IoT-Enabled Waste Management in Smart Cities: A Systematic Literature Review

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***Abstract*—The growing population of cities has increased the pressure on the waste management systems and therefore, new and better approaches are needed. This paper aims to present the theoretical underpinning of the application of Internet of Things (IoT) technologies in the improvement of waste collection in smart cities. In this regard, this paper reviews the latest trends, methodologies, and technologies from a vast collection of peer-reviewed papers published between 2018 and 2024. The areas of focus include real-time monitoring systems, predictive analytics, and optimization algorithms that have created new norms in traditional waste management. The review discusses the novel concept of IoT-based smart bins, dynamic waste collection routing, and data-based decision-making frameworks which yield significant environmental and economic benefits. According to established studies, reported outcomes include reduced overflow and manual labor costs, improved routing efficiency, enhanced recycling processes, optimized bin placement, and increased energy savings. Across a variety of cities, reports comparing pre-IoT operations with IoT-enhanced ones have found remarkable decreases in operating costs, resource allocation, and overall sustainability performance improvements. However, challenges in data security, interoperability and scalability still exist, highlighting the need for a standardized framework and policies. This review contributes to the existing body of knowledge by identifying research gaps and proposing directions for future work. It emphasizes the importance of hybrid approaches combining IoT with emerging technologies such as artificial intelligence and blockchain to address the limitations of current systems. The findings offer valuable insights for policymakers, urban planners, and researchers aiming to foster sustainable and smart urban ecosystems.**

Keywords*—*Waste management; smart cities; Internet of Things (IoT); smart bins; urban planning

I. Introduction

Big cities are facing overpopulation and increasing reliance on the challenges of industrial activities [1], [2]. This requires urgent action, such as in waste management [3], [4]. Overcoming this requires a new approach to waste management [5]. Traditional approaches to waste management is inefficient and results in environmental degradation and inappropriate use of resources [6], [7]. Recent advances in information and communication technology in particular, [8] the Internet of Things (IoT) and artificial intelligence (AI) have improved waste management, such as increasing the efficiency of garbage collection and achieve higher recycling rates [9], [10], [11]. IoT-enabled smart bins use sensors to monitor waste levels in real-time [12], which allows periodic trash collection and avoid overflow incidents [13], [14]. AI algorithms can perform a data analysis that can have insights into optimization of collection routes based on waste generation patterns [15], [16], [17] thus, improving the operational efficiency.

The use of blockchain technology enhances trustworthiness through traceability and transparency when it comes to waste management [18], [19]. There is a move towards a more sustainable approach through recycling and using waste for energy[5], [6]. When it comes to waste sustainability, data quality is key; it also plays a vital role in decision-making[3], [20]. Using comprehensive and real-time data enables predicting trends on waste generation [20] and also allows assessing the impact of waste management practices on the environment.

New technologies help to improve resource usage, as well as to preserve the environment [7]. The effective waste management practices could only be achieved once academia, industry, and policymakers join hands in the quest of developing new and sustainable solutions [2]. The integration of IoT-based solutions in waste management has shown significant improvements in collection efficiency [17] and resource optimization.

Furthermore, the application of artificial intelligence-enabled analytics facilitates the anticipation of waste generation and the optimization of collection pathways [10], [21], [22]. Recent research underscores the significance of sustainable economic frameworks within waste management [23], accentuating the contribution of circular economy strategies [2]. Circular economy frameworks have been extensively examined [24], [25], [26] to improve waste valorization and reduce ecological repercussions.

This paper is organized as follows; the next section describes the research methodology, including the data sources, inclusion and exclusion criteria, and analysis procedures. Section III summarizes the literature and addresses the core research questions through an in-depth review of current practices, technological advancements, and thematic trends. In Section IV, we discuss the key findings, highlight persistent challenges, and suggest relevant directions for future research. The paper is concluded with a summary of key contributions and implications in Section V.

We will demonstrate the used methodology in the study in the subsequent section, and then the relationship between selected papers will be delved into in the synthesis section.

II. Methodology

Throughout this research, we are carrying out a defined and carefully engineered process to guarantee the exactitude and significance of our results. Fig. 1 encompasses the five main parts of this study that we are working on. The first step is formulating IoT and household waste collection ideas and holding to the selection of correct criteria and research questions. This stage is the cornerstone of the research, as it is necessary for building a strong study. Phase 2 is about locating studies from the best sources, like ScienceDirect and Scopus, to get exact data. Whereas the Phase 3 is characterized by the use of strict inclusion and exclusion criteria, which allow the selection of only high-quality, English-written literature between 2018 and 2024, then it concentrates on the examination of the different research works, through strategies like categorical analysis and statistical reference to be able to find the coherence in the data. In the fourth phase we will answer to the most important questions in the study, Finally, Phase 5 discusses the findings, challenges and suggestions, and signals the current gaps in research for the future exploration.

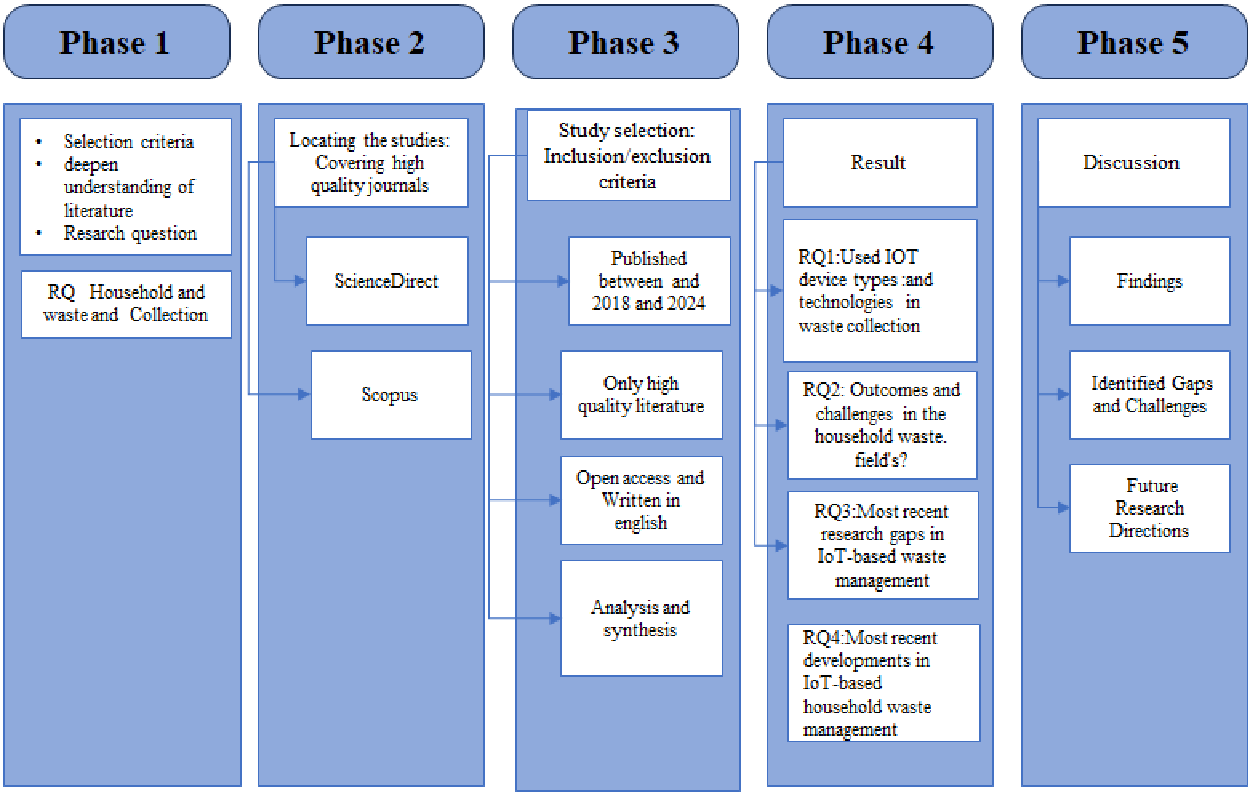

Fig. 1. Research process.

A. Pilot Search and Data Research Question

We have conducted a preliminary search to get an in-depth overview of IoT applications in urban waste management and mapping of the existing literature in our introductory stage. Sources of relevance were identified by applying a defined search string across the most important and trustworthy electronic databases from different publishers outlined in Table I as described by [27]. The preliminary search also supported the development of inclusion and exclusion criteria for literature selection.

TABLE I RESEARCH QUESTION DETAILS

Database	Search within	Fields	Search string	Time Span
Web of Science	Title, abstract, keywords	All Fields	household waste collection	2018..2024
Scopus	Title, abstract, keywords	All Fields	household waste collection	2018..2024

B. Locating the Studies

The utilization of prominent databases and the development of a research question driven by specific objectives are essential for a comprehensive exploration of the literature. To encompass a broad spectrum of documents related to the domain of household waste, a general inquiry is articulated. The Web of Science and Scopus databases are utilized to perform a comprehensive literature review, employing search criteria that encompass open access publications from the period spanning 2018 to January 2025, authored in English, and focusing on innovations and current trends within the research-oriented field regarding household waste collection.

C. Papers Selection

The preliminary analysis carried out on December 26 discovered 5,100 entries in the Scopus and Web of Science repositories. The two principal parameters employed for the delineation of the search were open-access publications released between the years 2018 and 2024, alongside the specific topic of "household waste collection".

In addition, we included only English-language peer- reviewed journals. Titles, keywords, and abstracts were searched to weed out publications beyond the scope of this study, such as those related to pharmacology, toxicology, chemistry, etc. The reference databases were combined in Rstudio, where 94 duplicate references were removed, resulting in 350 articles for further analysis.

D. Research Questions (RQ)

Research questions that are both well-structured and answerable are necessary for an exhaustive literature review [28]. These questions serve as the foundation for the entire inquiry and help to create the research design by influencing the kinds of techniques and tactics used [9]. After a thorough literature analysis and multiple rounds of pilot searching, the study's main research question—"How can IoT technologies improve household waste collection systems?"—was refined. To ensure a sharp focus on the inquiry and presentation of all pertinent features, four sub-research questions are developed inside the framework of the above all-inclusive question in order to delve deeper into this inquiry. These include:

- RQ1: What are the different types of IoT device types used in household waste collection?
- RQ2: What are the outcomes and challenges IoT technologies for household waste collection are facing?
- RQ3: What are the research gaps in IoT-based household waste collection domain?
- RQ4: What are the most recent developments in IoT-based household waste management?

E. Analysis and Synthesis

After getting a good blend of relevant papers, data analysis and synthesis can start. The purpose of the analysis is to take each study apart and map its concepts, while the synthesis focusses on finding cross-study commonalities and patterns. Such efforts forms the basis for an investigation of the applications of IoT on waste management practices in smart cities. Analysis and synthesis of this review are presented briefly in following sub-section.

Out of the 350 articles identified for review, 60 articles contribute to the field of Computer Science, Information Systems, 52 to Environmental Sciences, 48 to Green and Sustainable Science and Technology, 48 to Electrical and Electronic Engineering, and 32 to Environmental Studies, as per Fig. 2, among other fields.

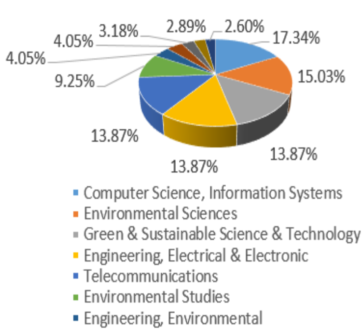

Fig. 2. Field type.

The time span of this review covers a broad range, with the earliest articles dating back to 2018 and the most recent published in 2025 (Fig. 3).

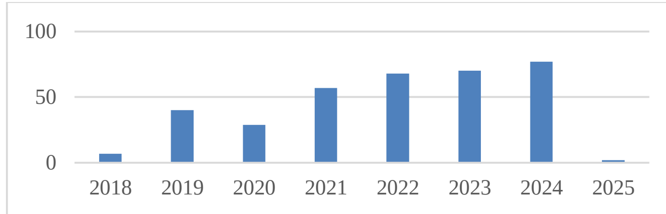

Fig. 3. Time distribution.

III. Results

This chapter addresses the research questions utilizing data gathered from selected articles.

A. Answer to the RQ1: What are the different Types of IoT Device Types used in Household Waste Collection?

Household waste management has witnessed the integration of various IoT devices and technologies [29], [30], offering innovative solutions to longstanding inefficiencies. Smart bins equipped with sensors are among the most commonly used technologies [31], [32], enabling real-time monitoring [8] of waste levels and reducing overflow issues [33]. Ultrasonic sensors are used to measure fill levels and Weight sensors to indicate garbage load as demonstrated in urban Malaysia using LoRaWAN networks [3], [34], [35]. Wireless Sensor Networks (WSNs) have also been implemented to enhance waste collection efficiency, where these technologies reduced fuel consumption and optimized routing [7], [36]. Advanced technologies such as AI and cloud computing have been utilized in Egyptian cities to improve waste generation predictions [37], leveraging cellular and Wi-Fi networks for real-time analytics [1], [38]. GPS tracking systems further contributed to waste management by optimizing collection routes and minimizing operational inefficiencies [4], [39], [40], [41] while solar- powered e-waste management solutions have been piloted in Bangladesh to promote recycling efforts using LoRaWAN networks [4], [5]. IoT-enabled optimization routes in Dublin and smart home solutions in Iran have also shown promise in reducing collection times and improving segregation at the household waste level, respectively [3], [7], [42]. These advancements demonstrate the potential of IoT in transforming waste management; Table II summarizes used IoT devices in the selected studies, the use case study geo-location, used technologies, communication methods, power source, the key outcomes, and the identified challenges for each study.

B. Answer to the RQ2: What are the Outcomes and Challenges of IoT Technologies for Household Waste Collection are Facing?

The integration of IoT in household waste collection has led to significant improvements in efficiency,[1], [43], cost reduction, [5], [44] and environmental sustainability [1]. One of the key outcomes is the optimization of waste collection routes,[36], [45], where smart sensors and AI-driven scheduling enable real-time monitoring of waste levels [46], reducing unnecessary trips and fuel consumption [10]. Several studies highlight the improvement in waste separation and classification, [47] with smart bins capable of distinguishing between organic, inorganic, and electronic waste, [43], [48] thereby enhancing recycling processes. [5], [49] Additionally, the use of real-time data transmission and cloud computing has enabled the automation of waste monitoring, [5] ensuring timely collection and preventing overflow issues. Cost efficiency is another major outcome, as IoT-driven waste collection systems reduce manual labor costs [4] and improve operational productivity. Furthermore, studies emphasize the role of energy- efficient smart bins, [1] which reduce power consumption while maintaining effective monitoring of waste accumulation. [34] Despite their advantages, these technologies face many challenges, next chapter dives to different challenges IoT devices are facing in household waste management domain.

TABLE II IOT DEVICES AND TECHNOLOGIES USED FOR HOUSEHOLD WASTE COLLECTION

Study	IoT Technology Used	Network Type	Key Outcomes	City/Country
Wong 2023 [3]	Smart bins, Sensors Raspberry Pi 4b as microcontroller. ultrasonic and tracker sensors	Wi-Fi	Reduced overflow, collection and classification of waste, Waste Separation	Urban Malaysia.
Abidin 2022 [43]	Sensors	LoRaWAN	Optimal waste bin placement using LoRa Network. Clustering method for waste bin placement. Sort organic and inorganic waste and monitor the volume, gas content, and weight of waste in waste bins	Rural Area in Indonesia
Anagnostopoulos 2021 [7]	Not specified	Not specified	Lowered fuel use, new system based swapping full bins for empty ones, real-time scheduling of waste collection, dynamic routing	St. Petersburg, Russia.
Ahmed 2023 [1]	AI, Cloud Computing	Not specified	Energy saving, optimal waste collection routes regenerate missing data, High-priority bins require immediate collection	Egyptian cities.
Sharma 2020 [9]	In general	In general	Finding barriers: data Security and Privacy High costs of implementation and maintenance, Heterogeneity and Lack of standardization. High energy consumption	India.
Okubanjo 2024 [4]	Arduino Uno as controller ultrasonic sensors	Wi-Fi module for data transmission.	Improved efficiency in waste collection processes. Reduced costs associated with manual labor.	Applied in Nigeria.
Farjana 2023 [5]	ultrasonic sensor	Cloud,	Separating E-waste, Converting E-waste plastic to bio-fuel and bio-char, improve recycling processes ,monitor waste levels and alert collectors	Tested in Bangladesh.
Ghahramani 2022 [2]	In general	microcontroller-based platform	Improved efficiency of waste management in urban areas. Optimizes waste collection routes, real time monitoring	Dublin.
Ehsanifar 2023 [6]	IoT in Smart Homes various IoT devices	Not specified	IoT enhances energy efficiency and waste management practices in smart homes	Conducted in Iran.
Hussain 2024 [10]	Ultrasonic sensors: fill levels Weight sensors: garbage load	various of networks	Real-time monitoring Ultrasonic Sensors, Weight Sensors: Predictive Routing System	Qatar.
Fataniya 2019 [11]	IoT sensors, Node MCU, Ultrasonic Sensor, Moisture Sensor, Gas Sensor	GSM technology	waste segregation and real-time monitoring	Ahmedabad: India.

C. *Answer to the RQ3: What are the Research Gaps in IoT-Based Household Waste Collection Domain*

Although the use of IoT technologies in household waste management has brought several benefits, these technologies continue to face challenges that limit their widespread adoption and scalability [50]. Common faced challenges are data privacy issues, limited scalability, incidental network and high implementation cost [9]. These barriers need to be addressed to achieve the full potential of IoT for smart cities environments Table III below summarizes challenges different IoT devices and technologies face:

TABLE III CHALLENGES THAT IOT SOLUTIONS FACE

Solution/ Technics	Challenges Identified
Waste classification [3]	Diversity of Waste Types, Technological Limitations
Mobile Depot Implementation [7]	Complex and resource-intensive, Real-Time Data Management, Traffic dependent, Costly solution, High coordination demanded.
IoT Waste management barriers [9]	Data quality, Implementation cost, Regulation, energy consumption.
Waste management using Smart bins [4]	data integrity and security, public attitude, sorting waste
Smart e-Waste classification [5]	Variability in e-waste feedstock.
Optimal waste collection routes [1],[2], [5], [39], [36]	Dependent of data accuracy, timeliness, and network connectivity. Optimization Complexity: multiple conflicting variables, Computational cost, Missing data, Big number of trucks: Coordination and Decision-making.

The use of smart waste management IoT devices such as smart sensors, bins, GPS tracking systems, and RFID tags can significantly reduce the inefficiency of waste collection processes [51]. LPWAN technologies, especially in the case of LoRaWAN technologies, have a wide application in the case of their efficacy and cost-effective coverage. Many studies recommend the use of new technologies (like blockchain and AI) to revolutionize the industry through improved security and preventive measures. Nevertheless, significant hurdles-data privacy, scalability, and network interference remain. Next sub- chapter treats recent developments and research gaps in household waste field.

D. *Answer to the RQ4: What are the Most Recent Developments in IoT-Based Household Waste Management?*

Recent advancements in IoT-based household waste management have introduced technologies such as smart bins equipped with sensors to prevent overflow and enhance efficiency, as demonstrated by Wong [3]. Blockchain has also been recommended to improve transparency and scalability in urban waste systems, as shown by Okubanjo [4]. AI-driven predictive analytics [52], [53], as highlighted by Ahmed [1], have enabled better forecasting of waste generation, while solar powered IoT systems have emerged to address e-waste recycling challenges, as evidenced by Farjana [5]. Despite these advancements, research gaps persist, particularly in terms of infrastructure, scalability, and data privacy, as reported by Ghahramani [2] and Ehsanifar [6]. Table IV summarizes the recent development and identified gaps, these gaps need further exploration and development.

TABLE IV RECENT DEVELOPMENT AND IDENTIFIED GAPS

References	Recent Development	Identified Gaps	Study Location
Wong, 2023 [3]	Smart bins with IoT sensors for overflow prevention	High initial cost, scalability challenges, limited adoption in rural areas	Urban Malaysia
Okubanjo, 2024 [4]	Blockchain integration for enhanced transparency	Scalability issues, lack of robust infrastructure, user adoption challenges	Nigeria
Ahmed, 2023 [1]	AI and cloud computing for predictive waste analytics	Data privacy concerns, high computational requirements	Egyptian cities
Farjana, 2023 [5]	Solar-powered IoT systems for e-waste recycling	Lack of infrastructure, insufficient funding for large-scale implementation	Bangladesh
Ehsanifar, 2023 [6]	Smart home solutions for waste segregation	User adaptation challenges, limited IoT integration at the household level	Iran
Ghahramani, 2022 [2]	IoT-enabled optimization for collection time reduction	Data reliability issues, dependence on battery-powered devices	Dublin

IV. DISCUSSION

IoT technology has significantly improved household waste management efficiency, cost reduction, and sustainability. Many studies have demonstrated that IoT-based waste collection systems can monitor waste in real-time, optimize routing dynamically, and automate waste separation, thereby reducing the overall environmental impact. Several cities in India, Malaysia, and Russia deploys ultrasonic sensors and microcontroller-based platforms to optimize waste collection routes, reduce fuel consumption, and improve waste management.

By implementing predictive models and AI-driven scheduling, waste collection logistics have also improved, ensuring high-priority bins receive timely service while preventing overflow. Furthermore, research illustrates how real time data and cloud computing offer municipalities valuable insights that can be used to reduce costs and improve public satisfaction.

Smart waste management systems continue to face several implementation challenges despite recent technological progress. The main implementation obstacle consists of heterogeneous IoT devices and non-uniform communication protocols, which produce challenges for interoperability. Municipal data security and privacy issues create significant risks during systems operation mainly because of sensitive information involved. The high price tag associated with implementing and maintaining these systems limits their spread specifically in developing nations that face strong financial restrictions. The proposed advantages of IoT for waste collection methods face limitations due to the poor public participation in waste segregation and recycling. Research into economical IoT deployment plans, improved cyber security systems and community involvement programs must be conducted to overcome present barriers in sustainable waste management practices.

Although the present study contributes to understanding IoT-based household waste management, it has certain limitations. One key limitation is the dependency on data quality and real-time transmission. IoT devices deployed in waste collection rely heavily on accurate and continuous data flow; however, sensor failures or data transmission errors can lead to inconsistencies in waste monitoring.

IoT-based waste systems requires robust data validation mechanisms and redundancy measures to enhance their reliability. Additionally, findings may not be generalizable. The majority of IoT studies are conducted in urban area, where infrastructure supports IoT deployment. Rural areas with limited connectivity and technology infrastructure face additional challenges. To extend IoT waste management solutions to non-urban environment, alternative network technologies such as LoRaWAN and GSM should be explored. It remains a challenge to optimize bin placement; current methods rely on static actions, though future research could explore AI-driven dynamic models that adapt to fluctuating waste generation patterns. Last but not least, future studies should address long-term sustainability of IoT-based waste management, considering maintenance costs, device longevity, and lifecycle environmental impacts.

A. Identified Gaps and Challenges

The widespread adoption and effectiveness of smart waste management are hindered by several key challenges. Infrastructure adaptation is among the most pressing issues, for example, mobile depots and IoT-based collection systems require significant changes to existing frameworks, making implementation complex and expensive. On top of that, the majority of research rely on theoretical models and simulations rather than real-world deployment and testing, raising concerns about the lack of real-world validation. The availability of IoT connectivity further complicates the situation, especially in regions with unstable network infrastructure, which affects data collection and communication. Moreover, consumer acceptance and behavioral adaptation are underexplored areas, as public perception and willingness to engage with automated waste systems are critical to their success. AI-driven waste classification and data management process also require optimization, as current systems are not adaptable to diverse and unpredictable real-life conditions. With IoT infrastructure requiring a high initial investment, scalability and cost efficiency remain challenges. Furthermore A lack of standardized metrics makes comparisons, evaluating efficiency, and identifying best practices difficult, Fig. 4 summarizes those challenges.

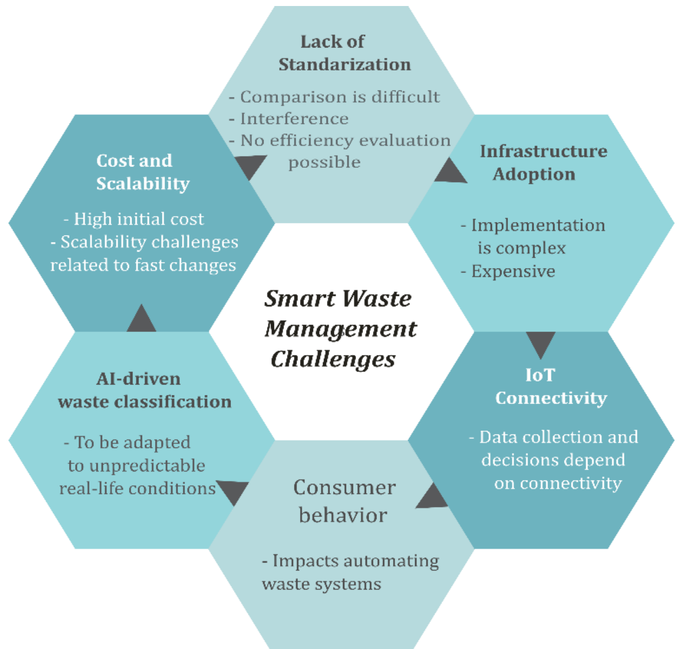

Fig. 4. Challenges in smart waste management.

B. Future Research Directions

In order to overcome these challenges, future research must enhance AI-based decision-making, particularly by optimizing waste detection, classification, and waste collection routes. To validate theoretical models and refine system performance, extending field implementation and pilot programs across diverse urban environments will be essential. In addition, improving IoT sensor efficiency by developing more reliable, energy-efficient, long-lasting sensors is essential for achieving sustainable long-term deployment.

Understanding public attitudes and participation through behavioral analysis of customers is another essential field of research to improve compliance with smart waste disposal systems. It would also be beneficial to conduct comparative studies between different cities to identify the most appropriate waste management strategies and key success factors. It is imperative that policymakers develop robust regulatory frameworks to foster the adoption of IoT-enabled solutions and push for infrastructure advancements. Lastly, improving the sustainability of smart waste management systems will require exploring alternative energy sources, such as solar-powered waste bins and mobile depots.

Data privacy concerns and reliability issues remain in IoT-based waste management [9]. For instance, enabled optimization systems in Dublin revealed challenges in ensuring consistent and reliable data [2]. Furthermore, privacy concerns associated with AI-driven systems need to be addressed through robust security measures, as noted in Egypt [54]. To bridge these gaps and maximize their impact on global waste management systems, future research should focus on cost-effective, scalable, and secure IoT solutions.

V. Conclusion

This systematic literature review highlights the significant advancements IoT technologies have brought to household waste management. These technologies poses the potential to optimize operations, improve resource allocation, and enhance sustainability metrics. In the future, more research should focus on developing affordable and scalable IoT solutions to ensure widespread adoption. To mitigate privacy concerns associated with cloud-based processing, enhanced data security measures are necessary. Hybrid approaches combining IoT with AI and blockchain will enhance waste management systems' robustness and efficiency. IoT devices can also become more sustainable by integrating renewable energy sources, such as solar power. It would be possible to establish more robust and efficient waste management systems through the exploration of hybrid approaches that combine IoT with advanced technologies, such as artificial intelligence and blockchain.

Collaboration among stakeholders, including policymakers, urban planners, and technologists, is essential to foster innovation and create standardized frameworks that address the limitations of current systems. These efforts are imperative for building sustainable smart cities that can effectively manage household waste while minimizing environmental impacts.

References

[1] M. M. Ahmed, E. Hassanien, and A. E. Hassanien, "IoT-based intelligent waste management system," Neural Comput & Applic, vol. 35, no. 32, pp. 23551–23579, Nov. 2023, doi: 10.1007/s00521-023-08970-7.

[2] M. Ghahramani, M. Zhou, A. Molter, and F. Pilla, "IoT-Based Route Recommendation for an Intelligent Waste Management System," IEEE Internet Things J., vol. 9, no. 14, pp. 11883–11892, Jul. 2022, doi: 10.1109/JIOT.2021.3132126.

[3] S. Y. Wong, H. Han, K. M. Cheng, A. C. Koo, and S. Yussof, "ESS-IoT: The Smart Waste Management System for General Household," Pertanika J. Sci. Technol., vol. 31, no. 1, pp. 311–325, 2023, doi: 10.47836/pjst.31.1.19.

[4] A. Okubanjo, O. BashiR Olufemi, A. Okandeji, and E. DaniEl, "Smart Bin and IoT: A Sustainable Future for Waste Management System in Nigeria," Gazi University Journal of Science, vol. 37, no. 1, pp. 222–235, Mar. 2024, doi: 10.35378/gujs.1254271.

[5] M. Farjana, A. B. Fahad, S. E. Alam, and Md. M. Islam, "An IoT- and Cloud-Based E-Waste Management System for Resource Reclamation with a Data-Driven Decision-Making Process," IoT, vol. 4, no. 3, pp. 202–220, Jul. 2023, doi: 10.3390/iot4030011.

[6] M. Ehsanifar, F. Dekamini, C. Spulbar, R. Birau, M. Khazaei, and I. C. Bărbăcioru, "A Sustainable Pattern of Waste Management and Energy Efficiency in Smart Homes Using the Internet of Things (IoT)," Sustainability, vol. 15, no. 6, p. 5081, Mar. 2023, doi: 10.3390/su15065081.

[7] T. Anagnostopoulos et al., "IoT-enabled tip and swap waste management models for smart cities," IJEWM, vol. 28, no. 4, p. 521, 2021, doi: 10.1504/IJEWM.2021.118862.

[8] D. Garcia-Retuerta, P. Chamoso, G. Hernández, A. S. R. Guzmán, T. Yigitcanlar, and J. M. Corchado, "An Efficient Management Platform for Developing Smart Cities: Solution for Real-Time and Future Crowd Detection," Electronics, vol. 10, no. 7, p. 765, Mar. 2021, doi: 10.3390/electronics10070765.

[9] M. Sharma, S. Joshi, D. Kannan, K. Govindan, R. Singh, and H. C. Purohit, "Internet of Things (IoT) adoption barriers of smart cities' waste management: An Indian context," Journal of Cleaner Production, vol. 270, p. 122047, Oct. 2020, doi: 10.1016/j.jclepro.2020.122047.

[10] Dr. I. Hussain, Dr. A. Elomri, Dr. L. Kerbache, and Dr. A. E. Omri, "Smart city solutions: Comparative analysis of waste management models in IoT-enabled environments using multiagent simulation," Sustainable Cities and Society, vol. 103, p. 105247, Apr. 2024, doi: 10.1016/j.scs.2024.105247.

[11] B. Fataniya, A. Sood, D. Poddar, and D. Shah, "Implementation of IoT Based Waste Segregation and Collection System," International Journal of Electronics and Telecommunications, pp. 579–584, Jul. 2019, doi: 10.24425/ijet.2019.129816.

[12] D. Abuga and N. S. Raghava, "Real-time smart garbage bin mechanism for solid waste management in smart cities," Sustainable Cities and Society, vol. 75, p. 103347, Dec. 2021, doi: 10.1016/j.scs.2021.103347.

[13] Md. A. Rahman, S. W. Tan, A. Taufiq Asyhari, I. F. Kurniawan, M. J. F. Alenazi, and M. Uddin, "IoT-Enabled Intelligent Garbage Management System for Smart City: A Fairness Perspective," IEEE Access, vol. 12, pp. 82693–82705, 2024, doi: 10.1109/ACCESS.2024.3412098.

[14] N. Abdullah et al., "Integrated Approach to Achieve a Sustainable Organic Waste Management System in Saudi Arabia," Foods, vol. 11, no. 9, p. 1214, Apr. 2022, doi: 10.3390/foods11091214.

[15] A. Omara, D. Gulen, B. Kantarci, and S. F. Oktug, "Trajectory-Assisted Municipal Agent Mobility: A Sensor-Driven Smart Waste Management System," JSAN, vol. 7, no. 3, p. 29, Jul. 2018, doi: 10.3390/jsan7030029.

[16] A. Martikkala, B. Mayanti, P. Helo, A. Lobov, and I. F. Ituarte, "Smart textile waste collection system – Dynamic route optimization with IoT," Journal of Environmental Management, vol. 335, p. 117548, Jun. 2023, doi: 10.1016/j.jenvman.2023.117548.

[17] P. Jiang, Y. Fan, and J. Klemes, "Data analytics of social media publicity to enhance household waste management," RESOURCES CONSERVATION AND RECYCLING, vol. 164, Jan. 2021, doi: 10.1016/j.resconrec.2020.105146.

[18] K. Govindan, F. Asgari, F. S. Naieni Fard, and H. Mina, "Application of IoT technology for enhancing the consumer willingness to return E-waste for achieving circular economy: A Lagrangian relaxation approach," J. Clean. Prod., vol. 459, 2024, doi: 10.1016/j.jclepro.2024.142421.

[19] C. Magrini et al., "Using Internet of Things and Distributed Ledger Technology for Digital Circular Economy Enablement: The Case of Electronic Equipment," Sustainability, vol. 13, no. 9, p. 4982, Apr. 2021, doi: 10.3390/su13094982.

[20] Hong Cing Cing and Nur Syaimasyaza Mansor, "Internet of Things (IoT): Real-Time Monitoring for Decision Making Among The Malaysian Contractors," ARASET, vol. 32, no. 3, pp. 455–470, Oct. 2023, doi: 10.37934/araset.32.3.455470.

[21] S. M. Cheema, A. Hannan, and I. M. Pires, "Smart Waste Management and Classification Systems Using Cutting Edge Approach," Sustainability, vol. 14, no. 16, p. 10226, Aug. 2022, doi: 10.3390/su141610226.

[22] R. W. Ahmad, K. Salah, R. Jayaraman, I. Yaqoob, and M. Omar, "Blockchain for Waste Management in Smart Cities: A Survey," IEEE Access, vol. 9, pp. 131520–131541, 2021, doi: 10.1109/ACCESS.2021.3113380.

[23] H. Yadav, U. Soni, and G. Kumar, "Analysing challenges to smart waste management for a sustainable circular economy in developing countries: a fuzzy DEMATEL study," SASBE, vol. 12, no. 2, pp. 361–384, Feb. 2023, doi: 10.1108/SASBE-06-2021-0097.

[24] H. Yadav, U. Soni, and G. Kumar, "Analysing challenges to smart waste management for a sustainable circular economy in developing countries: a fuzzy DEMATEL study," SASBE, vol. 12, no. 2, pp. 361–384, Feb. 2023, doi: 10.1108/SASBE-06-2021-0097.

[25] A. Zhang, V. Venkatesh, Y. Liu, M. Wan, T. Qu, and D. Huisingh, "Barriers to smart waste management for a circular economy in China,"

JOURNAL OF CLEANER PRODUCTION, vol. 240, Dec. 2019, doi: 10.1016/j.jclepro.2019.118198.

[26] F. Altarazi, “Optimizing Waste Reduction in Manufacturing Processes Utilizing IoT Data with Machine Learning Approach for Sustainable Production,” SCPE, vol. 25, no. 5, pp. 4192–4204, Aug. 2024, doi: 10.12694/scpe.v25i5.3191.

[27] “Denyer, D., & Tranfield, D. (2009). Producing a systematic review.”.

[28] counsell, “Formulating questions and locating primary studies for inclusion in systematic reviews.”

[29] A. Van Der Hoogen, I. Fashoro, A. P. Calitz, and L. Luke, “A Digital Transformation Framework for Smart Municipalities,” Sustainability, vol. 16, no. 3, p. 1320, Feb. 2024, doi: 10.3390/su16031320.

[30] V. Malik et al., “Building a Secure Platform for Digital Governance Interoperability and Data Exchange Using Blockchain and Deep Learning-Based Frameworks,” IEEE Access, vol. 11, pp. 70110–70131, 2023, doi: 10.1109/ACCESS.2023.3293529.

[31] P. Zoumpoulis, F. K. Konstantinidis, G. Tsimiklis, and A. Amditis, “Smart bins for enhanced resource recovery and sustainable urban waste practices in smart cities: A systematic literature review,” Cities, vol. 152, p. 105150, Sep. 2024, doi: 10.1016/j.cities.2024.105150.

[32] S. Ahmed, S. Mubarak, J. T. Du, and S. Wibowo, “Forecasting the Status of Municipal Waste in Smart Bins Using Deep Learning,” IJERPH, vol. 19, no. 24, p. 16798, Dec. 2022, doi: 10.3390/ijerph192416798.

[33] A. A. I. Shah, S. S. M. Fauzi, R. A. J. M. Gining, T. R. Razak, M. N. F. Jamaluddin, and R. Maskat, “A review of IoT-based smart waste level monitoring system for smart cities,” IJEECS, vol. 21, no. 1, p. 450, Jan. 2021, doi: 10.11591/ijeecs.v21.i1.pp450-456.

[34] E. Aktay and N. Yalçın, “A smart city application: A waste collection system with long range wide area network for providing green environment and cost effective and low power consumption solutions,” IET Smart Cities, vol. 3, no. 3, pp. 142–157, Sep. 2021, doi: 10.1049/smc2.12014.

[35] B. Döníz and B. Lajos, “Challenges of LoRaWAN technology in smart city solutions,” Interdisciplinary Description of Complex Systems, vol. 20, no. 1, pp. 1–10, Feb. 2022, doi: 10.7906/indecs.20.1.1.

[36] M. Belhiah, M. El Aboudi, and S. Ziti, “Optimising unplanned waste collection: An IoT-enabled system for smart cities, a case study in Tangier, Morocco,” IET Smart Cities, vol. 6, no. 1, pp. 27–40, Mar. 2024, doi: 10.1049/smc2.12069.

[37] A. Hussain et al., “Waste Management and Prediction of Air Pollutants Using IoT and Machine Learning Approach,” Energies, vol. 13, no. 15, p. 3930, Aug. 2020, doi: 10.3390/en13153930.

[38] J. Gillespie et al., “Real-Time Anomaly Detection in Cold Chain Transportation Using IoT Technology,” Sustainability, vol. 15, no. 3, p. 2255, Jan. 2023, doi: 10.3390/su15032255.

[39] S. Ahmad, Imran, F. Jamil, N. Iqbal, and D. Kim, “Optimal Route Recommendation for Waste Carrier Vehicles for Efficient Waste Collection: A Step Forward Towards Sustainable Cities,” IEEE Access, vol. 8, pp. 77875–77887, 2020, doi: 10.1109/ACCESS.2020.2988173.

[40] U. Ramanathan, R. Ramanathan, A. Adefisan, T. Da Costa, X. Cama-Moncunill, and G. Samriya, “Adapting Digital Technologies to Reduce Food Waste and Improve Operational Efficiency of a Frozen Food Company—The Case of Yumchop Foods in the UK,” Sustainability, vol. 14, no. 24, p. 16614, Dec. 2022, doi: 10.3390/su142416614.

[41] N. C. A. Sallang, M. T. Islam, M. S. Islam, and H. Arshad, “A CNN-Based Smart Waste Management System Using TensorFlow Lite and LoRa-GPS Shield in Internet of Things Environment,” IEEE Access, vol. 9, pp. 153560–153574, 2021, doi: 10.1109/ACCESS.2021.3128314.

[42] Department of Electronics and Communication, SRM Institute of Science and Technology, Kattanulathur, Chennai, Tamilnadu, India et al., “Development f Smart Garbage Bins for Automated Segregation of Waste with Real-Time Monitoring using Iot,” IJEAT, vol. 8, no. 6s, pp. 344–348, Sep. 2019, doi: 10.35940/ijeat.F1072.0886S19.

[43] A. Z. Z. Abidin, M. F. I. Othman, A. Hassan, Y. Murdianingsih, U. T. Suryadi, and M. Faizal, “LoRa-Based Smart Waste Bins Placement using Clustering Method in Rural Areas of Indonesia,” Int. J. Adv. Soft Comput. Appl., vol. 14, no. 3, pp. 105–123, 2022, doi: 10.15849/IJASCA.221128.08.

[44] Student at the School of Electrical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu- 632014, India. et al., “Cost-Effective Autonomous Garbage Collecting Robot System Using Iot And Sensor Fusion,” IJITEE, vol. 9, no. 1, pp. 1–8, Nov. 2019, doi: 10.35940/ijitee.A3880.119119.

[45] A. Mishra and A. Kumar Ray, “IoT cloud-based cyber-physical system for efficient solid waste management in smart cities: a novel cost function based route optimisation technique for waste collection vehicles using dustbin sensors and real-time road traffic informatics,” IET Cyber-Phy Sys Theory & Ap, vol. 5, no. 4, pp. 330–341, Dec. 2020, doi: 10.1049/iet-cps.2019.0110.

[46] R. S. N. Varma, P. J. Swaroop, B. K. Anand, N. Yadav, N. Janarthanan, and T. V. Sarath, “IOT BASED INTELLIGENT TRASH MONITORING SYSTEM WITH ROUTE OPTIMIZATION METHOD,” INTERNATIONAL JOURNAL OF ELECTRICAL ENGINEERING AND TECHNOLOGY, vol. 11, no. 4, Apr. 2020, doi: 10.34218/IJEET.11.4.2020.006.

[47] S. M. Cheema, A. Hannan, and I. M. Pires, “Smart Waste Management and Classification Systems Using Cutting Edge Approach,” Sustainability, vol. 14, no. 16, p. 10226, Aug. 2022, doi: 10.3390/su141610226.

[48] A. Kumar, “A novel framework for waste management in smart city transformation with industry 4.0 technologies,” Research in Globalization, vol. 9, p. 100234, Dec. 2024, doi: 10.1016/j.resglo.2024.100234.

[49] X. Chen, “Machine learning approach for a circular economy with waste recycling in smart cities,” Energy Reports, vol. 8, pp. 3127–3140, Nov. 2022, doi: 10.1016/j.egyr.2022.01.193.

[50] I. Pencea et al., “An improved balanced replicated sampling design for preliminary screening of the tailings ponds aiming at zero-waste valorization. A Romanian case study,” Journal of Environmental Management, vol. 331, p. 117260, Apr. 2023, doi: 10.1016/j.jenvman.2023.117260.

[51] F. Khan and Y. Ali, “A facilitating framework for a developing country to adopt smart waste management in the context of circular economy,” Environ Sci Pollut Res, vol. 29, no. 18, pp. 26336–26351, Apr. 2022, doi: 10.1007/s11356-021-17573-5.

[52] N. Sengupta and R. Chinnasamy, “Designing of an Immaculate Smart City with Cloud Based Predictive Analytics,” IJCDS, vol. 09, no. 6, pp. 1079–1089, Nov. 2020, doi: 10.12785/ijcds/090606.

[53] “Enhancing Resource Allocation and Optimization in IoT Networks Using AI-Driven Firefly Optimized Hybrid CNN-BILSTM Model,” IJIES, vol. 16, no. 6, pp. 824–837, Dec. 2023, doi: 10.22266/ijies2023.1231.68.

[54] “HEZAM, Ibrahim M., GAMAL, Abduallah, ABDEL-BASSET, Mohamed, et al. Facile and optimal evaluation model of intelligent waste collection systems based on the Internet of Things: a new approach toward sustainability. Environment, Development and Sustainability, 2024, vol. 26, no 5, p. 12639-12677.”.