Advances in Internet of Things, 2025, 15(4), 96-119
https://www.scirp.org/journal/ait
ISSN Online: 2161-6825
ISSN Print: 2161-6817

Critical Systematic Review of the Transferability of IoT Solutions for Smart Waste Collection in Low-Resource Settings

Didi Tshimpanga Badibanga[1,2*], Olivier Baraka Mushage[3], Audace Manirabona[1], Jérémie Ndikumagenge[1]

[1]Center for Research in Infrastructure, Environment and Technologies (CRIET), University of Burundi, Bujumbura, Burundi
[2]Department of Computer Science, Higher Institute of Commerce of Kisangani (ISC Kisangani), Kisangani, DR Congo
[3]Faculty of Applied Sciences and Technologies (ULPGL-Goma), Goma, DR Congo
Email: *tyanatshim@gmail.com, olivier.baraka@gmail.com, audace.manirabona@ub.edu.bi, jeremie.ndiukumagenge@ub.edu.bi

How to cite this paper: Tshimpanga Badibanga, D., Baraka Mushage, O., Manirabona, A. and Ndikumagenge, J. (2025) Critical Systematic Review of the Transferability of IoT Solutions for Smart Waste Collection in Low-Resource Settings. *Advances in Internet of Things*, **15**, 96-119.
https://doi.org/10.4236/ait.2025.154006

Received: September 22, 2025
Accepted: October 25, 2025
Published: October 28, 2025

Abstract

This study assesses the transferability of IoT solutions applied to smart waste collection in low-resource settings. In line with PRISMA guidelines, a systematic review covering the period 2016-2024 was conducted across four databases (IEEE Xplore, ScienceDirect, SpringerLink, Scopus). Out of 329 records, 36 studies were included. Results highlight the predominance of ultrasonic sensors (~46%), the widespread use of Arduino/ESP32 (~72%) and Wi-Fi (~27%) despite their limited robustness in low-connectivity environments, while LoRa/LoRaWAN (~20%) is gaining ground. Community engagement remains marginal, with about 60% of the systems lacking any user interaction. The most transferable solutions are those that combine technical simplicity, low-power architectures, and lightweight interfaces (USSD/SMS), together with context-specific route optimization. It is therefore recommended to prioritize open, modular, and locally tested systems, to strengthen community involvement, and to align pilot projects with municipal policies.

Keywords

IoT Technologies, Smart Waste Collection, Environmental Challenges, Low-Resource Settings

1. Introduction

The adaptation of Internet of Things (IoT) technologies to waste management in developing countries is attracting growing attention [1] [2]. Rapid urbanization, population growth, and the persistent weakness of collection infrastructures reinforce the challenges associated with this field of research [3]-[7]. Various IoT applications have emerged in recent years, ranging from simple sensors to integrated systems combining automated management, geolocation, and data processing [7], [8]-[12]. These systems aim to improve operational efficiency, address public health issues, and reduce environmental impacts [13] [14]. However, such devices often rely on assumptions that are hardly compatible with the realities of cities in developing contexts: access to electricity and stable connectivity is limited, technical expertise is sometimes lacking, and the fragmented structure of public services complicates their deployment [15]-[18]. Few studies focus on African cities, while the existing literature remains largely centered on research conducted in Asia or in major cities of the Global North [19] [20]. This orientation prevents a nuanced understanding of local challenges and limits the transferability of proposed models.

In this paper, transferability is defined as the capacity of a technological solution initially designed in one geographical or socio-economic context to be effectively adapted and operationalized in another, while preserving both functionality and contextual relevance [21].

This review examines the adaptability of IoT systems designed for waste collection to low-resource urban environments, such as those observed in the Democratic Republic of Congo [22]-[25]. The analysis is based on a critical reading that integrates technical performance, structural constraints, community engagement, and economic realities [26] [27]. It provides a state of the art, identifies recurring obstacles, and highlights relevant practices in order to propose concrete pathways for context-appropriate development [28]-[30]. Through the examination of thirty-six empirical studies, the aim is to better align technological innovation with local feasibility in a perspective that is both pragmatic and grounded in field realities.

2. Methodology

2.1. Rationale for Choosing the PRISMA Protocol

To ensure the rigor, transparency, and reproducibility of this systematic review, the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was adopted as the reference framework [31]. This internationally recognized standard structures the different stages of the process, from source identification to final analysis, while ensuring consistency and traceability of methodological decisions. This choice is fully justified in a field as cross-cutting as IoT-enabled smart waste management, which draws on research from engineering sciences, urban planning, and the social sciences. By clarifying inclusion and exclusion criteria, PRISMA helps reduce selection bias and ensures maximum representativeness of relevant studies.

2.2. Selection of Databases

Given the fundamentally interdisciplinary nature of smart waste management, this review relies on four scientific databases selected for the complementarity of their contributions. IEEE Xplore was used for its comprehensive coverage of Internet of Things technologies, sensor architectures, and microcontrollers. ScienceDirect provides essential insights into applied environmental engineering approaches. SpringerLink enriches the corpus with studies combining technology, urban planning, and social sciences, which are particularly relevant for analyzing waste management systems from an integrated urban perspective. Finally, Scopus was chosen for its broad coverage, advanced bibliometric tools, and ability to interconnect publications across diverse disciplines. This combination ensures a balanced coverage of the technical, ecological, and socio-institutional dimensions of the topic, while limiting biases linked to disciplinary silos.

2.3. Search Strategy

The search strategy was based on a combination of generic and specialized keywords, incorporating synonyms, terminological variants, and expressions commonly used in the field of IoT applied to waste management. The queries were formulated in English, the dominant language of scientific publications on this topic. Boolean operators (AND, OR) were used to cross-reference the main concepts: IoT technologies ("IoT", "Internet of Things"), waste management ("waste collection", "garbage monitoring"), logistics optimization ("route optimization", "smart bins", "sensor-based garbage"), and social or territorial dynamics ("community engagement", "developing countries", "Africa", "Asia").

The search period, set between 2016 and 2024, captures recent developments in the field, including the diffusion of low-cost solutions (such as Arduino and ESP32), the emergence of long-range networks (LoRaWAN), and the introduction of decentralized technologies such as blockchain into connected waste management systems.

The search strategy was conducted across four major databases (Scopus, IEEE Xplore, ScienceDirect, and SpringerLink), selected for their broad coverage of peer-reviewed literature in engineering, computer science, and environmental studies. These databases were prioritized to ensure access to the most relevant publications on IoT applications and smart waste management. Although other repositories such as Web of Science or certain regional databases may also contain relevant studies, the chosen sources already provide extensive disciplinary and geographical coverage.

2.4. Inclusion and Exclusion Criteria

A rigorous set of criteria was defined to ensure scientific relevance, contextual adequacy, and technological consistency with the objectives of this review. Priority was given to empirical research conducted in low-resource countries that effectively implemented IoT devices applied to waste collection. Publications that were purely theoretical, focused on industrialized countries, or addressed related domains such as recycling were automatically excluded. **Table 1** summarizes the main inclusion and exclusion criteria used to filter the 329 publications initially identified. These criteria narrowed the final corpus to 36 studies relevant for analysis. This filtering framework ensured analytical coherence while maintaining a diversity of case studies useful for examining the transferability of solutions in low-resource contexts, particularly in sub-Saharan Africa.

Table 1. Summary of inclusion and exclusion criteria applied to the systematic review.

Category	Inclusion Criteria	Exclusion Criteria
Geographical scope	Studies conducted in developing countries or low-resource settings	Studies focused on high-income countries or areas with high technological density
Application domain	Solid waste collection through IoT devices (sensors, networks, platforms)	Studies limited to sorting, recycling, or general environmental management
Type of technology	Effective integration of sensors, microcontrollers, wireless networks, or IoT cloud platforms	Conceptual works without deployment or non-operational prototypes
Methodology	Empirical studies, pilot projects, or field experiments	Theoretical models without validation or purely abstract simulations
Publication period	Studies published between 2016 and 2024	Publications prior to 2016 or not peer-reviewed
Language of publication	Articles written in English or French	Works in other languages that are inaccessible or not translated

2.5. Selection Process

The selection process of studies was conducted in accordance with the principles of the PRISMA protocol, ensuring transparency in the steps leading from the initial identification to the constitution of the final corpus. Only publications meeting the defined inclusion criteria (**section 2.4**) were retained, with a constant emphasis on traceability.

The literature search, carried out between March and May 2025, identified 329 publications from IEEE Xplore, ScienceDirect, SpringerLink, and Scopus. After removing duplicates and performing an initial screening based on titles and abstracts, 137 articles were selected for full-text reading. Of these, 101 were excluded due to lack of contextual relevance, purely theoretical approaches, or no direct connection to IoT-enabled waste collection. The final corpus thus consists of 36 empirical studies. Figure 1 illustrates this process through a simplified PRISMA flow diagram, showing the number of records at each stage and the main reasons for exclusion. This scheme reinforces the methodological robustness of the selection.

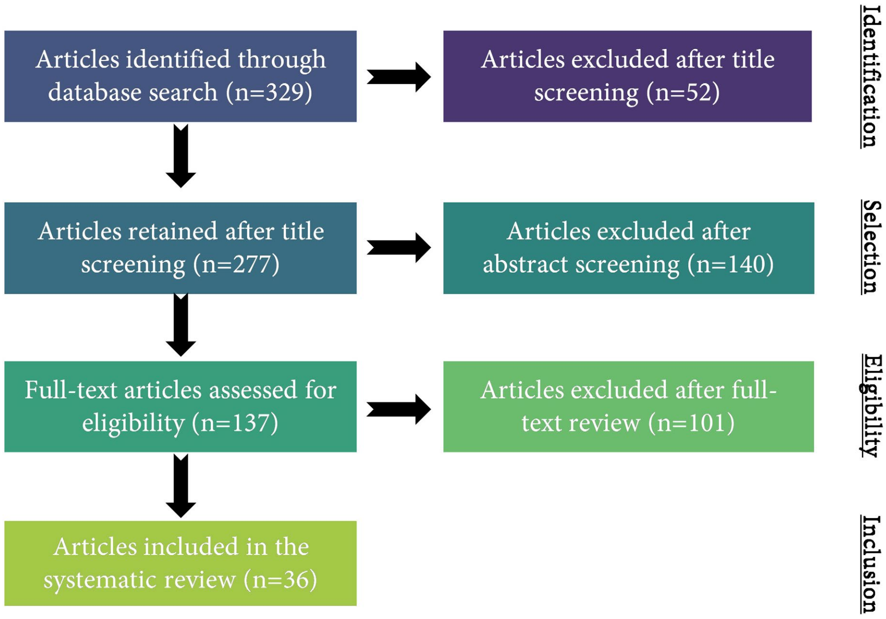

Figure 1. PRISMA flow diagram of study selection process (2016 - 2024).

2.6. Quality Appraisal

The methodological rigor of the 36 included studies was assessed using the Mixed Methods Appraisal Tool [32] across five dimensions: clarity of research questions, adequacy of data collection, appropriateness of study design, risk of bias and validity of measurements, and quality of analysis.

All studies obtained high scores (86% - 97%), indicating a solid and homogeneous evidence base. Even at the lower end of this range, the studies reflected satisfactory design and reporting, excluding any weak evidence. This homogeneity results from the rigorous PRISMA-guided inclusion and exclusion process and reinforces the internal validity of the synthesis, while also providing a benchmark for future comparative reviews on IoT-enabled waste collection.

2.7. Thematic Coding and Method of Analysis

The analysis of the 36 selected studies was based on an inductive thematic coding approach, allowing the identification of recurring dimensions, differentiating factors, and areas of tension related to the adaptation of IoT technologies in low-resource countries. This method enabled the structuring of extracted data into coherent analytical categories, combining technical, social, economic, and environmental dimensions.

The analysis process was carried out in two phases. First, a coding framework was developed around five main thematic axes, which also served as concrete criteria for assessing transferability: (i) technology, including type of sensors, microcontrollers, and energy compatibility; (ii) infrastructure and connectivity, *i.e.* network reliability and energy autonomy; (iii) community participation, such as citizen involvement and social acceptability; (iv) operational efficiency, including measurable gains in collection frequency or fuel savings; and (v) cost and scalability, covering deployment and maintenance feasibility. A solution was considered transferable when it achieved satisfactory performance across these dimensions while remaining compatible with the constraints of low-resource African urban settings.

Second, each article was read in full and manually coded using a matrix that cross-referenced these five axes (Table 2). Quantitative data (e.g., frequency of use of a sensor or network protocol) were aggregated to produce statistical visualizations. Qualitative data (narratives, contextual limitations, local successes) were synthesized as comparative observations. This dual reading, both qualitative and interpretative, provided a cross-cutting view of practices in smart waste collection and helped build a typology of approaches adapted to low-resource environments.

Data extraction was carried out using a structured synthesis table specifically designed for this review. This tool centralized key information from each study in a systematic and comparable manner, directly linked to the thematic coding axes. The table was developed in Microsoft Excel, which facilitated sorting, linking variables, and generating statistical graphs. This process proved essential for structuring the comparative analysis and highlighting trends, convergences, and divergences across geographical and technological contexts.

The coding framework was organized along thematic dimensions such as hardware (sensors, microcontrollers), network technologies, user/community participation, governance mechanisms, and contextual implementation factors. While the review included 36 studies, some of them reported multiple occurrences (e.g., different sensors, microcontrollers, or network types), meaning that a single study could contribute to several categories within a dimension. As a result, denominators vary across figures, which prevents totals from exceeding 100% and ensures a transparent representation of the coded distributions.

Table 2. General description of the 36 smart waste management initiatives.

Study	**Adaptation** Techniques	Connectivity Solutions	Integration of Community Engagement	Operational Efficiency Gains	Cost and Scalability
[33]	Low-cost smart bins with remote monitoring adapted for Nigerian urban areas	Sensor data transmission via Wi-Fi for real-time monitoring	Limited direct community participation; focus on environmental justice	Improved efficiency in terms of time and energy; reduced bin congestion	Focus on accessibility and sustainability in low-income settings
[1]	Ultrasonic sensors and dynamic routing algorithms adapted to Lahore's infrastructure	LoRaWAN and cellular networks for city-wide coverage	No explicit community engagement; system-centered optimization	32% improvement in route efficiency; 29% fuel reduction	Demonstrated scalability through cloud analysis and pilot validation

Continued

[34]	Sensor models with regression and classification for waste forecasting in Indian metropolises	Internet-based data transmission with GPS tracking	No direct community participation; focus on system automation	Dynamic route optimization and waste prediction	Focus on cost reduction through sensor-based automation
[35]	Arduino-based smart bins with ultrasonic and infrared sensors for Bangladesh	Wi-Fi, GPS, and GSM modules for connectivity	No community engagement; system alerts waste collectors	Alerts reduce overflow and save collection time	Designed to be cost-effective in resource-limited settings
[36]	Solar-powered smart bins with intermittent cloud connectivity for Bangladesh	Cloud-based data storage with intermittent connectivity	Mobile apps for waste collectors; indirect community interface	Dynamic route planning via mobile apps	Renewable energy integration enhances sustainability and scalability
[37]	Blockchain-enabled VANET for decentralized solid waste management in Pakistan	UHF and geofencing with blockchain for secure communication	No direct community engagement; focus on system security	Real-time vehicle tracking and waste collection monitoring	Pilot results suggest scalable and reliable deployment
[38]	Ultrasonic, weight, and gas sensors with Arduino for rapid waste collection	Data sent to municipal server via IoT	No community engagement; system alerts municipal authorities	Real-time monitoring allows rapid waste collection	Focus on practical and low-cost implementation for developing cities
[39]	Smart bins with mobile app integration for Bangladeshi municipalities	IoT-based communication between bins and control centers	Mobile app allows citizens to report and provide feedback	Sensors and human inputs improve waste management responsiveness	Community acceptance survey; system designed for scalability
[40]	IoT smart bins with semantic web and gamification for Indonesia	ESP32 Wi-Fi for data transmission; load cells and ultrasonic sensors	Gamification encourages user participation and waste reduction	Automated updates of bin weight and status improve management	Prototype tested; gamification enhances engagement and sustainability
[2]	Low-cost smart bins with Wi-Fi sensors for Nigerian cities	Wi-Fi network for remote bin level monitoring	No direct community engagement; focus on operational benefits	Time, energy efficiency, and congestion reduction	Emphasis on economic benefits for sustainable urban deployment
[41]	Theoretical analysis of challenges and benefits of IoT adoption in India	Not specified; focus on communication framework	Discusses producer acceptance and waste management	Potential to improve monitoring and management efficiency	Highlights initial investment and training costs as barriers

Continued

[17]	Identification of IoT adoption barriers in India using Fuzzy DEMATEL	Not applicable; focus on barrier analysis	Highlights lack of awareness and community engagement	Barriers include lack of planning and dynamic routing	Financial and regulatory challenges limit scalability
[42]	Review of smart collection and transport technologies for urban areas	ICT-based real-time monitoring and tracking technologies	Notes lack of social awareness and public participation	Stresses need for data-driven planning and route optimization	Cost-effectiveness and resource constraints are crucial in developing countries
[16]	MADM framework to evaluate IoT adoption barriers in Indian smart cities	Not applicable; decision-making framework for barrier prioritization	Identifies community awareness and service provider challenges	Barriers impact operational efficiency and technology adoption	Supports policy decisions for better scalability and cost management
[20]	Performance analysis of LoRaWAN and NB-IoT for developing countries	LoRaWAN more energy-efficient; NB-IoT more reliable	No community engagement goal; technical performance study	Network reliability and latency impact operational efficiency	Trade-offs between cost and energy consumption affect scalability
[43]	IoT waste collection system adapted to Parakou, Benin	Sensor-equipped bins with real-time alerts	No explicit community engagement; system-centered approach	Optimizes resource deployment and reduces operational costs	Designed for urban, resource-limited environments
[44]	Smart bin system with optimized routing for Ghana	Bin-level detection via microcontroller with GSM alerts	Mobile app for drivers; indirect community interface	Real-time monitoring improves collection efficiency	GSM latency noted; system designed for scalability
[45]	Smart bin with ultrasonic sensor and cloud communication for rural areas	Cloud-based remote monitoring via IoT	App monitors waste levels; no direct community role	90% fill-level detection accuracy improves scheduling	Cost-effective design for underdeveloped and rural environments
[46]	ESP8266-based system with ultrasonic and soil moisture sensors	Wi-Fi module for real-time data transmission	No community engagement; system alerts authorities	Dynamic route adjustment reduces fuel and operational costs	Promotes circular economy and environmental sustainability
[47]	IoT-based waste segregation with machine learning for smart cities	ESP32 and ultrasonic sensors with IoT communication	No direct community involvement; system alerts municipality	Automated segregation and timely collection improve efficiency	Focus on reducing human effort and enhancing scalability

Continued

[26]	Real-time monitoring and separation of dry and wet waste using IoT	Sensor network with automatic data logging and notifications	No explicit community engagement; focus on system automation	Optimizes collection and route planning	Suitable for both large and small urban environments
[48]	LoRa technology for real-time monitoring of bin fill level and air quality	LoRa communication for low-power, long-distance data transfer	No community engagement; technology-centered approach	Data-driven resource allocation and environmental monitoring	Cost-effective and scalable for residential and commercial areas
[49]	IoTBinCap algorithm for optimized collection schedules in urban areas	Sensor integration with IoT and simulation-based validation	No community engagement; focus on operational efficiency	Improved bin usage and reduced overflows	Algorithm allows scalable management of urban waste
[50]	Smart waste management based on LoRa with Floyd-Warshall routing	Low-cost sensors and LoRa for real-time data transmission	No community engagement; system-centered approach	Shortest path routing saves time and resources	Affordable, easy-to-replace components enhance scalability
[51]	Dual-detection bins equipped with ultrasonic and methane sensors for decay detection	ESP32 Wi-Fi modules with cloud analytics and machine learning	No direct community engagement; data-driven approach	15% improvement in route efficiency; decay monitoring	Scalable AI-enhanced system for urban cleanliness
[52]	Smart bins with machine learning for route optimization	Arduino MKR Wi-Fi and ultrasonic sensors for real-time data	No community engagement; focus on automation	Reduced collection time, costs, and environmental impact	Practical implementation for smart urban waste management
[53]	Deep learning and IoT for autonomous waste sorting and route planning	IoT sensors combined with AI algorithms for classification	User engagement features encourage responsible disposal	Reduced operational costs and environmental footprint	Scalability challenged by infrastructure and data needs
[54]	IoT smart bins with real-time monitoring in urban settings	Sensor-equipped bins with machine learning and AI integration	No direct community engagement; system-centered	50% increase in collection frequency; 20% fuel savings	High initial costs offset by operational benefits
[55]	Multi-sensor IoT system with cloud server for waste monitoring	Wi-Fi communication for remote data access	No explicit community engagement; system alerts authorities	Real-time monitoring supports waste reduction strategies	Cloud-based system designed for urban scalability

Continued

[56]	IoT smart waste system with RFID, sensors, and admin website	Wi-Fi module for real-time bin status notifications	User website informs public about nearest bin status	Prevents overflow and reduces financial costs	Cement bin bodies improve safety and durability
[57]	IoT waste management using RPL protocol for optimized routing	RPL routing protocol for efficient, low-power data transfer	No community engagement; focus on network efficiency	Reduces time, fuel, and labor for waste collection	Protocol supports scalable IoT network deployment
[13]	Real-time IoT-based monitoring for urban waste management in India	Cloud platform with automated alerts for municipal response	No direct community engagement; system alerts authorities	Enables rapid intervention and reduces illegal dumping	Designed for proactive, scalable urban deployment
[58]	Multi-sensor IoT system with machine learning for waste monitoring	Arduino and ESP32 platforms with real-time data alerts	No direct community engagement; system automation	Improves efficiency of waste collection and separation	Cost-effective solution suited for urban environments
[59]	IoT-based smart waste management integrating all stakeholders	Android and web apps for coordination between households and disposal sites	High community involvement through mobile and web platforms	Automated system streamlines entire waste management chain	360-degree system designed for full automation and scalability
[8]	IoT architecture based on LoRa for Bangalore solid waste management	LoRa for long-distance, low-power data transmission	No community engagement; focus on system architecture	Efficient data collection and monitoring via MQTT protocol	Low-power, long-range features enable urban scalability
[60]	IoT-based framework with two types of smart bins designed specifically for COVID-19 affected households; dynamic waste collection scheduling and route optimization	Hybrid architecture: Wi-Fi for residential bins + LoRaWAN for public bins; integration with Blynk app, push notifications, and Telegram alerts	Indirect: special teams designated to collect from COVID households to avoid contamination spread	Improves packet delivery ratio and throughput compared to existing systems; reduces operational costs; ensures timely waste collection from sensitive areas	Cost-effective due to hybrid networking; scalable to urban areas; reduces segregation costs since waste is separated at source

3. Results

3.1. Temporal and Geographical Evolution of Research

The annual distribution of publications identified in this review reveals a relatively stable dynamic between 2016 and 2022, with an average ranging from one to four articles per year. A clear inflection point, however, is observable from 2023 onward, marking a turning point in the attention given to the adaptation of IoT technologies to waste management in low-resource countries. This growth is linked to the democratization of low-cost microcontrollers and the wider adoption of low-power wide-area networks (LPWAN), particularly LoRa [8] [20] [48] [50].

This trend, illustrated in Figure 2, reflects renewed interest in more accessible technological solutions capable of addressing the structural constraints of precarious urban contexts. The dips observed in 2020 and 2022 may be associated both with the global disruption of research caused by the COVID-19 pandemic and with a stagnation in methodological approaches on this topic, due to the absence of significant renewal in analytical frameworks.

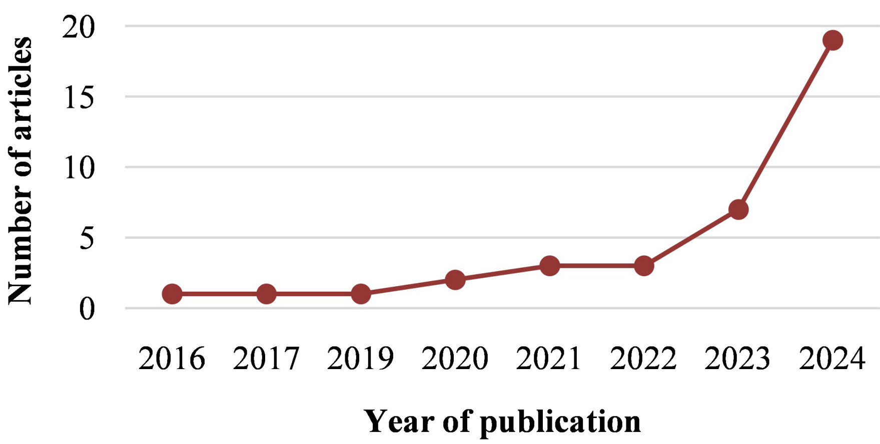

Figure 2. Temporal distribution of included studies by year of publication (2016 - 2024, n = 36).

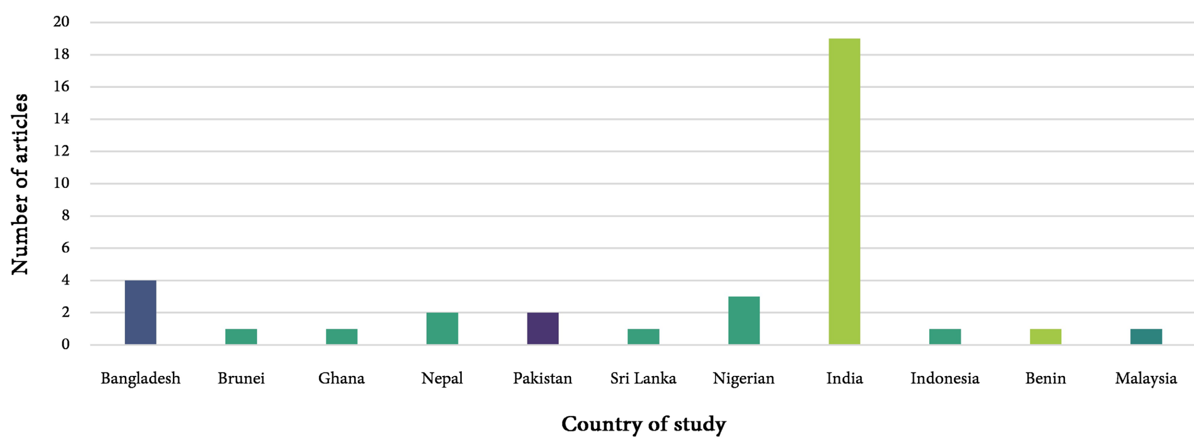

Figure 3. Geographical distribution of included studies across regions (n = 36).

From a geographical perspective, **Figure 3** highlights a strong concentration of studies in South Asia, particularly in India, which alone represents a large majority of the corpus, followed by Bangladesh and Pakistan. In Africa, Nigeria emerges as the main contributor, alongside a few West African countries such as Benin and Ghana. By contrast, Francophone Africa, and particularly the Democratic Republic of Congo, is almost absent from the experiments identified. This imbalance in scientific production raises questions about the representativeness of the existing results and limits the scope of the developed models in terms of transferability. It underscores the need to broaden study sites in order to better capture the diversity of contexts and local constraints when reflecting on the implementation of IoT in urban waste management.

3.2. Typologies of Technological Solutions

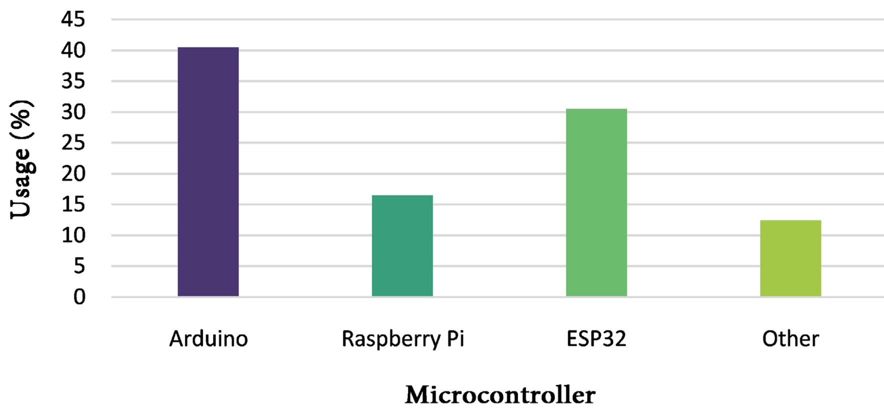

Figure 4. Distribution of microcontroller platforms (n = 38 coded occurrences across 36 studies).

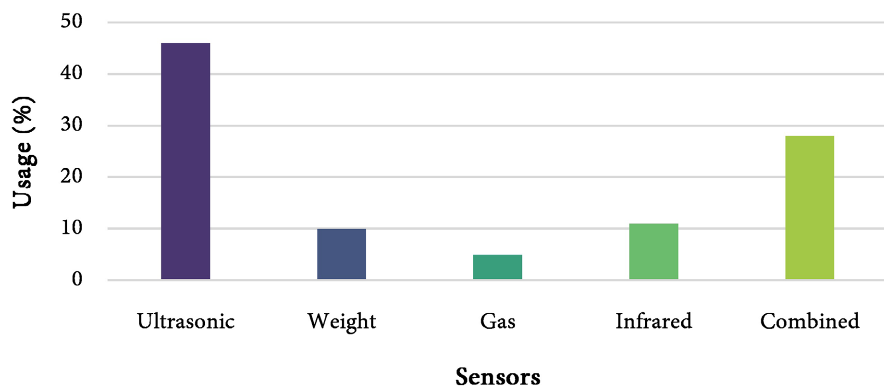

Figure 5. Distribution of sensor types (n = 51 coded occurrences across 36 studies).

The majority of the devices identified rely on a homogeneous architecture centered on ultrasonic sensors, present in nearly 46% of cases (**Figure 4**). This choice reflects a compromise between cost, energy consumption, and ease of integration, but limits adaptability to complex or highly heterogeneous urban environments. Multi-sensor configurations, still in the minority (28%), introduce gains in precision but remain underexplored, particularly in low-infrastructure settings.

In terms of microcontrollers, Arduino dominates (42%), followed by ESP32 (30%) and Raspberry Pi (17%) (**Figure 5**). These platforms are favored for their low cost and technical accessibility, but their adoption often remains disconnected from contextual constraints such as energy stability or the need for embedded processing. The use of more advanced microcontrollers, or those specifically designed for constrained environments, remains marginal, highlighting a standardized approach with limited orientation toward frugal engineering or contextual resilience.

3.3. Communication Networks Used

Communication protocols play a key role in the viability of these systems. **Figure 6** highlights the predominance of Wi-Fi–based systems, used in approximately 27% of the studies analyzed. This frequency of use can be attributed to the ease of integrating Wi-Fi modules into low-cost hardware architectures, particularly via microcontrollers such as Arduino or ESP8266. However, this technical option assumes the existence of a stable network, a condition rarely met in low-resource urban contexts, which raises questions about the actual transferability of these devices.

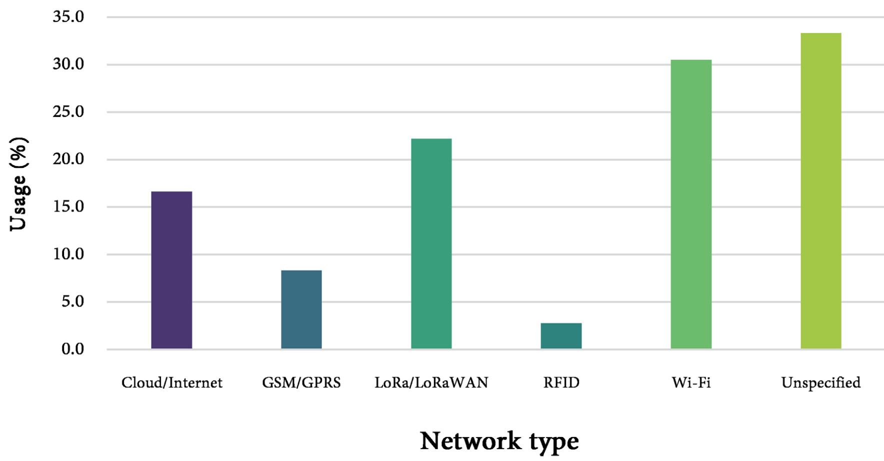

Figure 6. Distribution of network technologies (n = 41 coded occurrences across 36 studies).

In parallel, the growing use of LoRa and LoRaWAN networks, present in nearly 20% of cases, reflects an attempt to adapt to connectivity constraints. These long-range, low-power protocols offer significant potential in environments where telecommunication infrastructures are fragmented or absent. Nevertheless, their deployment often remains confined to experimental frameworks, with their long-term viability not systematically demonstrated.

Other communication modes, such as cloud-based solutions, GSM, or RFID, remain marginal, while nearly 30% of the studies do not specify the transmission modalities, thus limiting the critical assessment of technological choices. Taken together, these observations underscore the presence of a technological bias in documented approaches, where local reliability is often relegated to the background in favor of theoretical performance. This tension between technical sophistication and infrastructural realities deserves greater attention in future research.

3.4. Community Integration and Local User Participation

Figure 7 highlights the limited consideration of end-users in the systems studied. Nearly 60% of the solutions include no form of user interaction, confirming a largely technocentric approach. Interaction through mobile applications, present in 31% of cases, is often limited to notification functions without genuine feedback mechanisms. Only 9% of the studies incorporate direct participation, through co-design tools, acceptability surveys, or gamified mechanisms aimed at strengthening user ownership. Although relevant, these initiatives remain marginal. The widespread absence of community engagement raises questions about the sustainability, maintainability, and local anchoring of the proposed solutions.

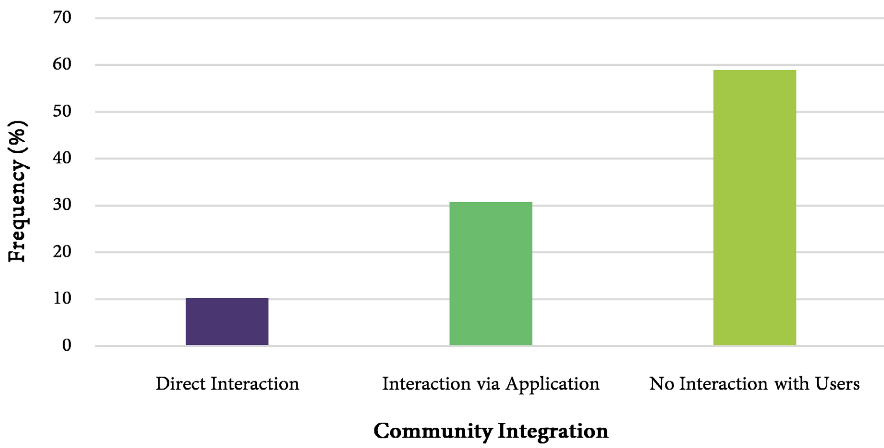

Figure 7. Community participation approaches (n = 36 studies).

3.5. Functional Objectives and Scalability Constraints

The most frequently pursued technological objectives relate to collection monitoring (Figure 8), improvements in operational efficiency, and route optimization. These priorities reflect a logistics-oriented approach, often at the expense of more systemic issues such as waste sorting or environmental analysis. While pragmatic, this functional concentration tends to reduce the transformative scope of the proposed solutions.

At the same time, the identified constraints reveal a persistent tension between technical ambitions and contextual feasibility (Figure 9). Although some solutions claim demonstrated scalability, nearly half of the cases mention economic, technical, or regulatory limitations. Profitability in low-resource settings constitutes a recurrent design criterion but is rarely associated with mechanisms for sustainable support. The integration of renewable energy remains marginal, highlighting a gap between sustainability discourse and actual technological choices. These trends point to the need to reorient system design toward architectures that are genuinely adapted to the constraints of low-resource territories.

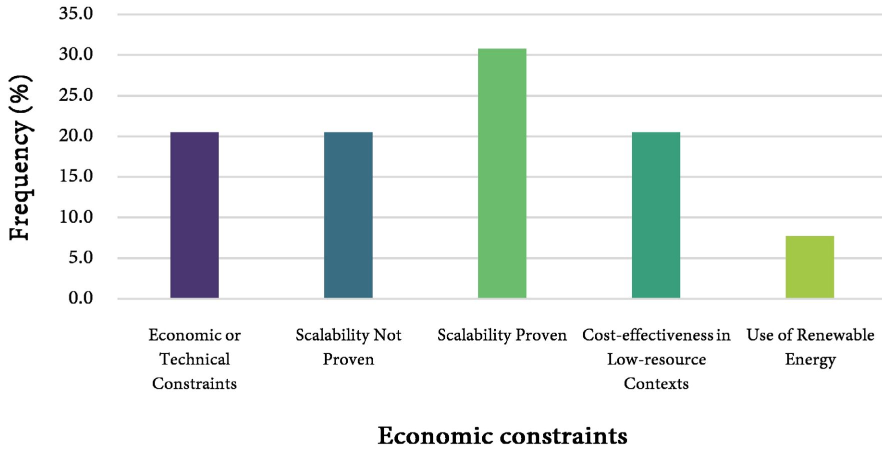

Figure 8. Governance and institutional mechanisms (n = 36 studies).

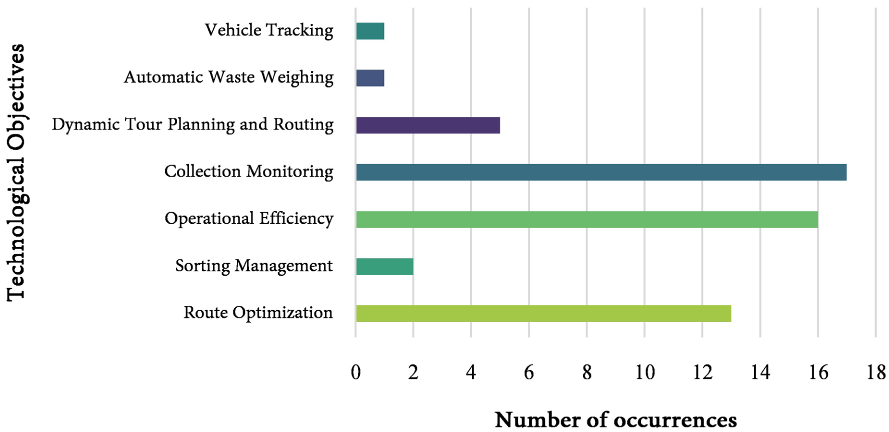

Figure 9. Contextual implementation barriers and enablers (n = 55 coded occurrences across 36 studies).

4. Discussion

4.1. Critical Synthesis of Results

The cross-analysis of studies reveals a constant finding: IoT solutions are transferable to low-resource countries only if they are deeply redesigned, not merely transposed. The most viable configurations are those that combine frugal engineering with a systemic sobriety logic. This is reflected in the use of low-power open-source electronic components, low-bandwidth long-range protocols such as LoRaWAN, and decentralized architectures that minimize dependence on the cloud [12] [35] [43] [61]. These technical choices, modest in appearance, enable resilience in the face of power outages, weak network coverage, and the absence of structured technical support. They contrast with dominant approaches, often inspired by smart city standards from the Global North, whose sophistication becomes counterproductive in environments where service continuity is a luxury.

Beyond technical considerations, the few projects that incorporated contextual variables into their optimization logics (such as road conditions, topographic accessibility, and overflow frequency) achieved significantly more operational results. In these cases, waste collection was no longer designed solely around distance but prioritized according to the physical and social realities of the field. However, the near-total absence of longitudinal evaluation, social acceptability assessments, or post-deployment monitoring limits the scope of the identified experiments. This gap reflects a recurrent bias in IoT approaches in Africa: innovation too often remains technocentric, ignoring usage dynamics, economic trade-offs, and local capacities for appropriation. Truly transferable projects are those that combine the demand for ingenuity with field pragmatism, envisioning technology as an adjustable lever rather than an end in itself [1] [27] [43].

4.2. Structural Limitations Encountered

The limitations identified in the studies reviewed are not solely the result of inappropriate technological choices but stem from a deeper mismatch between the implicit requirements of the systems designed and the social and material realities of the contexts where they are deployed. Many projects rest on the tacit assumption of a minimum functional infrastructure: stable electricity, continuous network coverage, and trained human resources. Yet, in the peripheral neighborhoods of many African cities, these conditions are rarely met [62] [63]. A single sensor requiring regular recharging or a GSM module dependent on a stable signal can become inoperative within the first weeks. The problem lies not in the complexity of the technology but in its inability to withstand discontinuity, irregularity, and lived realities.

Another striking observation is the institutional isolation in which these projects are embedded. Very few are integrated into municipal or regional waste management policies. Most are the result of ad hoc initiatives led by research consortia or startups, often without lasting connections to local authorities. This lack of anchoring prevents the creation of governance, maintenance, and financing ecosystems capable of sustaining the solution beyond the experimental stage. In the absence of structured dialogue among engineers, policymakers, operators, and citizens, technology becomes an alien body, deployed in a territory that cannot support or repair it. This institutional vacuum is not only a technical obstacle; it also contributes to the invisibilization of communities, who remain excluded from decisions that directly concern them.

4.3. Observed Pathways of Innovation

In response to the structural limitations identified, some studies reveal forms of innovation that are discreet yet significant. These advances do not lie in the introduction of sophisticated technologies but in the capacity to adapt simple solutions to constrained environments. The recurring combination of minimalist sensors and LoRaWAN networks illustrates this logic. Unlike heavier and unstable protocols in Global South contexts, LoRa provides wide coverage with very low energy consumption, enabling systems that can operate for several months without recharging. The integration of microcontrollers such as ESP32 or Arduino, which are locally available and well documented, reinforces system autonomy while facilitating maintenance by non-specialist technicians. Here, innovation is not about power, but about robustness and continuity.

Other studies have proposed devices that go beyond the technical dimension alone by introducing a form of dialogue between the collection system and inhabitants. This link is established through accessible interfaces, SMS alerts, or community reporting systems. In some cases, sending notifications when bins are full or awarding reward points for punctual reports has helped strengthen user adherence. These approaches suggest that the intelligence of a system lies not only in its algorithms but also in its capacity to recognize citizens as co-actors. Finally, attempts to model waste collection routes contextually, by integrating variables such as road conditions, area usage, or risk levels, demonstrate a fine-grained understanding of the urban fabric. Where standardization fails, these approaches show that it is possible to design systems capable of embracing the shapes, ruptures, and urgencies of a living city.

4.4. Proposal for an Adapted Hybrid Model

The lessons drawn from this review suggest that a truly functional IoT system in low-resource contexts cannot be limited to superficial adaptation. It must be redesigned from the ground up, based on both vulnerabilities and often underestimated capacities [64]. The model proposed here does not aim to mimic Western standards reduced to their simplest form. On the contrary, it seeks to compose a sober yet intelligent architecture that combines technical robustness, social accessibility, and sensitivity to local dynamics. As illustrated in **Figure 10**, this hybrid architecture integrates both the technological components and the governance mechanisms required to adapt IoT-based waste collection to African urban contexts.

The device is based on a contextual priority index constructed from variables rooted in urban realities: physical accessibility of sites, road quality, frequency of overflows, and vulnerability of serviced areas such as markets, schools, or health centers. This index makes it possible to rank waste collection points according to a relevant order of treatment, not based on abstract metrics but on concrete criteria that directly affect residents' quality of life. Once this prioritization is established, collection routes are optimized locally within each sector by an algorithm that takes into account terrain discontinuities.

On the hardware side, the system relies on ultra-low-power sensors powered by small solar modules, supported by microcontrollers capable of performing simple local computations. This reduces dependence on constant connectivity. Intelligence is distributed rather than centralized, protecting the system against network outages. On the user side, the interface is designed to work with tools already in common use: basic phones, SMS, and USSD menus. This approach is not about reducing technological ambitions but about cultivating an attentive form of ingenuity that turns constraints into drivers of innovation. In a country such as the DRC, it is less about importing technology than about claiming the right to a better organized city, where digital tools act as mediators rather than barriers.

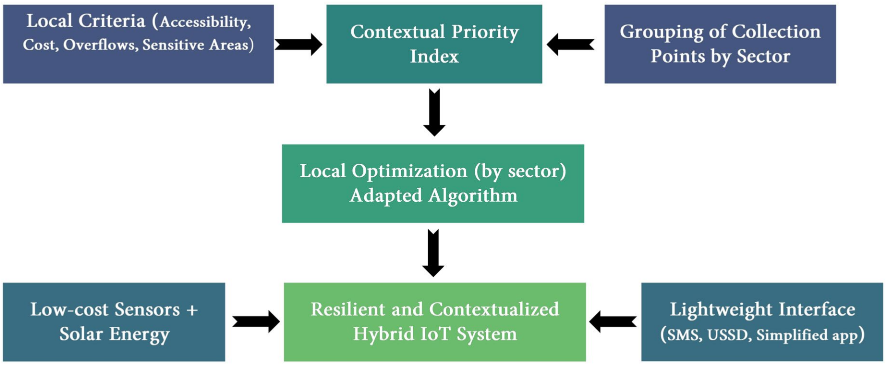

Figure 10. Conceptual diagram of the adapted hybrid IoT model.

4.5. Limitations

While this review provides valuable insights into IoT-enabled waste collection in developing contexts, several limitations should be acknowledged. First, the search strategy relied on four major scientific databases, which, although comprehensive, may have excluded relevant studies indexed in other repositories, particularly regional databases. Second, only articles published in English and French were included, introducing a potential language bias and possibly overlooking contributions in other widely spoken languages in Africa and Asia. Third, this review synthesized findings descriptively without conducting a meta-analysis, which limits the ability to quantify effect sizes and statistically compare outcomes across studies.

Despite these limitations, the systematic PRISMA-guided approach, combined with the quality appraisal of included studies, ensures that the evidence base remains methodologically robust and relevant for informing future IoT-enabled waste management initiatives in African cities.

4.6. Implications for Research and Public Policy

The lessons drawn from this review extend beyond the technological field. They call for a broader reflection on how research is produced and how public policies are formulated in low-resource environments. On the academic side, it has become urgent to move beyond the paradigm of isolated technological demonstrations. Too many initiatives still focus on validating prototypes under ideal conditions, without considering the human, economic, and institutional variables that determine their viability. Research on IoT applied to waste management would gain in relevance if it adopted a transdisciplinary stance, bridging engineering sciences, urban studies, the sociology of practices, and the political economy of infrastructures. Such a shift in approach would also require a rethinking of performance evaluation criteria by integrating indicators of social sustainability, operational resilience, and citizen appropriation.

For public policymakers, this review highlights that useful innovation is not that which comes from outside, but that which is adjusted to the local fabric. An effective policy for modernizing waste management in the African context cannot be reduced to tenders for the import of turnkey technologies. It must begin with the establishment of flexible regulatory frameworks, open to experimentation, and capable of supporting local initiatives. This also involves financing pilot projects rooted in neighborhoods, training technicians capable of maintaining equipment, and fostering stronger articulation between municipalities, private operators, and communities. At the municipal level, it would be relevant to create urban innovation units able to test, adapt, and gradually scale up co-constructed solutions. For behind every uncollected waste item lies less a technical problem than a failure of collective organization. And this is precisely what public policies can address if they build on knowledge drawn from the field.

5. Conclusions

The results of this systematic review highlight a fundamental truth: in low-resource environments, it is not the technology itself that makes the difference, but its ability to adjust to reality. The direct export of IoT models designed for very different contexts has little impact, and may even reinforce inequalities in access to services. Adaptation, not importation, must therefore guide all technological innovation efforts in the field of urban waste management.

The most promising approaches identified in this review are not those that are the most technologically advanced, but those that combine three essential principles. Technical simplicity, which allows for local ownership and maintenance. Contextual logic, which grounds every choice in a fine-grained understanding of the constraints and opportunities of the territory. And finally, citizen participation, which transforms users into co-responsible actors within the system. It is at this intersection that truly transferable, effective, and sustainable solutions can be found.

In light of these findings, several recommendations can be formulated. First, technology should be conceived as a support tool rather than an end in itself, carefully adapted to local uses, skills, and expressed needs. Second, open, modular, and scalable architectures should be favored in order to enable progressive adjustments rather than uniform and rigid deployments. Finally, each experiment should be firmly anchored in a localized process that integrates evaluation, iteration, and collective learning before any national-scale extension.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Addas, A., Khan, M.N. and Naseer, F. (2024) Waste Management 2.0 Leveraging Internet of Things for an Efficient and Eco-Friendly Smart City Solution. *PLOS ONE*, **19**, e0307608. https://doi.org/10.1371/journal.pone.0307608

[2] Okubanjo, A., Bashir Olufemi, O., Okandeji, A. and Daniel, E. (2024) Smart Bin and

IoT: A Sustainable Future for Waste Management System in Nigeria. *Gazi University Journal of Science*, **37**, 222-235. https://doi.org/10.35378/gujs.1254271

[3] Nsokimieno Eric, M.M., Shouyu, C. and Li Qin, Z. (2010) Sustainable Urbanization's Challenge in Democratic Republic of Congo. *Journal of Sustainable Development*, **3**, Article No. 242. https://doi.org/10.5539/jsd.v3n2p242

[4] Pardini, K., Rodrigues, J.J.P.C., Diallo, O., Das, A.K., de Albuquerque, V.H.C. and Kozlov, S.A. (2020) A Smart Waste Management Solution Geared Towards Citizens. *Sensors*, **20**, Article 2380. https://doi.org/10.3390/s20082380

[5] Pour, M., James, L., Singh, K., Mampunza, S., Baer, F., Scott, J., *et al.* (2020) Increased HIV in Greater Kinshasa Urban Health Zones: Democratic Republic of Congo (2017-2018). *AIDS Research and Therapy*, **17**, Article No. 67. https://doi.org/10.1186/s12981-020-00322-y

[6] Semeki Ngabinzeke, J., Kaki Mokuba, H., Tasi Mbuangi, J., Baraka Lucungu, P., Bolaluembe Boliale, P. and Kahindo Muhongya, J. (2021) Perceptions of Residents of the Kinkole Neighborhood on the Role of Trees in the Peri-Urban Environment of Kinshasa, Democratic Republic of Congo. *Journal of Plant Sciences*, **9**, Article 46. https://doi.org/10.11648/j.jps.20210902.13

[7] Zoumpoulis, P., Konstantinidis, F.K., Tsimiklis, G. and Amditis, A. (2024) Smart Bins for Enhanced Resource Recovery and Sustainable Urban Waste Practices in Smart Cities: A Systematic Literature Review. *Cities*, **152**, Article 105150. https://doi.org/10.1016/j.cities.2024.105150

[8] Bharadwaj, A.S., Rego, R. and Chowdhury, A. (2016) IoT Based Solid Waste Management System: A Conceptual Approach with an Architectural Solution as a Smart City Application. 2016 *IEEE Annual India Conference* (*INDICON*), Bangalore, 16-18 December 2016, 1-6. https://doi.org/10.1109/indicon.2016.7839147

[9] Denih, A., Matsumoto, T., Rachman, I., Putra, G.R., Anggraeni, I., Kurnia, E., *et al.* (2025) Identification of Plastic Waste with Unmanned Aerial Vehicle (UAV) Using Deep Learning and Internet of Things (IoT). *Journal of Hazardous Materials Advances*, **18**, Article 100622. https://doi.org/10.1016/j.hazadv.2025.100622

[10] Henaien, A., Ben Elhadj, H. and Chaari Fourati, L. (2024) A Sustainable Smart IoT-Based Solid Waste Management System. *Future Generation Computer Systems*, **157**, 587-602. https://doi.org/10.1016/j.future.2024.03.056

[11] Hussain, D.I., Elomri, D.A., Kerbache, D.L. and Omri, D.A.E. (2024) Smart City Solutions: Comparative Analysis of Waste Management Models in IoT-Enabled Environments Using Multiagent Simulation. *Sustainable Cities and Society*, **103**, Article 105247. https://doi.org/10.1016/j.scs.2024.105247

[12] Sumathi, M., Hanumanthappa, J., Santhosh Kumar, K.S., Shiva Prakash, S.P. and J., M. (2025) IoT-Based Efficient Waste Management on University Campus: Enhancing Monitoring and Optimization through Machine Learning. *Procedia Computer Science*, **258**, 4157-4168. https://doi.org/10.1016/j.procs.2025.04.666

[13] Ingale, K., Jaiswal, K.N., Kawane, A.P., Kalushe, T. and Kurkute, P. (2024) Transforming Waste, Safegurading Cities: An IoT-Driven Revolution for Smarter and Greener Urban Management. 2024 5*th International Conference for Emerging Technology* (*INCET*), Belgaum, 24-26 May 2024, 1-8. https://doi.org/10.1109/incet61516.2024.10593089

[14] Lopez-Vargas, A., Fuentes, M. and Vivar, M. (2020) Challenges and Opportunities of the Internet of Things for Global Development to Achieve the United Nations Sustainable Development Goals. *IEEE Access*, **8**, 37202-37213. https://doi.org/10.1109/access.2020.2975472

[15] Ansari, A., Dutt, D. and Kumar, V. (2024) Catalyzing Paradigm Shifts in Global Waste Management: A Case Study of Saharanpur Smart City. *Waste Management Bulletin*, **2**, 29-38. https://doi.org/10.1016/j.wmb.2023.12.003

[16] Mishra, A.R., Rani, P., Saha, A., Hezam, I.M., Pamucar, D., Marinovic, M., *et al.* (2022) Assessing the Adaptation of Internet of Things (IoT) Barriers for Smart Cities' Waste Management Using Fermatean Fuzzy Combined Compromise Solution Approach. *IEEE Access*, **10**, 37109-37130. https://doi.org/10.1109/access.2022.3164096

[17] Yadav, H., Soni, U. and Kumar, G. (2021) Analysing Challenges to Smart Waste Management for a Sustainable Circular Economy in Developing countries: A Fuzzy DeMatel Study. *Smart and Sustainable Built Environment*, **12**, 361-384. https://doi.org/10.1108/SASBE-06-2021-0097

[18] Yousefian, F., Hassanvand, M.S., Nodehi, R.N., Amini, H., Rastkari, N., Aghaei, M., *et al.* (2020) The Concentration of BTEX Compounds and Health Risk Assessment in Municipal Solid Waste Facilities and Urban Areas. *Environmental Research*, **191**, Article 110068. https://doi.org/10.1016/j.envres.2020.110068

[19] Singh, D., Dikshit, A.K. and Kumar, S. (2024) Smart Technological Options in Collection and Transportation of Municipal Solid Waste in Urban Areas: A Mini Review. *Waste Management & Research*: *The Journal for a Sustainable Circular Economy*, **42**, 3-15. https://doi.org/10.1177/0734242x231175816

[20] Ugwuanyi, S., Paul, G. and Irvine, J. (2021) Survey of IoT for Developing Countries: Performance Analysis of Lorawan and Cellular Nb-IoT Networks. *Electronics*, **10**, Article 2224. https://doi.org/10.3390/electronics10182224

[21] Coghlan, D. and Brydon-Miller, M. (2014) The SAGE Encyclopedia of Action Research. Sage.

[22] Bhuiyan, S.H. (2010) A Crisis in Governance: Urban Solid Waste Management in Bangladesh. *Habitat International*, **34**, 125-133. https://doi.org/10.1016/j.habitatint.2009.08.002

[23] Peng, L., Gu, M. and Peng, Z. (2020) Study on the Optimized Mode of Waste Governance with Sustainable Urban Development—Case from China's Urban Waste Classified Collection. *Sustainability*, **12**, Article 3706. https://doi.org/10.3390/su12093706

[24] Sugandha, Freestone, R. and Favaro, P. (2025) Social Sustainability, Smart Cities and the Global South: Learning from the Indian Experience. *Cities*, **165**, Article 106149. https://doi.org/10.1016/j.cities.2025.106149

[25] Zyoud, S. and Zyoud, A.H. (2025) Advancing Sustainable Cities and Communities with Internet of Things: Global Insights, Trends, and Research Priorities for SDG 11. *Results in Engineering*, **26**, Article 104917. https://doi.org/10.1016/j.rineng.2025.104917

[26] Chandre, V., Gharat, O., Ghonge, R., Kulkarni, S. and Jadhav, V. (2024) Intelligent Waste Management System using IOT. *International Journal of Innovative Science and Research Technology* (*IJISRT*), **9**, 2467-2472. https://doi.org/10.38124/ijisrt/ijisrt24apr2236

[27] Channi, H.K. and Kaur, S. (2025) Smart Waste Management Systems Integrating IoT for Real-Time Monitoring and Optimization. In: Mitra, D., Choudhury, T., Madan, A., Chattaraj, S. and Pellegrini, M., Eds., *Advances in Environmental Engineering and Green Technologies*, IGI Global, 319-348. https://doi.org/10.4018/979-8-3693-7282-1.ch015

[28] Lumami, K., Muyisa, S. and Jung, C.G. (2016) Contribution à l'état des lieux de déchets solides ménagers dans la ville D'Uvira, Sud-Kivu, République Démocratique

du Congo. *International Journal of Biological and Chemical Sciences*, **10**, Article 1413. https://doi.org/10.4314/ijbcs.v10i3.39

[29] Mpinda, M.T., Zakari, S., Abass, O.K., Nsokimieno, E.M.M., Sebagenzi, G.D., Basheke, L.L., *et al.* (2017) Characterization of Household Wastes in D.R. Congo, a Case Study of Lubumbashi. *American Journal of Environmental Sciences*, **13**, 277-288. https://doi.org/10.3844/ajessp.2017.277.288

[30] Munyaka, J.B. and Yadavalli, V.S.S. (2021) Using Transportation Problem in Humanitarian Supply Chain to Prepositioned Facility Locations: A Case Study in the Democratic Republic of the Congo. *International Journal of System Assurance Engineering and Management*, **12**, 199-216. https://doi.org/10.1007/s13198-020-01031-5

[31] Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., *et al.* (2021) The Prisma 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ*, **372**, n71. https://doi.org/10.1136/bmj.n71

[32] Hong, Q.N., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., *et al.* (2018) The Mixed Methods Appraisal Tool (MMAT) Version 2018 for Information Professionals and Researchers. *Education for Information*, **34**, 285-291. https://doi.org/10.3233/efi-180221

[33] Akintayo, T.A., Enabulele, E.C., Paul, C., Okereke, R.O., Sobajo, M.S., Afolabi, O.J., *et al.* (2024) Intelligent Recycling Facilities with IoT Sensors and Data Analytics for Environmental Justice and Sustainable Materials Processing in Low-Income Areas. *Journal of Multidisciplinary Science*: *MIKAILALSYS*, **2**, 399-413. https://doi.org/10.58578/mikailalsys.v2i3.3827

[34] Udhayakumar, C., Nithin Nandha, M., Pradeesh, V., Praveen, S. and Rohith, S. (2023) Smart Waste Management System for Metropolitan Areas. 2023 *International Conference on Computer Communication and Informatics* (*ICCCI*), Coimbatore, 23-25 January 2023, 1-3. https://doi.org/10.1109/iccci56745.2023.10128496

[35] Rifat, R.I., Haque, F.B., Jahan, T., Zahir, Z.B. and Khan, R. (2022) IoT Based Smart Garbage Management System. 2022 *International Conference on Communication*, *Computing and Internet of Things* (*IC3IoT*), Chennai, 10-11 March 2022, 1-6. https://doi.org/10.1109/ic3iot53935.2022.9767993

[36] Zahur, M.I., Saidur Rahman, M., Akther, A. and Alam, K.M. (2019) An IoT Based Green Waste Management System for Bangladesh. 2019 1*st International Conference on Advances in Science*, *Engineering and Robotics Technology* (*ICASERT*), Dhaka, 3-5 May 2019, 1-6. https://doi.org/10.1109/icasert.2019.8934475

[37] Saad, M., Ahmad, M.B., Asif, M., Khan, M.K., Mahmood, T. and Mahmood, M.T. (2023) Blockchain-Enabled VANET for Smart Solid Waste Management. *IEEE Access*, **11**, 5679-5700. https://doi.org/10.1109/access.2023.3235017

[38] Mohan, A., Johar, S. and Mini, S. (2017) A Waste Collection Mechanism Based on IoT. 2017 14*th IEEE India Council International Conference* (*INDICON*), Roorkee, 15-17 December 2017, 1-5. https://doi.org/10.1109/indicon.2017.8487711

[39] Paul, L., Mohalder, R.D. and Alam, K.M. (2024) An IoT Based Smart Waste Management System for the Municipality or City Corporations. arXiv:2411.09710.

[40] Tundjungsari, V., Putranto, B.P.D., Ulum, M.B. and Anwar, N. (2025) An Integrated Model for Circular Waste Management Using the Internet of Things, Semantic Web, and Gamification (Circonomy): Case Study in Indonesia. *JMIR Serious Games*, **13**, e66781-e66781. https://doi.org/10.2196/66781

[41] Das, P. and Gargate, G. (2024) IoT for Solid Waste Management in India: A Road Towards Sustainability. 2024 *Portland International Conference on Management of Engineering and Technology* (*PICMET*), Portland, 4-8 August 2024, 1-15.

https://doi.org/10.23919/picmet64035.2024.10653160

[42] Singh, S., Chhabra, R. and Arora, J. (2023) A Systematic Review of Waste Management Solutions Using Machine Learning, Internet of Things and Blockchain Technologies: State-of-Art, Methodologies, and Challenges. *Archives of Computational Methods in Engineering*, **31**, 1255-1276. https://doi.org/10.1007/s11831-023-10008-z

[43] Ange Mousse, M. (2024) IOT-Based Waste Collection Management System for Cities: Case Study of Parakou City in Benin. *International Journal of Advanced Research*, **12**, 654-659. https://doi.org/10.21474/ijar01/18597

[44] Xenya, M.C., D'souza, E., Woelorm, K.D., Nii Adjei-Laryea, R. and Baah-Nyarkoh, E. (2020) A Proposed IoT Based Smart Waste Bin Management System with an Optimized Route: A Case Study of Ghana. 2020 *Conference on Information Communications Technology and Society* (*ICTAS*), Durban, 11-12 March 2020, 1-5. https://doi.org/10.1109/ictas47918.2020.234005

[45] Kumar, N.V.M., Nagappan, G., Deepak, I.S., Charishma, J. and Sruthi, K.B. (2023) Smart Trash Bin-An Effective Solution for Rural and under Developed Areas. 2023 *International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics* (*IITCEE*), Bengaluru, 27-28 January 2023, 596-600. https://doi.org/10.1109/iitcee57236.2023.10090865

[46] Thangam, S., M, G., Yadav, C.S.K., Harshith, M. and Kumar, M.S. (2024) A Smart Waste Management System Using ESP8266. 2024 4*th International Conference on Sustainable Expert Systems* (*ICSES*), Kaski, 15-17 October 2024, 1-5. https://doi.org/10.1109/icses63445.2024.10762967

[47] Beena, K. and Santhi, P. (2024) IoT Based Waste Management and Segregation System. *International Journal of Multidisciplinary Research*, **6**, Article 21809.

[48] Azmi, A.Z., Mohd Sahar, N. and Islam, M.T. (2024) Smart Waste Management System Using Lora Technology. *E*3*S Web of Conferences*, **599**, Article 04007. https://doi.org/10.1051/e3sconf/202459904007

[49] Sankar, G.R. and Fathima, G. (2024) IoT-Enabled Smart Waste Management: A Comprehensive Study on Sensor Technologies and Implementation Strategies. 2024 *International Conference on Inventive Computation Technologies* (*ICICT*), Lalitpur, 24-26 April 2024, 1755-1764. https://doi.org/10.1109/icict60155.2024.10544982

[50] Laha, S.R., Pattanayak, B.K., Pattnaik, S. and Kumar, S. (2023) A Smart Waste Management System Framework Using IoT and Lora for Green City Project. *International Journal on Recent and Innovation Trends in Computing and Communication*, **11**, 342-357. https://doi.org/10.17762/ijritcc.v11i9.8370

[51] Rathnayake, R.M.P.M.D., Chanaka, T.M.M., Dabare, P.T.R. and Hewagamage, K.P. (2024) IoT-Enabled Dual-Sensing Smart Waste Management System: Enhancing Urban Cleanliness and Sustainability in Smart Cities. 2024 8*th SLAAI International Conference on Artificial Intelligence* (*SLAAI-ICAI*), Ratmalana, 18-19 December 2024, 1-6. https://doi.org/10.1109/slaai-icai63667.2024.10844960

[52] Dharan, P. and Manikandan, V.M. (2024) A Smart Waste Management System with Optimized Routing Method. 2024 15*th International Conference on Computing Communication and Networking Technologies* (*ICCCNT*), Kamand, 24-28 June 2024, 1-6. https://doi.org/10.1109/icccnt61001.2024.10725635

[53] Bonala, K., Saggurthi, P., Kambala, P.K., Voruganti, S., Utukuru, S. and Sugamya, K. (2024) Efficient Handling of Waste Using Deep Learning and IoT. 2024 2*nd International Conference on Sustainable Computing and Smart Systems* (*ICSCSS*), Coimbatore, 10-12 July 2024, 368-373. https://doi.org/10.1109/icscss60660.2024.10625621

[54] Mehta, S. and Singh, A. (2024) Real-Time Data and Waste Management Efficiency: Insights from IoT-Enabled Smart Bins. 2024 10*th International Conference on Electrical Energy Systems* (*ICEES*), Chennai, 22-24 August 2024, 1-5. https://doi.org/10.1109/icees61253.2024.10776870

[55] J, A., Elangovan, V., Muthukumar, V. and Chandrasekar, T. (2023) Waste Management System Using IoT for Sustainable Cities. 2023 *Second International Conference on Augmented Intelligence and Sustainable Systems* (*ICAISS*), Trichy, 23-25 August 2023, 1634-1639. https://doi.org/10.1109/icaiss58487.2023.10250610

[56] Bhowmik, A., Miah, M.S.U. and Mohaimen-Bin-Noor, (2020) IoT (Internet of Things)-Based Smart Garbage Management System. *AIUB Journal of Science and Engineering* (*AJSE*), **19**, 33-40. https://doi.org/10.53799/ajse.v19i1.55

[57] Logesswari, S. (2022) An IoT Based Waste Management System Using RPI Protocol. *AIP Conference Proceedings*, **2519**, Article 030090. https://doi.org/10.1063/5.0110685

[58] Srividya, K., Nivedhana, J., Amrudha, R. and Vijayaraj, M. (2024) Effective Sentitrash System for Urban and Rural Environments Using IoT and ML Technology-: A Comprehensive Solution Integrating Multiple Sensors with ESP32 and Arduino Platforms. 2024 *International Conference on Power*, *Energy*, *Control and Transmission Systems* (*ICPECTS*), Chennai, 8-9 October 2024, 1-6. https://doi.org/10.1109/icpects62210.2024.10780305

[59] Patil, S.C. and Gidde, M.R. (2024) An IoT-Based Waste Management Approach for Environmental Sustainability. *Journal of Integrated Science and Technology*, **12**, Article 769. https://doi.org/10.62110/sciencein.jist.2024.v12.769

[60] Saha, S. and Chaki, R. (2023) IoT Based Smart Waste Management System in Aspect of COVID-19. *Journal of Open Innovation*: *Technology*, *Market*, *and Complexity*, **9**, Article 100048. https://doi.org/10.1016/j.joitmc.2023.100048

[61] Ouattara, I., Diya, A., Diarra, Y. and Dembélé, O. (2021) Acteurs et stratégies de gestion des déchets solides ménagers à Bamako. *Revue Africaine des Sciences Sociales et de la Sante Publique*, **3**, 76-90. https://revue-rasp.org/index.php/rasp/article/view/138

[62] Guerrero, L.A., Maas, G. and Hogland, W. (2013) Solid Waste Management Challenges for Cities in Developing Countries. *Waste Management*, **33**, 220-232. https://doi.org/10.1016/j.wasman.2012.09.008

[63] Mpiana Tshitenge, J. (2018) Le service public d'électricité dans la périphérie de Kinshasa: Entre régulation de contrôle et régulation autonome. *Anthropologie & développement*, **48**, 67-95. https://doi.org/10.4000/anthropodev.674

[64] Kayisu, A.K., Mikusova, M., Bokoro, P.N. and Kyamakya, K. (2024) Exploring Smart Mobility Potential in Kinshasa (DR-Congo) as a Contribution to Mastering Traffic Congestion and Improving Road Safety: A Comprehensive Feasibility Assessment. *Sustainability*, **16**, Article 9371. https://doi.org/10.3390/su16219371