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Urban Waste Management Systems for Solid Waste with Simulation Approach: A Bibliometric Analysis

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ABSTRACT

This research aims to thoroughly examine the research progress in dynamic simulation modeling for urban waste management through bibliometric approaches. This Research methodically retrieved data from the Scopus database for the period 2010–2024, focusing exclusively on peer-reviewed articles in Environmental Science and Engineering. The literature search approach utilized a collection of key terms such as the journal of "urban waste management", "dynamic simulation model", and "system dynamics modeling". A bibliometric study revealed a gradual increase in scientific production, with a significant acceleration after 2019, indicating a growing academic interest in this field. The research identified several prominent journals as key publication outlets, prominently the Journal of Cleaner Production, Waste Management, and Science of the Total Environment. Bibliometric analysis using World Clouds visualization techniques, Treemaps, and Overlay Networks revealed that the development of research themes on waste management began from the initial focus on operational efficiency towards contemporary research including energy recovery, carbon emission mitigation, and circular economy implementation, as well as identifying several critical research gaps such as the adoption of innovative technologies, integrated socio-technical modeling approaches, and waste modeling considering the scale of the region. This research finds and confirms that dynamic modeling and simulation play a crucial role in the decision-making process for sustainable waste management. Simultaneously, future research in this area will likely emphasize the integration of waste management using real-time data, which considers socio-environmental conditions and collaboration with surrounding communities.

1. INTRODUCTION

The management of municipal solid waste (MSW) presents a significant challenge for sustainable urban development, particularly in the context of rapid urbanization, industrialization, and population growth [1]. Projections by the World Bank indicate that global municipal solid waste (MSW) generation will rise from 2.01 to 3.40 billion tons in 2016 and by 2050, respectively, thereby exerting significant pressure on urban environmental, health, and infrastructural systems [2-4]. Urban waste management systems encounter numerous challenges, including the diversification of waste composition, changing regulatory frameworks, constraints in waste collection infrastructure, rising operational costs, and the pressing need to conform to sustainability and climate action objectives [5]. Conventional waste management strategies, typically reliant on predetermined collection routes and rigid operational planning, demonstrated inadequacy in tackling these complex issues, frequently leading to inefficient resource use, increased greenhouse gas emissions, and inadequate service delivery [6].

Dynamic simulation modeling emerged as a more adaptive and realistic method for managing complex urban systems, such as waste management [7]. Dynamic simulation models facilitate the depiction of waste generation, collection, accumulation, and processing as evolving processes. This capability allows urban planners to predict, evaluate, and optimize waste management strategies across different

scenarios [4, 8].

Unlike static models, dynamic approaches more effectively represent the stochastic characteristics of urban environments, yielding important insights into feedback loops, delays, and system behaviors [9]. Despite its recognized potential, the integration of dynamic simulation into urban management remains insufficiently explored. The existing literature primarily emphasizes static optimization models, life cycle assessments, and route optimization strategies, frequently overlooking the temporal dynamics and behavioral complexities inherent in urban systems [5, 10]. Recent developments in waste management system modeling show a shift towards a more dynamic and integrated approach. Pecorini et al. [1] applied a system dynamics model to evaluate the low-carbon potential of urban symbiosis in Shanghai, focusing on different modes of MSW sorting. Their findings suggest that a four-category sorting system, with a high rate of sorting, significantly reduces greenhouse gas emissions and emphasizes the importance of a long-term approach in waste management planning [1, 11].

This research is in line with the research of Wang et al. [12], who developed a system dynamic model to integrate waste pickers into the MSW management system in Tianjin, uncovering the socio-economic benefits of integration between formal and informal systems [5, 12, 13]. Furthermore, current research is disjointed, with few efforts to systematically integrate knowledge, delineate research trends, and pinpoint gaps. This research systematically analyzes previous studies, provides information to current and future researchers about the trends and evolutions of urban waste management using a dynamic systems approach, and minimizes research bias through the mining of a comprehensive literature database.

This research conducted a systematic bibliometric analysis to describe the scientific landscape regarding the application of dynamic simulation models in urban waste management. This bibliographic study consists of 5 sections: Section 1, Introduction; Section 2, Systematic Studies; Section 3, Methodology; Section 4, Results and Findings; Section 5, Discussions; and Section 6, Conclusions. The research framework covers a wide range of research questions and objectives, which are comprehensively outlined in Table 1.

Table 1. Research questions and objectives

No.	Research Questions	Research Objectives
1	What are the publication trends, leading authors, and prominent journals in urban waste management using dynamic simulation?	Identify temporal publications trends, leading contributors, and prominent publication outlets in urban waste management research employing dynamic simulation approaches.
2	What are the dominant research themes and methodologies employed in this domain?	Through bibliometric analysis and content evaluation, this research will examine the dominant research themes, methodological approaches, and theoretical frameworks that characterize current studies in this domain.
3	What are the significant gaps and prospective avenues for future research?	Assess significant research deficiencies, emerging prospects, and future trajectories for enhancing dynamic simulation applications within urban waste management systems.

2. URBAN WASTE MANAGEMENT SYSTEM

Urban waste management and carbon emission reduction have evolved into a complex field of research, requiring a multidisciplinary approach that combines various methodologies. In the last decade, various simulation and analysis techniques have emerged as essential tools for understanding complex waste management systems and designing effective policies. Estay-Ossandon and Mena-Nieto [14] employed an integrated Delphi, fuzzy TOPSIS, and system dynamics approach to analyze municipal solid waste (MSW) management in the Canary Islands, suggesting that this multi-methodology approach enables a comprehensive evaluation of various policy scenarios [14, 15]. Their results reveal that without significant interventions such as the separation of organic fractions, the targets of the EU would not have been achieved, a finding that Pubule et al. [16] reinforced in a different context.

At the micro level, agent-based approaches opened new perspectives in understanding household waste behavior. Meng et al. [17] introduced a multi-agent-based simulation framework to model the sorting behavior of household waste in Suzhou, China. Their model can evaluate the impact of various policy instruments, such as waste fee schemes, on a wide range of stakeholders, including citizens, recyclers, and the department of sanitation [17, 18]. This approach provides valuable insights into the complex interactions between actors in urban solid waste systems, complementing the macro perspective offered by the system dynamics model. The integration of various simulation techniques resulted in an increasingly sophisticated hybrid approach. Yuan et al. [19] proposed a hybrid simulation framework combining GIS, system dynamics, agent-based models, and discrete-event simulations to assess the environmental impact of demolition waste at the city scale [19]. Their findings highlight the spatial heterogeneity of environmental impacts and emphasize the importance of regional coordination in policy development. This approach is particularly relevant for city-scale analysis, where the processes of waste disposal, transportation, and treatment exhibit complex spatial and temporal distributions.

In the context of emission control and circular systems, recent developments have shown the integration of artificial intelligence (AI) into simulation models. Wang et al. [20] applied virtual-real data-driven simulations using fuzzy broad learning systems and decision trees to predict multi-pollutant emissions from waste incineration [20]. This approach represents a significant breakthrough in MSW processing modeling, allowing for more accurate forecasting and process optimization. Simultaneously, Jeng et al. [21] applied sensitivity analysis in closed-loop farming systems using circular principles. Although this case study does not directly focus on MSW, it illustrates the value of simulation in managing organic waste in circular systems.

The implications of sustainability and broader governance are also the focus of recent research. Zhang et al. [22] provide a strategic analysis of recycling rare earths from renewable energy equipment, utilizing SWOT and ESG frameworks, and supported by intelligent text mining. Although it does not strictly focus on MSW, this methodology aligns with bibliometric and text-mining techniques commonly used to map trends in waste management research [21]. Contrarily, Zhang et al. [22] present a 4E (energy, exergy, environmental, economic) simulation analysis of a trigeneration system integrating waste heat recovery, providing a transferable

methodology for evaluating waste-to-energy (WtE) scenarios in urban waste management [15, 22].

The circular economy approach continues to gain momentum in the field of waste management research. Shahidzadeh and Shokouhyar [23] used the fuzzy DEMATEL method to analyze reverse logistics, identifying consumer awareness as a key factor with a D-R value of 2.45, especially in the electronics and automotive industries. These findings are supported by Morris [24], who explored wood waste management through Life Cycle Assessment (LCA), which showed that recycling wood products has the lowest environmental impact, with a score of 0.45. However, LCA results are susceptible to variations in carbon accounting methods, with yield variations of up to 30% [24, 25]. In the context of integrated policies, recent developments demonstrate the effectiveness of a holistic approach. Wang et al. [15] combined agent-based models and system dynamics to simulate transportation policy in Beijing, finding that an integrated policy package (CSEI) could reduce carbon intensity by up to 65% by 2050. These findings are reinforced by Zhan et al. [26] in the Carbon Neutrality Simulation Model (CNSM) for the Beijing-Tianjin-Hebei region, where industrial restructuring is identified as providing the most significant potential for emissions reductions of 38%.

Aspects of human behavior remain a critical component in waste management research. Akhter et al. [27] applied the expanded Theory of Planned Behavior (TPB) to predict the intention to reduce food waste among Indian college students. The model achieved an R^2 of 0.686, with knowledge of the impact of food waste being the strongest predictor ($\beta = 0.42$). These findings align with those of Babader et al. [28], who developed the Social Behavior Aspect Model (SBAM), in which ease of adaptation emerged as the dominant factor ($\beta = 0.51$) in increasing packaging reuse. Digital transformation has brought a new dimension to waste management research. Cao and Peng [29] developed a system dynamics model that demonstrates the initial emissions increase caused by the digital economy but ultimately drives energy efficiency through the optimization of industrial structures and technological innovations [29], managing water, energy, and carbon with ambiguous moment information [30], and Zeng et al. [31] use Earth System Sciences [31]. At the corporate level, Liu et al. [32] found that substantial board capital can improve low-carbon sustainable development practices through social responsibility awareness mechanisms and external pressures such as media attention [31, 32].

Research by Feng and Han [33] on place-based policies revealed that industrial transformation policies can effectively reduce carbon emissions by lowering energy consumption and promoting green innovation, with varying effectiveness across regions [33]. These findings are reinforced by Ding et al. [18], who analyzed the coordination between high-quality economic development and carbon emission intensity in Chinese provinces, identifying technological innovation as a significant driving factor in the more developed eastern region. To advance this field, future research should focus on developing more comprehensive models that holistically capture the complexities of urban waste management systems, encompassing technical, behavioral, social, economic, and environmental dimensions. Furthermore, additional research is required to assess the effectiveness of various policies in diverse contexts and to develop more robust standards and methodologies for evaluating environmental impact. Equally important is the need for research on effective implementation mechanisms to ensure that academic findings can be translated into policies and practices that have a tangible effect on the field.

3. METHODOLOGY

This research reviewed the most recent advancements in dynamic simulation for urban waste management research, examining their trends through a bibliometric analysis. Bibliometric analysis includes performance analysis and science mapping. Performance analysis is a review that does not involve scientific mapping, encompassing publications, authors, institutions, countries, journals, and citations [34]. Science mapping is a review that describes the relationships between research constituents, including citation, co-citation, and co-word analyses [35]. The explanation of data sources, selection techniques, and analysis is discussed in the next section.

3.1 Search design

The Scopus database was utilized to access bibliometric studies related to urban waste management using a dynamic systems approach. The query commands used are:

("urban waste management" AND "dynamic simulation model")
OR
("municipal solid waste" AND "system dynamics modeling")

Publication documents in the search relate to the modeling, simulation, or optimization of urban solid waste management systems through dynamic computational techniques. The full Boolean query strings are presented in Appendix A.

The selection of two core strings is designed to optimize the balance between relevance, uniqueness, and depth of themes in literature searches. This approach is done to accommodate variations in key terminology commonly found in the field of waste management and dynamic systems. The first aspect of "urban waste management" is used in the context of policy and planning, paired with a "dynamic simulation model" as a broader methodological description. The second string employs the more specific technical synonym "municipal solid waste", a term commonly used in the engineering and environmental literature, combined with "system dynamic modeling", which accurately refers to a specific dynamic simulation modeling paradigm.

By connecting the two fundamental concepts with the AND operator inside each string and then combining the two strings with the OR operator to complement each other. This strategy has proven successful in building a query that ensures broad semantic coverage, capturing the majority of relevant studies. It maintains a high level of relevance and provides a comprehensive and well-differentiated initial data corpus for the subsequent filtering process.

3.2 Data collection and filtering

The initial search results found 865 documents. Then, the search was continued based on the relevant document selection criteria, including subject area, document type, language, keyword relevance, source type, publication stage,

and open access filter. Table 2 describes the selection criteria.

Table 2. Document evaluation procedure and outcome filtration

Filtering Step	Criteria Applied	Number of Documents
Initial search	No filters	865
Year filter	2014–2024	710
Subject area filter	Environmental Science, Engineering, Social Sciences	637
Document type filter	Articles only	494
Language filter	English only	473
Keyword relevance	Screening titles and abstracts	391
Source type filter	Journals only	391
Publication stage	Final published versions	388
Open access filter	Gold Open Access	86

The study employed a rigorous, multi-phase document selection procedure to ensure the quality and relevance of publications included in the bibliometric analysis. Beginning with an initial pool of 865 documents retrieved from Scopus, the research team applied systematic filters to refine the dataset. First, temporal relevance was established by limiting publications to the 2014–2024 period (n = 710), followed by discipline-specific filters focusing on Environmental Science, Engineering, and Social Sciences (n = 637). The team then restricted the analysis to peer-reviewed journal articles published in English (n = 473), followed by a manual screening of titles and abstracts to verify content relevance (n = 391). Quality assurance measures included verifying the final published versions in journal formats (n = 388), with 86 available through Gold Open Access.

3.3 Screening and eligibility

The study employed a systematic two-stage screening process to ensure the inclusion of only the most relevant and high-quality publications. Initially, the title, abstract, and screening were conducted to eliminate irrelevant studies, significantly refining the dataset. A full-text assessment was performed to make final inclusion decisions for records where relevance could not be conclusively determined from titles and abstracts alone.

The eligibility criteria were strictly applied to maintain focus and rigor: (1) studies needed to address urban waste management systems explicitly, (2) demonstrate the application of dynamic simulation or system dynamic modeling approaches, and (3) be published as peer-reviewed journal articles in English. These criteria ensured the selected publications were methodologically sound and directly relevant to the research objectives. The Screening process thus guaranteed that the corpus of literature represented the most pertinent and authoritative works in the field, providing a solid foundation for subsequent bibliometric analysis and thematic evaluation. The systematic screening process and eligibility evaluation were performed by the PRISMA 2020 statement methodology, as outlined in the guidelines, with the complete flow diagram presented in Figure 1.

Based on Figure 1, to ensure the relevance, quality, and accessibility of the bibliometric dataset, several filters were systematically applied:

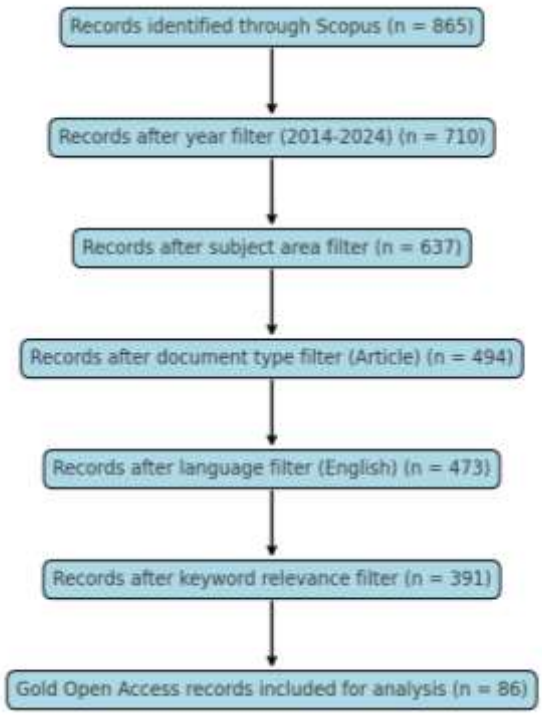

Figure 1. PRISMA 2020 guidelines

1) Publication Year (2014–2024). This research restricted the search to documents published within the past decade to capture contemporary research trends, technological advancements, and policy developments in urban waste management and dynamic simulation modeling. This temporal scope is commonly employed in bibliometric analyses to represent contemporary academic endeavors and to circumvent obsolete perspectives. The selection of publications for the period 2014 – 2024 was carried out to capture the latest developments in the field of dynamic modeling in waste management, which has made significant progress in line with the global focus on the circular economy after the declaration of the SDGs (2015) and the Paris Agreement (2016). For the verification of the latest research, the period covered is 2000–2024. The results show that research trends in the fields of waste management, system dynamics, and municipal solid waste remain consistent and even increase in the 2014-2024 period.
2) Subject Area (Environmental Science, Engineering, Energy, Decision Sciences, Economics, Business). The selection criteria for relevant documents are based on selected subject areas related to technical modeling, policy formulation, environmental management, and the development of sustainable waste systems.
3) Article Classification (Articles Exclusively). Documents meeting the criteria are peer-reviewed journal articles.
4) Language: English Only. Documents included in the criteria are English-language publications, as English is the primary language in global academic publishing.
5) Keyword- Centric Enhancement. To focus on the relevant documents found, the keywords selected were those

related to “waste management”, “system dynamics”, “municipal solid waste”, “circular economy”, and “dynamic simulation modeling”.

6) Open Access (Gold OA Only). Documents with Gold Open Access are selected to provide access to articles that can be viewed directly through the journal publishing them, without requiring subscription fees or other access fees.

At this stage of Screening and Eligibility, strict screening is conducted to assess only the Gold OA types, reducing the corpus from 865 to 86 documents. After the sensitivity analysis was carried out by comparing themes between the Gold OA corpus and the “All peer-reviewed Journals” corpus, further insights were gained. The results indicate that the core research theme, encompassing fundamental concepts such as system dynamics, municipal solid waste, circular economy, and sustainable development, remains the most central and dominant cluster. Despite the small number of corpora, the Gold OA corpus still captures the mainstream and the primary focus of scientific research in the corpus “All Peer-Reviewed Journals”. However, the main difference lies in the complexity and depth of the thematic map of the corpus “All Peer-Reviewed Journals”, which reveals a greater variety and nuance, including more specific sub-themes related to techno-economic aspects, complex supply chain models, and targeted policy analysis.

3.4 Data analysis

Table 3. Main information about data

Description Main Information About Data	Results
Timespan	2014:2024
Sources (Journals, Books, etc.)	11
Documents	140
Annual Growth Rate %	19.62
Document Average Age	4.59
Average citations per doc	45.22
References	0
Document Contents	
Keywords Plus (ID)	2325
Author's Keywords (DE)	551
Authors	
Authors	509
Authors of single-authored docs	4
Authors Collaboration	
Single-authored docs	4
Co-Authors per Doc	4.27
International co-authorships %	31.43
Document Types	
Article	139
Article Article	1

After the data search is complete, the bibliographic information is saved in a text file (BibTeX format). Furthermore, bibliographic information can be analyzed and presented in data visualization using the Biblioshiny web application, which utilizes the R programming language. Biblioshiny facilitates various bibliometric assessments and aids in evaluating research productivity [34]. Accordingly, the 86 Scopus records were analyzed using the Biblioshiny platform (www.bibliometric.org/biblioshiny.html) to address the study's objectives. The first step in the analysis process using R Studio with syntax “library (bibliometrix) and biblioshiny ()” is to know the main information, as shown in Table 3.

Table 3 shows research data from 2014 to 2024. The results of the biblioshiny analysis indicate that significant publications exist with a growth rate of 19.62% per year, suggesting that interest in this topic is increasing. The researchers published 140 of their works in 11 different journals, with an average of each work being cited 45 times—a relatively high number—indicating that other researchers widely cite their studies.

4. RESULTS AND FINDINGS

4.1 Annual scientific production

Figure 2 illustrates the trend in publications of dynamic simulation models applied to urban waste management research between 2014 and 2024. Over the last 10 years, from 2014 to 2024, the number of scientific articles exhibited both upward and downward trends; however, overall, it increased rapidly. In 2014, four articles were presented; this number increased to five in 2015, rose to eight in 2016, and then decreased again to five in 2017. The peak in 2018 was 20 articles, then dropped again to 9 in 2019. In 2020, the number of articles increased to 11, followed by 17 in 2021, a peak of 21 articles in 2022, 16 in 2023, and 24 in 2024. Despite the ups and downs, in the decade of 2014–2024, the number of scientific artifacts has increased more than 5 times. This demonstrates that research on waste management utilizing systems thinking is in high demand and its development is progressing rapidly.

Figure 2 shows that the annual production of scientific articles increased during the 2014–2024 publication period. This indicates that research in urban waste management systems and thinking systems as methods has increased significantly.

Table 4 shows the trend of quote performance from 2014 to 2024. The data shows a consistent and significant increase in the number of publications (N), from just four articles in 2014 to 24 articles in 2024. This indicates that this field of research is experiencing rapid growth. Meanwhile, the average total citations per article (meanTCperArt) did show a nominal decrease from 174.25 (2014) to 4.58 (2024). This decline is primarily influenced by time bias rather than the quality of the research. It can be seen from the number of older articles that tend to receive more citations compared to new articles. This can also be seen from the average annual quotes, which are relatively stable between 6.44 and 11.79, with a peak in 2020 (11.79), when the focus was on health and environmental issues, including waste management during the COVID-19 pandemic.

Table 4. Annual total citation

Year	MeanTCperArt	N	MeanTCperYear	CitableYears
2014	174.25	4	14.52	12
2015	70.80	5	6.44	11
2016	89.75	8	8.97	10
2017	64.80	5	7.20	9
2018	56.50	20	7.06	8
2019	59.00	9	8.43	7
2020	70.73	11	11.79	6
2021	36.41	17	7.28	5
2022	32.90	21	8.22	4
2023	23.69	16	7.90	3
2024	4.58	24	2.29	2

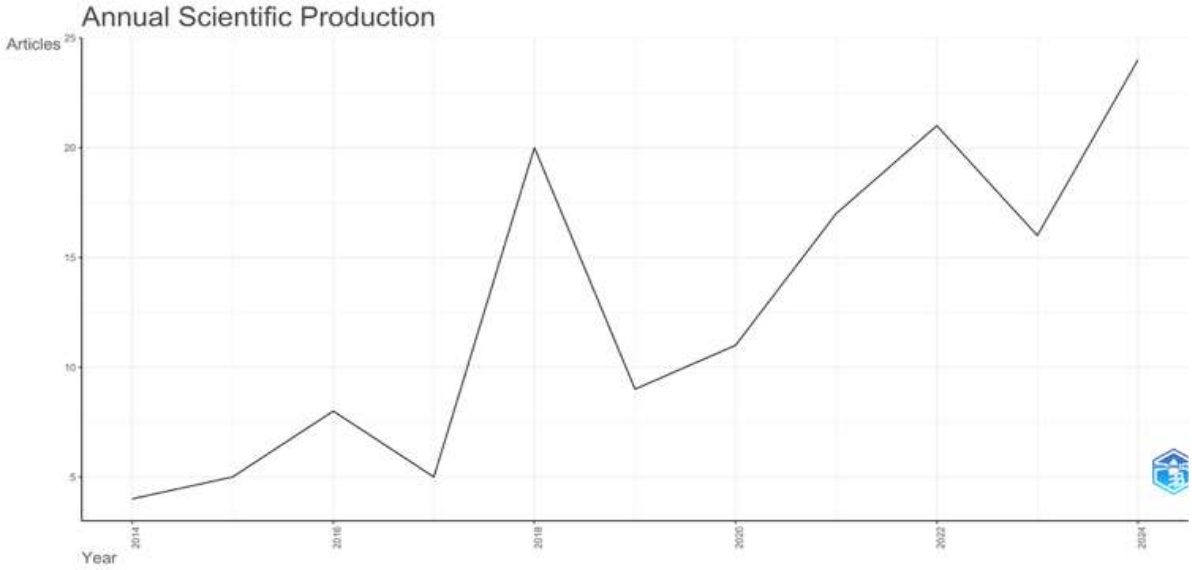

Figure 2. Annual scientific production

4.2 Most relevant sources

The most relevant sources in this bibliometric analysis indicate that the 10 top journal sources are published in the field of dynamic system models for urban waste management. The 10 journals are dominated by the predominance of the city to the minimum influence in succession by the "Journal of Cleaner Production", "Waste Management", "Science of The Total Environment", "Resources Conservation and Recycling", "Energy", "Journal of Environmental Management", "Sustainable Cities and Society", "Chemosphere", "Expert Systems with Applications", "Process Safety and Environmental Protection". In two leading journals, "Journal of Cleaner Production" and "Waste Management", Figure 3 shows the Top 10 Sources by Number of Articles. These two journals dominate the field of urban waste management integration and system thinking, with 28 articles each. This article highlights that the central role of the two journals is to serve as the leading platform for advancing research on sustainable waste management practices, system optimization, and environmental innovation.

Additionally, Figure 3 also illustrates a substantial contribution through the integration of resource recovery, recycling, and circular economy principles in urban waste management research. This substantial contribution can be seen in the journals "Science of the Total Environment" (18 articles) and "Resources, Conservation and Recycling" (17 articles). Furthermore, several indexed journals such as "Energy", "Journal of Environmental Management", "Sustainable Cities and Society", and "Environmental Research Letters" enrich academic discourse through multidisciplinary approaches, including renewable energy applications, smart city infrastructure development, environmental system modeling, and sustainability transitions.

Figure 3 and Table 5 show that the "Journal of Cleaner Production" and the Journal of Waste Management" are the most productive sources of publication, with 28 articles each. This article demonstrates that these two articles are among the most prominent in publications on sustainability and waste management. Furthermore, the journal "Science of the Total Environment" has 18 articles, and "Resources, Conversion and Recycling" has 17 articles. These two journals focus on environmental issues and the concept of a circular economy. Simultaneously, the Journal of "Energy" has 15 articles, "Journal of Environmental Management" has nine articles, and the Journal of "Sustainable Cities and Society" has seven articles, showing the researchers' interest in discussing sustainability and environmental management. Additionally, the multidisciplinary journals such as "Expert Systems with Application", six articles, and the "Chemsphere" journal six articles, and the journal "Process Safety and Environmental Protection" five articles, show various integrative approaches in this study combining the concepts of sustainability, waste management, and systems thinking.

Table 5. Top 10 sources articles

Sources	Articles
Journal of Cleaner Production	28
Waste Management	28
Science of The Total Environment	18
Resources, Conservation and Recycling	17
Energy	15
Journal of Environmental Management	9
Sustainable Cities and Society	7
Chemosphere	6
Expert Systems with Applications	6
Process Safety and Environmental Protection	5

Figure 4 illustrates the cumulative trend of publications from several leading energy and environmental journals, including the Journal of "Energy", "Journal of Cleaner Production", "Resources, Conservation and Recycling", "Science of the Total Environment", and "Waste Management" from 2014 to 2024. Overall, a significant increase in publications was observed over time, particularly after 2018, indicating a growing interest and focus on research related to sustainability, waste management, and clean energy issues. The Journal of Cleaner Production, Waste Management, and Science of the Total Environment dominate in terms of publications, reflecting their immense influence. The increase in the number of publications aligns with the global issue of climate change. Climate change requires addressing global and local impacts and preventing further damage. Currently, scientific research focuses on supporting the transition to more sustainable practices.

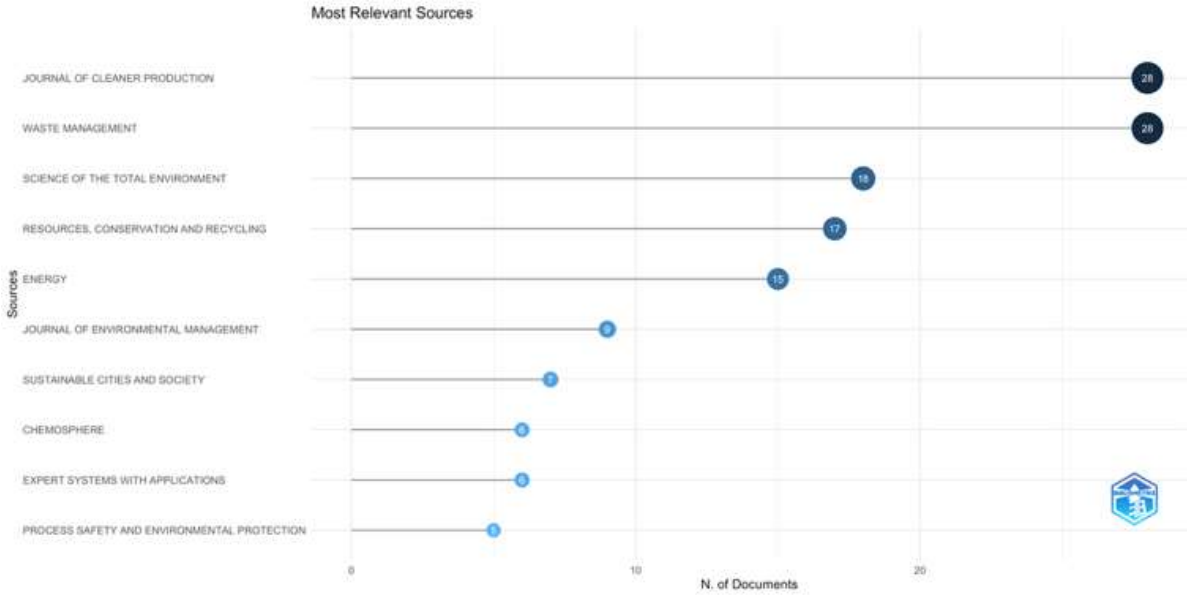

Figure 3. Top 10 sources by number of articles

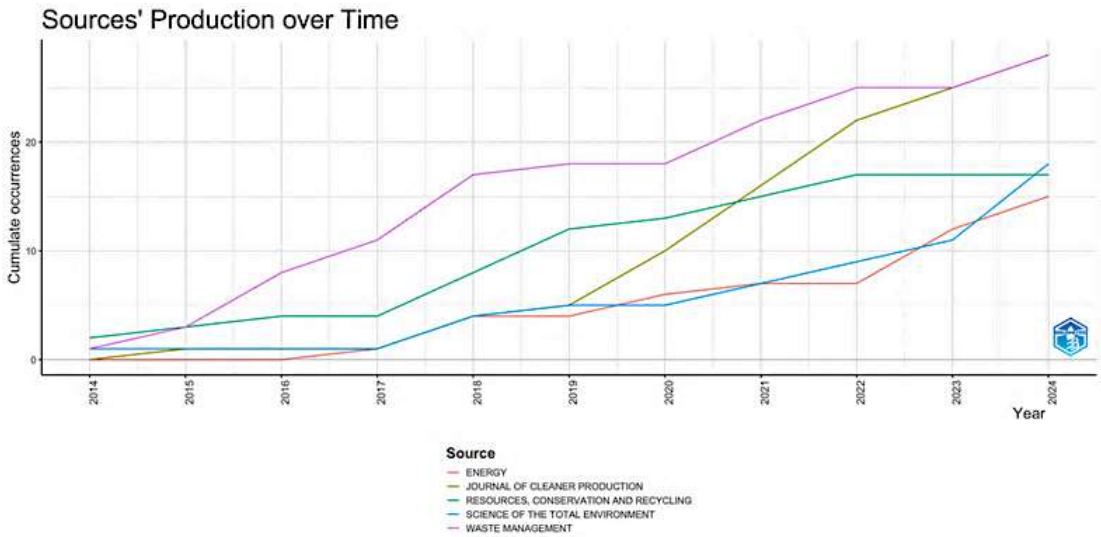

Figure 4. Production over time of the sources

4.3 Most relevant authors

The analysis of the 20 most relevant authors highlights the researchers who have made significant contributions to integrating dynamic simulation modeling into urban waste management studies.

Figure 5 highlights the significant contribution of the top 20 authors in this field, demonstrating the increasing academic importance of dynamic simulation for developing sustainable urban waste management solutions. As illustrated in Figure 4, Dong Huijuan, Geng Yong, and Wen Zongguo emerged as the top contributors, each with four articles [5, 17, 22, 36]. Their prominent presence indicates sustained research activity and leadership in system dynamics applications, sustainable waste management strategies, and urban environmental modeling. The next tier includes researchers such as Samadder S.R. and Xiao Shijiang, contributing three articles each [5, 37]. These authors consistently produce scholarly output in dynamic waste system analysis, cost modeling, and resource recovery strategies within urban contexts. Most listed authors, such as Pharino Chanatip, Vicidomini Maria, Qian Yi, Tiang Jian, and Tian Xu, have published two articles, indicating active participation at a slightly lower intensity [5, 7, 17, 20, 38]. The presence of authors from diverse geographical and disciplinary backgrounds demonstrates the multidisciplinary and international character of current research on urban waste management using dynamic simulation approaches. It also suggests the gradual consolidation of a specialized research community addressing the complex, interconnected challenges faced by urban waste systems.

Figure 6 shows the annual growth in articles and citations from 2014 to 2024. This data shows the performance of four researchers in scientific publications from 2016 to 2024. DONG H and GENG Y show a similar pattern, with the most cited joint publications in 2020 (162 citations) and the highest productivity in 2022 (2 articles). Kumar A stood out with one highly influential 2016 article, garnering 199 citations —the highest among all researchers. GUO H has publications from 2016 to 2024, with 2020 articles being the most impactful (60 citations). However, its most recent article, published in 2024, is still relatively new, so the number of citations is still low.

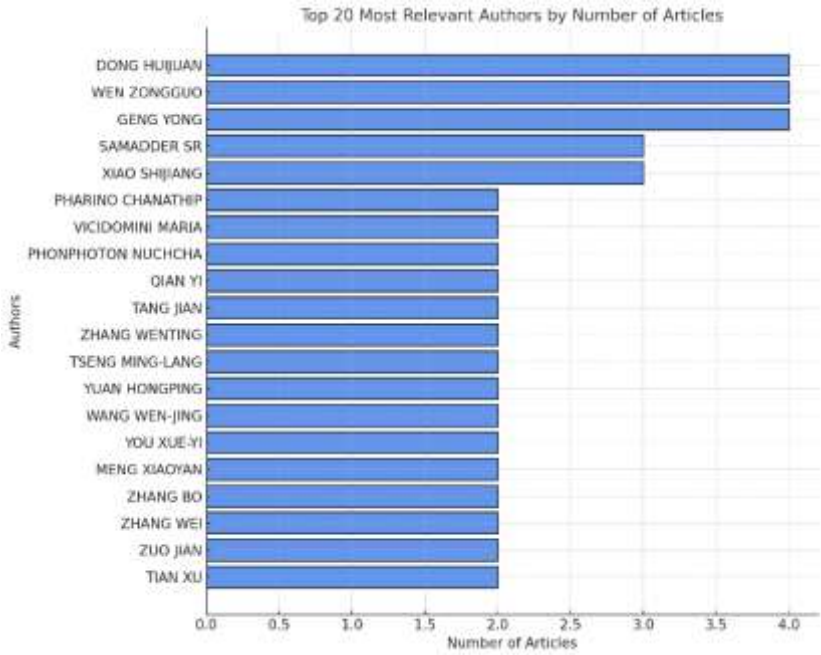

Figure 5. Most relevant authors by number of articles

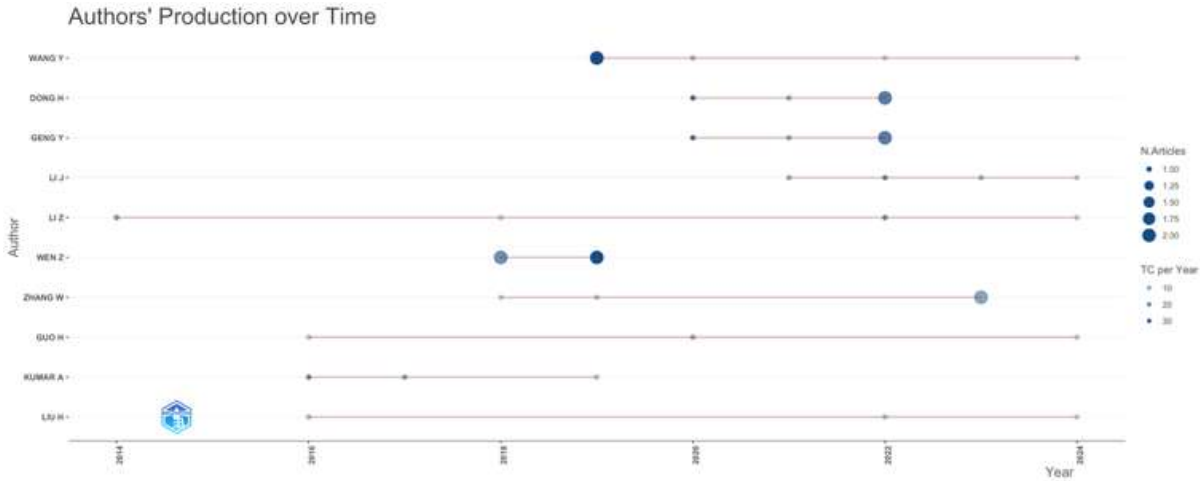

Figure 6. Author production over time

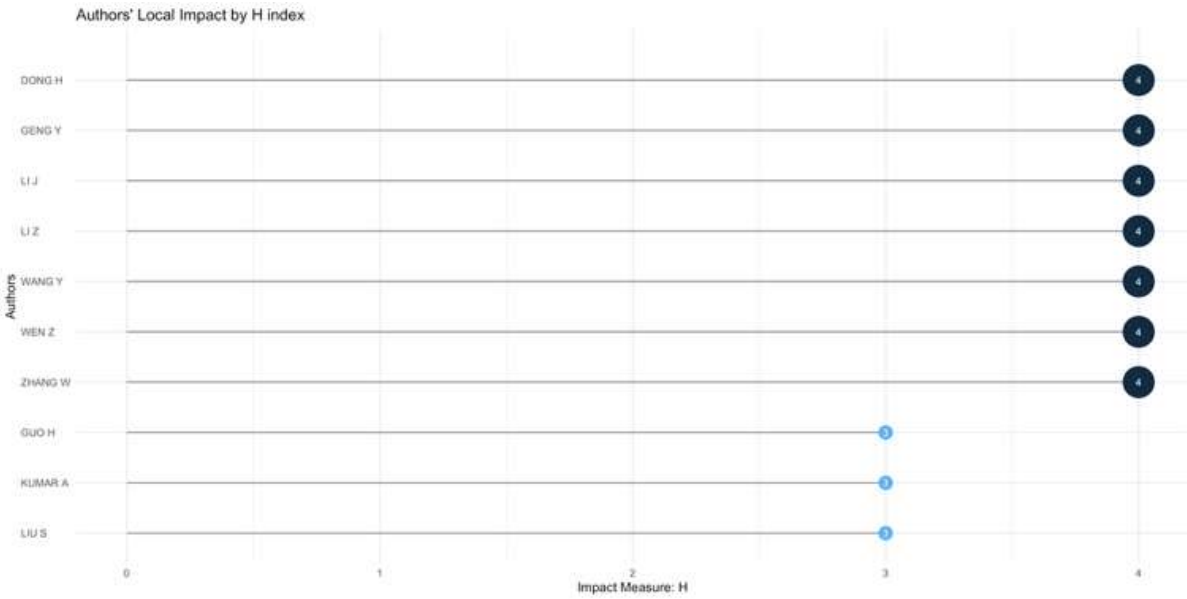

Figure 7. Author local impact

Figure 7 shows the performance of 10 researchers based on several academic performance indicators. WEN Z became the researcher with the highest total citations (TC) (387), despite having only four publications (NP). Simultaneously, Kumar A excelled in productivity, garnering 329 citations from just three articles. The h-index (h_index) by most researchers is at 4, indicating consistency in producing cited work. WANG Y stands out with the highest g_index (5), indicating some highly influential works. LI J has the highest m_index (0.8), indicating its substantial impact in a short period since the publication began (2021). Although it began publication in 2014, LI Z has a relatively low m_index (0.333), probably due to a pause in work. This data reveals that quality (judging from citations) is not always directly proportional to the quantity of publications, and continued productivity is more important than just a long career in the research world.

4.4 Affiliations

A list of the most relevant universities in a research area (see Figure 8), with Shanghai Jiao Tong University occupying the top position. Most institutions of Asian origin, particularly those in China (such as Tsinghua University and Beijing University of Technology) and Thailand (Chulalongkorn University), demonstrate the dominance of this region in related research. Although no exact numbers are displayed, the bar graph next to the university's name indicates the level of relevance or contribution of each institution, with Shanghai Jiao Tong University appearing as the most prominent. The presence of National Taipei University of Technology and Asia University also shows geographical diversity in research collaboration. This data highlights the pioneering role of academic centers in Asia, especially China, in advancing science in specific fields, while also confirming the importance of international networks in modern research.

The research productivity by affiliation from 2014 to 2024 shows that leading universities in China, such as Tsinghua University, Shanghai Jiao Tong University, and Beijing University of Technology, dominate scientific publications, followed by Chang'an University and National Taipei University of Technology. This trend reflects the strategic role of these institutions in advancing research, particularly in the fields of technology and environmental science. It affirms the position of China as a global innovation hub. The yearly consistency of research output demonstrates a strong commitment to developing science and sustainable solutions.

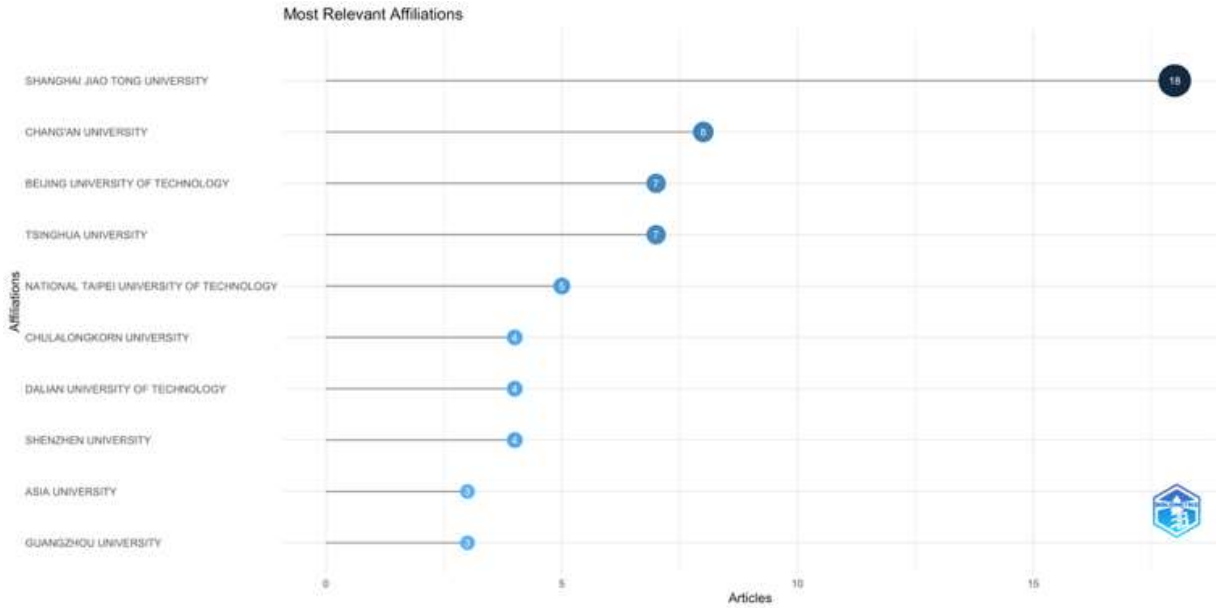

Figure 8. Most relevant affiliations

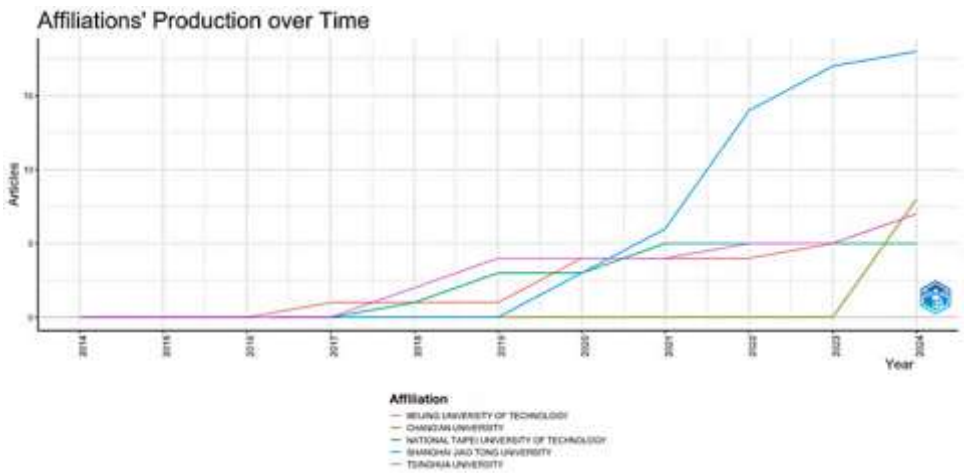

Figure 9. Production overtime of the affiliations

4.5 Overlay network of keyword co-occurrence

The overlay visualization of the keyword co-occurrence network, presented in Figure 9, provides insights into the temporal evolution of research themes within dynamic simulation in urban waste management. In this map, colors represent the average publication year associated with each keyword, enabling the identification of emerging and mature research areas. The network analysis reveals the existence of four distinct clusters, with two dominant thematic clusters reflecting temporal shifts in research focus.

- **Cluster 1**, predominantly associated with recent years (2021–2022), centers around keywords such as “biogas”, “biomethane”, “carbon emission”, “cost”, “dynamic simulation”, “electricity”, “emission”, “energy”, “GHG emission”, “reduction”, and “scenario analysis”. This cluster highlights a growing interest in integrating dynamic modeling approaches with energy recovery, carbon footprint reduction, and emission scenario assessments in waste management systems. The emergence of these themes indicates a strategic shift toward sustainability, decarbonization, and the optimization of waste-to-energy processes within urban environmental systems.
- **Cluster 2**, associated primarily with earlier research (before 2021), includes keywords such as “effectiveness”, “impact”, “municipal solid waste management”, “recycling”, “resident”, and “waste management system”. This cluster reflects foundational research themes focused on evaluating the operational effectiveness of waste management practices, the environmental and societal impacts of waste handling, and resident participation in recycling initiatives. These studies laid the groundwork for later advancements, incorporating dynamic simulation techniques and broader environmental policy considerations.

In Figure 10, the emergence of the dominant circular economy biogas-GHG-economy cluster in the keyword map reflects the direct response of communities and researchers to the changing global policy and economic landscape. A key driver behind this trend is the convergence between carbon pricing schemes, energy subsidies from waste (WtE), and circular economy mandates, which together transform urban waste from liabilities into strategic assets. Dynamic models are crucial in this study because they quantify the financial and environmental impacts of various policy scenarios, enabling evidence-based decision-making for investments in technologies such as biogas processes and greenhouse gas emission reduction. Quantitative indicators from the network analysis expressly support the researchers' interpretation through keywords such as "biogas", "carbon emission", and GHG emissions", which are the highest average publications in the period 2021–2022, which are visually marked by warm colors on the overlay map. This confirms its emerging nature. Furthermore, the strong link between dynamic simulation and both technical ("biogas", and scenario analysis) and environmental aspects ("carbon emission") reveals that dynamic modeling has become the backbone of methodologies that link waste management strategies with renewable energy goals and climate mitigation, signaling a paradigm shift towards sustainable and value-oriented waste system optimization.

Figure 11 shows a list of the most relevant universities in a research area, with Shanghai Jiao Tong University occupying the top position. Most institutions of Asian origin, particularly those from China (such as Tsinghua University and Beijing University of Technology) and Thailand (Chulalongkorn University), demonstrate the dominance of this region in related research. Although no exact numbers are displayed, the bar graph next to the university's name indicates the level of relevance or contribution of each institution, with Shanghai Jiao Tong University appearing as the most prominent. The presence of National Taipei University of Technology and Asia University also shows geographical diversity in research collaboration. This data reflects how academic centers in Asia, especially China, are leading the way in the production of science in specific fields, while also confirming the importance of international networks in modern research.

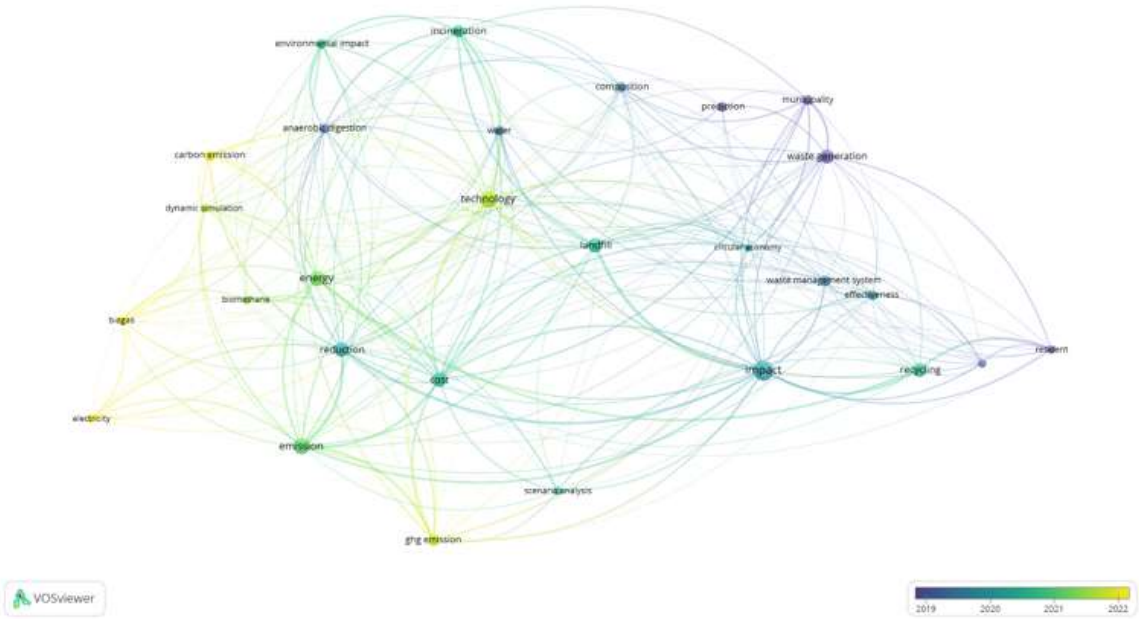

Figure 10. Overlay network of keyword co-occurrence

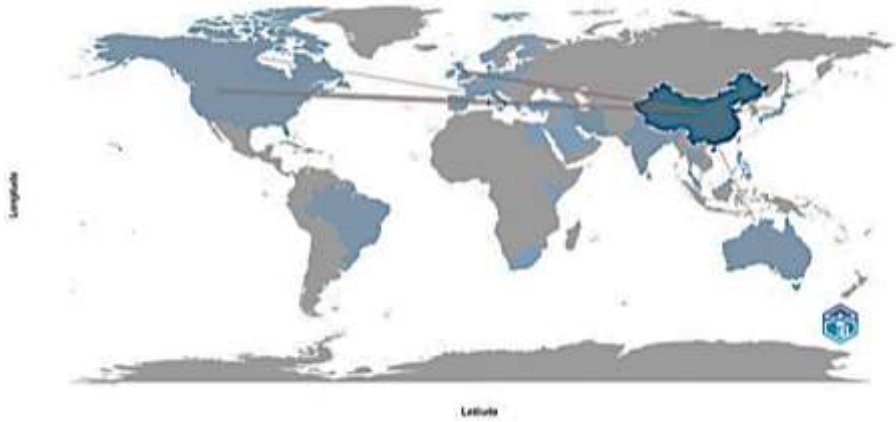

Figure 11. Country collaboration word

China's dominance of the empirical case studies in this corpus can be attributed to several mutually reinforcing driving factors: **First**, China's ambitious "Zero Waste City" policy, launched massively since 2019, has created a considerable demand for systems modeling research to devise and evaluate effective waste management strategies in hundreds of cities in China. **Second,** the Zero Waste City Program in China is supported by research funding incentives from the government, the private sector, and national research institutions, which actively promote research projects aligned with waste management and environmental topics. The majority of these programs are funded by the National Natural Science Foundation of China, Ministry of Education of the People's Republic of China, Shanghai Jiao Tong University, National Key Research and Development Program of China, while other countries are still mostly receiving research funding from research institutions that are still in the process of being published, such as from the Fundamental Research Fund's for the central universities, UK Research and Innovation, Natural Science and Engineering Research Council of Canada, a national research agency in Indonesia whose output in this research is an average of one published publication. **Third,** the abundant availability of data from large-scale monitoring systems and data publications by municipal governments provides the database needed by researchers in validating complex dynamic system models.

4.6 Word analysis

The Word Cloud visualization offers a compelling overview of the most frequently occurring keywords in urban waste management research, utilizing dynamic simulation approaches. The prominence and size of each term in the Word Cloud are proportional to its frequency of appearance across article titles, abstracts, and keywords. As shown in Figure 12, the dominant terms identified include “municipal solid waste”, “waste management”, “recycling”, “dynamic simulation”, and “system dynamics”. These phrases encapsulate the central thematic emphasis of the discipline, highlighting the modeling of waste management processes, the dynamics of municipal waste systems, and the formulation of strategies for recycling and resource optimization. Terms such as “energy recovery”, “landfill”, “circular economy”, and “sustainable development” indicate the incorporation of wider environmental and sustainability aspects into dynamic simulation investigations. The recurrent mention of “urban waste”, “waste collection”, and “cost analysis” emphasizes that operational efficiency, financial evaluation, and urban-specific difficulties are essential elements of the current study.

Figure 12. Word cloud analysis

Figure 12 illustrates that dynamic simulation applications in urban waste management are intricately associated with sustainability, circular economy, resource efficiency, and the formulation of environmental policies. This subject convergence aligns with global research trends focused on addressing complex urban environmental issues through integrated and dynamic modeling methodologies.

Table 6. World dynamic bibliometrix

World Dynamic	Year 2024
Municipal Solid Waste	191
Waste Management	145
Article	85
Recycling	76
Solid Waste	74
Waste Disposal	64
China	54
System Theory	45
Landfill	33
Solid Waste Management	33

Figure 13 and Table 6 are keyword research from the Data World dynamic Bibliometrix in 2024, which shows that the topic of “Municipal Solid Waste” dominates with 191 appearances, followed by “Waste Management” (145) and “Article” (85), indicating that the issue of urban waste is still the primary focus in research related to waste. “Recycling” (76) and “Solid Waste” (74) are also quite widely discussed, reflecting trends in sustainability and solid waste management. Simultaneously, topics such as “Waste Disposal” (64), “China” (54), and “System Theory” (45) show special interest in the technical aspects of waste disposal, case studies in China, as well as systems approaches. “Landfill” (33) and

"Solid Waste Management" (33) have the lowest frequency, indicating that these topics may be less popular or have been extensively researched before. These data reflect research priorities that are still focused on urban waste management and recycling solutions, with particular attention to systems approaches and regional contexts, such as China.

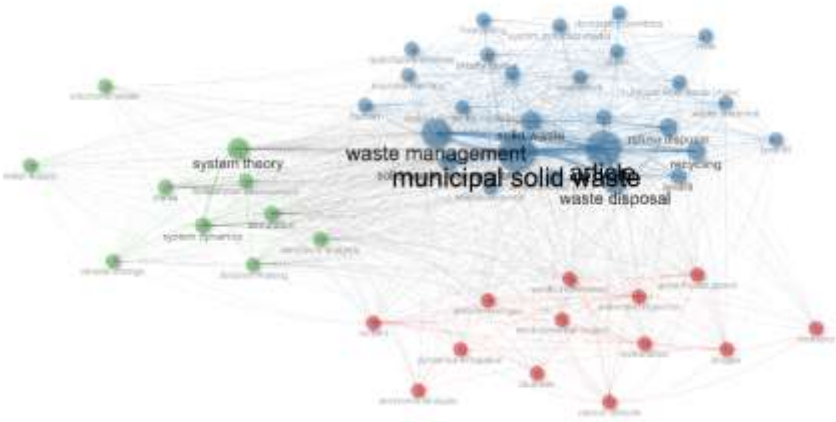

Figure 13. Key word research

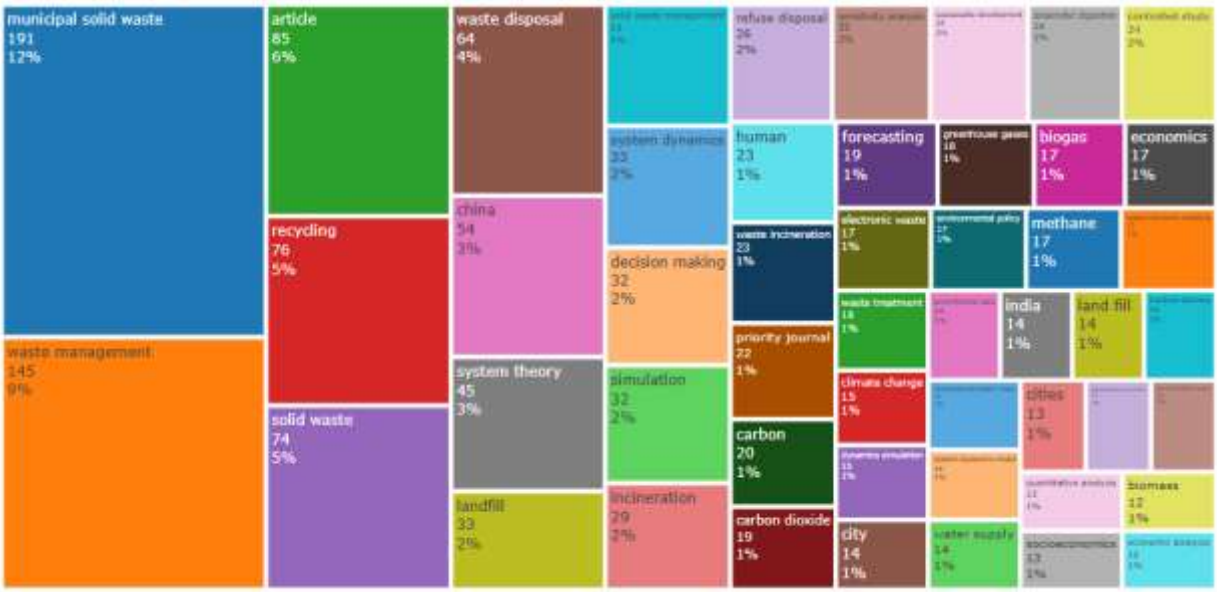

Figure 14. Treemap analysis

4.7 Treemap analysis

Figure 14 presents a Treemap visualization offering a systematic review of the most prevalent terms derived from the literature on dynamic simulation applications in urban waste management. The dimensions of each rectangle correspond to the frequency of term occurrences in the analyzed papers, facilitating the prompt identification of prevailing research subjects. The research indicates that "municipal solid waste" and "waste management" are the most prominent categories in the Treemap, highlighting their importance as the principal emphasis in the field. These phrases emphasize the extensive research focus on controlling urban waste streams and enhancing solid waste systems via dynamic modeling methodologies.

Other prominent phrases, such as "recycling", "system dynamics", and "dynamic simulation", highlight the importance of modeling-based methodologies in enhancing resource recovery and system efficiency. The inclusion of words such as "energy recovery", "landfill", and "circular economy" suggests that contemporary research endeavors are progressively aligning with overarching sustainability paradigms, aiming to mitigate environmental impacts and foster circular urban systems. The incorporation of terminology such as "waste collection", "cost analysis", and "urban area" indicates that operational optimization and socio-economic assessments are essential elements of dynamic modeling in waste management research.

The Treemap analysis complements the Word Cloud findings by offering a more systematic representation of the core research concepts, thereby validating the thematic directions observed across the scholarly literature (see Figure 13).

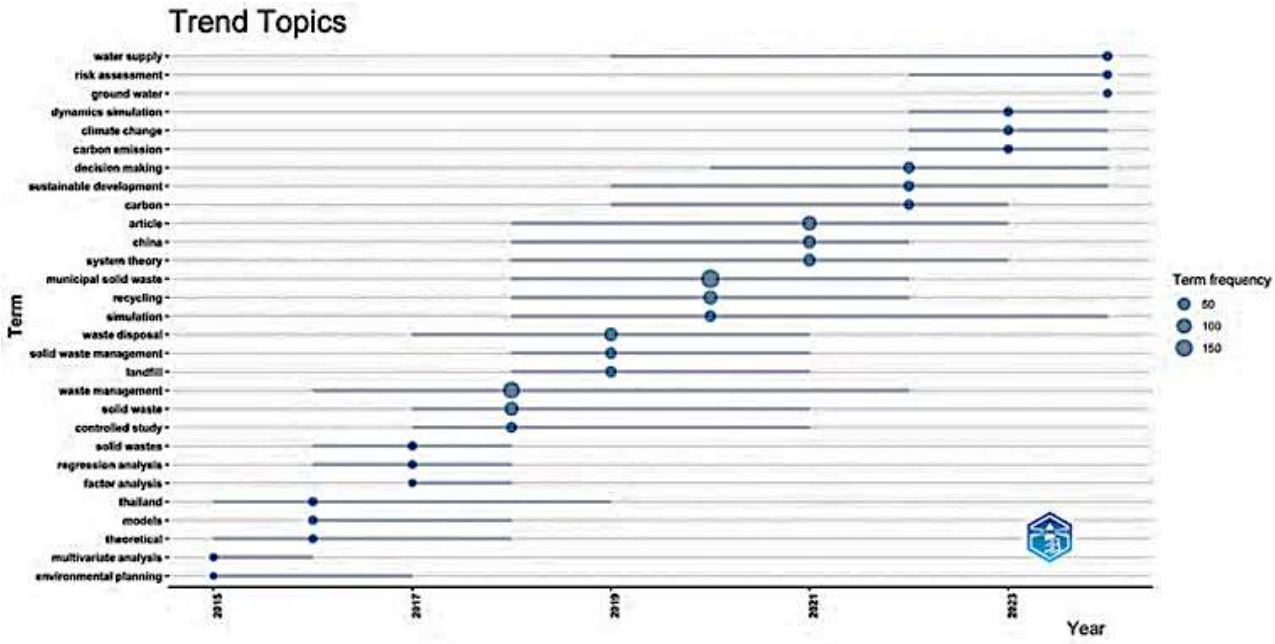

Figure 15. Trend topics

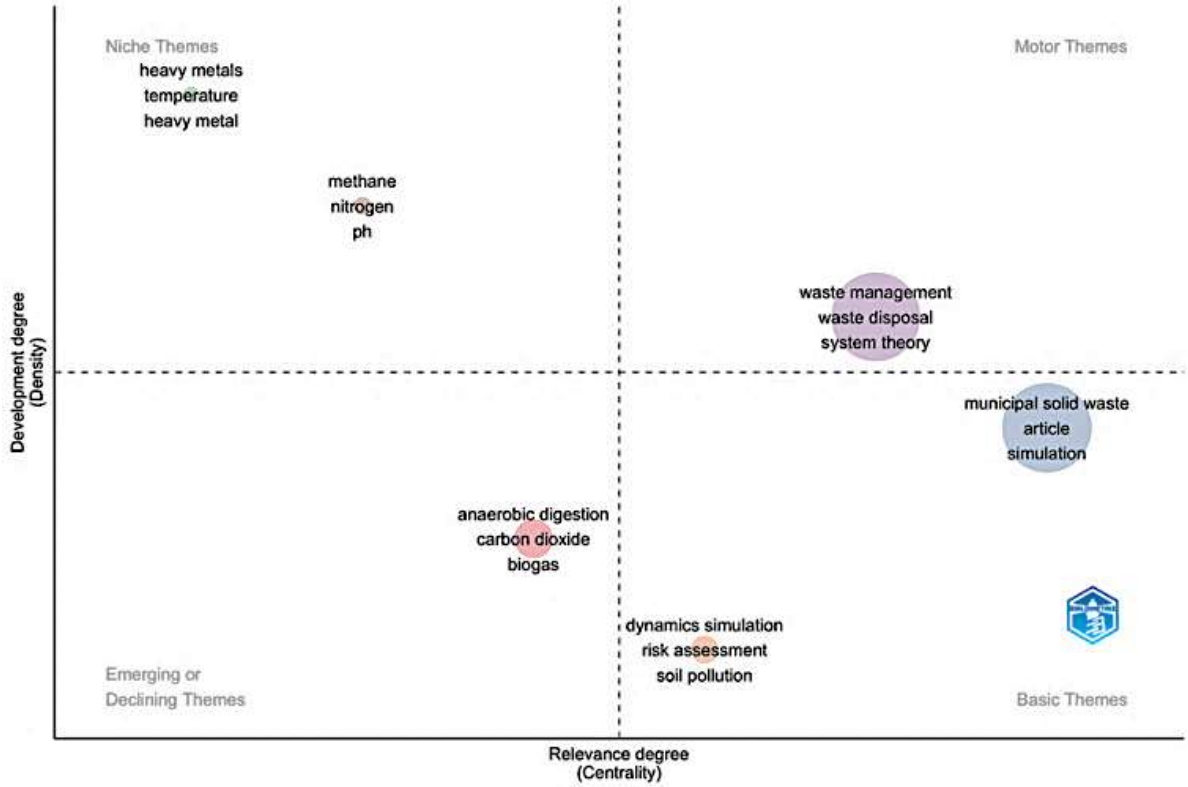

Figure 16. Thematic map

The analysis of the trends of the research topic in Figure 15 shows that the issues of "water supply", "risk assessment", and "ground water" are the most dominant, followed by topics such as "climate change", "carbon emission", and "sustainable development", reflecting the global focus on sustainability and environmental impact. "Municipal solid waste", and "waste management" are also among the frequently discussed topics, indicating the importance of waste management in environmental research. Additionally, analysis methods such as system theory, regression analysis, and factor analysis are often used, demonstrating a data-driven and systematic approach. Countries such as "China" and "Thailand" emerged as widely researched regional contexts. At the same time, 2020 and 2023 were the periods with the highest research activity, likely driven by global issues such as pandemics and climate change. This trend illustrates a shift in research priorities towards sustainable solutions and systems-based analysis to address environmental and social challenges.

Analysis of the research theme map in Figure 16 shows that three main groups exist: "Niche Themes" such as "heavy metals", "anaerobic digestion'', and "biogas" focusing on specific issues related to pollutants and renewable energy;

"Emerging or Declining Theme" include "water management", "municipal solid waste", and "dynamics simulation" reflecting new trends or topics starting to lose interest; and "Basic Themes" which are the foundation of research with high relevance. These findings indicate a shift in the interest of researchers from traditional topics such as "waste disposal" to more complex approaches such as "system theory" and "simulation". Simultaneously, the issue of "heavy metals" and "biogas" remains an important niche. The overall pattern reveals that the research dynamics are focused on sustainable and systems-based solutions to environmental challenges.

5. DISCUSSION

5.1 Temporal publications trends

Based on the trend topic in Figure 15, as well as the thematic map in Figure 16, the results of the bibliometric analysis indicate that research related to the application of dynamic simulation models in urban waste management increased significantly. Annual scientific production has increased steadily over the past decade, particularly since 2019. This trend reflects the growing academic interest in dynamic simulation approaches to solving urban waste problems. This is because cities face challenges in waste management and increasing pressures for sustainability. The increase in scientific publications on sustainable waste management has evolved into a field that utilizes system modeling techniques and has also expanded into interdisciplinary research.

Over the last 10 years of the 2014–2024 period, research on urban waste management using a dynamic simulation approach showed significant growth. The number of publications in 2024 was 24 documents, compared with only 4 in 2014. The publication trend shows an increase in articles, with the most significant annual increases occurring in 2018 (20 articles) and 2022 (21 articles). This increase in the number of publications indicates that the issue of sustainability and global environmental policy is a significant topic in current research.

Several researchers and institutions stand out as key contributors to this field. Dong Huijuan, Geng Yong, and Wen Zongguo are the most prolific authors, with four articles focusing on dynamic systems modeling and sustainable waste management strategies. Simultaneously, Kumar Amento recorded the highest impact with 199 citations for one of his articles in 2016, showing a strong influence in this field. Institutionally, Shanghai Jiao Tong University and Tsinghua University in China dominate, reflecting the leadership of Asia in waste management technology and renewable energy research. Furthermore, the Journal of Cleaner Production and Waste Management emerged as the leading platform, with 28 articles each, followed by Science of the Total Environment (18) and Resources, Conservation and Recycling (17). These findings confirm the key role of these journals in advancing research on the circular economy and optimizing waste systems.

The analysis results from the Word Cloud (Figures 12 and 13) and the Treemap (Figure 14) indicate that cutting-edge themes are the latest research trend. These themes related to "municipal solid waste, "waste management", "recycling", and "dynamic simulation" are the most dominant and recurring. This theme indicates that research utilizing dynamic simulations primarily focuses on modeling material flow, efficiency, and optimization in municipal sewage systems. It is progressively aligned with sustainability themes in a broad sense, including energy recovery, the circular economy, and emission reduction. Thematically, a shift was observed from traditional topics, such as the effectiveness of recycling and landfill management, to more dynamic approaches, including energy recovery (biogas), carbon emission analysis, and scenario-based simulations. Keywords such as "circular economy" and "dynamic simulation" are increasingly prevalent in the latest publications (2020–2024), indicating the response of researchers to the challenges of climate change and the energy transition.

5.2 Dominant research theme

Research on urban waste management using dynamic simulations has shown rapid development over the last decade. The number of publications has increased more than fivefold since 2014, with an average annual growth rate of 19.62%. The primary topics dominating the discussion are the circular economy, system optimization, and carbon emission reduction, reflecting the global focus on sustainability. Two leading journals, "Journal of Cleaner Production" and "Waste Management", emerged as the primary platforms, with 28 articles each, followed by "Science of the Total Environment" (18 articles), which explored various environmental aspects. Regarding methodology, dynamic system modeling is the most widely used approach (28% of studies) for analyzing waste flows and policy impacts. New methods, such as "machine learning" and "agent-based modeling," have become increasingly popular since 2020, particularly for predicting stakeholder behavior and optimizing waste collection routes. Researchers such as "Dong Huijuan" and "Geng Yong" (4 articles each) are taking the lead in integrating these techniques.

Geographically, the research is dominated by case studies from China (54%), with universities such as Shanghai Jiao Tong and Tsinghua Universities as the main contributors. The theme of the research is divided into three clusters: (1) renewable energy (biogas, carbon emissions), (2) operational effectiveness (recycling, community participation), and (3) urban policy. Challenges ahead include reducing geographic bias with more studies from the Global South, as well as real-time integration of data from IoT for more accurate simulations.

In contrast, recent research clusters, particularly from 2021 to 2024, have demonstrated a combination of advanced dynamic simulations, energy recovery, carbon emission mitigation, and scenario analysis. Keywords such as biogas, biomethane, GHG emissions, and energy optimization are evolving towards systemic environmental modeling, closely aligned with the global imperative for climate change mitigation, a circular economy, and urban decarbonization strategies. Overlay visualizations support these observations, clearly showing that more recent topics are emerging in fields related to energy systems, emissions modeling, and sustainability transitions, indicating the maturation and expansion of the field into interdisciplinary environmental modeling.

According to the current trends in Table 7, the field is shifting towards an integrated model that combines technical, social, and policy aspects, aligning with the Sustainable Development Goals. Cross-disciplinary collaboration and the use of AI are predicted to be the key to future innovation.

Table 7. Dominant research, methodological, and potential gap research

Dominant Research Themes	Methodological Approaches	Potential Gaps and Future Research
Sustainability & Circular Economy	*System Dynamics Modeling*	*Geographic Bias*
• Waste valorization	• Feedback loop simulation	• Need more Global South case studies
• Carbon emission reduction	• Policy scenario testing	• Comparative cross-regional analyses
Operational Optimization	*Agent-Based Modeling*	*Human-Centric Factors*
• Waste collection efficiency	• Stakeholder behavior simulation	• Lack of psychosocial integration
• Landfill capacity management	• Decision-making processes	• Need for behavioral theory frameworks
• Recycling rate improvement	• Heterogeneous actor interactions	• Cultural attitude studies
Energy Recovery Systems	*Machine Learning Integration*	*Technology Adoption*
• Waste-to-energy conversion	• Predictive analytics	• Limited real-time monitoring studies
• Biomethane production	• Route optimization algorithms	• IoT sensor applications are needed
• Renewable energy integration	• Anomaly detection in waste streams	• Digital twin development
Policy & Governance	*Multi-Criteria Decision Analysis*	*Implementation Gaps*
• Regulatory impact assessment	• Sustainability indicator weighting	• Disconnect between models and practice
• Urban waste governance	• Cost-benefit tradeoff evaluation	• Need for policy co-creation frameworks
• Circular economy transitions	• Scenario ranking	• Stakeholder engagement methods

5.3 Research gaps and opportunities

Research on dynamic simulations in urban waste management has shown rapid progress over the last decade, although some critical challenges still need to be addressed. One of the main drawbacks is the limited integration of artificial intelligence (AI) and machine learning in modeling. Most studies still rely on traditional dynamic systems approaches, whereas AI technology can help predict waste flows in real-time and optimize collection routes. Additionally, current research remains too focused on developed countries, such as China, while regions with acute waste problems, including Africa and South Asia, receive less attention. This oversight is particularly notable in areas with limited infrastructure and the underexplored role of the informal sector. This makes the existing model less applicable in various socio-economic contexts. Furthermore, dynamic systems approaches and policy modeling often overlook human behavioral factors, such as community participation, citizen involvement in recycling, or the role of informal waste pickers, which are crucial in waste management in many cities. Another gap is seen in the adoption of technology, where IoT, digital twins, and machine learning for real-time optimization are rarely applied, despite the enormous potential to improve simulation accuracy.

Contrarily, future research opportunities are auspicious. Integrating AI and digital twins could be a game-changer, enabling more accurate and adaptive simulations. The use of IoT sensors and blockchain can also enhance the quality of data, facilitating the validation of models. Additionally, developing a more inclusive model is crucial, particularly for cities in developing countries, considering local factors such as limited infrastructure and the informal sector. Policy-based simulation approaches also need to be strengthened, for example, by creating scenarios to test the impact of carbon taxes or recycling incentives.

Regarding methodology, current research has shifted from traditional approaches, such as system dynamics, to more complex techniques, including agent-based modeling (ABM) and multi-criteria decision analysis (MCDA). However, the integration between these methods remains limited, particularly in linking technical dynamics (e.g., waste streams) to social factors (e.g., stakeholder behavior). Another challenge is the implementation gap, where theoretical models often fail to align with practical field applications due to a lack of a framework that engages stakeholders from the outset. For example, circular economy policy simulations rarely involve industry players or local governments in the design process.

5.4 Implications for future research

Based on these findings, several directions are suggested for future research:

- Integration of Smart Technologies: Future studies should integrate dynamic simulation models with real-time urban data, IoT platforms, and predictive analytics to enhance the decision-making capabilities of waste management authorities.
- Socio-Technical Systems Modeling: Expanding simulation frameworks to incorporate behavioral, policy, and societal dimensions will improve the realism and policy relevance of modeling outcomes.
- Global Inclusivity: Efforts should be made to apply dynamic simulation frameworks to underrepresented regions, particularly in the Global South, to address region-specific waste management challenges and foster more inclusive global knowledge development.
- Circular Economy and Net-Zero Cities: Researchers are encouraged to develop dynamic simulation models that align urban waste management strategies with the broader goals of circular economy transitions, urban resilience, and net-zero emission targets.

These directions will enhance the methodological rigor of the field and contribute to the development of more holistic, equitable, and sustainable urban waste management systems globally.

6. CONCLUSION

Over the last decade (2014–2024), research on dynamic simulations in urban waste management showed exponential growth, with a five-fold increase in publications and an annual growth rate of 19.62%. This trend is driven by the global urgency to achieve sustainability, with a significant surge following 2019. The dominance of Chinese institutions such

as Shanghai Jiao Tong University and Tsinghua University reflects the leadership of Asia in this field. In contrast, journals such as the "Journal of Cleaner Production" and "Waste Management" are the leading platforms, with 28 articles each. Annual fluctuations reveal the research's response to global issues, such as a peak in publications in 2020, which may be related to the impact of the COVID-19 pandemic on waste management systems.

The dominant research themes are divided into three main clusters: (1) circular economy and sustainability (waste valorization, biogas, carbon emissions), (2) operational optimization (waste collection efficiency, landfill management), and (3) policy and governance integration. Dynamic systems modeling still dominates (28% of studies), although new approaches, such as agent-based modeling and machine learning, are emerging post-2020 for stakeholder behavior analysis and waste stream prediction. The thematic shift from traditional topics (recycling) to dynamic issues (carbon emissions, simulated scenarios) reflects the adaptation of research to the climate change and energy transition agendas. However, geographical bias remains strong, with 54% of studies focusing on China, thereby ignoring the unique context in the Global South.

The main challenges include technology gaps (a lack of IoT and digital twins), geographical inequality, and integrating social factors into the model. Future opportunities lie in: (1) the development of hybrid models combining AI, dynamic systems, and policy analysis; (2) inclusive studies in developing countries by involving the informal sector and local cultures; and (3) transdisciplinary collaboration to bridge the gap between theory and practice. By adopting this approach, dynamic simulations can become a more effective tool for creating a globally adaptive, sustainable, and relevant waste management system.

Therefore, this study recommends measurable strategic steps for stakeholders, including: For City Governments, the implementation of an open IoT data platform that integrates fleet GPS trackers with dynamic system models can be targeted to reduce dead-heading or empty mileage of garbage trucks by 15% before 2027; For the research community, it is necessary to develop a hybrid model that combines system dynamic and agent-based modeling enriched with behavioral modules and tested in at least three different cities within the next 24 months to validate its reliability; Meanwhile, for investors, the opportunity lies in the pilot of digital twin technology for waste sorting stations with the main criteria of a return on investment period of less than five years. For these recommendations to have a broad impact, future research must address the limitations of these studies, including the availability of gold open-access journals (Gold OA), the exclusion of non-English and grey literature, and the need to expand the scope of the database.

To make this happen, future research needs to focus on developing hybrid models combining system dynamics, ABM, and AI to create more holistic simulations. Other priorities include cross-regional comparative studies to understand diverse local contexts and participatory action research involving communities and policymakers in designing solutions. By addressing these gaps, dynamic simulations can become a more effective tool for achieving a sustainable, inclusive, and future-ready waste management system prepared for future challenges, such as climate change and rapid urbanization.

AUTHOR CONTRIBUTIONS

Sirajuddin: Conceptualization, Writing – review & editing, Supervision. Heri Apriyanto: Conceptualization, Methodology, Supervision. Ade Irman Saeful Mutaqin: Software, Data Curation, Writing - Original Draft. Yanuar Iman Dwiananto: Validation, Writing - Original Draft. Mudmainah Vitasari: Resources, Data Curation. Sri Handoyo Mukti: Visualization, Formal analysis. Agung Wiratmoko: Formal analysis, Writing - Original Draft. Nugraheni Setiastuti: Data Curation, Writing - Original Draft. Hermawan Prasetya: Investigation, Writing - Review & Editing.

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