

Review

Framework of Smart and Integrated Household Waste Management System: A Systematic Literature Review Using PRISMA

Yekti Wirani , Imairi Eitiveni  and Yudho Giri Sucahyo 

Faculty of Computer Science, Universitas Indonesia, Depok 16424, Indonesia; imairi@cs.ui.ac.id (I.E.); yudho@cs.ui.ac.id (Y.G.S.)

* Correspondence: yektiwirani@cs.ui.ac.id

Abstract: Household waste is the primary source of environmental pollution due to global population growth compared to other waste sources. This article aims to develop a framework for a smart and integrated household waste management system through a Systematic Literature Review (SLR) using the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA). The resulting framework not only focuses on information technology dimensions but also links them with other integrated dimensions. The framework's design identifies the types of household waste management processes based on the Integrated Sustainable Waste Management (ISWM) framework, dimensions that support smart household waste management system, and the stakeholders involved. The SLR results, which include dimensions and subdimensions supporting the smart and integrated household waste management system framework, were validated by experts from the Indonesian Ministry of Environment and Forestry. The developed framework includes five main dimensions: Information Technology, Operational Infrastructure, Governance, Economy, and Social–Culture. It also addresses stakeholder engagement to support smart household waste management systems and identifies waste management processes based on the ISWM framework. This research uses the PRISMA technique to provide an initial framework for smart and integrated household waste management system. The proposed framework has been validated and can be further developed as a smart and integrated household waste management system. Additionally, it highlights the involvement of various dimensions identified to address waste problems.

Keywords: smart household waste management system; integrated household waste management system; household waste; framework; integrated sustainable waste management; PRISMA



Citation: Wirani, Y.; Eitiveni, I.; Sucahyo, Y.G. Framework of Smart and Integrated Household Waste Management System: A Systematic Literature Review Using PRISMA. *Sustainability* **2024**, *16*, 4898. <https://doi.org/10.3390/su16124898>

Academic Editor: Agostina Chiavola

Received: 4 May 2024

Revised: 31 May 2024

Accepted: 3 June 2024

Published: 7 June 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

As the global population increases, household waste has become the primary source of environmental pollution compared to other types of waste from different sources [1]. Rising living standards and community welfare levels without appropriate waste management infrastructure can trigger an increase in household waste [2]. This increase is also driven by unsustainable patterns of production and consumption, which are among the concerns of Sustainable Development Goal (SDG) 13. A significant rise in household waste without proper management can lead to problems such as environmental damage and threats to human health [3]. Improper management of household waste can impact human health, causing injuries from radiation or chemical content, psychological and social issues related to waste, long-term non-communicable diseases such as cancer, and diseases due to biological factors like outbreaks of worm infections, diarrhea, dysentery, or skin irritation [4]. Conversely, proper household waste management can reduce greenhouse gas emissions and support the achievement of carbon neutrality [5]. The United Nations (UN) states that efforts to support household waste management align with the 12th SDG, which focuses on responsible consumption and production [6].

Managing household waste in various countries requires diverse efforts, including the use of smart systems. A smart system for managing household waste can help achieve sustainability goals by reducing waste, increasing awareness and education, improving the economy, and developing information technology infrastructure. A smart system uses information technology components and data to address household waste problems [7]. Based on the Integrated Sustainable Waste Management (ISWM) framework, there are 11 waste management processes: generation, separation, collection, transfer, transport, treatment, disposal, reduction, reuse, recycling, and recovery [8]. Each process is expected to be supported by smart and integrated waste management. Previous research has shown that smart systems can assist in the separation of household waste through the Convolution Neural Network (CNN) algorithm and machine vision technology as a system interface [9]. In addition to waste separation, the literature identifies smart systems for household waste collection from previous studies. Chile has optimized the placement of waste collection locations using network design systems that utilize the Large Neighborhood Search (LNS) heuristics and the Mixed Integer Linear Programming (MILP) model [10]. Prior research has also addressed the issue of household waste by designing a smart system for the waste transport process. For example, research in Portugal modeled the problem of stair waste collection by designing travel routes for waste trucks using the generalization of the Mixed Capacitated Arc Routing Problem (MCARP) and Geographic Information System (GIS) [11].

Smart systems can also be applied to other household waste management processes, such as waste recycling, waste disposal, or prediction of future waste generation. The use of a smart system in the recycling process has been demonstrated through the development of an IoT-based recycling bin prototype that can detect waste density and monitor the decomposition process [12]. Other research has used the Analytical Hierarchy Process (AHP) and GIS methods to make decisions on household waste disposal management [13]. Forecasting to predict waste generation supports waste management planning. A deep learning approach using a multi-site Long Short Term Memory (LSTM) neural network was used to estimate household waste generation levels in Denmark [14]. Machine learning modeling can predict waste generation in residential areas in Vietnam by identifying variables such as waste generation characteristics, demographics, economic levels, and community consumption levels [15]. The ensemble learning approach can also be used to predict waste generation and has been shown to be more accurate than other individual machine learning approaches [16].

Smart systems for household waste management have been identified from previous research attempts to solve waste problems by addressing only one process or part of the process. A smart system that facilitates all household waste management processes in an integrated manner has the potential to monitor and optimize waste management activities comprehensively. Previous research has demonstrated that implementing a smart system in household waste management can effectively reduce the amount of waste produced. This article aims to bridge the research gap by proposing a framework for a smart waste management system that integrates all household waste management processes. A framework for a smart and integrated waste management system for household waste helps systematically design, implement, and evaluate waste management strategies. These strategies are useful for guiding actions and making structured decisions regarding household waste handling. The purpose of this article is to produce a framework for smart and integrated household waste management. The employed methodology is a Systematic Literature Review (SLR) using the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) protocol. In the concept design, the type of household waste management process based on the ISWM framework, dimensions that support the smart household waste management system, and involved stakeholders are first identified. The developed framework is integrated because it involves the entire waste management process and system integration. The primary dimensions identified are then used to design a framework for smart household waste management.

Aside from identifying primary dimensions, this research also identifies waste management processes and data. The identification of waste management processes aims to improve the performance of smart systems in waste management [17,18], enhance the effectiveness of resource allocation [19], and explore opportunities for process integration with smart systems such as sensors [20], machine learning algorithms [15], and communication network technologies [21]. Meanwhile, the identification of data managed by the smart waste management system can support real-time monitoring to determine appropriate actions for waste management [19], optimize waste transport vehicle routes for more efficient management [11], and develop IoT-based solutions [22]. The identification of the technology dimension based on processes and data is intended to support the framework of a smart and integrated household waste management system.

There are four research questions:

- RQ1. What types of household waste management processes are supported by smart waste management?
- RQ2. What dimensions support smart waste management for managing household waste?
- RQ3. What are the information technology subdimensions that support smart waste management for managing household waste?
- RQ4. What is a framework for a smart and integrated household waste management system?

The results can be used as a framework for implementing a smart and integrated household waste management system for stakeholders. The framework aids in designing sustainable development strategies [23]. Additionally, a smart and integrated household waste management system can support policies for handling waste, appropriate waste management technology, and decision-making processes to achieve sustainable development goals (SDGs) [24]. Stakeholders can implement this framework to reduce household waste. Moreover, this framework can support a circular economy through smart separation and collection devices, helping households to reduce waste generation, reuse waste into valuable goods, and improve the environment.

There are several parts discussed. Section 1 presents the history and background of the smart waste management system. Section 2 explains the methodology of the SLR, using PRISMA, and the validation method. Section 3 covers bibliometric analysis and the analysis of the smart and integrated household waste management system framework. Section 4 discusses the framework of the smart and integrated household waste management system and future research. Section 5 presents conclusions and implications.

2. Materials and Methods

This SLR was based on the PRISMA protocol. PRISMA is an appropriate protocol for conducting SLR because it encourages reviewers to document their review plans carefully to avoid making arbitrary decisions [25]. This SLR involved three team members who conducted a series of activities: compiling the manuscript, developing selection criteria and bias assessment strategies, extracting data, determining the search strategy, processing statistics, providing feedback, and approving the manuscript. The SLR revealed no changes, so there are no amendments. PRISMA consists of four main components: determining eligibility criteria, selecting articles, carrying out data extraction, determining the quality of articles to reduce the risk of bias, and synthesizing data [26]. Figure 1 shows the stages of PRISMA. CADIMA is used to support PRISMA method. CADIMA is an online platform that supports collaboration in conducting SLR using the PRISMA protocol [27].

The supporting dimensions and subdimensions of the framework for the smart household waste management system obtained from the SLR were then validated using questionnaires and interviews. The expert involved in the validation stage was a staff member from the Directorate of Waste Management at the Indonesian Ministry of Environment and Forestry. The Indonesian Ministry of Environment and Forestry manages government affairs in the environmental and forestry sectors and supports waste management efforts in Indonesia [28]. The expert involved is competent to validate supporting dimensions and subdimensions, having four years of experience handling regulations and policies,

and monitoring Indonesia's national waste management information system. The national waste management information system is a platform that manages data related to national waste management in Indonesia [29]. The expert completed a questionnaire explaining the dimensions and subdimensions of the framework. The researcher asked for arguments supporting each yes or no choice regarding the subdimension requirements in the smart household waste management system framework. The interview method was used to understand the expert's arguments.

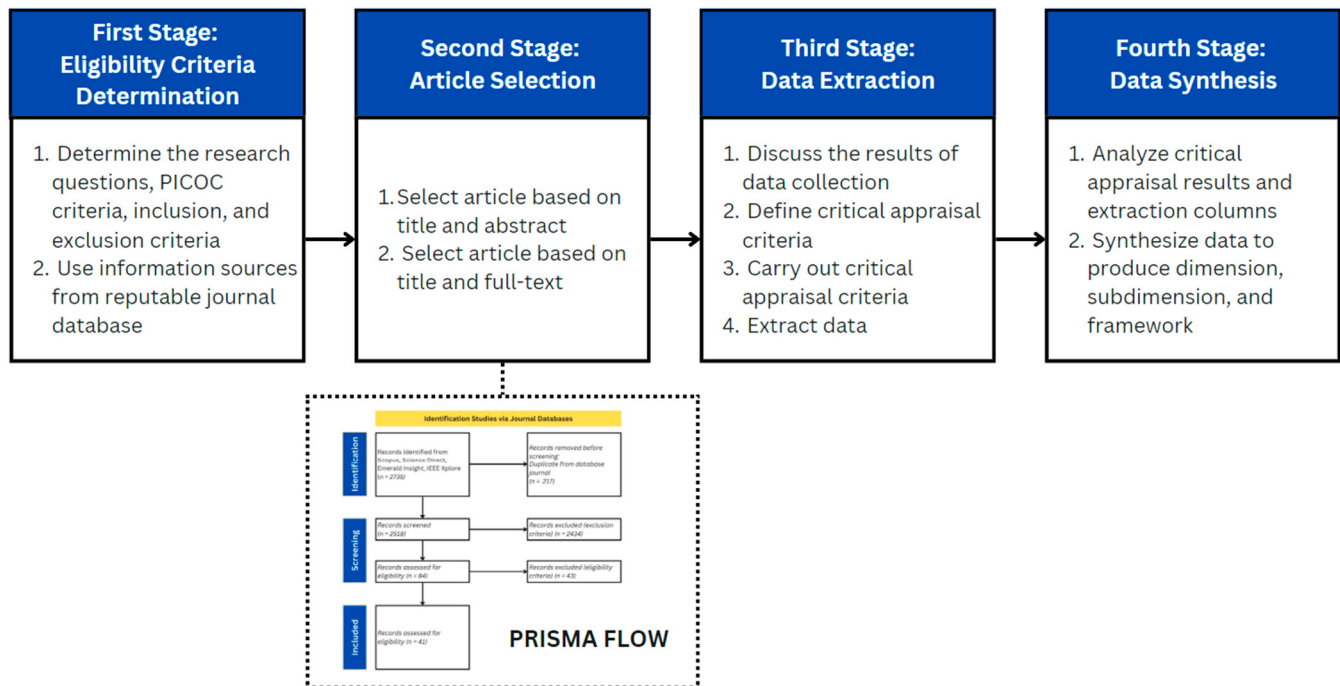


Figure 1. Stages of PRISMA.

2.1. Determining Eligibility Criteria

SLR is intended to identify previous research that discusses smart waste management for managing household waste. SLR results included process categories, managed data, and smart waste management dimensions for household waste. Eligibility criteria are determined using the Participants, Intervention, Comparison, Outcome, and Context (PICOC) criteria shows in Table 1.

Table 1. PICOC criteria.

PICOC Criteria	Description
Population	smart waste, intelligent waste, software for waste, waste information systems, IoT for waste, sensor-enabled waste, digital platform waste, digital solution waste, and household waste.
Intervention	business process, business flow, data, and information
Comparison	smart waste components, smart waste elements, smart waste diagrams, and smart waste user requirements
Outcome	framework of smart and integrated household waste management
Context	household waste management

PRISMA protocol uses exclusion and inclusion criteria to filter the quality of articles at the selection stage [25]. There are three selection stages: the initiation stage, title and abstract selection, and full-text selection. At the initiation stage, the inclusion criteria for articles are that they match the search keywords, are in English, and were published between 2019 and 2023. The exclusion criteria at this stage include articles in languages other than English and those published outside the 2019–2023 period. The next stage is the title and

abstract selection stage. At this stage, inclusion criteria include smart waste management, intelligent waste management, software for waste, waste information systems, IoT for waste, sensor-enabled waste, waste digital platforms, waste digital solutions, household waste, domestic waste, or family waste. The exclusion criteria at this stage are resources that include demolition waste, commercial waste, government waste, municipal waste, construction waste, industrial waste, agricultural waste, water waste, emissions waste, medical waste, animal waste, medical waste, biomedical waste, or business waste. The inclusion and exclusion criteria at the full-text selection stage are the same as those at the title and abstract selection stages.

This SLR uses search terms based on PICOC and sources information from electronic databases: Scopus, ScienceDirect, Emerald Insight, and IEEE Xplore. Inaccessible studies could be obtained through contact with the author. The literature search included article types such as research articles and conference articles, publication year, and use of English. Search keywords were determined with the help of subject matter experts who have expertise in conducting SLR reviews through electronic journal databases. Search keywords can be duplicated for information sources from other electronic journal databases. The search on PROSPERO and OSF was aimed at identifying other similar or relevant studies to avoid duplication. Based on these search results, no previous research was found that designed a framework for a smart household waste management system. The systematic review was registered at OSF with the link <https://doi.org/10.17605/OSF.IO/WAZMR>. The Boolean search string was derived from the PICO criteria and can be duplicated for the identified journal databases. The Boolean search string was (*"smart waste"* OR *"intelligent waste"* OR (*"software"* OR *"information systems"* OR *"IoT"* OR *"sensor-enabled"* OR *"digital platform"* OR *"digital solution"*) AND *"household waste"*)).

2.2. Article Selection

All articles that satisfy the Boolean search string are entered into CADIMA. Researchers screened titles and abstracts simultaneously and independently based on inclusion criteria. The results of the title and abstract screening were categorized into three groups: suitable, not suitable, and possibly suitable. Articles categorized as possibly suitable were further reviewed. If there were differences in categorizing the title and abstract screening results among researchers, discussions were held to reach a consensus.

The article selection stage aims to identify all articles that meet the requirements and can be included in the SLR process. At this stage, the selection criteria registered with CADIMA must obtain approval from all researchers. Keywords used in CADIMA include *"smart waste"*, *"intelligent waste"*, *"software"*, *"information systems"*, *"internet of things"*, *"IoT"*, *"waste sensors"*, *"digital platforms"*, *"digital solutions"*, *"sensors"*, *"sensor-enabled"*, *"household"*, *"household waste"*, *"business processes"*, *"business flow"*, *"data"*, *"information"*, *"components"*, *"elements"*, and *"architecture"*. These keywords are grouped based on similar meanings and use different colors for different groups. The criteria list used aligns with the determined PICOC and is applied for checking the title and abstract, as well as the full text. Figure 2 presents the PRISMA flow for identifying the number and sources of previous research at each stage.

2.3. Data Extraction and Synthesis

The data extraction stage begins by collecting article data that meets the full-text selection requirements. The researchers discussed the results of the data collection process to obtain feedback and make joint decisions. If there were differences in opinion, the team resolved them through discussion. Based on identification from previous research, when data were unclear, the researcher contacted the author of the extracted article to obtain missing or unclear data. The first stage in data extraction, defining critical appraisal criteria, aims to avoid systematic errors resulting from internal validity testing and support the external validity of the research results. This stage also aims to determine the quality of resources to reduce the risk of bias. In the CADIMA tool, this stage begins by defining

the critical appraisal criteria. The identified criteria help test the validity of the extracted articles. A scale of 1–3 is used to test the quality of the extracted articles, with a scale of 3 indicating the highest value, which is categorized as high quality.

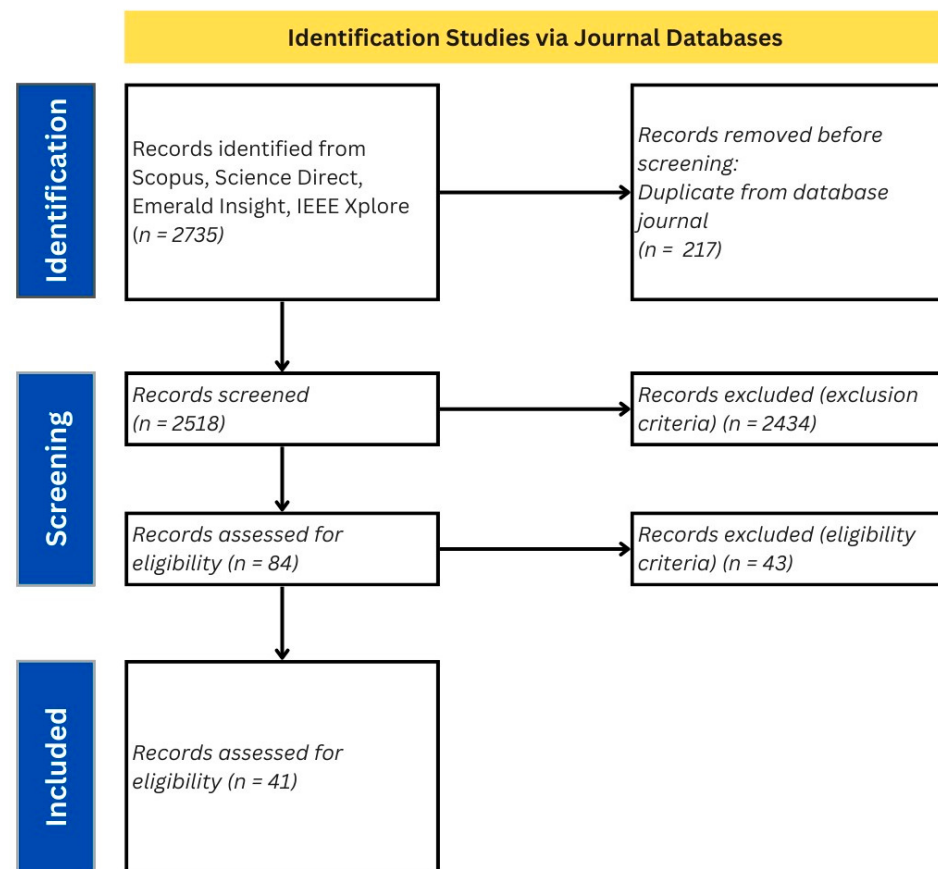


Figure 2. PRISMA flow.

In the first stage, researchers applied four critical appraisal criteria, namely the research context, waste data type associated with smart waste management, waste management process, technologies, and stakeholder. In the research context criteria, to assess external validity, article must identify *household, domestic, or family waste*. In the context of waste data types, the article must determine main *waste and waste-supporting data*. Main waste data such as *waste type, waste weight, waste images*, etc. Meanwhile, *waste-supporting data includes spatial data, incentive data*, etc. In the waste management process criteria, the article must identify the *generation, separation, collection, transfer, transport, treatment disposal, reduction, reuse, recycling, or recovery processes*. In the technology components, the article must identify the *sensors and IoT devices, data collection and communication, data processing and analytics, cloud-based platform, machine learning and AI, routing and scheduling optimization, user interfaces, alerts and notifications, integration with fleet management, energy management, and sustainability, security, and privacy, remote management and updates, feedback, and continuous improvement, reporting and analytics, regulatory compliance, or incentive programs*. Each article was assessed based on these four criteria and mapped to value levels.

The quantitative aspects of the articles obtained have been examined. The critical appraisal results show that the average value of the appraisal outcome is 2.65 on a scale of 3, or the equivalent of 88.29%. This value is obtained from the average of all appraisal outcome scores for each article. Based on these values, 41 articles were extracted and synthesized. In the next stage, researchers extracted data from previous articles containing demographic information, methodology, scope, research results, suggestions for future research, waste types, system features, and stakeholders involved. Data extraction was also

carried out to obtain answers to the research questions, namely *the type of household waste management process, the data managed, and information technology*.

The final stage involves carrying out data synthesis based on the results of quantitative analysis of the quality of the articles. The extraction results from data items related to the research questions were synthesized to produce a framework for smart and integrated household waste management. The smart and integrated household waste management framework is generated by identifying the dimensions and stakeholders involved. The data synthesis stage uses thematic analysis techniques, which involve finding appropriate codes to collect into specific themes [30]. The themes were determined using the descriptions provided in the PRISMA checklist and critical appraisal criteria. The NVivo tool was used to assist in the thematic analysis of previous research.

3. Results

This section presents the results of bibliometric analysis, data extraction, and synthesis in accordance with the previously explained research questions

3.1. Bibliometric Analysis Based on Co-Authorship Analysis

Bibliometric analysis was carried out using VOSviewer version 1.6.19, producing a map based on bibliographic data. The analysis of co-authorship supports the identification of collaborative networks of researchers and researchers who have a significant influence on the field of research regarding smart waste management systems in the context of household waste. The results of the co-authorship analysis show that five authorship networks stand out and facilitate collaboration: Venkatesh, V.G. with six links, Liu, Y. with five links, Qu, T. with five links, Wan, M. with five links, and Zhang, A. with five links. Based on the analysis of all documents, five authors have the largest number of documents: Khan, A., Qu, T., Wan, M., Yang, J., and Zhang, A., each with nine documents. Figure 3 shows the results of the co-authorship analysis based on the number of links.

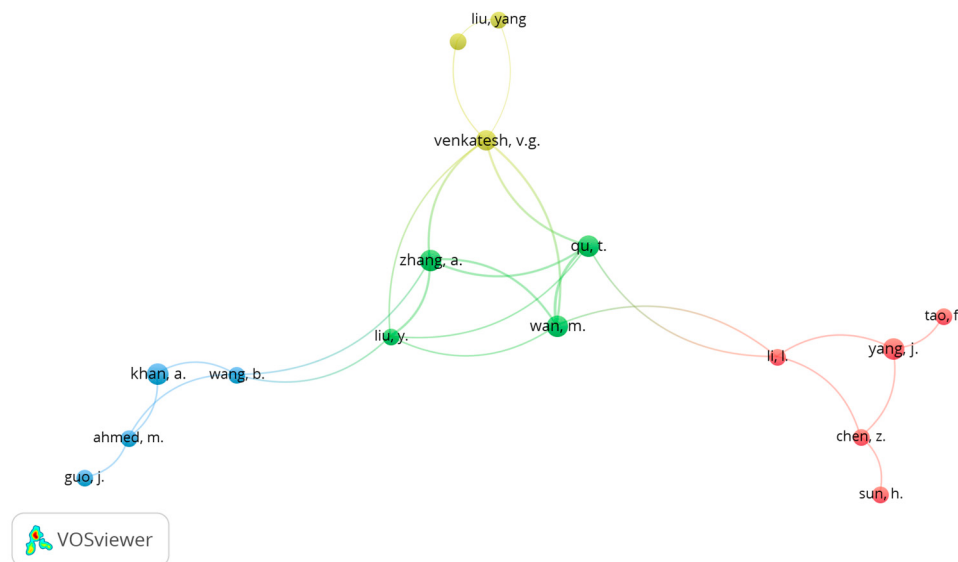


Figure 3. Co-authorship analysis.

3.2. Bibliometric Analysis Based on Co-Occurrence of Keywords

Bibliometric analysis has also been carried out using co-occurrence of keywords. The co-occurrence of keywords analysis results show 9286 keywords from 2735 records. Figure 4 shows keywords that appear more than 50 times, with 1107 keywords meeting the threshold. The co-occurrence of keywords analysis highlights keywords with the highest number of occurrences, including waste management with 878 occurrences, Internet of Things (IoT) with 836 occurrences, bins with 354 occurrences, smart city with 344 occurrences, waste management system with 325 occurrences, recycling with 231 occurrences, waste

disposal with 215 occurrences, circular economy with 202 occurrences, waste collection with 200 occurrences, deep learning with 166 occurrences, smart waste management with 162 occurrences, sustainable development with 158 occurrences, municipal solid waste with 147 occurrences, machine learning with 144 occurrences, and solid waste with 142 occurrences. The repeated appearance of these keywords indicates their trending status in research regarding smart waste management systems in the context of household waste.

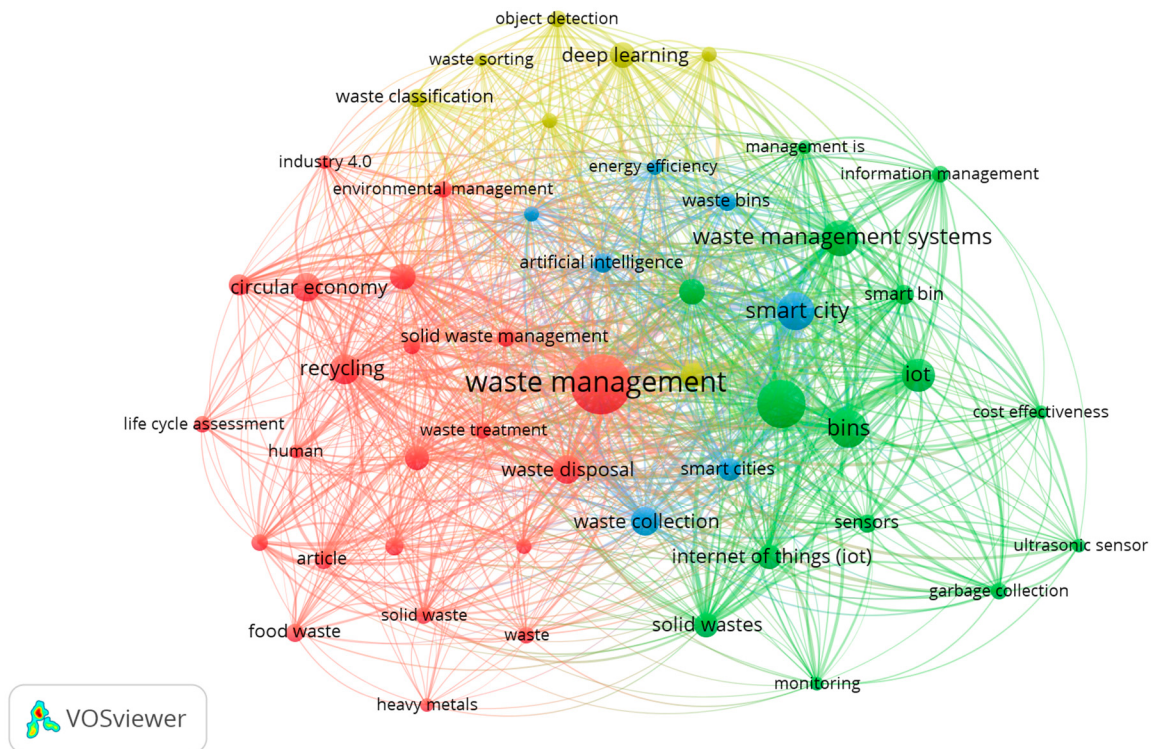


Figure 4. Co-occurrence of keywords analysis.

3.3. Previous Research Demographics

The SLR has produced 41 articles that focus on designing and implementing smart waste management for household waste. Based on the demographic distribution in the journal database sources, 15 articles come from IEEE, 13 from ScienceDirect, 12 from Scopus, and one from Emerald Insight. One way to assess the quality of the references used in the SLR is to identify the number of citations in the reference articles. Figure 5 shows the number of citations in the articles used as references. The previous research articles were published between 2019 and 2023. The data collection deadline is September 2023, so the number of citations may have increased since then. The highest number of citations came from articles published on ScienceDirect, with 695 citations from 2019 to September 2023. A demographic description of previous research based on citation counts and publications is presented in Appendix A.

3.4. Waste Types in Smart Household Waste Management System

This review identifies waste that originates from households. Twenty types of waste have been identified from previous research, including recycled waste, solid waste, hazardous waste, organic waste, inorganic waste, textile waste, dry waste, wet waste, residual waste, irrecoverable waste, electronic waste, biowaste, kitchen waste, food waste, plastic waste, paper waste, glass waste, metal waste, and perishable waste. Based on previous research, recycled waste is the most researched type in smart waste management. This review classifies waste types based on criteria and waste categories. The categories of waste types use waste taxonomy based on waste classification [31]. Textile waste is included in the solid waste category because not all types of textile waste can be recycled [32]. General

waste is not included in the categories of hazardous waste, organic waste, or recyclable waste, so it can be categorized as non-recyclable waste or residual waste [33,34]. The components of perishable waste include bones, peels, and vegetables, and when landfilled, it produces a lot of leachates [35]. Therefore, perishable waste is included in the organic waste category. The mapping of waste types from previous research is presented in Table 2.

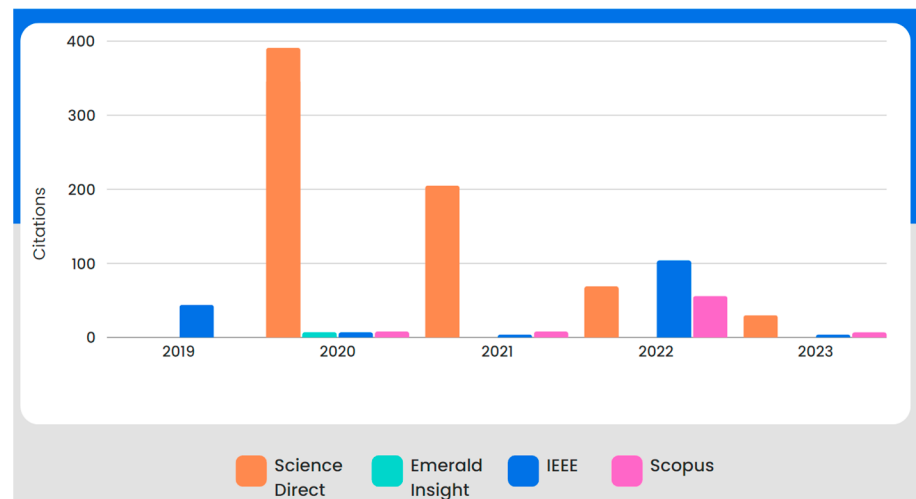


Figure 5. Source citations by year.

Table 2. The mapping of waste types.

No	Criteria	Category	Type
1.	The physical condition of the waste	Solid waste	1. Solid waste [15,20,36–38] 2. Textile waste [39]
2.	The risk level of waste	Hazardous waste	Hazardous waste [22,40–47]
		Electronic waste	Electronic waste [8]
3.	Composition of waste materials	Inorganic waste	1. Inorganic waste [17,21,48] 2. Dry waste [46,49–51] 3. Plastic waste [16,52,53] 4. Paper waste [16,53] 5. Glass waste [16] 6. Metal waste [49,50]
		Organic waste	1. Organic waste [12,17,21,48] 2. Wet waste [46,49–51] 3. Biowaste [19] 4. Kitchen waste [39–45,53] 5. Food waste [47,54,55] 6. Perishable waste [42]
		Recyclable waste	Recycled waste [9,10,13,18,39–47,56–59]
4.	Recovery feasibility of waste	Non-recyclable waste	1. Non-recyclable waste [45] 2. General waste [47] 3. Residual waste [14]

3.5. Type of Waste Management Process

Waste management process identification is carried out using the ISWM framework as a reference. Based on previous research, 11 processes have been identified: separation, collection, transfer, transport, generation, disposal, treatment, reduction, reuse, recycling, and recovery. The ISWM framework elements can be used to map processes in waste management. The separation element involves separating waste at its source [60]. The collection

element involves collecting waste from the source, often integrated with separation [61]. The transfer element involves the community delivering waste to designated disposal locations, while the transportation element involves the government collecting waste for disposal at the final disposal site [61]. Treatment elements include facilities, equipment, or methods for processing waste into final products before disposal [61,62]. The disposal element involves the facilities or locations for final waste disposal [60,61]. The reduction element involves reducing waste at the source and minimizing the carbon embedded in products discarded as waste [61,63]. The reuse element involves reusing a product after maintenance, repair, or remanufacturing to extend its benefits [64]. The recycling element involves dismantling products to minimize residue [62]. The recovery element involves material recovery from products [62], such as gas recovery in landfills for energy or fuel for recycling [63].

Based on the SLR results, previous research has developed smart waste management processes involving combinations of separation & collection, collection & transport, and transfer & transport. Two studies identified the reduction process in smart waste management systems, one study identified the reduction, reuse, recycling, and recovery processes, 16 studies identified the separation process, five studies identified the separation & collection process, nine studies identified the collection process, two studies identified the collection & transport process, one study identified the transfer & transport process, three studies identified the generation process, and one study each identified the treatment and disposal processes. The result indicates that the most frequently developed process in smart waste management systems for household waste is separation. The mapping of waste management process types from previous research is presented in Table 3.

Table 3. The mapping of waste management process.

No	Process	Source
1.	Separation	[9,19,36,40,41,43,44,46–51,53,55,59]
2.	Collection	[10,18,21,22,52,56,57,65,66]
3.	Separation & collection	[16,39,42,45,58]
4.	Transfer & transport	[17]
6.	Collection & transport	[11,37]
7.	Treatment	[12]
8.	Disposal	[13]
9.	Generation	[14,15,20]
10.	Reduction	[8,54,67]
11.	Reuse	[8]
12.	Recycling	[8]
13.	Recovery	[8]

Studies have shown that smart systems can assist in the separation of waste. The Convolution Neural Network (CNN) algorithm and machine vision technology can help households automatically separate waste through a system interface [9]. A computer vision-based waste separation system in a conveyor prototype can separate waste based on color and coordinate position [36]. IoT through sensors integrated with Android applications can also help sort waste [51]. The literature uses three types of sensors: sensitivity sensors to detect movement, moisture sensors, and touch sensors to detect wet and dry waste. A household waste classification system using voice recognition has been proven to help sort waste by detecting types of waste based on human voices and detecting the fullness of waste containers [45].

Smart systems for household waste collection have also been identified from previous research. Chile has optimized the placement of waste collection locations using network design systems that employ the Large Neighborhood Search (LNS) heuristics and the Mixed Integer Linear Programming (MILP) model [10]. Determining the location of trash bins based on the Internet of Things (IoT) according to community conditions can also enhance waste management effectiveness [21]. Prior research has also addressed household waste

issues by designing a smart system for the waste transport process. Previous research has modeled the problem of stair waste collection through the design of travel routes for waste trucks in Portugal using the generalization of the Mixed Capacitated Arc Routing Problem (MCARP) and Geographic Information System (GIS) [11]. GIS technology can help policymakers measure and map waste generation based on specific locations [52]. The use of GIS in the waste transfer and transport process can increase the efficiency of waste collection by optimizing routes, considering factors such as the quantity of waste produced, population density, location of waste bins, and vehicle capacity [18].

Smart systems can also be applied to other household waste management processes, such as waste recycling, waste disposal, or prediction of future waste generation. The use of a smart system in the recycling process involves building an IoT-based recycling bin prototype that can detect the level of waste density and the decomposition process [12]. Other research has used the Analytical Hierarchy Process (AHP) and GIS methods to make decisions on household waste management [13]. The literature resulted in a waste management model involving a waste recycling process and energy recovery technology, which can increase energy supply and extend the landfill's life. Forecasting to predict waste generation aims to support waste management planning. A deep learning approach using a multi-site Long Short Term Memory (LSTM) neural network was used to estimate household waste generation levels in Denmark [14]. Machine learning modeling can predict waste generation in residential areas in Vietnam by identifying variables such as waste generation characteristics, demographics, economic levels, and community consumption levels [15]. The ensemble learning approach can also be used to predict waste generation and has been proven to be more accurate than other individual machine learning approaches [16].

3.6. Features and Data in Smart Household Waste Management System

Twenty-three features support a smart waste management system. These features are mapped to the waste management process and presented in Appendix B. Based on the identification results from previous research, the waste management process that has developed the most features is the collection process, with 17 features. Thirty-one data types that support features in the smart waste management system have been identified. The identified data types are location of containers, trash bin capacity, vehicle capacity, collection routes, the position of vehicle, transportation travel time, total distance, duration of work shift, total volume of waste, waste type, waste collection time, prediction of waste volume, amount of recycled waste, waste prices, waste fees, price adjustments, weight of waste per type, weather, stakeholder involved, impact on the environment spatial/geographical, spatial distribution of waste; pictures/photos of trash, fuel costs, waste humidity, deposit frequency, depositor identity, degree of container fullness, separation accuracy, voice keywords, and incentives.

3.7. Stakeholders Involved in Smart Household Waste Management System

Nine stakeholders in the smart waste management system have been examined. The stakeholders involved are mapped to the waste management process. The stakeholders involved in the reduction, reuse, recycling, and recovery processes are the government, household actors, non-government organizations (NGOs), and product manufacturers. Table 4 explains the role of stakeholders in the reduction, reuse, recycling, and recovery processes.

Meanwhile, six stakeholders are involved in the separation process: the government, household actors, waste management companies, NGOs, and scavengers. Table 5 explains the role of stakeholders in the separation process.

Table 4. Stakeholder's role in the reduction, reuse, recycling, and recovery process.

Actor's Role	
Process: reduction, reuse, recycling, and recovery	
1. Government:	• implement policies, regulations, and initiatives related to waste management [8] • manage food risks using labels as a consumer protection tool [67]
2. Household:	• reduce food waste [67] • generate waste [8] • manage food supplies and make sustainable choices [54]
3. NGOs:	raise awareness, advocate, and assist with waste management practices [8]
4. Product manufacturers:	• manage proper disposal or treatment at the end of waste life [8], • involved in registering and tracking electronic waste through a digital system [8], • offering special discounts or promotions [54]

Table 5. Stakeholder's role in the separation process.

Actor's Role	
Process: separation	
1. Government:	• ensure the classification scheme and measurement of resource utilization [9], • improve the waste processing system [9] • provide education and guidance on waste separation [9] • implement scheduled or flexible segregated waste pickup [9] • be responsible for waste disposal and recycling [53] • assist in the implementation and promotion of waste classification policies [40] • encourage citizen awareness of waste classification [40] • get a notification that the trash can is complete [50] • implement waste management policies and regulations [59] • provide smart waste containers for the community to rent [47].
2. Household:	• separate waste with digital artifacts [9,19,40,48] • create waste reservations and prepare waste [51] • use smart waste containers [48] • rent smart waste containers through the digital platform [47]
3. Waste management companies:	• provide messages to pick up waste [51] • collect and manage waste [59] • manage property for waste management [47] • receive messages when the waste level has reached the specified [48].

Five stakeholders are involved in the separation and collection process: the government, household actors, waste management companies, waste recycling companies, and NGOs. Table 6 explains the role of stakeholders in the separation and collection process.

Five stakeholders are involved in the collection process: the government, household actors, waste management companies, waste recycling companies, and NGOs. Table 7 explains the role of stakeholders in the separation and collection process.

There are four stakeholders in the collection and transport process: the government, household actors, waste management companies, and mobile network operators. Table 8 explains the role of stakeholders in the collection and transport process.

Table 6. Stakeholder's role in the separation and collection process.

Actor's Role	
Process: separation and collection	
1. Government:	- provide policies and guidelines for the implementation of the smart waste classification system [42] - implement and enforce waste management policies and accountability mechanisms [39]
2. Household:	- participate in depositing and separating waste [42] - separate recyclable waste [39,58] - participate in proper waste collection into smart waste bins [58] - purchase recycled products using incentives received from recyclable waste collection [58]
3. Waste management companies:	operate devices to support the smart waste management system and the administration of reward and penalty systems [42]
4. Waste recycling companies:	- recycle raw materials from waste to make recycled products [58] - collect and pick up waste [39] - collaborate with the government to implement systems that support IoT [39]
5. NGOs:	promote and support waste management initiatives and increase citizen awareness [39].

Table 7. Stakeholder's role in the collection process.

Actor's Role	
Process: Collection	
1. Government:	- provide data, insight, and guidance on waste management practices and policies [10] - release or modify policies for household waste recycling onto the digital platform [18] - determine bin locations with minimum total waste costs and maximum population coverage [57] - collaborate in the development and evaluation of digital applications [65] - do prototype testing for pilot study [65] - decide on the location of landfills and waste collection centers [66].
2. Household:	- provide participation through waste collection, system acceptance, and feedback [10] - submit comments and reviews of waste management services and policies [18] - choose the minimum distance to dispose of household waste [57] - provide input regarding the mobile application [65] - dispose of e-waste using collection boxes and mobile apps [22]
3. Waste management company:	- collect waste in the community [10] - provide input and feedback on system design and implement proposed solutions in pilot projects [56] - observe a pattern of unequal collection quantities that suggested price increases [18] - collect e-waste with a smart system [22]
4. NGOs:	provide insight, support, and feedback regarding the proposed system's environmental impacts [10]
5. Waste recycling company:	process and recycle collected e-waste [22].

There are two stakeholders in the generation process: the government and the waste management companies. Table 9 explains the role of stakeholders in the generation process. The government has a role in the disposal process, namely ensuring effective and sustainable waste management treatments [12]. Meanwhile, based on previous research, the recycling process in the smart waste management system needs to convey that stakeholders are involved.

Table 8. Stakeholder's role in the collection and transport process.

Actor's Role	
Process: collection and transport	
1.	Government: optimize the household waste collection system to increase efficiency and effectiveness [11].
2.	Household: • collect waste [11] • receive benefits from a timely and efficient waste collection system [11] • perceive improved waste management practices that are low cost [37].
3.	Waste management companies: optimize waste disposal logistics [37].
4.	Mobile network operators: improve network technology [37].

Table 9. Stakeholder's role in the generation process.

Actor's Role	
Process: generation	
1.	Government: • develop new policies and regulations related to waste management • do recycling and resource recovery [20] • develop and provide smart waste management technology [15].
2.	Waste management companies: • use developed predictive models to plan and implement effective waste management strategies [20] • handle waste collection, disposal, and recycling [15].

3.8. Framework for Smart and Integrated Household Waste Management System

Five main dimensions supporting a smart household waste management system have been identified: Information Technology, Operational Infrastructure, Governance, Economy, and Social-culture. The five main dimensions are also supported by stakeholders involved in the smart household waste management system: Government Authority, Waste Management Company, Waste Recycling Company, Environmental NGO, Mobile Network Operator, Household, and Scavenger. Five main dimensions support every waste management process: Separation, Collection, Transfer, Transport, Treatment, Disposal, and Generation. These processes also support the Reduction, Reuse, Recycling, and Recovery principles. Each central dimension is supported by several subdimensions explained in the following subchapters. A framework image of smart and integrated household waste management system is available in Figure 6.

3.8.1. Information Technology Dimension

Information technology in smart and integrated household waste management systems comprises hardware, software, machine learning and artificial intelligence (AI), network infrastructure, human–computer interaction, cloud computing, social media, and databases. It plays an essential role in supporting the entire waste management process. Table 10 presents descriptions and device support for the information technology dimension in the framework of the smart and integrated household waste management system.

In the hardware subdimension, there is a need for devices such as digital cameras and sensors to take pictures of waste and detect it. Digital cameras are used to take pictures of everyday waste [9,17,36], contributing to the collection of waste images [46]. These waste images can be used for visual image analysis and classification [43,44].

Additionally, sensor devices are needed with the following functionalities: (1) detecting the movement of people throwing rubbish into containers using motion sensors [51] and passive infrared (PIR) sensors [12]; (2) capturing images of trash using an image sensor [41]; (3) detecting the presence of waste using ultrasonic sensors [9,17,43] and infrared sensor [44]; (4) weighing the waste stored in the container [20,42] and determining

the type, weight, and ratio of waste impurities [53] using load-cell sensors [21,59]; (5) measuring the level of waste in the container using an ultrasonic sensor [21,22,37,49,59], overflow sensor [41], tracker sensor [43] infrared sensor [45]; (6) detecting the number of solid or liquid particles in the waste container using an ultrasonic sensor [12], (7) detecting wet or dry waste using a capacitive sensor based on water content [49], temperature and humidity sensors based on temperature and humidity levels [50], and moisture sensors and touch sensors [51]; (8) detecting the presence of metal waste using metallic sensors [49], induction sensors [46], and inductive proximity sensors [48,50]; (9) detecting the presence of plastic and wood waste using capacitance proximity sensors [48]; (10) storing and managing time in the waste recycling process using a real-time clock (RTC) sensor [12].

In the software subdimension, there is a need for alerts and notifications, waste container location-allocation algorithms, data analytics, integration with geospatial information systems (GIS), mobile applications, web applications, scheduling and routing optimization, blockchain technology, voice recognition, machine learning, and artificial intelligence (AI). Alerts can provide a message if the trash container is full, prompting immediate emptying by the service provider [48,49], in the form of voice and message [41], and automatic email alerts [22]. There are also alerts to prevent expired food [67]. Notifications play an essential role as well. They can include a green indicator for food that is about to expire [67], notifications in the system about news on government social media [65], and notifications to back-end waste management companies to clean trash cans on time [39].

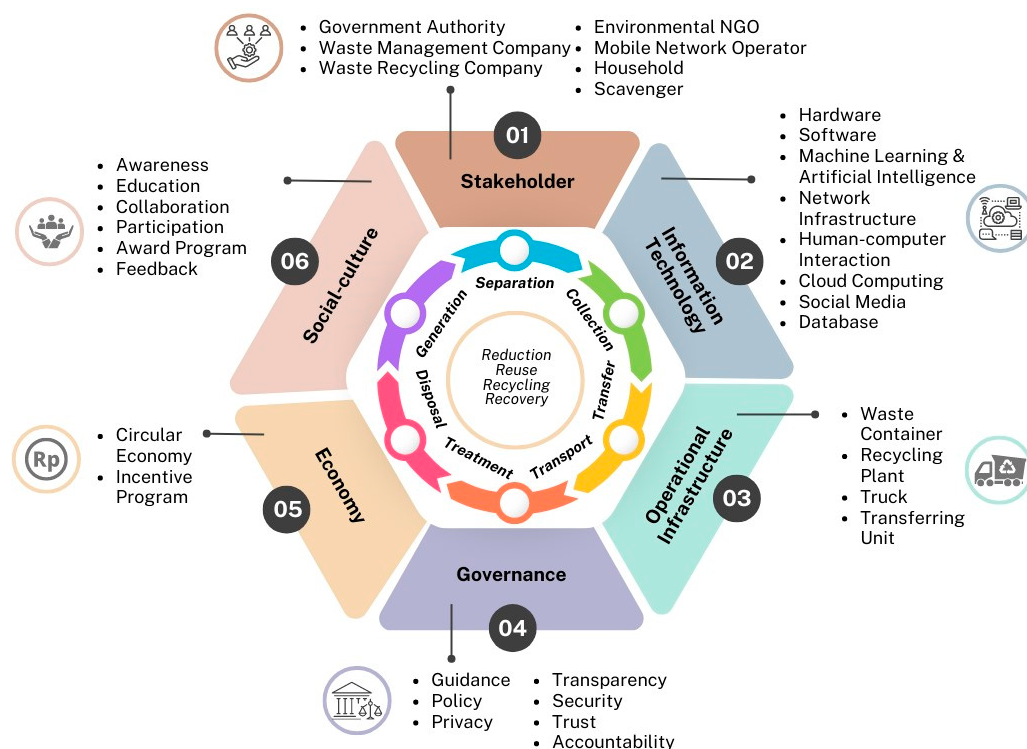


Figure 6. Framework for a smart and integrated household waste management systems.

The availability of waste container location-allocation algorithms helps determine the type, amount, and location of waste at collection locations using the mixed integer linear programming (MILP) model [10] and the maximal covering location problem (MCLP) [57]. Analytical data can predict patterns [20] and trends in waste collection during specific periods [42], supporting decision-making regarding price adjustments [19]. Integration with GIS is helpful in managing waste services by displaying layers containing road segments, traffic signs, and embedded buildings [11], displaying GPS coordinate locations [52], providing visualization of spatial parameters to support waste management plans [13], visualizing and analyzing the distribution of waste generation points and potential collec-

tion locations [57], storing and managing spatial data related to bin attributes, routes, and schedules, finding optimal routes [18], analyzing spatial data, managing geographic data, and connecting with decision-making support processes like AHP [66].

Table 10. Description of information technology dimension.

Description	Devices
Subdimension: hardware	
There is hardware to take pictures of trash	Digital camera
The existence of hardware to detect the presence of waste, the level of fullness of waste containers, the types and characteristics of waste	Sensor
Subdimension: software	
There is software that can provide signals and warning messages to waste service managers if the waste container is full	Alert and notification
Availability of a waste container location-allocation algorithm to determine the type, number, and location of waste containers at waste collection locations	MILP/MCLP algorithm
The role of ability that determines trends and predictions of waste collection based on specific periods	Data analytic
The importance of integrating spatial data with waste service management attributes	GIS
Availability of digital applications to monitor waste management services	Mobile & web application
Availability of algorithms to support optimization of scheduling and routing in vehicle fleets that pick-up waste	MCARP algorithm
Availability of technology to ensure transparency and accountability of waste management services	Blockchain
There is sound detection-based technology to guide the determination of waste containers in specific categories	Voice recognition
Availability of game element concepts to increase participation of household actors in waste management	Gamification
Subdimension: machine learning & AI	
There is artificial intelligence technology that can support the waste separation process	CNN, MC-CNN, Lightweight CNN, GECM-EfficientNet, KNN, data recognition model
Availability of artificial intelligence technology to predict the amount of waste generation	LSTM neural network, RF, KNN, ensemble learning
Subdimension: network infrastructure	
Availability of data collection technology that can identify tags and codes on waste bags/containers	QR code, barcode, NFC reader with communication node
Availability of technology for efficient data transmission and communication	NB-IoT, GSM, LoRA, Wi-Fi, smart gateway, Bluetooth
Subdimension: human–computer interaction	
There is a digital application prototype to monitor waste management services and exchange information between stakeholders	Mobile or web application prototype, gamification
Subdimension: cloud computing	
Platforms based on cloud computing technology are available to support the operational efficiency of waste management	Application platforms based on cloud computing
Subdimension: social media	
Availability of social media for communication between waste service managers and household actors and distributing advertisements	Telegram
Subdimension: database	
Availability of technology to store and manage data related to waste	Cloud-based database

Mobile and web applications play an essential role in directly monitoring waste management services. The availability of comprehensive mobile application functionality can help household owners manage their waste. Mobile applications can be used to monitor waste collection locations, order waste pick-up services, adjust drivers, book trash slots [39,51], communicate between smart device consumers in order to reduce food waste [67], guide users to the nearest waste collection point [22], and control all recycling processes via smartphone [12]. Users can use web applications to communicate with smart devices [54] and monitor the fullness level of trash containers [59].

Optimizing scheduling and routing in the vehicle fleet is crucial for supporting the efficiency of waste management services. This includes optimizing scheduling and routing based on efficient routes for the vehicle fleet, potential improvements in distance traveled, utilization rate per fleet compared to the existing system, and pick-up frequency [10]. An algorithm that supports scheduling and routing optimization is the mixed capacitated arc routing problem (MCARP) [11].

Blockchain technology helps ensure transparency and accountability. Blockchain technology that can be used includes a hybrid blockchain [56] and the Private Ethereum Network to measure transactions linked to gas fees for each computing transaction [58]. Voice recognition technology is used in waste containers to detect the type of waste the user speaks of and rotate the system's waste container accordingly [45]. Gamification can encourage household participation in waste management through competitions, achievements, and prizes connected to the blockchain system [56].

The availability of machine learning and AI can support the waste management process through easy waste classification and prediction of the amount of waste generated. Artificial intelligence technology for predicting waste can use a multi-site Long Short-Term Memory (LSTM) neural network, which is a deep-learning artificial neural network [14], Random Forest and K-nearest neighbor models [15], and ensemble learning [16]. AI technology that can be used to detect and classify waste includes machine vision technology and convolutional neural network (CNN) algorithms [9,55], a neural network to train several photos of waste to assist in sorting based on color and location coordinates [36], multi-modal cascaded convolutional neural network (MC-CNN) combining DSSD, YOLOv4, and Faster-RCNN for automatic detection and classification of domestic waste [53], Lightweight CNN model using MobileNet V2 to accurately classify various types of waste, including recyclable waste, kitchen waste, hazardous waste, and other waste [41], CNN and Random Forest to classify waste according to categories [43], CNN with the VGG16 type classifies captured waste images into categories of plastic, paper, and glass to order the trash container to open according to category [17], CNN with VGG16 to identify waste images with the registered dataset and sort the waste [46], the GECM-EfficientNet model, which uses a trained dataset to classify trash based on its categories [44], and the K-nearest neighbor (KNN) algorithm to classify bio and non-biodegradable waste levels and toxic gas concentrations [48]. The data recognition model can also be used for waste classification [40]. AI is also used in facial recognition and image identification for authentication [42].

The network infrastructure subdimension includes technology to support data collection and data communication. For data collection, barcode cards are used to identify user IDs after non-smartphone users register with local street agents [39]. Smartphone users receive a QR code on the trash bag to identify household participants based on user ID [39]. NFC reader and communication node technology can read product tags and communicate via WiFi with a router to a web application [54]. For data communication, a Low-power Wide-area Network (LPWAN) with the NB-IoT type can transmit container fullness data from solid waste containers to remote servers, enabling efficient monitoring and management of waste collection systems [37]. GSM technology can send SMS alerts when trash bins are full [49]. Developing an IoT LoRa network consisting of LoRa nodes, LoRa gateways, and servers in IoT-based waste containers can help improve network efficiency [21]. Other data communication technologies include data transmission using WiFi, smart gateways, and Bluetooth [47].

In the human–computer interaction subdimension, there are interface interactions to support information exchange between stakeholders [19], application prototypes equipped with gamification elements, tips, and information [20], and a prototype for monitoring waste in the electronic category [8]. Prototypes can be developed through mobile and website applications [65]. The subdimension of cloud computing technology plays a vital role in waste management services. Cloud computing technology is used as a platform for smart fridge applications [54], Android application platforms [51], and cloud resource management architecture serving household needs [47]. Additionally, cloud computing technology can be part of a LoRa system connected to an IoT platform in a cloud application and connected to the internet [21]. Cloud computing-based systems can also be used to monitor if containers are full [39].

The use of social media subdimensions aims to introduce waste management behavior from household actors. The application of social media includes advertisements for sustainable IoT electronic waste management for households [8] and telegrams used to connect with users [21]. Databases are useful for storing and managing data related to waste. Implementation of a database can take the form of a centralized database to support an information exchange platform for stakeholders and data analytics [19], a database that manages user login data, waste classification data, user payment data, integral data, announcement data and other data [40], a database that stores waste classification data [42], a database for storing photos of waste objects [17], a database for storing user data for each trash bag [39], a database that stores data resulting from the processing of the microcontroller board (MCU) node [59], and a database for storing data on resources integrated with IoT, such as the level of fullness of trash cans, vehicle routes, and the positions of waste workers [47]. Using cloud databases to collect and store information [22] can support operational efficiency in waste management.

3.8.2. Operational Infrastructure Dimension

The operational infrastructure consists of subdimensions: waste containers, recycling plants, transfer units, and transport trucks. These are useful for supporting the operational process of managing waste received from household actors. Table 11 presents a description and device support for operational infrastructure dimensions in the framework of the smart and integrated household waste management system.

Table 11. Description of operational infrastructure dimension.

Description	Devices
Subdimension: Waste container The availability of waste containers with specific characteristics can make it easier for household actors to manage waste	RFID-based key, user identity via QR code/RFID
Subdimension: Recycling plant Availability of industrial facilities to process waste into new products through waste recycling activities	Recycling facilities with location and product status data
Subdimension: Transferring unit A tool can be used to move waste from one place to another	Conveyor
Subdimension: Truck Availability of tools to transport waste from one location to another	Waste transport trucks

The availability of waste containers with specific characteristics is helpful in facilitating the waste disposal process for household operators. Waste containers can have characteristics based on the type of size, price of the container, and the number of containers [10,21], equipped with a unique key in the form of RFID to open and close the container [56], and a QR code or RFID from the user’s identity on the bag registered to the blockchain to track

specific users and provide rewards or penalties based on their performance [56]. Containers can rotate up to 270 degrees [9], be equipped with information technology [42,58], have double doors to facilitate waste replacement, and use different colors to distinguish types of waste [46]. Waste service managers can arrange various categories of waste bins according to their colors: blue for recycling waste, red for hazardous waste, green for food waste, and gray for general waste [47]. The trash box for household actors opens automatically if a resident approaches and consists of two compartments, one for biodegradable and one for non-biodegradable waste [48].

Recycling factories play an essential role in processing waste into recycled materials. The availability of recycling plants can be determined based on location, status, and rpK. “Loc” indicates the location of the recycling plant, “status” corresponds to whether the plant receives waste as raw material or sends the final product for market distribution, and “rpK” is the public key of the recycling plant [58]. Apart from the recycling plant, the transferring unit also moves waste from one place to another [36]. The conveyor belt is a tool that can be used to move non-biodegradable waste from household waste containers [48]. Another tool that can be used to move waste from one location to another is a trash truck [53]. Trucks can be differentiated based on the color of the container and different pick-up schedules for certain types of waste [8].

3.8.3. Governance Dimension

The governance dimension consists of subdimensions: guidance, policy, privacy, transparency, security, and trust. Table 12 presents the description and device support for governance dimensions in the framework of the smart and integrated household waste management system.

Table 12. Description of governance dimension.

Description	Devices
Subdimension: Guidance There are guidelines for managing waste sustainably	Guidelines for sustainable waste management
Subdimension: policy Implementing policies made by the government for all stakeholders	Waste management policy
Subdimension: Privacy Availability of efforts to protect personal data from users when using the system	Using pseudonyms when making transactions
Subdimension: Transparency Availability of information transparency of waste management carried out by household actors and connected to the policy of giving penalties and awards	Transparency of user recycling performance
Subdimension: Security There are efforts to prevent unwanted user behavior, such as DDos or spam	Economic security through charging transaction fees
Subdimension: Trust There is an element of trust in information disclosure in the system	Using blockchain to increase trust
Subdimension: Accountability Availability of responsibility from stakeholders for waste management performance	Accountability of waste collectors and household actors

In the guidance subdimension, guidelines for managing waste can support sustainable waste management [8]. The government can create policies for stakeholders and incorporate feedback from them [19]. The government can also establish specific policies for product manufacturers to manage waste from their products, known as extended producer responsibility (EPR) [8]. Privacy is an effort by waste service providers to protect the

personal data of system users, achieved by providing a pseudonym when the user makes a transaction [56]. Transparency in the system can be enhanced by providing transparent waste and recycling management performance information connected to penalty and reward policies, forming the basis of an economic incentive system [56]. Household actors consider that transparency in their recycling performance provides fairness in incentives.

The use of blockchain technology can support system security efforts. To prevent unwanted user behavior, such as denial-of-service (DDoS) attacks or spam, economic security measures like charging transaction fees can be implemented [56]. Blockchain technology also plays a vital role in forming trust. It supports increasing the trust of household actors through transparency and adherence to penalties and rewards [56]. The responsibility of household actors and waste service providers can be represented by accountability. Accountability from waste collectors helps achieve high flexibility and efficiency in the waste collection operations carried out. In contrast, accountability from household actors is shown by disposal data such as disposal time, weight, category, and accuracy, along with related rewards that reflect their performance [39].

3.8.4. Economy Dimension

The economy dimension consists of the circular economy subdimension and the incentive program. Table 13 presents a description and device support for economy dimension in the framework of the smart and integrated household waste management system.

Table 13. Description of economy dimension.

Description	Devices
Subdimension: Circular economy There is a strategy to reuse recycled waste into resources	Implementation of circular economy strategies in digital applications
Subdimension: Incentive program There is a program to provide rewards and punishments for the recycling performance of household actors	Implementation of rewards and punishments through blockchain

The circular economy is a strategy to address the increasing amount of waste by reusing waste recycling as a resource [20]. Circular economy strategies can be implemented by limiting single-use plastic, recycling plastic waste, and recovering plastic waste [52]. These strategies can be facilitated using mobile and web applications, which can help household owners find places to collect recyclable waste, preventing it from being sent to final landfills [52].

The implementation of incentive programs can increase the use of waste management systems among household actors [68]. Incentive programs can be carried out using the pay-as-you-throw (PAYT) model, where household actors receive reward tokens based on their recycling performance [56]. These programs can encourage household actors to increase their recycling behavior and motivate informal collectors from recycling companies to work more actively [19]. Incentive programs can award points to users who correctly separate waste [20] and impose penalties for incorrect waste classification [42]. Rewards are transferred to each household actor's wallet using blockchain technology [58]. Reward points are awarded based on the type, size, and quantity of recycled items [22]. The application of rewards and penalties in incentive programs needs support from the government, the community, household actors, and local council bodies [39].

3.8.5. Social–Culture Dimension

The social–culture dimension consists of subdimensions such as awareness, education, collaboration, participation, award programs, and feedback. Table 14 presents a description and device support for social–cultural dimensions in the framework of the smart and integrated household waste management system.

Table 14. Description of social–culture dimension.

Description	Devices
Subdimension: Awareness There are efforts to support the level of awareness of waste management	Use of AI to support awareness
Subdimension: Education There is a program to increase household knowledge regarding types of waste, how to manage it, and how to use smart systems	Tips and information features
Subdimension: Collaboration Various stakeholders have made collaborative efforts to solve household waste problems	Collaboration in sharing information and monitoring household behavior
Subdimension: Participation There is involvement of household actors to play a role in waste management	A system with fair point acquisition and a system that protects personal data
Subdimension: Award program There is a program that can encourage the involvement of household actors in managing their waste	Publication of winners' names
Subdimension: Feedback Availability of mechanisms to provide input or criticism of household waste management performance, services, and policies	Feedback on performance, services, and management policies

Awareness and attitudes toward waste types can facilitate classification and automatically support smart systems [9]. Education is an effort to increase awareness and build common sense in sorting waste [8]. Education can be implemented in the system through tips and information features about various types of waste and their disposal, aiming to increase user confidence and convenience [20]. Education can include information on the concepts of reduction, reuse, and recycling, as well as waste separation and environmentally friendly waste management at the household level [65]. Education on the use of the system, especially regarding the functionality of the smart system, can support accountability for household actors [39]. Information for educational materials can come from government, academic, and environmental campaign plans and programs [65].

Collaboration is a cooperative effort between various stakeholders to solve household waste problems. It is realized through sharing information and resources regarding waste recycling among various parties [19,54]. The central government, communities, city councils, media organizations, non-governmental organizations, and volunteers monitor the performance behavior of household waste management using the collaboration concept [39]. Participation can be built on trust in protecting primary personal information [19] and the availability of a system that is easy for household actors to use in sorting and classifying waste [47]. The participation of household actors can be maintained through a fair and objective point acquisition and exchange system [42] and the availability of an IoT-based system that maintains accountability [39]. Rewards programs can encourage household involvement in managing their waste. Community administrators can routinely give awards to households with the best performance and publish the names of winners [39]. Feedback is information about a user's recycling performance that helps inform how well users sort waste into different recycling categories. Users may receive penalties for incorrect product categories [56]. Household actors can provide feedback on government policies and waste services provided by recycling companies [19]. Feedback can also be used to evaluate the ease of waste sorting [20].

3.8.6. Validation Results of the Smart and Integrated Household Waste Management System Framework

The dimensions and subdimensions of the smart and integrated household waste management system framework have been validated. The questionnaire instrument ac-

commodates all subdimensions, with 38 statements describing the subdimensions and representing the five main dimensions. The questionnaire includes 19 statements supporting the information technology dimensions, four statements supporting the operational infrastructure dimensions, seven statements supporting the governance dimensions, two statements supporting the economic dimensions, and six statements supporting the social-cultural dimensions. Based on the results of the questionnaire, one statement from the information technology dimension does not support the framework of the smart and integrated household waste management system, namely voice recognition. The average calculated value of the questionnaire is 97.37%. Based on these values, the interviewee agreed that most of the subdimensions support the framework of a smart and integrated household waste management system. Therefore, the framework of the smart and integrated household waste management system remains the same.

The voice recognition subdimension is part of the information technology dimension. According to the source person, voice recognition is not needed if it is based on the social-culture conditions of households in Indonesia. There is a possibility that household actors may not pronounce the type of waste correctly, resulting in the waste container opening incorrectly. For example, if household actors bring metal waste but say “glass,” the waste container will open the valve for glass waste, causing classification mismatches. The expert stated that using sensors to detect types of waste is more appropriate for Indonesia than voice recognition. However, voice recognition is still needed in a smart and integrated household waste management system to help household actors with visual limitations, the elderly, or children [47]. The presence of voice recognition needs to be complemented with sensor devices [45] or artificial intelligence [47].

4. Discussion and Future Research

4.1. Discussions

Several previous studies on smart waste management systems for household waste have been examined. It uses PRISMA as one of the SLR methods and identifies 41 previous studies that examined smart waste management systems for household waste. This article’s snapshot is divided into two parts: Table 15 contains the SLR results of previous research, and Table 16 shows the design of the framework of a smart and integrated household waste management system.

Table 15. Snapshot of previous research.

Waste types	Solid waste, hazardous waste, electronic waste, inorganic waste, organic waste, recyclable waste, and non-recyclable waste
Process types	Separation, Collection, Transfer, Transport, Treatment, Disposal, Generation, Reduction, Reuse, Recycling, and Recovery
Features	Allocate bin placement, allocate waste collection routes, track the waste supply chain, provide incentives, weigh the amount of waste, suggest adjustments to waste prices, analyze waste data, predict the amount of waste, share information among stakeholders, provide feedback, generate waste collection reports, visualize separation performance, detect trash images, put the waste in the appropriate container, provide gamification, provide advice, guidance, information, and product offerings, mark readings with NFC, scan QR code, display geographic data visualization, support decision making on solutions, detect the density level of waste containers, and provide notification of container density levels.
Data	Location of containers, trash bin capacity, vehicle capacity, collection routes, the position of vehicle, transportation travel time, total distance, duration of work shift, total volume of waste, waste type, waste collection time, prediction of waste volume, amount of recycled waste, waste prices, waste fees, price adjustments, weight of waste per type, weather, stakeholder involved, impact on the environment spatial/geographical, spatial distribution of waste; pictures/photos of trash, fuel costs, waste humidity, deposit frequency, depositor identity, degree of container fullness, separation accuracy, voice keywords, and incentives.
Stakeholders	Government, household, NGOs, waste management company, waste recycling company, scavenger, mobile network operator

Table 16. Snapshot of the framework of smart and integrated household waste management system.

Information technology	Hardware, software, machine learning & AI, network infrastructure, human–computer interaction, cloud computing, social media, database
Operational infrastructure	Waste container, recycling plant, transferring unit, truck
Governance	Guidance, policy, privacy, transparency, security, trust, accountability
Economy	Circular economy, incentive program
Social–culture	Awareness, education, collaboration, participation, award programs, and feedback

Four waste criteria based on previous research have been identified: the physical condition of the waste, the risk level of waste, the composition of waste materials, and the recovery feasibility of waste. Each criterion includes several different types of waste. Based on the physical condition of the waste, the type that dominates is solid waste [15,16,36,37,66]. Regarding the risk level of waste, the most dominant type is hazardous waste [22,40–47]. The focus on hazardous waste indicates efforts to manage it to prevent environmental harm. Based on the composition of waste material, organic waste is the type most widely developed using a smart waste management system in the context of household waste. However, the number of studies identifying inorganic waste is similar. Regarding recovery feasibility, recyclable waste is the most studied because it constitutes 50% of all solid waste but often ends up in landfills without any recycling process [58].

Eleven waste management processes supported by smart waste management in household waste have been identified. These processes align with the ISWM framework. Based on the SLR results, separation is the most supported waste management process in household waste, with 21 studies developing smart systems for sorting household waste [9,17,20,36,39–51,53,55,58,59]. A smart system supporting the separation process can help obtain recyclable waste, preventing it from being mixed with other waste so that recycled waste can become a resource for other parties [9].

Twenty-three features supporting a smart household waste management system have been identified. In the smart waste management system for household waste, three main functions are applied: detecting waste images for sorting [9,36,41,43,44,46,55], placing the waste in appropriate containers [17,36,41,43,44,46,50,53], and detecting the density level of waste containers [12,13,42,45,48–50]. Thirty-one data sets that support the features of the smart waste management system for household waste have been identified. The three most commonly used data sets in the smart waste management system for household waste are waste type, waste volume, and waste container location. Seven stakeholders are involved in the smart waste management system for household waste: Government Authority, Waste Management Company, Waste Recycling Company, Environmental NGO, Mobile Network Operator, Household, and Scavenger. The involvement of all stakeholders can support the successful implementation of the smart household waste management system.

An expert from the Indonesian Ministry of Environment and Forestry validated the dimensions and subdimensions of a smart and integrated household waste management system framework. The average value of the questionnaire calculations was 97.37%. Based on these values, it can be concluded that the interviewee agrees that most of the dimensions and subdimensions support the smart and integrated household waste management system framework. The framework developed not only focuses on information technology dimensions but also identifies the roles of operational infrastructure, governance, and economic and social–cultural dimensions. Additionally, the framework identifies the roles and involvement of stakeholders in the smart and integrated household waste management system. The developed framework integrates all processes identified by the ISWM framework, based on the principles of reduction, reuse, recycling, and recovery. All dimensions of information technology need to be integrated to produce efficient, effective, and sustainable household waste management services.

4.2. Future Research

The results of the bibliometric analysis identified trends from many previous studies. These trends provide valuable insights into the direction of future research regarding smart household waste management systems. Future research directions are organized based on keywords often found in previous research, including IoT, bins, recycling, waste disposal, circular economy, waste collection, deep learning, smart waste management, sustainable development, and machine learning. Figure 7 shows a visualization of future research mapping.

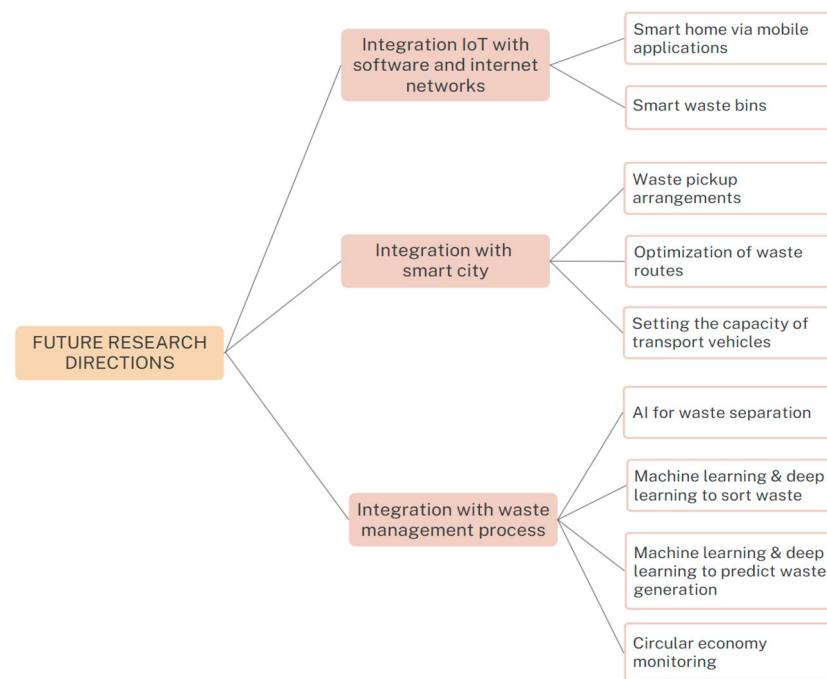


Figure 7. Visualization of future research mapping.

Future research on smart household waste management systems needs to integrate IoT technology. In the context of a smart household waste management system, IoT is represented by hardware in the form of sensors connected to the internet to collect waste data in every waste management process. Future research can integrate IoT with software and internet networks to support waste data monitoring integrated with smart homes via mobile applications. This integration can help householders monitor the condition of their trash cans automatically and has the potential to increase householders' comfort. Future research could develop smart waste bins integrated with sensors in people's homes [43]. Smart waste bins support automatic monitoring of fullness levels, allowing householders to report full trash bins to waste management service officers via a mobile application. Future research needs to identify the characteristics of smart waste bins that are economical, easy to use, and have sufficient storage capacity for household users.

Future research can link the development of a smart household waste management system to support smart cities. Smart household waste management needs to be linked to support for one of the smart city dimensions, namely the smart environment. The relationship between a smart city and a smart household waste management system lies in the efficiency of the smart household waste management system, which can be integrated with household waste pickup arrangements based on the level of fullness of the smart waste bins, optimal routes [69], setting the capacity of transport vehicles, and scheduled pickups to support waste management efficiency in the city. Future research can identify opportunities for smart household waste management systems to encourage sustainable development goals for smart cities, aiming to create clean and sustainable cities.

Future research can develop various technologies that support smart household waste management systems in waste collection, recycling, and disposal processes. Research on smart household waste management systems utilizing artificial intelligence for waste sorting can support the waste recycling process and offers opportunities for further development. Future research can develop a smart household waste management system integrated with machine learning and deep learning to sort waste [53] and predict waste generation [14]. Additionally, future research could develop smart household waste management systems for recycling and final processing facilities by applying digital technologies to monitor and process waste efficiently. Developing a smart household waste management system in recycling facilities can reduce the waste sent to final processing and improve the circular economy. Future research can develop a smart household waste management system integrated with circular economy monitoring to produce sustainable waste management with high economic value [19].

5. Conclusions and Implications

This research aims to design a framework for a smart and integrated household waste management system derived from SLR results using the PRISMA method. It presents an SLR using the PRISMA method to examine the development of smart waste management for household waste. RQ1 identifies 11 household waste management processes supported by smart waste management. RQ2 identifies dimensions that support smart waste management for household waste. The dimensions identified are used to design a smart and integrated household waste management system. RQ3 identifies dimensions of information technology that support smart waste management for managing household waste. The information technology dimension of the smart waste management system for household waste helps to plan for better waste management, streamline waste management operations, and optimize waste management. RQ4 was answered by developing a smart and integrated household waste management system framework.

Research implications for academics are expanding the body of knowledge, encouraging multi-disciplinary studies, and suggesting further research on smart household waste management systems. It contributes to expanding the knowledge of household waste management based on smart technology with a comprehensive approach. It can bridge multi-disciplinary research collaboration and provide opportunities for multi-disciplinary studies that utilize information systems science, engineering, computer science, economics, and social and cultural sciences. It provides suggestions for further research developed from identifying trends in bibliometric analysis results.

This research provides a practical contribution by offering a framework for a smart and integrated household waste management system that can be implemented as a waste management strategy for stakeholders in the era of digital transformation. The implemented framework can resolve practical problems and improve the operational sustainability of household waste management practices in an integrated manner for the entire process.

There are several areas for improvement in future research. It does not focus on certain types of countries, such as differentiating between developing and developed countries. Differences in country types can impact the development of smart waste management systems used to manage household waste because the problems are also different. There are five dimensions of the framework of a smart and integrated household waste management system. However, referring to the ISWM framework, several other dimensions have yet to be identified in the framework developed, including institutional, environmental or health, and political and legal dimensions. Meanwhile, the policy dimension has been identified in the governance dimension. Future research can identify other dimensions to be combined with the framework of a smart and integrated household waste management system. Future research can use this framework to validate it with all stakeholders involved in household waste management, namely waste management companies, waste recycling companies, environmental NGOs, mobile network operators, households, and scavengers.

Author Contributions: Conceptualization, Y.G.S. and Y.W.; methodology, I.E.; software, Y.W.; validation, I.E.; formal analysis, Y.W.; investigation, Y.W.; resources, Y.W.; data curation, I.E.; writing—original draft preparation, Y.W.; writing—review and editing, Y.W. and I.E.; visualization, Y.W. and Y.G.S.; supervision, Y.G.S.; project administration, Y.W.; funding acquisition, Y.G.S. and I.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received funding from Universitas Indonesia through grant PUTI Q2 number NKB-569/UN2.RST/HKP.05.00/2023.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

Appendix A

Table A1. Citation Counts and Publications.

No	Year	Title	Journal Name	Journal Database	Country	Citation Counts
1	2020	Electronic waste collection systems using Internet of Things (IoT): Household electronic waste management in Malaysia [22]	Journal of Cleaner Production	ScienceDirect	Malaysia	143
2	2020	Household Waste Management System Using IoT and Machine Learning [48]	Procedia Computer Science	ScienceDirect	India	131
3	2021	Development of machine learning—based models to forecast solid waste generation in residential areas: A case study from Vietnam [20]	Resources, Conservation & Recycling	ScienceDirect	Vietnam	97
4	2022	Automatic Detection and Classification System of Domestic Waste via Multimodel Cascaded Convolutional Neural Network [53]	IEEE Transactions on Industrial Informatics	IEEE	China	92
5	2020	Multi-site household waste generation forecasting using a deep learning approach [14]	Waste Management	ScienceDirect	Denmark	71
6	2021	Internet of Things (IoT)-Enabled accountability in source separation of household waste for a circular economy in China [39]	Journal of Cleaner Production	ScienceDirect	China	56
7	2021	Designing a smart incentive-based recycling system for household recyclable waste [18]	Waste Management	ScienceDirect	China	52
8	2020	Network design of a household waste collection system: A case study of the commune of Renca in Santiago, Chile [10]	Waste Management	ScienceDirect	Chile	46
9	2019	IoT based Automatic Waste segregator [49]	IEEE	IEEE	India	27
10	2023	Bringing trust and transparency to the opaque world of waste management with blockchain: A Polkadot parathread application [56]	Computers & Industrial Engineering	ScienceDirect	Portugal	25
11	2022	The development of sustainable IoT E-waste management guideline for households [8]	Chemosphere	ScienceDirect	Malaysia	24
12	2022	An Ensemble Learning Based Classification Approach for the Prediction of Household Solid Waste Generation [15]	Sensors	Scopus	N/A	23

Table A1. Cont.

No	Year	Tittle	Journal Name	Journal Database	Country	Citation Counts
13	2022	Smart strategies for household food waste management [54]	Prodia Computer Science	ScienceDirect	Italy	19
14	2022	Quantification and mapping of domestic plastic waste using GIS/GPS approach at the city of Guayaquil [52]	CIRP Life Cycle Engineering ConferenceQuantification	ScienceDirect	Ecuador	18
15	2019	Sustainable Household Food Management Using Smart Technology [67]	IEEE	IEEE	United Kingdom	17
16	2022	Solving the bin location–allocation problem for household and recycle waste generated in the commune of Renca in Santiago, Chile [57]	Waste Management & Research	Scopus	Chile	15
17	2022	An Intelligent Waste-Sorting and Recycling Device Based on Improved EfficientNet [44]	International Journal of Environmental Research and Public Health	Scopus	N/A	13
18	2022	Arc routing with trip-balancing and attractiveness measures—A waste collection case study [11]	Computers and Operations Research	ScienceDirect	Portuguese	8
19	2020	Cloud-based product-service systems platform for household solid waste classification management [47]	IET Collaborative Intelligent Manufacturing	Scopus	China	8
20	2020	Design and implementation of smart waste recycling bin for the household environment based on IoT [47]	Sensor Review	Emerald Insight	N/A	7
21	2020	Research on Computer Vision-Based Waste Sorting System [55]	IEEE	IEEE	China	6
22	2023	Circular economy is key! Designing a digital artifact to foster smarter household biowaste sorting [19]	Journal of Cleaner Production	ScienceDirect	German	5
23	2023	ESS-IoT: The Smart Waste Management System for General Household [43]	Pertanika Journal of Science and Technology	Scopus	Malaysia	5
24	2021	Domestic Solid Waste Disposal Logistic Optimization Using Internet of Things Technologies [37]	IEEE	IEEE	Ukraine	4
25	2022	LoRa-Based Smart Waste Bins Placement using Clustering Method in Rural Areas of Indonesia [21]	International Journal of Advances in Soft Computing and its Applications	Scopus	Indonesia	4
26	2022	Internet of Things based Intelligent Waste Segregation and Management System for Smart Home Application [50]	IEEE	IEEE	N/A	4
27	2022	A Household Garbage Classification and Collection Device Based on Machine Vision and Deep Learning [41]	IEEE	IEEE	N/A	3

Table A1. Cont.

No	Year	Tittle	Journal Name	Journal Database	Country	Citation Counts
28	2021	Optimal routing of household waste collection using ArcGIS application: a case study of El Bousten district, Sfax city, Tunisia [17]	Arabian Journal of Geosciences	Scopus	Tunis	3
29	2021	Use of GIS for digital mapping and spatial analysis of landfills: Case of the settat province in Morocco [66]	Journal of Ecological Engineering	Scopus	Morocco	3
30	2023	Evaluation of a data-driven intelligent waste classification system for scientific management of garbage recycling in a Chinese community [42]	Environmental Science and Pollution Research	Scopus	China	2
31	2023	Smart Waste Segregation for Home Environment [16]	IEEE	IEEE	N/A	2
32	2022	A Reward-based Framework for Recovery and Utilization of Recyclable Wastes using Blockchain [58]	IEEE	IEEE	N/A	2
33	2022	Smart Household Waste Classification System using Artificial Intelligence [9]	IEEE	IEEE	China	1
34	2023	Disposal of Solid Household Waste Using Computer Vision [36]	IEEE Smart Information Systems and Technologies (SIST)	IEEE	Kazakhstan	1
35	2020	Application of analytical hierarchy process and GIS to analyse management plans for household and similar waste in Marrakech prefecture, Morocco [13]	IEEE	IEEE	Morocco	1
36	2023	An Android Application for Smart Garbage Monitoring System using Internet of Things (IoT) [51]	IEEE	IEEE	India	1
37	2022	Design and Development of Intelligent Community Management Service Platform Integrating Garbage Image Recognition and Classification [40]	IEEE	IEEE	China	1
38	2022	Design of Voice Recognition of Intelligent Household Waste Classification System [45]	Proceedings of SPIE	Scopus	China	1
39	2022	Design of Intelligent Household Separated-Waste Containers Based on Deep Learning [46]	IEEE	IEEE	China	1
40	2021	Ciudad Limpia Valdivia: A Mobile and Web Based Smart Solution Based on Foss Technology to Support Municipal and Household Waste Collection [65]	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Scopus	Chile	1
41	2021	IoT-Based Waste Height and Weight Monitoring System [59]	Journal of Computer Science	Scopus	Indonesia	1

Appendix B

Table A2. Features of Smart Household Waste Management System.

Process: Reduction	
1.	Track the waste supply chain/traceability [54]
2.	Provide advice, guidance, information, and product offers [54,67]
3.	Mark reading with near-field communication (NFC) [54,67]
4.	Provide notification of container density levels [67]
Process: Reduction, Reuse, Recycling, and Recovery	
1.	Track the waste supply chain/traceability [8]
2.	Provide advice, guidance, information, and product offers [8]
Process: Separation	
1.	Provide incentives [47]
2.	Identify/weigh the amount of waste [59]
3.	Visualize sorting performance [9,19,53,55]
4.	Detect waste images for sorting [9,36,41,43,44,46,55]
5.	Put the waste in appropriate containers [36,41,43,44,46,50,53]
6.	Provide advice, guidance, information, and product offers [19,40]
7.	Detect the density level of waste containers [48–50]
8.	Provide notification of container density levels [48,49]
9.	Provide a mechanism for providing feedback [19]
10.	Provide elements of gamification [19]
Process: Separation and Collection	
1.	Provide incentives according to transactions [39,58]
2.	Identify/weigh the amount of waste [58]
3.	Analyze waste data [39,42]
4.	Generate reports or history of waste collection [19,58]
5.	Detect trash images for sorting [42]
6.	Support waste sorting/classification [16,42]
7.	Put the waste in the appropriate container [16]
8.	Detect the density level of waste containers [42,45]
9.	Provide notification of container density levels [39,42,45]
Process: Collection	
1.	Allocate bin placement [10,21,57]
2.	Allocate waste collection routes [10,65]
3.	Track the waste supply chain/traceability [56]
4.	Provide incentives according to transactions [22,56]
5.	Identify/weigh the amount of waste [10,18,19]
6.	Suggest adjusting waste prices [18]
7.	Analyze waste data [18,21]
8.	Predict the amount of waste in a certain period [18,21]
9.	Share information among stakeholders [18,65]
10.	Generate waste collection reports or history [22]
11.	Visualize sorting performance [21]
12.	Support waste sorting/classification [21]
13.	Provide advice, guidance, information, and product offers [22]
14.	Scan QR code [22]
15.	Display geographic data visualization [52,57,66]
16.	Support decision-making on waste management solutions [57,66]
Process: Collection and Transport	
1.	Display geographic data visualization [11,37]
2.	Support decision-making on waste management solutions [11]
Process: Transfer and Transport	
1.	Allocate bin placement [17]
2.	Display geographic data visualization [17]
Process: Generation	

Table A2. Cont.

Predict the amount of waste in a certain period [14,15,20]	
Process: Treatment	
1.	Detect the density level of waste containers [12]
2.	Provide notification of container density levels [12]
Process: Disposal	
1.	Display geographic data visualization [13]
2.	Support decision-making on waste management solutions [13]
3.	Detect the density level of waste containers [13]

References

1. Tang, D.; Cai, X.; Nketiah, E.; Adjei, M.; Adu-Gyamfi, G.; Obuobi, B. Separate Your Waste: A Comprehensive Conceptual Framework Investigating Residents' Intention to Adopt Household Waste Separation. *Sustain. Prod. Consum.* **2023**, *39*, 216–229. [\[CrossRef\]](#)
2. Jia, Y.; Cheng, S.; Shi, R. Decision-Making Behavior of Rural Residents' Domestic Waste Classification in Northwestern of China—Analysis Based on Environmental Responsibility and Pollution Perception. *J. Clean. Prod.* **2021**, *326*, 129374. [\[CrossRef\]](#)
3. Knickmeyer, D. Social Factors Influencing Household Waste Separation: A Literature Review on Good Practices to Improve the Recycling Performance of Urban Areas. *J. Clean. Prod.* **2020**, *245*, 118605. [\[CrossRef\]](#)
4. Fadhillah, W.; Imran, N.I.N.; Ismail, S.N.S.; Jaafar, M.H.; Abdullah, H. Household Solid Waste Management Practices and Perceptions among Residents in the East Coast of Malaysia. *BMC Public Health* **2022**, *22*, 1–20. [\[CrossRef\]](#)
5. Wen, Z.; Li, H.; Wang, Y.; Zhao, X.; Deng, X. Can the Implementation of Household Waste Classification Mitigate Greenhouse Gas Emissions in Beijing? A Comprehensive Analysis of Recent Trends and Future Scenarios. *Heliyon* **2023**, *9*, e23132. [\[CrossRef\]](#)
6. United Nations SDGs Report 2023. In *The Sustainable Development Goals Report 2023: Special Edition*; United Nations: New York, NY, USA, 2023; p. 80.
7. Anjum, M.; Shahab, S.; Umar, M.S. Smart Waste Management Paradigm in Perspective of IoT and Forecasting Models. *Int. J. Environ. Waste Manag.* **2022**, *29*, 34–79. [\[CrossRef\]](#)
8. Razip, M.M.; Savita, K.S.; Kalid, K.S.; Ahmad, M.N.; Zaffar, M.; Abdul Rahim, E.E.; Baleanu, D.; Ahmadian, A. The Development of Sustainable IoT E-Waste Management Guideline for Households. *Chemosphere* **2022**, *303*, 134767. [\[CrossRef\]](#)
9. Liang, Z.; Gumabay, M.V.N. Smart Household Waste Classification System Using Artificial Intelligence. In Proceedings of the 2022 5th International Conference on Advanced Electronic Materials, Computers and Software Engineering (AEMCSE 2022), Wuhan, China, 22–24 April 2022; pp. 766–771. [\[CrossRef\]](#)
10. Blazquez, C.; Paredes-Belmar, G. Network Design of a Household Waste Collection System: A Case Study of the Commune of Renca in Santiago, Chile. *Waste Manag.* **2020**, *116*, 179–189. [\[CrossRef\]](#)
11. Janela, J.; Mourão, M.C.; Santiago Pinto, L. Arc Routing with Trip-Balancing and Attractiveness Measures—A Waste Collection Case Study. *Comput. Oper. Res.* **2022**, *147*, 105934. [\[CrossRef\]](#)
12. Harjoseputro, Y.; Julianto, E.; Handarkho, Y.D.; Ritonga, Y.I.T. Design and Implementation of Smart Waste Recycling Bin for the Household Environment Based on IoT. *Sens. Rev.* **2020**, *40*, 657–663. [\[CrossRef\]](#)
13. Edderkaoui, R.; Khomsi, D.; Hamidi, A.; Baiti, H.B.; Souidi, H.; Elhachmi, D.; Aqil, M. Application of Analytical Hierarchy Process and GIS to Analyse Management Plans for Household and Similar Waste in Marrakech Prefecture, Morocco. In Proceedings of the 2020 IEEE International Conference of Moroccan Geomatics (Morgeo 2020), Casablanca, Morocco, 11–13 May 2020. [\[CrossRef\]](#)
14. Cubillos, M. Multi-Site Household Waste Generation Forecasting Using a Deep Learning Approach. *Waste Manag.* **2020**, *115*, 8–14. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Namoun, A.; Hussein, B.R.; Tufail, A.; Alrehaili, A.; Syed, T.A.; Benrhouna, O. An Ensemble Learning Based Classification Approach for the Prediction of Household Solid Waste Generation. *Sensors* **2022**, *22*, 3506. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Rijah, U.L.M.; Abeygunawardhana, P.K.W. Smart Waste Segregation for Home Environment. In Proceedings of the 2023 3rd International Conference on Advanced Research in Computing (ICARC 2023), Belihuloya, Sri Lanka, 23–24 February 2023; pp. 184–189. [\[CrossRef\]](#)
17. Sallem, R.; Serbaji, M.M.; Alamri, A.M.; Kallel, A.; Trabelsi, I. Optimal Routing of Household Waste Collection Using ArcGIS Application: A Case Study of El Boustien District, Sfax City, Tunisia. *Arab. J. Geosci.* **2021**, *14*, 1038. [\[CrossRef\]](#)
18. Zhou, J.; Jiang, P.; Yang, J.; Liu, X. Designing a Smart Incentive-Based Recycling System for Household Recyclable Waste. *Waste Manag.* **2021**, *123*, 142–153. [\[CrossRef\]](#) [\[PubMed\]](#)
19. Crome, C.; Graf-Drasch, V.; Hawlitschek, F.; Zinsbacher, D. Circular Economy Is Key! Designing a Digital Artifact to Foster Smarter Household Biowaste Sorting. *J. Clean. Prod.* **2023**, *423*, 138613. [\[CrossRef\]](#)
20. Nguyen, X.C.; Nguyen, T.T.H.; La, D.D.; Kumar, G.; Rene, E.R.; Nguyen, D.D.; Chang, S.W.; Chung, W.J.; Nguyen, X.H.; Nguyen, V.K. Development of Machine Learning—Based Models to Forecast Solid Waste Generation in Residential Areas: A Case Study from Vietnam. *Resour. Conserv. Recycl.* **2021**, *167*, 105381. [\[CrossRef\]](#)
21. Abidin, A.Z.Z.; Othman, M.F.I.; Hassan, A.; Murdianingsih, Y.; Suryadi, U.T.; Faizal, M. LoRa-Based Smart Waste Bins Placement Using Clustering Method in Rural Areas of Indonesia. *Int. J. Adv. Soft Comput. Its Appl.* **2022**, *14*, 105–123. [\[CrossRef\]](#)

22. Kang, K.D.; Kang, H.; Ilankoon, I.M.S.K.; Chong, C.Y. Electronic Waste Collection Systems Using Internet of Things (IoT): Household Electronic Waste Management in Malaysia. *J. Clean. Prod.* **2020**, *252*, 119801. [\[CrossRef\]](#)
23. Zhang, Q.; Li, H.; Wan, X.; Skitmore, M.; Sun, H. An Intelligent Waste Removal System for Smarter Communities. *Sustainability* **2020**, *12*, 6829. [\[CrossRef\]](#)
24. Fatimah, Y.A.; Govindan, K.; Murniningsih, R.; Setiawan, A. Industry 4.0 Based Sustainable Circular Economy Approach for Smart Waste Management System to Achieve Sustainable Development Goals: A Case Study of Indonesia. *J. Clean. Prod.* **2020**, *269*, 122263. [\[CrossRef\]](#)
25. Shamseer, L.; Moher, D.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A.; Group, P. Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015: Elaboration and Explanation. *BMJ* **2015**, *349*, 7647. [\[CrossRef\]](#) [\[PubMed\]](#)
26. Moher, D.; Shamseer, L.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A.; Group, P. Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015 Statement. *Syst. Rev.* **2015**, *4*, 1–9. [\[CrossRef\]](#)
27. Kohl, C.; McIntosh, E.J.; Unger, S.; Haddaway, N.R.; Kecke, S.; Schiemann, J.; Wilhelm, R. Online Tools Supporting the Conduct and Reporting of Systematic Reviews and Systematic Maps: A Case Study on CADIMA and Review of Existing Tools. *Environ. Evid.* **2018**, *7*, 8. [\[CrossRef\]](#)
28. Indonesian Ministry of Environment and Forestry Organization. Available online: <https://www.menlhk.go.id/profile/organization/> (accessed on 26 March 2024).
29. Indonesian Ministry of Environment and Forestry Waste Management Performance Achievements. Available online: <https://sipsn.menlhk.go.id/sipsn/> (accessed on 27 March 2024).
30. Barnett-Page, E.; Thomas, J. Methods for the Synthesis of Qualitative Research: A Critical Review. *BMC Med. Res. Methodol.* **2009**, *9*, 59. [\[CrossRef\]](#) [\[PubMed\]](#)
31. Maghsoudi, M.; Shokouhyar, S.; Khanizadeh, S.; Shokoohyar, S. Towards a Taxonomy of Waste Management Research: An Application of Community Detection in Keyword Network. *J. Clean. Prod.* **2023**, *401*, 136587. [\[CrossRef\]](#)
32. Zargar, T.I.; Alam, P.; Khan, A.H.; Alam, S.S.; Abutaleb, A.; Abul Hasan, M.; Khan, N.A. Characterization of Municipal Solid Waste: Measures towards Management Strategies Using Statistical Analysis. *J. Environ. Manag.* **2023**, *342*, 118331. [\[CrossRef\]](#) [\[PubMed\]](#)
33. Leeabai, N.; Siripaiboon, C.; Taweengern, K.; Buttanoo, C.; Sujirapatpong, W.; Yimyam, D.; Takahashi, F.; Areeprasert, C. The Integrated Study of the Effects of Infographic Design on Waste Separation Behavior and the Behavioral Outcome Implementation on Waste Composting. *Waste Manag.* **2023**, *169*, 276–285. [\[CrossRef\]](#) [\[PubMed\]](#)
34. Osman, A.M.; Ukundimana, Z.; Wamyil, F.B.; Yusuf, A.A.; Telesphore, K. Quantification and Characterization of Solid Waste Generated within Mulago National Referral Hospital, Uganda, East Africa. *Case Stud. Chem. Environ. Eng.* **2023**, *7*, 100334. [\[CrossRef\]](#)
35. Wang, Y.; Chen, Z.; Ma, J.; Wang, J.; Li, L. Migration and Transformation of Main Components during Perishable Waste Bio-Drying Process. *J. Environ. Manag.* **2022**, *319*, 115720. [\[CrossRef\]](#)
36. Nurkadem, K.; Karymsakova, N.; Mansurova, M. Disposal of Solid Household Waste Using Computer Vision. In Proceedings of the 2023 IEEE International Conference on Smart Information Systems and Technologies (SIST), Astana, Kazakhstan, 4–6 May 2023; pp. 474–478. [\[CrossRef\]](#)
37. Yamenko, J.; Kurdecha, V.; Gvozdetka, N. Domestic Solid Waste Disposal Logistic Optimization Using Internet of Things Technologies. In Proceedings of the 2021 IEEE International Conference on Information and Telecommunication Technologies and Radio Electronics (UkrMiCo), Kyiv, Ukraine, 29 November–3 December 2021; pp. 150–154. [\[CrossRef\]](#)
38. Benezzine, G.; Zouhri, A.; Koulali, Y. AHP and GIS-Based Site Selection for a Sanitary Landfill: Case of Settat Province, Morocco. *J. Ecol. Eng.* **2022**, *23*, 1–13. [\[CrossRef\]](#)
39. Wang, B.; Farooque, M.; Zhong, R.Y.; Zhang, A.; Liu, Y. Internet of Things (IoT) -Enabled Accountability in Source Separation of Household Waste for a Circular Economy in China. *J. Clean. Prod.* **2021**, *300*, 126773. [\[CrossRef\]](#)
40. Fu, L. Design and Development of Intelligent Community Management Service Platform Integrating Garbage Image Recognition and Classification. In Proceedings of the 2022 4th International Conference on Applied Machine Learning (ICAML), Patnaik, Srikanta, 23–25 July 2022.
41. Xie, W.; Wang, X.; Li, S.; Xu, W.; Duan, X. A Household Garbage Classification and Collection Device Based on Machine Vision and Deep Learning. In Proceedings of the 2022 4th International Conference on Robotics and Computer Vision (ICRCV), Wuhan, China, 25–27 September 2022; pp. 209–214. [\[CrossRef\]](#)
42. Zhao, Z.; Yang, J.; Yu, K.; Wang, M.; Zhang, C.; Yu, B.; Zheng, H. Evaluation of a Data Driven Intelligent Waste Classification System for Scientific Management of Garbage Recycling in a Chinese Community. *Environ. Sci. Pollut. Res.* **2023**, *30*, 87913–87924. [\[CrossRef\]](#)
43. Wong, S.Y.; Han, H.; Cheng, K.M.; Koo, A.C.; Yussof, S. ESS-IoT: The Smart Waste Management System for General Household. *Pertanika J. Sci. Technol.* **2023**, *31*, 311–325. [\[CrossRef\]](#)
44. Feng, Z.; Yang, J.; Chen, L.; Chen, Z.; Li, L. An Intelligent Waste-Sorting and Recycling Device Based on Improved EfficientNet. *Int. J. Environ. Res. Public Health* **2022**, *19*, 15987. [\[CrossRef\]](#) [\[PubMed\]](#)
45. He, H.; Li, Q. Design of Voice Recognition of Intelligent Household Waste Classification System. In Proceedings of the Artificial Intelligence, and Information Engineering (RAIIE 2022), Hohhot, China, 15–17 July 2022; p. 113. [\[CrossRef\]](#)

46. Lin, A.; Zhang, F. Design of Intelligent Household Separated-Waste Containers Based on Deep Learning. In Proceedings of the 2022 5th International Conference on Intelligent Robotics and Control Engineering (IRCE), Tianjin, China, 23–25 September 2022; pp. 56–59. [\[CrossRef\]](#)
47. Wan, M.; Qu, T.; Huang, M.; Li, L.; Huang, G.Q. Cloud-Based Product-Service Systems Platform for Household Solid Waste Classification Management. *IET Collab. Intell. Manuf.* **2020**, *2*, 66–73. [\[CrossRef\]](#)
48. Dubey, S.; Singh, P.; Yadav, P.; Singh, K.K. Household Waste Management System Using IoT and Machine Learning. *Procedia Comput. Sci.* **2020**, *167*, 1950–1959. [\[CrossRef\]](#)
49. Lopes, S.; MacHado, S. IoT Based Automatic Waste Segregator. In Proceedings of the 2019 International Conference on Advances in Computing, Communication and Control (ICAC3), Mumbai, India, 20–21 December 2019; pp. 1–5. [\[CrossRef\]](#)
50. Bhuvaneshwari, M.; Tansin, K.; Ahamed, S.T.; Ram, N.T.S.; Prasath, S.V. Internet of Things Based Intelligent Waste Segregation and Management System for Smart Home Application. In Proceedings of the 2022 7th International Conference on Communication and Electronics Systems (ICCES), Coimbatore, India, 22–24 June 2022.
51. Jayanth, S.; Jayalakshmi, C.; Parthive, M.; Chandra Kala, V.; Uhasushma, B. An Android Application for Smart Garbage Monitoring System Using Internet of Things (IoT). In Proceedings of the 2023 7th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 23–25 February 2023; pp. 1242–1248. [\[CrossRef\]](#)
52. Hidalgo-Crespo, J.; Álvarez-Mendoza, C.I.; Soto, M.; Amaya-Rivas, J.L. Quantification and Mapping of Domestic Plastic Waste Using GIS/GPS Approach at the City of Guayaquil. *Procedia CIRP* **2022**, *105*, 86–91. [\[CrossRef\]](#)
53. Li, J.; Chen, J.; Sheng, B.; Li, P.; Yang, P.; Feng, D.D.; Qi, J. Automatic Detection and Classification System of Domestic Waste via Multimodel Cascaded Convolutional Neural Network. *IEEE Trans. Ind. Inform.* **2022**, *18*, 163–173. [\[CrossRef\]](#)
54. Cappelletti, F.; Papetti, A.; Rossi, M.; Germani, M. Smart Strategies for Household Food Waste Management. *Procedia Comput. Sci.* **2022**, *200*, 887–895. [\[CrossRef\]](#)
55. Cai, H.; Cao, X.; Huang, L.; Zou, L.; Yang, S. Research on Computer Vision-Based Waste Sorting System. In Proceedings of the 2020 5th International Conference on Control, Robotics and Cybernetics (CRC), Wuhan, China, 16–18 October 2020; pp. 117–122. [\[CrossRef\]](#)
56. Scott, I.J.; de Castro Neto, M.; Pinheiro, F.L. Bringing Trust and Transparency to the Opaque World of Waste Management with Blockchain: A Polkadot Parathread Application. *Comput. Ind. Eng.* **2023**, *182*, 109347. [\[CrossRef\]](#)
57. Letelier, C.; Blazquez, C.; Paredes-Belmar, G. Solving the Bin Location–Allocation Problem for Household and Recycle Waste Generated in the Commune of Renca in Santiago, Chile Waste. *Waste Manag. Res.* **2022**, *40*, 154–164. [\[CrossRef\]](#) [\[PubMed\]](#)
58. Gupta, Y.S.; Mukherjee, S. A Reward-Based Framework for Recovery and Utilization of Recyclable Wastes Using Blockchain. In Proceedings of the 2022 OITS International Conference on Information Technology (OCIT), Bhubaneswar, India, 14–16 December 2022; pp. 609–613. [\[CrossRef\]](#)
59. Gunawan, T.; Hernawati, E.; Aditya, B.R. IoT-Based Waste Height and Weight Monitoring System. *J. Comput. Sci.* **2021**, *17*, 1085–1092. [\[CrossRef\]](#)
60. Anshütz, J.; Ijgosse, J.; Scheinberg, A. *Putting Integrated Sustainable Waste Management into Practice*; WASTE: Gouda, The Netherlands, 2004; ISBN 9076639051.
61. Mir, I.S.; Cheema, P.P.S.; Singh, S.P. Implementation Analysis of Solid Waste Management in Ludhiana City of Punjab. *Environ. Chall.* **2021**, *2*, 100023. [\[CrossRef\]](#)
62. Ignatuschtschenko, E. Electronic Waste in China, Japan, and Vietnam: A Comparative Analysis of Waste Management Strategies. *Vienna J. East Asian Stud.* **2018**, *9*, 29–58. [\[CrossRef\]](#)
63. United Nations Human Settlements Programme. *Solid Waste Management in the World's Cities—Water and Sanitation in the World's Cities 2010*; Routledge: London, UK, 2010; Volume 21, ISBN 9781849711692.
64. Wilson, D.C.; Velis, C.A.; Rodic, L. Integrated Sustainable Waste Management in Developing Countries. *Proc. Inst. Civ. Eng. Waste Resour. Manag.* **2013**, *166*, 52–68. [\[CrossRef\]](#)
65. Lühr Sierra, D.V.; Balinos, M.; Gatica, J.; Lagomarsino, C. Ciudad Limpia Valdivia: A Mobile and Web Based Smart Solution Based on Foss Technology To Support Municipal And Household Waste Collection. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. ISPRS Arch.* **2021**, *46*, 97–102. [\[CrossRef\]](#)
66. Benezzine, G.; Zouhri, A.; Koulali, Y. Use of Gis for Digital Mapping and Spatial Analysis of Landfills: Case of the Settat Province in Morocco. *Ecol. Eng. Environ. Technol.* **2021**, *22*, 3. [\[CrossRef\]](#)
67. Phiri, G.; Trevorrow, P. Sustainable Household Food Management Using Smart Technology. In Proceedings of the 2019 10th International Conference on Dependable Systems, Services and Technologies (DESSERT), Leeds, UK, 5–7 June 2019; pp. 112–119. [\[CrossRef\]](#)
68. Vorobeve, D.; Scott, I.J.; Oliveira, T.; Neto, M. Adoption of New Household Waste Management Technologies: The Role of Financial Incentives and pro-Environmental Behavior. *J. Clean. Prod.* **2022**, *362*, 132328. [\[CrossRef\]](#)
69. Ahmad, S.; Imran Jamil, F.; Iqbal, N.; Kim, D. Optimal route recommendation for waste carrier vehicles for efficient waste collection: A step forward towards sustainable cities. *IEEE Access* **2020**, *8*, 77875–77887. [\[CrossRef\]](#)

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.