



Efficiency in Municipal Solid Waste Management: A Bibliometric Review of the Last 20 Years

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Eficiência na Gestão de Resíduos Sólidos Urbanos: Uma Revisão Bibliométrica dos Últimos 20 Anos

RESUMO

A geração de resíduos sólidos representa um desafio mundial, pois a complexidade dos materiais e dos métodos empregados para o seu descarte, tais como o aterro sanitário e a incineração, não garantem a redução na fonte e ainda contribuem para emissão de gases do efeito estufa. É fundamental que os países adotem sistemas de avaliação da gestão de resíduos sólidos, a fim de monitorar os serviços, estabelecer metas e desenvolver projetos adequados para garantir a qualidade ambiental. Este estudo propõe investigar a literatura científica para identificar os métodos de avaliação da gestão de resíduos sólidos empregados em diferentes países ao redor do mundo. O objetivo desta pesquisa é mapear as principais tendências de publicações científicas sobre avaliação da gestão de resíduos sólidos urbanos. A base de dados Scopus foi utilizada para realizar a pesquisa bibliográfica e a bibliometria foi empregada para identificar a evolução científica de artigos publicados sobre o tema. Foram utilizadas ferramentas de gráficos, como pacote Bibliometrix do R e o software VOSviewer, para gerar mapas de redes. Os resultados destacam a China como país com maior produtividade e citações. A revista Waste Management apresenta o maior número de artigos sobre o tema. Os autores mais relevantes foram Bovea MD, Medeiros GA e Mancini SD. As redes de palavras identificaram a evolução dos temas pesquisados ao longo das décadas. Nos métodos empregados na análise de 10% dos artigos, predominou a metodologia de Avaliação do Ciclo de Vida. Entre esses, os cenários de reciclagem e compostagem foram os mais adequados ambientalmente a serem empregados nos sistemas de gestão municipais.

PALAVRAS-CHAVE: Gestão de Resíduos Sólidos. Avaliação. Resíduos Sólidos Municipais. Bibliometria.

Efficiency in Municipal Solid Waste Management: A Bibliometric Review of the Last 20 Years

ABSTRACT

The generation of solid waste represents a global challenge, as the complexity of materials and the methods used for disposal, such as landfills and incineration, do not ensure reduction at the source and contribute to greenhouse gas emissions. It is essential that countries adopt solid waste management assessment systems to monitor services, establish goals, and develop appropriate projects that ensure environmental quality. This study proposes to investigate the scientific literature to identify methods of solid waste management assessment used across different countries. The objective of this research is to map the main trends in scientific publications on the assessment of urban solid waste management. A bibliographic search was conducted using the Scopus database, and bibliometric analysis was applied to track the scientific evolution of articles on the subject. Graphic tools, including the R Bibliometrix package and VosViewer software, were used to generate network maps. The results highlight China as the most productive country in terms of publications and citations. The Waste Management journal featured the largest number of articles on this topic, and the most influential authors were Bovea MD, Medeiros GA, and Mancini SD. Word networks revealed the evolution of research topics over the decades. Among the methods analyzed in 10% of the articles, the Life Cycle Assessment (LCA) methodology was predominant. Within this framework, recycling and composting were identified as the most environmentally suitable scenarios for use in municipal management systems.

KEYWORDS: Solid Waste Management. Assessment. Municipal Solid Waste. Bibliometrics.

Eficiencia en la Gestión de Residuos Sólidos Urbanos: Una Revisión Bibliométrica de los Últimos 20 Años

RESUMEN

La generación de residuos sólidos representa un desafío global, ya que la complejidad de los materiales y los métodos empleados para su disposición, como el vertedero sanitario y la incineración, no garantizan la reducción en la fuente y además contribuyen a la emisión de gases de efecto invernadero. Es fundamental que los países adopten sistemas de evaluación de la gestión de residuos sólidos para monitorear los servicios, establecer metas y desarrollar proyectos adecuados que garanticen la calidad



ambiental. Este estudio propone investigar la literatura científica para identificar los métodos de evaluación de la gestión de residuos sólidos empleados en diferentes países del mundo. El objetivo de esta investigación es mapear las principales tendencias de publicaciones científicas sobre la evaluación de la gestión de residuos sólidos urbanos. Se utilizó la base de datos Scopus para realizar la búsqueda bibliográfica, y la bibliometría se empleó para identificar la evolución científica de los artículos publicados sobre el tema. Se utilizaron herramientas gráficas como el paquete Bibliometrix de R y el software VOSviewer para generar mapas de redes. Los resultados destacan a China como el país con mayor productividad y citas. La revista *Waste Management* presenta el mayor número de artículos sobre el tema. Los autores más relevantes fueron Bovea MD, Medeiros GA y Mancini SD. Las redes de palabras identificaron la evolución de los temas investigados a lo largo de las décadas. Entre los métodos empleados en el análisis del 10% de los artículos, predominó la metodología de Evaluación del Ciclo de Vida. Entre estos, los escenarios de reciclaje y compostaje fueron los más adecuados ambientalmente para ser implementados en los sistemas de gestión municipales.

PALABRAS CLAVE: Gestión de Residuos Sólidos. Evaluación. Residuos Sólidos Municipales. Bibliometría.

1 INTRODUCTION

Solid waste management is one of the global challenges for environmental sustainability (RAHAMAN et al., 2022), as it involves a complex and dynamic system encompassing life cycle management and multiple stakeholders, including producers, consumers, regulators, and recyclers (YANG et al., 2023). The organization and efficiency of a solid waste management system are often linked to a country's level of development. Developed countries tend to implement strategies that focus on recycling and minimizing environmental impact, while developing countries continue to face issues such as irregular waste disposal and dependence on landfills (CHOWDHURY; BAKSH, 2020).

Authorities and stakeholders involved in waste management must recognize the problems that can arise from irregular waste disposal. Plastic pollution and inadequate management lead to environmental impacts, as well as financial and social damage (FERRONATO; TORRETTA, 2019; JACOBI; BESEN, 2011). Municipalities, which are responsible for waste management, face the challenge of providing an effective and efficient system for their residents. This requires multidimensional planning that addresses economic, environmental, and social aspects (GUERRERO; MAAS; HOGLAND, 2013). Additionally, it is essential to implement integrated management strategies aimed at reducing, mitigating, avoiding, or even eliminating issues related to solid waste, based on the pillars of sustainability (MARSHALL; FARAHBAKSH, 2013; ALVES; LEHFELD; CONTIN, 2021).

Raising environmental standards alone is insufficient; an integrated approach to waste management is necessary, employing assessment methodologies to understand the current municipal waste scenario, identify gaps, and propose system improvements (WILSON, 2007). Integrated management must encompass all stages, from generation to disposal, as decisions made regarding one element influence all others (PEREIRA; CURI; CURI, 2018).

The use of assessment tools for municipal management of urban waste will indicate the current situation of policies at the local level and may contribute more assertively to the problems identified, proposing improvements to the system and actions for more sustainable management (CETRULO et al., 2020; CHAVES; SIMAN; SENA, 2020; HARBACHE; CÉSAR; MOZER, 2023).

The Sustainable Development Goals (SDG) set targets that include solid waste management (SDGs 6, 7, 11, 12, and 13), based on a shift from a linear economy focused on production and excessive use of resources to a circular economy based on the three pillars of sustainable development: economic growth, social inclusion, and environmental protection (SHARMA et al., 2021).

Within this context of complexity of solid waste management, the challenges faced by cities, and its importance in terms of environmental, social, and economic contexts, this study aims to assess the progress of research on solid waste management evaluation. A scientific mapping methodology will be employed using bibliometrics to analyze the scientific evolution of the topic. Bibliometrics involves mapping cumulative scientific knowledge and tracking the evolutionary nuances of established fields by analyzing the social and structural relationships among different research components (DONTHU et al., 2021). Its value lies in performance analysis, enabling an objective assessment of research productivity and impact (MUKHERJEE et al., 2022).

Bibliometrics, as an analytical technique, contributes significantly to the dissemination of scientific knowledge. In this research, the use of bibliometrics aimed to demonstrate how evaluation methods for solid waste management contribute to the efficiency of public policies

2 OBJECTIVES

The objective of this research is to map the main trends in scientific publications on the evaluation of urban solid waste management. To achieve this, the following questions were addressed: (1) How has scientific production evolved over time? (2) Which universities are leading in scientific production? (3) Which journals are the most prominent in publishing on solid waste management? (4) Who are the main authors and which countries are contributing most to this field?

3 METHODS

This research employed a bibliometric approach, supplemented by content analysis of selected articles, to obtain insights of the global portrait of solid waste management assessment. The bibliometric approach allows quantitative analyses of academic productions on the topic, including institutions, countries, journals, citations, authors, and keywords.

3.1 Research Strategy

The Scopus database was used due to its extensive collection of indexed articles, which includes information on authors, institution affiliations, and bibliographic references for each article (MONGEON; PAUL-HUS, 2016). Produced by Elsevier, Scopus has provided access to journal articles and references since 1966 (BURNHAM, 2006). This database allows researchers from various fields to identify scientific publications throughout the world.

To identify articles on the assessment of solid waste management, a series of tests were conducted using different keywords and synonyms until an optimal set of results was achieved to address the research questions. Boolean connectors, such as AND, were used to combine terms, while OR was used to search for intersections between different sets of terms. The search for publications in the Scopus database covered the period from 1970 to 2022, focusing on scientific articles published in English. The final search string included a set of keywords (Table 1) that yielded a satisfactory number of publications to address the research questions.

Table 1 - Terms and keywords searched

Steps	Search String
Definition	TITLE-ABS-KEY (("solid waste") AND ("management" OR "urban management" OR "integrated management" OR "municipal management" OR "sustainable management") AND ("assessment" OR "assessment management" OR "assessment sustainability") AND ("indicator*" OR "index" OR "methodolog*")) AND PUBYEAR < 2023 AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar"))
Trial	Reading the title and abstract to select articles of interest for the research.

Source: The authors (2024).

Based on the initial results from Scopus, a second stage of screening was conducted to assess the relevance of the publications to the research objective and questions. The titles, abstracts, and keywords of all articles were reviewed, and a subset comprising 10% of the articles was selected for further analysis using elements of systematic review.

3.1.2 Data Analysis

The third methodological stage involved creating tables, graphs, and maps to examine various aspects, including general publication statistics, trends in scientific publications, citation trends, and the roles of institutions, journals, authors, and international collaborations. These visualizations were generated using the Bibliometrix extension within R Studio (CUCCURULLO; ARIA; SARTO, 2016).

The bibliometric study identified the number of publications, institutions, journals, authors, and countries. Additionally, it mapped the keywords from articles by decade to analyze how terms and themes have evolved over time. To analyze the correlations between countries, authors, and citations, VOSviewer software was employed to create network and flow maps. VOSviewer is a tool designed for constructing and visualizing bibliometric maps, including those related to authors, journals, co-citations, and keywords (VAN ECK; WALTMAN, 2010).

4 RESULTS AND DISCUSSION

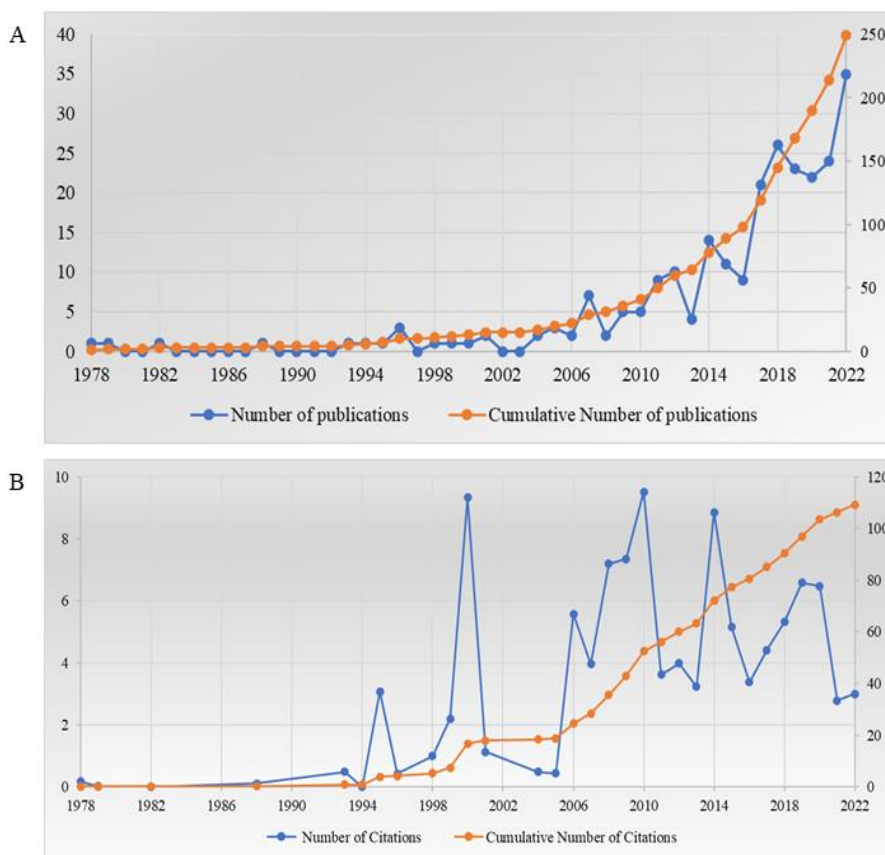
The overall search yielded 1109 articles published between 1978 and 2022. After refining the search to focus on articles examining the relationship between solid waste management assessment and sustainability, 249 articles were selected for bibliometric analysis. These 249 articles were published between 1978 and 2022, with an annual growth rate of 8.42% and an average citation rate of 35.84. They were written by 838 authors and published in 93 journals. Only 15 documents have a single authorship, while the remaining articles have an average of 3.7 authors and an international co-authorship rate of 26.5%.

4.1 Publications and Citations

The dataset of published articles reveals an average of 5.3 articles per year, with a standard deviation of 8.6. The earliest articles on solid waste management date back to 1978. Over time, there has been a noticeable increase in both the number and the evolution of publications. The peak years for publication were 2017 (21 articles), 2018 (26 articles), 2019 (23 articles), 2020 (22 articles), 2021 (24 articles), and 2022 (25 articles). The year 2022 demonstrates a continuing upward trend in publications on this topic. This trend is consistent with findings by Bijos et al. (2022) and Yang et al. (2023), who reported that 2023 presented the highest peak in articles related to solid waste and life cycle assessment.

The most cited documents do not align with the overall publication trend over the years. Papers from 1995, 1996, 2000, 2006, and 2009 exhibited the highest average citation rates. This indicates that these earlier publications serve as key references and foundational sources for subsequent research in the following decades.

Figure 1 - Number of publications (A) and citations (B) from 1978 to 2022 found in the Scopus database.



Source: The Authors (2024).

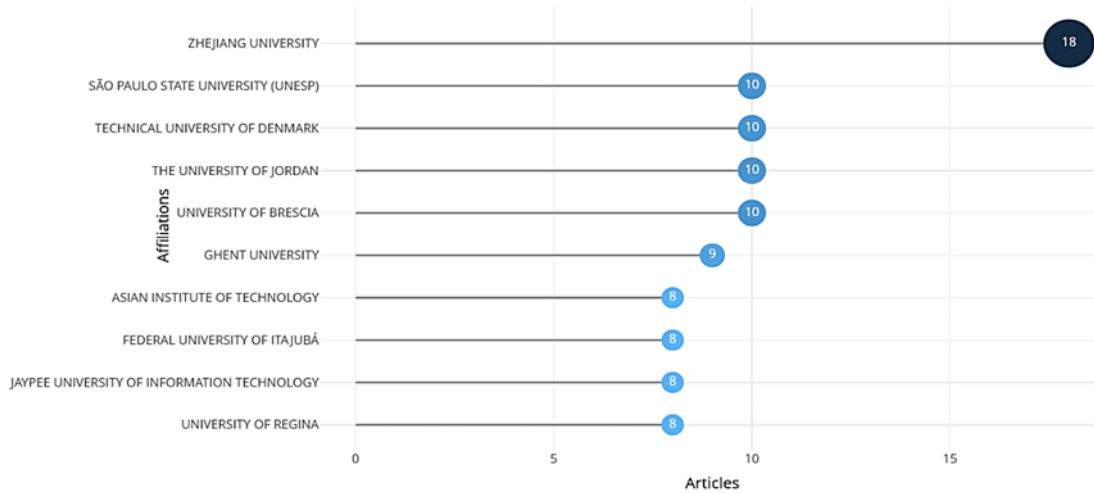
4.1.2 Relevant Institutions and Scientific Journals

The most prominent institutions in terms of number of papers are Zhenjiang University (China) with 18 publications, followed by the University of São Paulo (Brazil), Technical University (Denmark), University of Jordan (Jordan), and University of Brescia (Italy), each with 10 publications (Figure 2). Additionally, Ghent University (Belgium), the Asian Institute of Technology (Thailand), the Federal University of Itajubá (Brazil), Jaypee Institute of Information Technology (Japan), and the University of Regina (Canada) each contributed with eight publications.

Chinese universities are leading in scientific publications among the top institutions, with Brazilian universities also making significant contributions, positioning Brazil as a key player in scientific research within Latin America.

The leading journals on solid waste management include Waste Management (28 articles); Journal of Cleaner Production (27); Waste Management and Research (23); Resources Conservation and Recycling (15); Sustainability (Switzerland) (9); Environmental Science and Pollution Research (7); International Journal of Life Cycle Assessment (7); Journal of Material Cycles and Waste Management (7); Journal of Environmental Management (6); and Management of Environmental Quality: An International Journal (6).

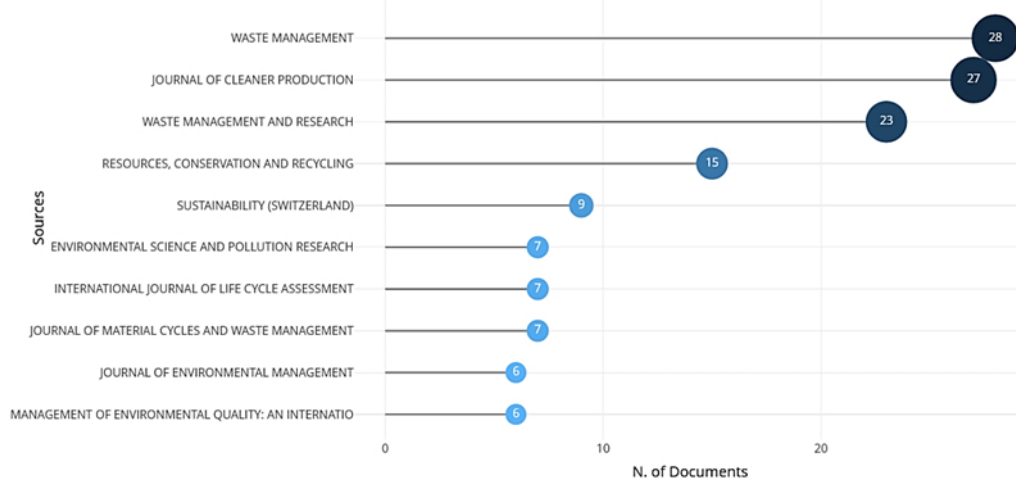
Figure 2 - Graph of the ten most relevant institutions in the publication of articles



Source: The Authors (2024).

The three most prominent journals are Waste Management (impact factor of 8.816), Journal of Cleaner Production (11.072), and Waste Management and Research (4.432) (Figure 3). The results of the Bijos (2022) and Yang et al. (2023) surveys highlighted the Journal of Cleaner Production, Resources Conservation and Recycling, and Waste Management as the most cited journals.

Figure 3 - Graph of the ten journals with the largest number of published articles



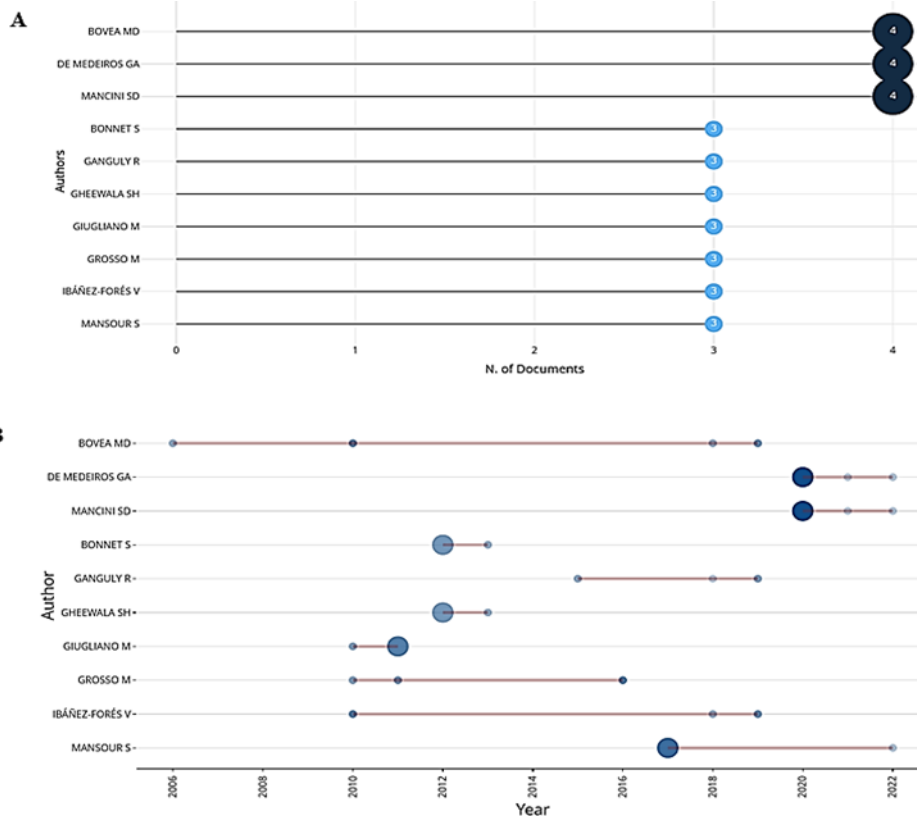
Source: The Authors (2024).

The Journal of Cleaner Production has the highest impact factor and is a leading international journal covering topics related to cleaner production, environment, and sustainability. Waste Management is another prominent international journal that addresses integrated waste management, science, and technology, with a focus on solid waste and environmental issues. Meanwhile, Waste Management and Research specializes in publications related to waste management, planning, governance, and engineering.

4.1.3 Relevant Authors and Scientific Production

In the set of 249 articles, a total of 838 authors were identified with an average of 3.73 authors per document. Outstanding contributors to the field of solid waste management include Bovea MD (4), Medeiros GA (4), Mancini SD (4), followed by Bonet S (3), Ganguly R (3), Gheewala SH (3), Gugliano M (3), Grosso M (3), Ibañez-Forés V (3), and Mansour R (3) (Figure 4). Medeiros GA and Mancini SD have the highest number of published articles, with their production starting in 2020. They are followed by Mansour S, whose publishing began in 2017, as well as Gugliano M and Bonet S, who also started in 2017. Bovea MD published articles from 2006 to 2018, while Ibañez-Fóres V published from 2010 to 2020, and Grosso M contributed from 2010 to 2016. The data indicates a sustained and continuous engagement in research and publication by these authors over the years.

Figure 4 - The most relevant authors (A) and their corresponding productions over the decades (B)



Source: The Authors (2024).

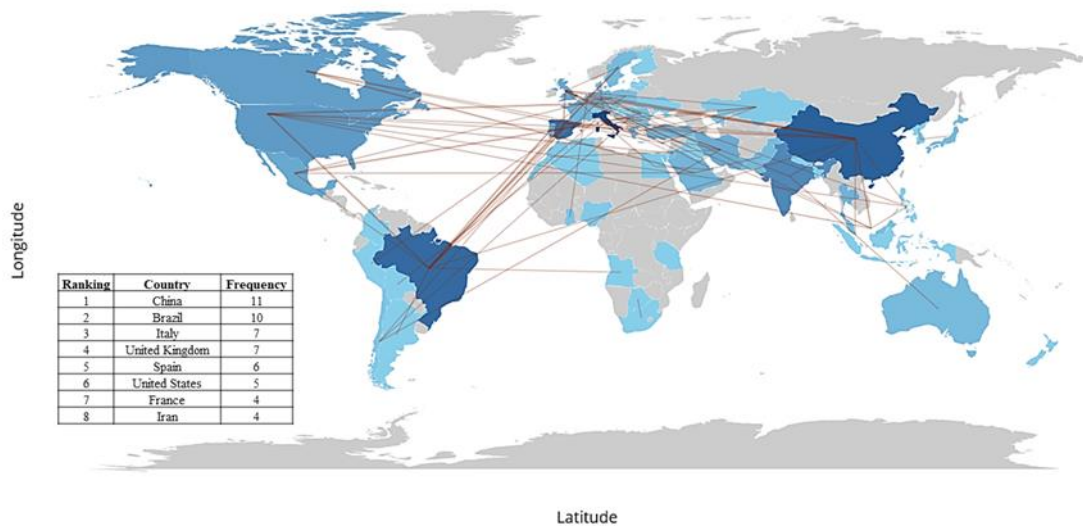
4.1.4 The Most Cited Countries

The collaboration network map between countries (Figure 5) reveals the following leading contributors in terms of publication and citation frequency: China (11), Brazil (10), Italy (7), United Kingdom (7), Spain (6), the United States (5), France (4), and Iran (4). China and Brazil are at the forefront of both publications and citations in the field of solid waste management.

4.2 Word Co-Occurrence Networks by Decades and General Term Network

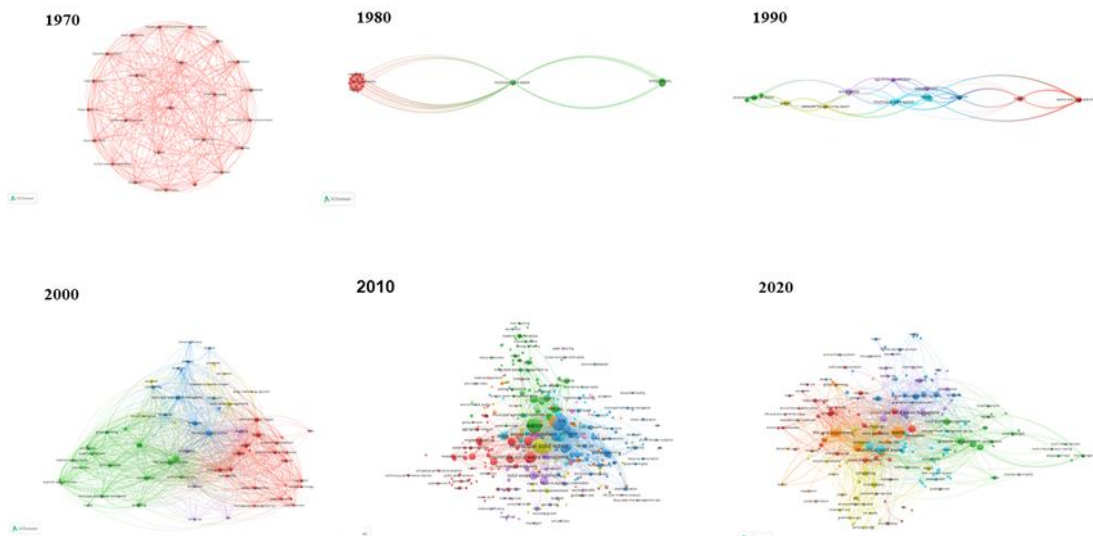
The keyword co-occurrence network is an important tool for analyzing the evolution of research terms and themes. As shown in Figure 6, a network of terms from the articles was constructed by decade: 1970s, 1980s, 1990s, with a minimum frequency of one citation per term, and 2000s, 2010s, and 2020s, with a minimum frequency of two citations per term.

Figure 5 - Map of collaboration between countries in published articles



Source: The Authors (2024).

Figure 6 - Co-occurrence network of words cited in the title, abstract and text by decades



Source: The Authors (2023).

In the 1970s, the keyword co-occurrence network revealed a distinct set of 32 terms (Figure 7). The most notable terms included: disposal, environmental protection, hazard potential, hazardous solid waste, heavy metal, heavy metal ion, hydrological disposal environment, industry, land use, and leaching.

network highlights the connection between countries and sustainable waste management, with a notable emphasis on biowaste and the use of analytical hierarchy and assessment methods.

In the 2020s, the network extends beyond the central axis, featuring eight groups and 191 terms. Prominent terms include greenhouse gas emissions, participation, demolition waste door collection system, cardboard, human health, neural network model, India, and governance environmental indicator. The focus in this decade is on governance, public participation, neural network models, and environmental indicators, reflecting current trends in the scientific field.

Overall, the general keyword co-occurrence network encompasses terms with a minimum frequency of two citations, totaling 638 terms organized into 12 clusters. The general network of terms highlights several key concepts with high relevance scores, including incinerator, collection efficiency, waste collection system, SDG, biowaste, global sustainability issue, life cycle environmental impact, sustainable solid waste management system, sustainable future, and sustainable waste management strategy. These terms emphasize sustainability, particularly the SDG, as integral strategies for managing solid waste. Additionally, they address techniques such as waste incineration to reduce impacts and waste disposal in landfills, as well as the importance of efficiency in the solid waste collection system.

4.3 Systematic Analysis

Criteria were established to analyze the articles based on systematic review elements. Out of the 249 articles, 10% were selected for detailed analysis, totaling 25 articles. These 25 articles involved 95 authors and contained 422 keywords, with an average of 113.1 citations per document. The most frequently used terms in these articles are recycling, waste management, and municipal solid waste.

Among the 49 different institutions identified, the network and collaboration between authors from different institutions are particularly notable. The countries with the highest publication frequency are Brazil, Sweden, and Denmark. The most prominent journals include *Journal of Cleaner Production* with seven articles, *Waste Management* with five articles, and *Resources Conservation and Recycling* with four articles.

The selected articles span multiple continents, including Europe, Asia, the Americas, Africa, and Oceania (Table 2). In terms of geographical coverage, Brazil and Turkey are the most represented, each with three articles. They are followed by Canada, the United States, and the European Union, with two articles each. Other countries represented by one article include Australia, China, Egypt, Spain, Hong Kong, Italy, Mexico, the Nordic Region, the United Kingdom, Sweden, Switzerland, Thailand, and Taiwan.

In the 1970s, Ingraham and Zechel (1979) proposed a decision-making model to evaluate the impact of water, air, and solid waste pollutants in Canada. In the 1980s, El-Halwagi (1988) introduced the use of windrow and mechanized composting for organic waste in Egypt, presenting these methods as alternatives to landfilling.

In the 1990s, several approaches emerged for assessing solid waste management, including structures for assessing the recycling potential of waste in North Carolina (USA), the life cycle assessment to calculate the potential emissions from the landfilling of urban and industrial waste, the assessment of environmental and waste management in the city of Hong Kong, the environmental risk assessment of solid waste disposal in Taiwan, the audit of environmental management of solid waste in Canada, and the life cycle assessment for solid waste generation in the USA.

In Canada, Dowie et al. (1998) conducted an environmental audit of solid waste in companies, emphasizing the importance of implementing environmental management practices

to reduce waste generation at the source and enhance recycling programs. Barlaz et al. (1993) applied material flow methodology to plastics in the United States, finding that PET beverage bottles are the most recycled plastics due to regulations in 10 states. Weitz (1999), in evaluating life cycle assessments in the USA, determined that the "Source Reduction + Collection + Transportation + Landfill" scenario was the most effective for waste management. This approach benefits from source reduction and the subsequent recycling of sorted materials. In Sweden, Finnveden (1999) conducted a life cycle assessment and found that potential CO₂ emissions from landfills are the largest source of greenhouse gases. This is due to the landfill's exposure to elements like water and air, which contribute to its environmental impact.

Table 2 – Articles selected for bibliometric analysis, discriminated by country, continent or region and method

Decade	Country	Method	Authors
1970	Canada	Simple decision-making model	Ingraham; Zechel (1979)
1980	Egypt	Composting	El-Halwagi et al. (1988)
1990	United States Sweden Hong Kong Taiwan Canada United States	Material Flow Methodology Life Cycle Assessment GRSU Life Cycle Assessment Environmental Management Assessment Environmental Risk Management ModelSolid Waste Audit GRS Life Cycle Assessment	Barlaz; Haynie; Overcash (1993) Finnveden (1999) Barron; Ng (1996) Chang; Wang (1996) Dowie; McCartney; Tamm (1998) Weitz et al. (1999)
2000	United Kingdom Turkey China Tailand Turkey Italy	GRSU Life Cycle Assessment GRS Life Cycle Assessment GEE Life Cycle Assessment Evaluation of Recycling Systems GRSU Life Cycle Assessment Life Cycle Assessment Environmental Impacts	Clift; Doig; Finnveden (2000) Özeler; Yetiş; Demirer (2006) Zhao et al (2009) Suttibak; Nitivattananon (2008) Banar; Cokaygil; Ozkan (2009) Feo; Malvano (2009)
2010	Europe Spain Brazil Australia Turkey Switzerland	GR Plastic Life Cycle Assessment GRSU Environmental Assessment Stroke Energy Recovery Zero Waste IndexGRS Life Cycle Assessment GR Material Flow Analysis	Lazarevic et al. (2010) Bovea et al. (2010) Leme et al. (2014) Zaman (2014) Erses Yay (2015) Haupt; Vadenbo; Hellweg (2017)
2020	Brazil Brazil Nordic Region Mexico European Union	AVC and Life Cycle Costing Aggregate Environmental Impact Indicator GRS Life Cycle Assessment GRS Technical Indicators Neural Network generation of plastic waste	Paes et al. (2020) Deus et al. (2020) Behzad et al. (2020) Olay-Romero et al. (2020) Fan et al. (2022) Wang et al. (2020)

Source: The Authors (2023).

Barron and Ng (1996) identified that Hong Kong faces significant challenges in solid waste management due to rapid economic growth and changing consumption patterns. The region experiences high levels of waste production, with plastic being one of the major components. In Taiwan, Chang and Wang (1996) emphasized the importance of resource recovery, including paper, glass, metal, plastics, and electricity. Their work aimed to mitigate the impacts of air pollution from incinerators and landfill leachate.

In the 2000s, several articles addressed various aspects of solid waste management through life cycle assessment, including integrated solid waste management in the United Kingdom; determining solid waste management systems in Turkey; assessing greenhouse gas

emissions related to solid waste in China; analyzing recycling performance in Thailand; municipal solid waste management in Turkey; and evaluating the environmental impact of solid waste management in Italy.

In the United Kingdom, Clift et al. (2000) proposed that integrated waste management should go beyond a simple hierarchy to systematically evaluate alternatives, aiming to identify the most beneficial use of waste. In Turkey, Özeler et al. (2006) analyzed waste impacts using life cycle assessment (LCA) and found that the "Source Reduction + Collection + Transportation + Landfill" scenario was the most viable due to the benefits of source reduction and subsequent recycling of sorted materials. Another LCA study by Banar et al. (2009) in Turkey indicated that the composting and recycling method was the most environmentally preferable. Similarly, in Italy, research by Feo and Malvano (2009) found that a composting and recycling scenario, combined with 80% selective collection, had the lowest environmental impact and significantly reduced the amount of waste sent to landfills.

Zhao et al. (2009) found that waste in China has a high organic content, significantly contributing to greenhouse gas emissions. They reported that landfilling and incineration account for approximately 68% and 26% of total greenhouse gas emissions, respectively, while recycling shows an inverse relationship with greenhouse gas emissions, with a coefficient of determination of $R^2 = 0.967$.

In Thailand, Suttibak and Nitivattananon (2008) used performance indicators—efficiency, effectiveness, and service index—to evaluate solid waste management. Their study revealed that while the recycling rate and diversion rate were at reasonable levels, recycling performance was weak in terms of participation rate. They concluded that integrating waste recycling systems could improve overall environmental performance.

In the 2010s, life cycle assessment methods were applied to various aspects of solid waste management across different regions:

- Europe, Spain, and Turkey: Life cycle assessments were used to evaluate solid waste management practices;
- Brazil: Life cycle assessment focused on energy recovery from waste;
- Australia: The Zero Waste Index was utilized to assess waste management practices; and
- Switzerland: A material flow assessment was conducted to evaluate waste management.

Lazarevic et al. (2010) conducted an LCA in Europe and found that mechanical recycling is preferred over incineration of solid waste. Their study indicated that recycling raw materials consumes fewer abiotic resources compared to incineration or combustion in cement kilns. In Spain, Bovea et al. (2010) applied LCA and concluded that scenarios involving biogas and landfill with energy recovery are superior to composting and recycling. This approach was found to mitigate the pollution load across all impact categories.

In Turkey, the incineration scenario was found to have a greater environmental impact due to atmospheric emissions. In contrast, the mechanical recycling scenario, which includes resource recovery and composting to produce compost and fertilizer, offered the best environmental benefits (ERSES YAY, 2015). Haupt et al. (2017) examined material flows in Switzerland, a country with high recycling rates. They discovered that 48% of the waste is directed to incineration plants, while 52% of recyclables are collected. Of these recyclables, 27% is exported for recycling in other countries. The remaining 73% of the collected and source-separated materials are recycled within Switzerland.

In Brazil, Leme et al. (2014) utilized LCA to evaluate energy recovery options. Their findings indicated that landfill systems are the least effective for waste management, while direct combustion of waste for electricity generation performed the best. Zaman (2014) applied

the zero waste index in Australia. The result indicated that material recovery, energy and water savings have increased since 2003, with an index of 0.32 and projections for 2020 were =0.45, to improve the index, establishing zero waste policies. It is essential to change management systems and implement long-term zero depletion principles and expand local recycling industries.

In the 2020s, various methods were applied to solid waste management studies, including LCA and cost assessment of solid waste management in Brazil, environmental impact assessment of solid waste management in Brazil using an aggregate indicator, waste management indicators in the Nordic countries and Mexico, and neural network models for plastic production in the European Union.

In the Nordic region, Sweden, Denmark, Norway, Finland, and Iceland are recognized as leaders in solid waste management. Despite their advanced waste treatment technologies, there is still a need to enhance waste prevention programs and improve selective collection systems (BEHZAD et al., 2020).

Fan et al. (2022) proposed a neural network model to forecast plastic waste generation in the European Union for 2030. Their findings indicated that the EU's target recycling rate of 55% is insufficient to mitigate the environmental impacts of plastic waste. Among the waste reduction scenarios analyzed, the combination of a 55% recycling rate with 42.6% energy recovery and a 50% recycling rate with 47.6% energy recovery were identified as the most effective. These scenarios showed the lowest global warming potential.

Paes et al. (2020) evaluated solid waste management using a life cycle approach with a focus on economic performance. Their analysis found that landfilling 96.6% of waste and recycling 3.4% was the least expensive option. However, scenarios combining recycling, improved transportation efficiency, and composting were preferred, as they reduced total social costs by 31% and 33%. Similarly, Deus et al. (2020) used an aggregate index to assess municipalities in Brazil and concluded that optimal environmental performance could be achieved through a combination of recycling and other waste treatment methods, such as composting.

In Mexico, a technical indicator was used to assess solid waste management across various municipalities. The study revealed that 33% of the municipalities utilize landfills but do not manage to dispose of 90% of their waste, while 51% rely on landfilling or controlled landfills for waste disposal. The findings indicate a need for improvement in the waste management system, including enhancements to selective collection and recycling efforts (OLAY-ROMERO et al., 2020).

Wang et al. (2020) analyzed the life cycle and costs of waste management in China and found that activities such as solid waste separation, brick manufacturing, and plastic recycling are significant electricity consumers. These costs can be mitigated by generating revenue from recycling and installing biogas systems for energy production.

There is a noticeable trend towards employing LCA methodology to identify the impacts of solid waste on municipal systems and to propose alternative solutions. Notably, composting and recycling have emerged as widely agreed-upon alternatives among researchers. These methods are recognized for their potential to minimize the environmental impacts of landfills and incineration while also benefiting the local economy.

LCA examines environmental interventions and potential impacts from cradle to grave, encompassing the entire lifecycle from raw material acquisition to production, use, and disposal (Clift et al., 2000). LCA is a crucial preventive measure for environmental protection within the solid waste management system, as it evaluates the entire lifespan of a product or process (Ivanova & Lisina, 2023).

The results of the analyzed articles underscore the importance of establishing assessment methods for solid waste management to ensure resource savings and promote sustainability through energy recovery, composting, and recycling. Several countries in Europe, Asia, and America have sought to establish legislation concerning solid waste, with targets aimed at increasing recycling rates and enhancing efficiency in public management.

5 CONCLUSIONS

This article reviewed the literature from 1970 to 2022, employing quantitative methods such as bibliometric analysis and keyword network maps to provide an overview of publication trends and evolution. Additionally, qualitative methods, including systematic review aspects, were integrated to identify the primary waste management assessment methods utilized across different countries.

There has been a notable evolution in research terms and methods over time, with a significant increase in the number of publications from 2020 onwards. The LCA method emerged as the most frequently used approach, particularly for evaluating the economic viability of recycling and composting scenarios. Europe stands out in scientific publications on this topic, largely due to its stringent regulations and directives on waste management. Meanwhile, developing countries such as China and Brazil have demonstrated substantial progress and growing interest in the field. This evolving focus contributes positively to decision-making processes and the selection of appropriate projects and management systems, impacting the environmental, economic, and social spheres.

This research pinpointed key areas within the scientific literature and emphasized the need for further exploration of the subject. The evolution of research has demonstrated that the efficiency of solid waste management must be linked to methods and practices that are based on sustainability, public investment, and social participation.

The evaluation of waste management models should be linked to the formulation of more effective public policies across different countries, taking into account local specificities. It is recommended that public policymakers and managers establish criteria to evaluate the implemented waste management model and seek partnerships with various institutional sectors, such as companies, NGOs, universities, and social mobilization groups, in association with sustainable practices focused on resource recovery, social participation, and strengthening the economy.

For future research, it is recommended to utilize sustainability indicators to identify various solid waste management scenarios and to map advancements and successful practices aimed at achieving the sustainable development goals outlined in the UN's 2030 Agenda.

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