepka) and A.R. (Angelika Remiszewska); writing—review and editing, D.S.; visualization, D.S. and A.R. (Angelika Remiszewska); supervision, D.S., funding acquisition and editing, D.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded under the International Academic Partnership Programme no. BPI/PST/2021/1/00011/U/00001 with the Polish National Agency for Academic Exchange.

Data Availability Statement: The data presented in this study are available on database Scopus and Web of Science.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Silva, B.N.; Khan, M.; Han, K. Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities. *Sustain. Cities Soc.* **2018**, *38*, 697–713. [CrossRef]
2. Kim, J. Smart city trends: A focus on 5 countries and 15 companies. *Cities* **2022**, *123*, 19. [CrossRef]
3. Shah, P.J.; Anagnostopoulos, T.; Zaslaysky, A.; Behdad, S. A stochastic optimization framework for planning of waste collection and value recovery operations in smart and sustainable cities. *Waste Manag.* **2018**, *78*, 104–114. [CrossRef] [PubMed]
4. Marques, P.; Manfroi, D.; Deitos, E.; Cegoni, J.; Castilhos, R.; Rochol, J.; Pignaton, E.; Kunst, R. An IoT-based smart cities infrastructure architecture applied to a waste management scenario. *Ad Hoc Netw.* **2019**, *87*, 200–208. [CrossRef]
5. Valenzuela-Levi, N. Factors influencing municipal recycling in the Global South: The case of Chile. *Resour. Conserv. Recycl.* **2019**, *150*, 104441. [CrossRef]
6. Baltac, V. Smart Cities-A View of Societal Aspects. *Smart Cities* **2019**, *2*, 538–548. [CrossRef]
7. Espinoza-Arias, P.; Poveda-Villalon, M.; Garcia-Castro, R.; Corcho, O. Ontological Representation of Smart City Data: From Devices to Cities. *Appl. Sci.* **2019**, *9*, 32. [CrossRef]
8. Caragliu, A.; Del Bo, C.; Nijkamp, P. Smart Cities in Europe. *J. Urban Technol.* **2011**, *18*, 65–82. [CrossRef]
9. Whaiduzzaman, M.; Barros, A.; Chanda, M.; Barman, S.; Sultana, T.; Rahman, M.S.; Roy, S.; Fidge, C. A Review of Emerging Technologies for IoT-Based Smart Cities. *Sensors* **2022**, *22*, 9271. [CrossRef]
10. Khan, F.I.; Gawade, A. Dynamic Routing for Waste Management using IoT for Cost-Efficient Service. In Proceedings of the International Conference on Current Trends in Computer, Electrical, Electronics and Communication, CTCEEC 2017, Mysore, India, 8–9 September 2018; pp. 222–230.
11. Zahoor, S.; Mir, R.N. An IoT enabled Smart City: Assessing the Applications, Resource Constraints, Existing Solutions and Research Directions. *Int. J. Comput. Digit. Syst.* **2022**, *12*, 269–283. [CrossRef]
12. Zhu, Y.J.; Jia, G.Y.; Han, G.J.; Zhou, Z.R.; Guizani, M. An NB-IoT-based smart trash can system for improved health in smart cities. In Proceedings of the 2019 15th International Wireless Communications and Mobile Computing Conference, IWCMC, Tangier, Morocco, 24–28 June 2019; pp. 763–768.

13. Zhmud, V.; Liapidevskiy, A.; Roth, H.; Nosek, J. The Concept of a Smart Home: Security, Additional Features and Augmented Reality. In Proceedings of the 2019 International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2019, Vladivostok, Russia, 1–4 October 2019.
14. Yuan, H.; Yin, Z.; Zhao, C.; Yang, Z.; Gao, S.; Zhao, S.; Xu, L.; Tan, T.; Fang, Y. Evaluation of Smart Environmental Protection Systems and Novel UV-Oriented Solution for Integration, Resilience, Inclusiveness and Sustainability. In Proceedings of the 5th International Conference on Universal Village, UV 2020, Boston, MA, USA, 24–27 October 2020.
15. Wlodarczak, P. Smart Cities—Enabling Technologies for Future Living. In *City Networks: Collaboration and Planning for Health and Sustainability, Karakitsiou, A., Migdalas, A., Rassia, S.T., Pardalos, P.M., Eds.*; Springer: Cham, Switzerland, 2017; Volume 128, pp. 1–16.
16. Vaidya, G.; Bindra, P.; Kshirsagar, M.; Tamane, S.C. Privacy and security technologies for smart city development. In *Studies in Systems, Decision and Control*; Springer Science and Business Media Deutschland GmbH: Berlin/Heidelberg, Germany, 2021; Volume 308, pp. 3–23.
17. Ghahramani, M.; Zhou, M.C.; Molter, A.; Pilla, F. IoT-Based Route Recommendation for an Intelligent Waste Management System. *IEEE Internet Things J.* **2021**, *9*, 11883–11892. [CrossRef]
18. The 2022 World Population Data Sheet. Available online: https://2022-wpds.prb.org/ (accessed on 20 July 2023).
19. Plastic Waste and Recycling in the EU: Facts and Figures. Available online: https://www.europarl.europa.eu/news/en/headlines/society/20181212STO21610/plastic-waste-and-recycling-in-the-eu-facts-and-figures (accessed on 20 July 2023).
20. Norouzi, M.; Chafer, M.; Cabeza, L.F.; Jimenez, L.; Boer, D. Circular economy in the building and construction sector: A scientific evolution analysis. *J. Build. Eng.* **2021**, *44*, 102704. [CrossRef]
21. Abdullah, N.; Alwesabi, O.A.; Abdullah, R. IoT-based smart waste management system in a smart city. In Proceedings of the 3rd International Conference of Reliable Information and Communication Technology, Advances in Intelligent Systems and Computing, Kuala Lumpur, Malaysia, 22–23 July 2018; pp. 364–371.
22. Ahmad, S.; Imran; Iqbal, N.; Jamil, F.; Kim, D. Optimal Policy-Making for Municipal Waste Management Based on Predictive Model Optimization. *IEEE Access* **2020**, *8*, 218458–218469. [CrossRef]
23. Folianto, F.; Low, Y.S.; Yeow, W.L. Smartbin: Smart waste management system. In Proceedings of the 2015 IEEE 10th International Conference on Intelligent Sensors, Sensor Networks and Information Processing, ISSNIP 2015, Singapore, 7–9 April 2015.
24. Wijaya, A.S.; Zainuddin, Z.; Niswar, M. Design a smart waste bin for smart waste management. In Proceedings of the 2017 5th International Conference on Instrumentation, Control, and Automation, ICA 2017, Yogyakarta, Indonesia, 9–11 August 2017; pp. 62–66.
25. Mingaleva, Z.; Vukovic, N.; Volkova, I.; Salimova, T. Waste management in green and smart cities: A case study of Russia. *Sustainability* **2020**, *12*, 94. [CrossRef]
26. Anagnostopoulos, T.; Zaslavsky, A.; Kolomvatsos, K.; Medvedev, A.; Amirian, P.; Morley, J.; Hadjieftymiades, S. Challenges and Opportunities of Waste Management in IoT-Enabled Smart Cities: A Survey. *IEEE Trans. Sust. Comp.* **2017**, *2*, 275–289. [CrossRef]
27. Aladayleh, K.J.; Qudah, S.M.A.A.; Bargues, J.L.F.; Gisbert, P.F. Global trends of the research on COVID-19 risks effect in sustainable facility management fields: A bibliometric analysis. *Eng. Manag. Prod. Serv.* **2023**, *15*, 12–28. [CrossRef]
28. Hannan, M.A.; Begum, R.A.; Al-Shetwi, A.Q.; Ker, P.J.; Al Mamun, M.A.; Hussain, A.; Basri, H.; Mahlia, T.M.I. Waste collection route optimisation model for linking cost saving and emission reduction to achieve sustainable development goals. *Sustain. Cities Soc.* **2020**, *62*, 102393. [CrossRef]
29. Anagnostopoulos, T.; Zaslavsky, A.; Sosunova, I.; Fedchenkov, P.; Medvedev, A.; Ntalianis, K.; Skourlas, C.; Rybin, A.; Khoruznikov, S. A stochastic multi-agent system for Internet of Things-enabled waste management in smart cities. *Waste Manag. Res.* **2018**, *36*, 1113–1121. [CrossRef]
30. Esmaeilian, B.; Wang, B.; Lewis, K.; Duarte, F.; Ratti, C.; Behdad, S. The future of waste management in smart and sustainable cities: A review and concept paper. *Waste Manag.* **2018**, *81*, 177–195. [CrossRef]
31. Vitorino de Souza Melaré, A.; Montenegro González, S.; Faceli, K.; Casadei, V. Technologies and decision support systems to aid solid-waste management: A systematic review. *Waste Manag.* **2017**, *59*, 584. [CrossRef]
32. Franchina, L.; Calabrese, A.; Inzerilli, G.; Scatto, E.; Brutti, G.; de los Ángeles Bonanni, M.V. Thinking green: The role of smart technologies in transforming cities' waste and supply Chain's flow. *Clean. Eng. Technol.* **2021**, *2*, 100077. [CrossRef]
33. Chauhan, R.; Shighra, S.; Madkhali, H.; Nguyen, L.; Prasad, M. Efficient Future Waste Management: A Learning-Based Approach with Deep Neural Networks for Smart System (LADS). *Appl. Sci.* **2023**, *13*, 4140. [CrossRef]
34. Ramadass, R.; Sathyanarayana, N.; Fathima, Y. Improving citizen lifestyle in green smart city. In *Green Blockchain Technology for Sustainable Smart Cities*; Elsevier: Amsterdam, The Netherlands, 2023; pp. 29–63.
35. Yu, Z.; Waqas, M.; Tabish, M.; Tanveer, M.; Ul Haq, I.; Khan, S.A.R. Sustainable supply chain management and green technologies: A bibliometric review of literature. *Environ. Sci. Pollut. Res.* **2022**, *29*, 58454–58470. [CrossRef] [PubMed]
36. Shahab, S.; Anjum, M.; Umar, M.S. Deep Learning Applications in Solid Waste Management: A Deep Literature Review. *Intl. J. Adv. Comput. Sci. Appl.* **2022**, *13*, 381–395. [CrossRef]
37. Maphosa, V.; Maphosa, M. E-waste management in Sub-Saharan Africa: A systematic literature review. *Cogent Bus. Manag.* **2020**, *7*, 17. [CrossRef]
38. Andrade, R.O.; Yoo, S.G. A comprehensive study of the use of LoRa in the development of smart cities. *Appl. Sci.* **2019**, *9*, 4753. [CrossRef]

39. Soesanto, H.; Maarif, M.S.; Anwar, S.; Yurianto, Y. Current Trend, Future Direction, and Enablers of e-Waste Management: Bibliometric Analysis and Literature Review. *Pol. J. Environ. Stud.* **2023**, *32*, 3455–3465. [CrossRef]
40. Caniato, M.; Tudor, T.; Vaccari, M. International governance structures for health-care waste management: A systematic review of scientific literature. *J. Environ. Manag.* **2015**, *153*, 93–107. [CrossRef]
41. Mangindaan, D.; Adib, A.; Febrianta, H.; Hutabarat, D.J.C. Systematic Literature Review and Bibliometric Study of Waste Management in Indonesia in the COVID-19 Pandemic Era. *Sustainability* **2022**, *14*, 2556. [CrossRef]
42. Boloy, R.A.M.; Reis, A.D.; Rios, E.M.; Martins, J.D.S.; Soares, L.O.; Machado, V.A.D.; de Moraes, D.R. Waste-to-Energy Technologies Towards Circular Economy: A Systematic Literature Review and Bibliometric Analysis. *Water Air Soil Pollut.* **2021**, *232*, 25. [CrossRef]
43. Valenzuela-Fernandez, L.; Escobar-Farfan, M. Zero-Waste Management and Sustainable Consumption: A Comprehensive Bibliometric Mapping Analysis. *Sustainability* **2022**, *14*, 16269. [CrossRef]
44. Ndou, V.; Rampedi, I.T. Bibliometric Analysis of Municipal Solid Waste Management Research: Global and South African Trends. *Sustainability* **2022**, *14*, 10229. [CrossRef]
45. Tsai, F.M.; Bui, T.D.; Tseng, M.L.; Lim, M.K.; Hu, J.Y. Municipal solid waste management in a circular economy: A data-driven bibliometric analysis. *J. Clean. Prod.* **2020**, *275*, 124132. [CrossRef]
46. Mayes-Ramirez, M.M.; Galvez-Sanchez, F.J.; Ramos-Ridao, A.F.; Molina-Moreno, V. Urban Waste: Visualizing the Academic Literature through Bibliometric Analysis and Systematic Review. *Sustainability* **2023**, *15*, 1846. [CrossRef]
47. Ma, J.; Hipel, K.W. Exploring social dimensions of municipal solid waste management around the globe—A systematic literature review. *Waste Manag.* **2016**, *56*, 3–12. [CrossRef]
48. Dias, J.L.; Sott, M.K.; Ferrao, C.C.; Furtado, J.C.; Moraes, J.A.R. Data mining and knowledge discovery in databases for urban solid waste management: A scientific literature review. *Waste Manag. Res.* **2021**, *39*, 1331–1340. [CrossRef]
49. Costa, A.M.; Mancini, S.D.; Paes, M.X.; Ugaya, C.M.L.; de Medeiros, G.A.; de Souza, R.G. Social evaluation of municipal solid waste management systems from a life cycle perspective: A systematic literature review. *Int. J. Life Cycle Assess.* **2022**, *27*, 719–739. [CrossRef]
50. Karunasena, G.; Gajanayake, A.; Wijeratne, W.; Milne, N.; Udawatta, N.; Perera, S.; Crimston, A.; Aliviano, P. Liquid waste management in the construction sector: A systematic literature review. *Int. J. Constr. Manag.* **2023**, *11*, 1–11. [CrossRef]
51. Aziminezhad, M.; Taherkhani, R. BIM for deconstruction: A review and bibliometric analysis. *J. Build. Eng.* **2023**, *73*, 17. [CrossRef]
52. Elshaboury, N.; Al-Sakkaf, A.; Abdelkader, E.M.; Alfalah, G. Construction and Demolition Waste Management Research: A Science Mapping Analysis. *Int. J. Environ. Res. Public Health* **2022**, *19*, 4496. [CrossRef]
53. Jin, R.Y.; Yuan, H.P.; Chen, Q. Science mapping approach to assisting the review of construction and demolition waste management research published between 2009 and 2018. *Resour. Conserv. Recycl.* **2019**, *140*, 175–188. [CrossRef]
54. Alnajem, M.; Mostafa, M.M.; ElMelegy, A.R. Mapping the first decade of circular economy research: A bibliometric network analysis. *J. Ind. Prod. Eng.* **2021**, *38*, 29–50. [CrossRef]
55. Negrete-Cardoso, M.; Rosano-Ortega, G.; Alvarez-Aros, E.L.; Tavera-Cortes, M.E.; Vega-Lebrun, C.A.; Sanchez-Ruiz, F.J. Circular economy strategy and waste management: A bibliometric analysis in its contribution to sustainable development, toward a post-COVID-19 era. *Environ. Sci. Pollut. Res.* **2022**, *29*, 61729–61746. [CrossRef]
56. Martinho, V.D.; Mourao, P.R. Circular Economy and Economic Development in the European Union: A Review and Bibliometric Analysis. *Sustainability* **2020**, *12*, 7767. [CrossRef]
57. Onungwe, I.; Hunt, D.V.L.; Jefferson, I. Transition and Implementation of Circular Economy in Municipal Solid Waste Management System in Nigeria: A Systematic Review of the Literature. *Sustainability* **2023**, *15*, 12602. [CrossRef]
58. Ghoushchi, S.J.; Dorosti, S.; Moghaddam, S.H. Qualitative and quantitative analysis of waste management literature from 2000 to 2015. *Int. J. Environ. Waste Manag.* **2020**, *26*, 471–486. [CrossRef]
59. Yalcintas, D.; Oguz, S.; Ozelturkay, E.Y.; Gulmez, M. Bibliometric Analysis of Studies on Sustainable Waste Management. *Sustainability* **2023**, *15*, 1414. [CrossRef]
60. Rafiq, M.; Dastane, O.; Mushtaq, R. Waste reduction as ethical behaviour: A bibliometric analysis and development of future agenda. *J. Glob. Responsib.* **2023**, *14*, 360–379. [CrossRef]
61. Concari, A.; Kok, G.; Martens, P. A Systematic Literature Review of Concepts and Factors Related to Pro-Environmental Consumer Behaviour in Relation to Waste Management Through an Interdisciplinary Approach. *Sustainability* **2020**, *12*, 4452. [CrossRef]
62. Soegoto, E.S.; Luckyardi, S.; Rafdhi, A.A.; Oktafiani, D. Computational Analysis of Waste Management and Entrepreneur using VosViewer application. *Moroc. J. Chem.* **2022**, *10*, 542–552. [CrossRef]
63. Suriyankietkaew, S.; Petison, P. A Retrospective and Foresight: Bibliometric Review of International Research on Strategic Management for Sustainability, 1991–2019. *Sustainability* **2020**, *12*, 91. [CrossRef]
64. Zacho, K.O.; Mosgaard, M.A. Understanding the role of waste prevention in local waste management: A literature review. *Waste Manag. Res.* **2016**, *34*, 980–994. [CrossRef] [PubMed]
65. Sosunova, I.; Porras, J. IoT-Enabled Smart Waste Management Systems for Smart Cities: A Systematic Review. *IEEE Access* **2022**, *10*, 73326–73363. [CrossRef]
66. Pardini, K.; Rodrigues, J.J.P.C.; Kozlov, S.A.; Kumar, N.; Furtado, V. IoT-Based Solid Waste Management Solutions: A Survey. *J. Sens. Actuator Netw.* **2019**, *8*, 5. [CrossRef]

67. Tiwari, P.; Ilavarasan, P.V.; Punia, S. Content analysis of literature on big data in smart cities. *Benchmarking-Int. J.* **2021**, *28*, 1837–1857. [CrossRef]
68. Nimmagadda, S.M.; Harish, K.S. Review paper on technology adoption and sustainability in India towards smart cities. *Multimedia Tools Appl.* **2022**, *81*, 27217–27245. [CrossRef]
69. Salman, M.Y.; Hasar, H. Review on environmental aspects in smart city concept: Water, waste, air pollution and transportation smart applications using IoT techniques. *Sustain. Cities Soc.* **2023**, *94*, 104567. [CrossRef]
70. Bornmann, L.; Haunschild, R. Quality and impact considerations in bibliometrics: A reply to Ricker (in press). *Scientometrics* **2017**, *111*, 1857–1859. [CrossRef]
71. Szum, K. IoT-based smart cities: A bibliometric analysis and literature review. *Eng. Manag. Prod. Serv.* **2021**, *13*, 115–136. [CrossRef]
72. Winkowska, J.; Szpilko, D.; Pejić, S. Smart city concept in the light of the literature review. *Eng. Manag. Prod. Serv.* **2019**, *11*, 70–86. [CrossRef]
73. Gudanowska, A.E. A Map of Current Research Trends within Technology Management in the Light of Selected Literature. *Manag. Prod. Eng. Rev.* **2017**, *8*, 78–88. [CrossRef]
74. Halicka, K. Main Concepts of Technology Analysis in the Light of the Literature on the Subject. In Proceedings of the 7th International Conference on Engineering, Project, and Production Management, Amman, Jordan, 20–22 September 2017; pp. 291–298.
75. Yarmak, V.; Rollnik-Sadowska, E. Research themes on the quality of public services exemplified by healthcare services—A bibliometric analysis. *Eng. Manag. Prod. Serv.* **2022**, *14*, 82–94. [CrossRef]
76. Siderska, J.; Jadaan, K.S. Cloud manufacturing: A service-oriented manufacturing paradigm. A review paper. *Eng. Manag. Prod. Serv.* **2018**, *10*, 22–31. [CrossRef]
77. Szpilko, D.; Ejdys, J. European Green Deal—research directions. A systematic literature review. *Ekon. I Srodowisko-Econ. Environ.* **2022**, *81*, 8–38. [CrossRef]
78. van Eck, N.J.; Waltman, L. VOSviewer Manual. Manual for VOSviewer Version 1.6.11 Software Documentation. 2019. Available online: https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.11.pdf (accessed on 1 August 2023).
79. Harrison, C.; Eckman, B.; Hamilton, R.; Hartswick, P.; Kalagnanam, J.; Paraszczak, J.; Williams, P. Foundations for Smarter Cities. *IBM J. Res. Dev.* **2010**, *54*, 1–16. [CrossRef]
80. Yao, H.; Wu, F.; Ke, J.; Tang, X.; Jia, Y.; Lu, S.; Gong, P.; Li, Z.; Ye, J.; Chuxing, D. Deep multi-view spatial-temporal network for taxi demand prediction. In Proceedings of the 32nd AAAI Conference on Artificial Intelligence, AAAI 2018, New Orleans, LA, USA, 2–7 February 2018; pp. 2588–2595.
81. Mehmood, Y.; Ahmad, F.; Yaqoob, I.; Adnane, A.; Imran, M.; Guizani, S. Internet-of-Things-Based Smart Cities: Recent Advances and Challenges. *IEEE Commun. Mag.* **2017**, *55*, 16–24. [CrossRef]
82. Ismagilova, E.; Hughes, L.; Dwivedi, Y.K.; Raman, K.R. Smart cities: Advances in research-An information systems perspective. *Int. J. Inf. Manag.* **2019**, *47*, 88–100. [CrossRef]
83. Higon, D.A.; Gholami, R.; Shirazi, F. ICT and environmental sustainability: A global perspective. *Telemat. Inform.* **2017**, *34*, 85–95. [CrossRef]
84. Harrison, C.; Donnelly, I.A. A theory of smart cities. In Proceedings of the 55th Annual Meeting of the International Society for the Systems Sciences 2011, Hull, UK, 17–22 July 2011; pp. 521–535.
85. Benevolo, C.; Dameri, R.P.; D'Auria, B. Smart mobility in smart city action taxonomy, ICT intensity and public benefits. In *Empowering Organizations*; Lecture Notes in Information Systems and Organisation; Springer: Berlin/Heidelberg, Germany, 2016; Volume 11, pp. 13–28.
86. Piro, G.; Cianci, I.; Grieco, L.A.; Boggia, G.; Camarda, P. Information centric services in Smart Cities. *J. Syst. Softw.* **2014**, *88*, 169–188. [CrossRef]
87. Nižetić, S.; Djilali, N.; Papadopoulos, A.; Rodrigues, J.J.P.C. Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management. *J. Clean. Prod.* **2019**, *231*, 565–591. [CrossRef]
88. Anagnostopoulos, T.; Kolomvatsos, K.; Anagnostopoulos, C.; Zaslavsky, A.; Hadjiefthymiades, S. Assessing dynamic models for high priority waste collection in smart cities. *J. Syst. Softw.* **2015**, *110*, 178–192. [CrossRef]
89. Aazam, M.; St-Hilaire, M.; Lung, C.H.; Lambadaris, I. Cloud-based smart waste management for smart cities. In Proceedings of the IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks, CAMAD, Toronto, ON, Canada, 23–25 October 2016; pp. 188–193.
90. Yuvaraj, N.; Praghash, K.; Raja, R.A.; Karthikeyan, T. An Investigation of Garbage Disposal Electric Vehicles (GDEVs) Integrated with Deep Neural Networking (DNN) and Intelligent Transportation System (ITS) in Smart City Management System (SCMS). *Wirel. Pers. Commun.* **2022**, *123*, 1733–1752. [CrossRef]
91. Medvedev, A.; Fedchenkov, P.; Zaslavsky, A.; Anagnostopoulos, T.; Khoruzhnikov, S. Waste management as an IoT-enabled service in smart cities. In Proceedings of the Internet of Things, Smart Spaces, and Next Generation Networks and Systems, Lecture Notes in Computer Science (Including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), St. Petersburg, Russia, 26–28 August 2015; pp. 104–115.

92. Kaur, M.; Aron, R. Fog computing and its role in development of Smart applications. In Proceedings of the 2018 IEEE Int Conf on Parallel & Distributed Processing with Applications, Ubiquitous Computing & Communications, Big Data & Cloud Computing, Social Computing & Networking, Sustainable Computing & Communications, Melbourne, Australia, 11–13 December 2018; pp. 1120–1127.
93. Chaudhari, S.S.; Bhole, V.Y. Solid Waste Collection as a Service using IoT-Solution for Smart Cities. In Proceedings of the 2018 International Conference on Smart City and Emerging Technology, ICSCET 2018, Mumbai, India, 5 January 2018.
94. Badve, M.; Chaudhari, A.; Davda, P.; Bagaria, V.; Kalbande, D. Garbage collection system using iot for smart city. In Proceedings of the 4th International Conference on IoT in Social, Mobile, Analytics and Cloud, ISMAC 2020, Palladam, India, 7–9 October 2020; pp. 138–143.
95. Salehi-Amiri, A.; Akbapour, N.; Hajiaghaei-Keshteli, M.; Gajpal, Y.; Jabbarzadeh, A. Designing an effective two-stage, sustainable, and IoT based waste management system. *Renew. Sustain. Energy Rev.* **2022**, *157*, 112031. [CrossRef]
96. Cerchecci, M.; Luti, F.; Mecocci, A.; Parrino, S.; Peruzzi, G.; Pozzebon, A. A low power IoT sensor node architecture for waste management within smart cities context. *Sensors* **2018**, *18*, 1282. [CrossRef]
97. Vishnu, S.; Jino Ramson, S.R.; Senith, S.; Anagnostopoulos, T.; Abu-Mahfouz, A.M.; Fan, X.; Srinivasan, S.; Kirubaraj, A.A. IoT-enabled solid waste management in smart cities. *Smart Cities* **2021**, *4*, 1004–1017. [CrossRef]
98. Ziouzios, D.; Dasygenis, M. A smart bin implementantion using LoRa. In Proceedings of the 2019 4th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference, SEEDA-CECNSM 2019, Piraeus, Greece, 20–22 September 2019.
99. Zha, Y.; Zhou, M.; Yang, J.; Yang, Y. A Design of Intelligent Garbage Bin System. *J. Phys. Conf. Ser.* **2021**, *1972*, 012056. [CrossRef]
100. Soni, G.; Kandasamy, S. Smart garbage bin systems—A comprehensive survey. In Proceedings of the Second International Conference on Intelligent Information Technologies, ICIIT 2017, Communications in Computer and Information Science, Chennai, India, 20–22 December 2018; pp. 194–206.
101. Siva Nageswara Rao, G.; Manojkumar, B.; Jaya Raj, R.; Sharma, A. IOT based garbage management system. *J. Adv. Res. Dyn. Control. Syst.* **2018**, *10*, 31–36.
102. Ramson, S.R.J.; Moni, D.J.; Vishnu, S.; Anagnostopoulos, T.; Kirubaraj, A.A.; Fan, X.Z. An IoT-based bin level monitoring system for solid waste management. *J. Mater. Cycles Waste Manag.* **2021**, *23*, 516–525. [CrossRef]
103. Ahmad, R.W.; Salah, K.; Jayaraman, R.; Yaqoob, I.; Omar, M. Blockchain for Waste Management in Smart Cities: A Survey. *IEEE Access* **2021**, *9*, 131520–131541. [CrossRef]
104. Baldo, D.; Mecocci, A.; Parrino, S.; Peruzzi, G.; Pozzebon, A. A multi-layer lorawan infrastructure for smart waste management. *Sensors* **2021**, *21*, 2600. [CrossRef]
105. Akbarpour, N.; Salehi-Amiri, A.; Hajiaghaei-Keshteli, M.; Oliva, D. An innovative waste management system in a smart city under stochastic optimization using vehicle routing problem. *Soft Comput.* **2021**, *25*, 6707–6727. [CrossRef]
106. Dubey, S.; Singh, P.; Yadav, P.; Singh, K.K. Household Waste Management System Using IoT and Machine Learning. In Proceedings of the International Conference on Computational Intelligence and Data Science (ICCIDS 2019), Procedia Computer Science, Gurgaon, India, 6–7 September 2020; pp. 1950–1959.
107. Zhang, P.C.; Zhao, Q.; Gao, J.; Li, W.R.; Lu, J.M. Urban Street Cleanliness Assessment Using Mobile Edge Computing and Deep Learning. *IEEE Access* **2019**, *7*, 63550–63563. [CrossRef]
108. Chen, X. Machine learning approach for a circular economy with waste recycling in smart cities. *Energy Rep.* **2022**, *8*, 3127–3140. [CrossRef]
109. Namoun, A.; Hussein, B.R.; Tufail, A.; Alrehaili, A.; Syed, T.A.; Benrhouma, O. An Ensemble Learning Based Classification Approach for the Prediction of Household Solid Waste Generation. *Sensors* **2022**, *22*, 3506. [CrossRef]
110. Karatangi, S.; Agarwal, R.; Singh, K.K.; Izonin, I. Innovative Ideas to Build Smart Cities with the Help of Machine and Deep Learning and IoT. In *Machine Learning Approaches for Convergence of IoT and Blockchain*; Wiley: Hoboken, NJ, USA, 2021; pp. 205–231.
111. Shahrokni, H.; Van Der Heijde, B.; Lazarevic, D.; Brandt, N. Big Data GIS analytics towards efficient waste management in stockholm. In Proceedings of the ICT for Sustainability 2014, ICT4S 2014, Stockholm, Sweden, 24–27 August 2014; pp. 140–147.
112. Mohammed, M.A.; Abdulhasan, M.J.; Kumar, N.M.; Abdulkareem, K.H.; Mostafa, S.A.; Maashi, M.S.; Khalid, L.S.; Abdulaali, H.S.; Chopra, S.S. Automated waste-sorting and recycling classification using artificial neural network and features fusion: A digital-enabled circular economy vision for smart cities. *Multimedia Tools Appl.* **2022**, *28*, 1–16. [CrossRef] [PubMed]
113. Yang, Z.H.; Li, D. WasNet: A Neural Network-Based Garbage Collection Management System. *IEEE Access* **2020**, *8*, 103984–103993. [CrossRef]
114. Al-Masri, E.; Diabate, I.; Jain, R.; Lam, M.H.; Nathala, S.R. Recycle.io: An IoT-Enabled Framework for Urban Waste Management. In Proceedings of the Proceedings–2018 IEEE International Conference on Big Data, Big Data 2018, Seattle, WA, USA, 10–13 December 2018; pp. 5285–5287.
115. Lella, J.; Mandlab, V.R.; Zhuc, X. Solid waste collection/transport optimization and vegetation land cover estimation using Geographic Information System (GIS): A case study of a proposed smart-city. *Sustain. Cities Soc.* **2017**, *35*, 336–349. [CrossRef]
116. Sharma, M.; Joshi, S.; Kannan, D.; Govindan, K.; Singh, R.; Purohit, H.C. Internet of Things (IoT) adoption barriers of smart cities' waste management: An Indian context. *J. Clean. Prod.* **2020**, *270*, 122047. [CrossRef]
117. Aceleanu, M.I.; Serban, A.C.; Suciu, M.C.; Bitoiu, T.I. The management of municipal waste through circular economy in the context of smart cities development. *IEEE Access* **2019**, *7*, 133602–133614. [CrossRef]

118. Chauhan, A.; Jakhar, S.K.; Chauhan, C. The interplay of circular economy with industry 4.0 enabled smart city drivers of healthcare waste disposal. *J. Clean. Prod.* **2021**, *279*, 123854. [CrossRef]
119. Kang, K.D.; Kang, H.; Ilankoon, I.M.S.K.; Chong, C.Y. Electronic waste collection systems using Internet of Things (IoT): Household electronic waste management in Malaysia. *J. Clean. Prod.* **2020**, *252*, 119801. [CrossRef]
120. Doctor, G.; Dalal, E. Awareness and management of e-waste in Ahmedabad. In Proceedings of the 10th International Conference on Theory and Practice of Electronic Governance, ACM International Conference Proceeding Series, New Delhi, India, 7–9 March 2017; pp. 359–365.
121. Saeidi, A.; Aghamohamadi-Bosjin, S.; Rabbani, M. An integrated model for management of hazardous waste in a smart city with a sustainable approach. *Environ. Dev. Sustain.* **2021**, *23*, 10093–10118. [CrossRef]
122. Khudyakova, T.; Shmidt, A.; Shmidt, S. Sustainable development of smart cities in the context of the implementation of the tire recycling program. *Entrep. Sustain. Issues* **2020**, *8*, 698–715. [CrossRef] [PubMed]
123. Monteiro, M.S.; De Caldas Filho, F.L.; e Souza, P.D.O.M.; Costa, V.S.; Da Luz, G.P.C.P.; Carvalho, L.F.D.O.; De Sousa, R.T. Solid waste management and monitoring system for smart cities: Development of a low-cost sustainable IoT architecture using GPRS/GSM. In Proceedings of the 2021 Workshop on Communication Networks and Power Systems, WCNPS 2021, Brasilia, Brazil, 18–19 November 2021.
124. Khan, U.T.; Zia, M.F. Smart city technologies, key components, and its aspects. In Proceedings of the 4th International Conference on Innovative Computing, ICIC 2021, Lahore, Pakistan, 9–10 November 2021; pp. 433–442.
125. Kurniawan, T.A.; Maiurova, A.; Kustikova, M.; Bykovskaia, E.; Othman, M.H.D.; Goh, H.H. Accelerating sustainability transition in St. Petersburg (Russia) through digitalization-based circular economy in waste recycling industry: A strategy to promote carbon neutrality in era of Industry 4.0. *J. Clean. Prod.* **2022**, *363*, 132452. [CrossRef]
126. Coccoli, M.; De Francesco, V.; Fusco, A.; Maresca, P. A cloud-based cognitive computing solution with interoperable applications to counteract illegal dumping in smart cities. *Multimedia Tools Appl.* **2022**, *81*, 95–113. [CrossRef]
127. Colangelo, G.; Facchini, F.; Ranieri, L.; Starace, G.; Vitti, M. Assessment of carbon emissions' effects on the investments in conventional and innovative waste-to-energy treatments. *J. Clean. Prod.* **2023**, *388*, 135849. [CrossRef]
128. Labib, S.M.T.; Ul Alam, S.; Ahmed, R.; Farshid, M.; Billah, A.; Hossain, M.A. Comparative study on WtE technologies in perspective of a developing country. In Proceedings of the 2019 International Conference on Computer Communication and Informatics (ICCCI 2019), Coimbatore, India, 23–25 January 2019.
129. Kaya, K.; Ak, E.; Yaslan, Y.; Oktug, S.F. Waste-to-Energy Framework: An intelligent energy recycling management. *Sustain. Comput. Inform. Syst.* **2021**, *30*, 100548. [CrossRef]
130. Maiurova, A.; Kurniawan, T.A.; Kustikova, M.; Bykovskaia, E.; Othman, M.H.D.; Singh, D.; Goh, H.H. Promoting digital transformation in waste collection service and waste recycling in Moscow (Russia): Applying a circular economy paradigm to mitigate climate change impacts on the environment. *J. Clean. Prod.* **2022**, *354*, 131604. [CrossRef]
131. Unnithan, C.; Ramkumar, P.S.; Babu, A.; Joseph, S.; Patil, S.; Joshi, A. Mobile waste management for smart cities: Monitoring sanitation through living labs. In Proceedings of the International Conference on ICT for Sustainable Development, Advances in Intelligent Systems and Computing, (ICT4SD 2015), Ahmedabad, India, 3–4 July 2015; pp. 625–633.
132. Lingaraju, A.K.; Niranjanamurthy, M.; Bose, P.; Acharya, B.; Gerogiannis, V.C.; Kanavos, A.; Manika, S. IoT-Based Waste Segregation with Location Tracking and Air Quality Monitoring for Smart Cities. *Smart Cities* **2023**, *6*, 1507–1522. [CrossRef]
133. Ak, E.; Duran, K.; Dobre, O.A.; Duong, T.Q.; Canberk, B. T6CONF: Digital Twin Networking Framework for IPv6-Enabled Net-Zero Smart Cities. *IEEE Commun. Mag.* **2023**, *61*, 36–42. [CrossRef]
134. Mohapatra, H.; Dehury, M.K.; Guru, A.; Rath, A.K. IoT-Enabled Zero Water Wastage Smart Garden. In *EAI/Springer Innovations in Communication and Computing*; Springer Science and Business Media Deutschland GmbH: Berlin/Heidelberg, Germany, 2023; pp. 71–89.
135. Sosunova, I.; Zaslavsky, A.; Matvienko, A.; Sadov, O.; Fedchenkov, P.; Anagnostopoulos, T. Context-Driven Heterogeneous Interface Selection for Smart City Applications. In Proceedings of the Internet of Things, Smart Spaces, and Next Generation Networks and Systems, Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), St. Petersburg, Russia, 27–29 August 2018; pp. 23–32.
136. Bălășescu, S.; Neacșu, N.A.; Madar, A.; Zamfirache, A.; Bălășescu, M. Research of the Smart City Concept in Romanian Cities. *Sustainability* **2022**, *14*, 10004. [CrossRef]
137. Bueno-Delgado, M.V.; Romero-Gázquez, J.L.; Jiménez, P.; Pavón-Mariño, P. Optimal path planning for selective waste collection in smart cities. *Sensors* **2019**, *19*, 1973. [CrossRef] [PubMed]
138. Elshamy, A.M. Smart city planning with sustainable utilization of virtual reality. *J. Eng. Res.* **2019**, *2*, 116–123. [CrossRef]
139. Aziz, K.; Tarapiah, S.; Ismail, S.H.; Atalla, S. Smart real-time healthcare monitoring and tracking system using GSM/GPS technologies. In Proceedings of the 2016 3rd MEC International Conference on Big Data and Smart City, ICBDSC 2016, Muscat, Oman, 15–16 March 2016; pp. 357–363.
140. Cello, M.; Degano, C.; Marchese, M.; Podda, F. Smart transportation systems (STSs) in critical conditions. In *Smart Cities and Homes: Key Enabling Technologies*; Elsevier Inc.: Amsterdam, The Netherlands, 2016; pp. 291–322.
141. Bharadwaj, A.S.; Rego, R.; Chowdhury, A. IoT Based Solid Waste Management System A conceptual approach with an architectural solution as a smart city application. In Proceedings of the 2016 IEEE Annual India Conference, INDICON 2016, Bangalore, India, 16–18 December 2016.

142. Lozano, Á.; Caridad, J.; De Paz, J.F.; González, G.V.; Bajo, J. Smart waste collection system with low consumption LoRaWAN nodes and route optimization. *Sensors* **2018**, *18*, 1465. [CrossRef]
143. Mohanty, A.; Mohanty, S.K.; Jena, B.; Mohapatra, A.G.; Rashid, A.N.; Khanna, A.; Gupta, D. Identification and evaluation of the effective criteria for detection of congestion in a smart city. *IET Commun.* **2022**, *16*, 560–570. [CrossRef]
144. Turner, S.W.; Uludag, S. Intelligent transportation as the key enabler of smart cities. In Proceedings of the NOMS 2016—2016 IEEE/IFIP Network Operations and Management Symposium, Istanbul, Turkey, 25–29 April 2016; pp. 1261–1264.
145. Hernández-Jiménez, R.; Cardenas, C.; Muñoz Rodríguez, D. Modeling and solution of the routing problem in vehicular delay-tolerant networks: A dual, deep learning perspective. *Appl. Sci.* **2019**, *9*, 5254. [CrossRef]
146. Kim, J.; Manna, A.; Roy, A.; Moon, I. Clustered vehicle routing problem for waste collection with smart operational management approaches. *Int. Trans. Oper. Res.* **2023**, *in press*. [CrossRef]
147. Bouleft, Y.; Alaoui, A.E. Dynamic Multi-Compartment Vehicle Routing Problem for Smart Waste Collection. *Appl. Syst. Innov.* **2023**, *6*, 30. [CrossRef]
148. Pardini, K.; Rodrigues, J.J.P.C.; Diallo, O.; Das, A.K.; de Albuquerque, V.H.C.; Kozlov, S.A. A smart waste management solution geared towards citizens. *Sensors* **2020**, *20*, 2380. [CrossRef]
149. Oralhan, Z.; Oralhan, B.; Yiğit, Y. Smart city application: Internet of Things (IoT) technologies based smart waste collection using data mining approach and ant colony optimization. *Int. Arab. J. Inf. Technol.* **2017**, *14*, 423–427.
150. Hamdala, M.R.; Perdana, D.; Hanurato, I.A.T. Capacity & Coverage Analysis for Planning Yogyakarta Smart City's Network (Use Case: LoRaWAN). In Proceedings of the APWiMob 2022—Proceedings: 2022 IEEE Asia Pacific Conference on Wireless and Mobile, Bandung, Indonesia, 9–10 December 2022.
151. de Camargo, E.T.; Spanhol, F.A.; Castro e Souza, Á.R. Deployment of a LoRaWAN network and evaluation of tracking devices in the context of smart cities. *J. Internet Serv. Appl.* **2021**, *12*, 8. [CrossRef]
152. Cruz, N.; Cota, N.; Tremoceiro, J. Lorawan and urban waste management—A trial. *Sensors* **2021**, *21*, 2142. [CrossRef] [PubMed]
153. Ahire, V.; Behera, D.K.; Saxena, M.R.; Patil, S.; Endait, M.; Poduri, H. Potential landfill site suitability study for environmental sustainability using GIS-based multi-criteria techniques for nashik and environs. *Environ. Earth Sci.* **2022**, *81*, 178. [CrossRef]
154. Mdukaza, S.; Isong, B.; Dladlu, N.; Abu-Mahfouz, A.M. Analysis of IoT-enabled Solutions in Smart Waste Management. In Proceedings of the IECON 2018—44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, USA, 21–23 October 2018; pp. 4639–4644.
155. Hayat, P. Smart cities: A global perspective. *India Q.* **2016**, *72*, 177–191. [CrossRef]