Global Perspectives on Municipal Solid Waste Disposal and Circular Economy: A Review

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Abstract

This research presents a review of the study trends on the disposal and utilization of solid wastes from a global perspective to identify the advances in technologies of utilization, recovery, and end use and how this topic has evolved toward the circular economy. The methodology used is the systematic review applying the PRISMA method and bibliometric analysis. The selected database is the Scopus. The bibliometric analysis was performed to identify the main countries, co-authored countries, keywords of the co-occurrence author, and research timeline. The analysis showed that China, Italy, the United Kingdom, and India have the largest publications. The countries with the highest number of partnerships are Italy, the United Kingdom, and China. The author's keywords, the most cited, were "municipal solid waste", "waste management", "circular economy", "recycling", "urban waste", "anaerobic digestion", "landfill", "life cycle assessment", "incineration", "waste-to-energy", and "biogas". The results indicate an interdisciplinary area and studies that aim to identify and propose solutions to the waste issue, including the incentive to recycle household waste, recovery of energy from landfills, and advanced systems.

Keywords: *Municipal solid waste; Final disposal; Systematic Literature Review; Bibliometric Analysis*

I. Introduction

Trends in urbanization and population growth are critical parts of sustainable development, given the pressure on natural resources, evidenced by the amount of waste produced [1]. The environmental issues related to solid waste are characterized as a global challenge, reflected by transformations in production processes, manufacturing automation, mass production, and standard of living rise and changes in consumption patterns [1, 2]. These factors result in inadequate disposal and its consequent negative environmental impacts, a global problem. This highlights the need for proper management, treatment, and disposal of these wastes, with sustainable environmental management [2, 3, 4].

According to the report presented by the World Bank, the world generates around two billion tons of urban solid waste per year [4]; if current trends continue, it is estimated that global waste production will be approximately 27 billion tons per year in 2050, which will double population growth [5, 6]. This surge in waste output poses challenges, not only in terms of quantity but also in managing its environmental implications. Another consequence is the carbon dioxide (CO_2) emissions, which should increase to 2.6 billion tons during this period, contributing to the greenhouse effect and worsening global warming, among other problems [5, 6].

The reflection of these problems over time has been issues of debates and discussions on the final disposal of waste, which has shown that these issues reflect the reality that the appropriate places for waste treatment are insufficient to meet the demand; approximately 33% of this total waste produced in the world has no environmental destination adequate, and this waste has its final disposal in landfills [4]. However, some countries in the European Union have made progress in finding solutions to this problem, such as Germany, Belgium, Denmark, the Netherlands, and Sweden, with the lowest rates of sending waste to landfills and public waste management policies [4].

In the quest to contain the aggravating factors arising from waste production, other examples are projects and innovations aimed at waste management. Cities and countries moving forward in improving waste management, such as San Francisco, California, presented the goal of achieving a "Zero Waste Program" with targets for 2030, reducing solid waste generation by at least 15% below 2015 levels. Solid waste discarded by incineration or dumping in landfills at least 50% below 2015 levels [7]. The city stood out for pioneering the first and largest municipal food waste compost collection program in the United States [8].

Germany is seen as a world leader in technologies, solid waste treatment, and waste management policies [4]. Becoming a forerunner in implementing the waste hierarchy that is based on reducing, reusing, recycling, reclaiming, and landfilling is the last step in the process, with extensive experience in circular carbon technologies in the sustainable and efficient management of system waste [9]. Another example is the city of Kawasaki in Japan, which improved industrial processes to treat the waste produced, becoming the first eco-industrial city in Japan, with the adoption of sustainable practices applying the principles of circular economy [10]

In this context, the concept of circular economy (CE) emerges as an efficient waste management approach covering the entire chain from production to disposal. Its relevance has sparked interest in several areas, including economics and engineering. In the last decade, research in this area has expanded significantly [11]. By emphasizing more significant social and environmental benefits, particularly in waste management at different spatial scales, the circular economy focuses on the final stages of a product's life cycle and its final disposal. This focus facilitates integration into the production chain, transforming waste into a valuable raw material source [1].

Given the above, the main purpose of this research is to review the studies on the disposal and use of municipal waste worldwide, to identify the advances in technologies and transformation, thus also, the final application given to waste to understand the current stage of this issue, towards the circular economy, integrating the concepts of eco-parks for sustainable waste management. Based on the studies already carried out on technologies regarding the final disposal of waste, this article applied a systematic review of the academic literature with the support of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and bibliometric analysis using VOSviewer software.

Several researchers have applied systematic review and bibliometric analysis. The PRISMA method was applied to how is the performance of waste management systems assessed globally [12] to update and expand the epidemiological evidence on the association between MSW management practices and resident populations' health risks [13] and to clarify the various terms used in describing recycling systems worldwide and to offer an overview of the present cutting-edge methods in managing recyclable waste materials from municipal solid waste (MSW) in both developed and developing economies. The focus is on highlighting their capacity to advance circularity [14].

However, it was found that no scientific research in the period analyzed brought together bibliometric and systematic reviews using the PRISMA method. Specifically, more studies are needed focusing on the final disposal of urban solid waste within the scope of the circular economy, as proposed in this research. Thus, the novelty of this review lies in its international scope, investigating the most recent data on the topic. Therefore, this article seeks to fill the gap in bibliometric studies on waste disposal and circular economy, offering an alternative for post-pandemic waste recovery. These findings can advance discussions on solid waste issues and disposal methods by surveying related studies, aiming to expand the scope of research into solutions to this problem.

The structure of this paper is as follows: in Section 2, the methodology is detailed. The results and discussion and the advances and challenges in waste management identified in the systematic review are presented in Section 3. Finally, Section 4 makes conclusions, contributions, limitations, and further research recommendations.

II. MATERIALS AND METHODS

The methodology employed to achieve the proposed objective involves a systematic literature review, utilizing the PRISMA Meta-analysis (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and bibliometric analysis. The systematic review is a qualitative, scientifically rigorous approach that collects and critically analyses numerous studies meeting eligibility criteria to address specific research questions [15, 16, 17].

Meta-analysis is broadly defined as a methodology to summarize existing study results, estimate relationships between them and explanatory variables, and identify heterogeneity among studies using statistical techniques to integrate findings [18]. The PRISMA method is a framework that covers both systematic reviews and meta-analyses. Systematic reviews involve a thorough and structured analysis of existing literature, while meta-analyses are used to consolidate, analyse, and synthesize data from multiple studies. They serve as powerful tools to provide a more comprehensive understanding of a subject by integrating and critically evaluating research evidence [19]. On the other hand, bibliometrics focuses on quantitative analysis of data related to publications, and when integrated with a systematic review, it forms a bibliometric review [20]. This combination allows for a quantitative assessment of the literature being reviewed.

2.1. Systematic Literature Review Methodology

The Systematic Literature Review is a research methodology known for its rigorous and structured approach. It involves rigorous and systematic methods, carefully selected to minimize bias, increasing the credibility and reliability of the analysis [17]. By searching, selecting, and evaluating existing literature, this method allows for a comprehensive and unbiased synthesis of evidence, providing a foundation of reliable information across multiple fields of study.

The PRISMA protocol was used to identify the primary studies that met the eligibility criteria [15]. This protocol involves steps for identification, selection, eligibility, and inclusion. Following the data collection in the systematic review, a bibliometric analysis was conducted [15, 16]. The data were processed using the OpenRefine software, a tool that allows both visualization and manipulation of data. This software not only allows the reorganization and cleaning of data sets but also allows possible errors to be corrected, guaranteeing the accuracy and reliability of the processed information [21].

The search was carried out in the Scopus database referring to the period from 2018 to 2022; in the searches, field labels were used for the keywords, ("urban solid waste*" OR "municipal solid waste*") AND ("final disposal" OR "waste management" OR "waste treatment" OR "waste recovery" OR dump* OR "open dumping*" OR "dumpsite" OR "controlled landfill*" OR "sanitary landfill*" OR "eco-park" OR "eco-park" OR "circular economy"). The database used Scopus was considered in the period between 2018 to 2022. The analyses were carried out in May 2023.

The search was refined using the following parameters: documents from the last five years, specific document types, and language criteria. Among articles and reviews in English from the past five years, 1,473 open-access items were found. From these, 1,302 publications were selected based on their titles alone. Further screening of titles and abstracts led to 1,223 items being included for analysis.

2.2. Bibliometric Analysis Methodology

Bibliometric analysis, a quantitative and statistical methodology [20], facilitates the exploration and in-depth analysis of vast scientific data [20]. Bibliometrics provides information about the impact of research, identifies influential works, and tracks the flow of knowledge within an area of expertise, helping to understand the dynamic nature of scientific publications over time [22]

The main parameters used were to identify the main countries highlighted by research number, co-authorship between countries, and the main keywords used by the authors. For this characteristic, the presented method has universal application in the different fields of knowledge [22]. Subsequently, they were analysed using VOSviewer software, a tool for visualizing and analyzing complex networks and bibliometric data. This software facilitates the exploration and representation of relationships among items in a dataset, such as co-authorship networks or citation patterns [20].

III. RESULTS AND DISCUSSION

3.1. Bibliometric Analysis

The bibliometric analysis consisted of parameters to identify some relationships between the publications analysed through VOSviewer software, such as co-authorship between countries, co-occurrence of author keywords, and co-citation of cited sources and authors.

3.1.1 Co-authorship between countries

The analysis of co-authorship between countries not only identifies collaborative partnerships but also the breadth of research networks. This parameter reveals the extent to which countries collaborate, promoting a better understanding of the global panorama of scientific collaboration and the interconnection of these partnerships. As shown in Figure 1, out of a total of 122 countries analysed, only 64 meet the restriction parameters: a maximum of 25 published documents and a minimum of 3 documents that reflect partnerships.

Italy has the highest co-authorships with several countries, including Spain, Chile, Colombia, the Czech Republic, Ecuador, Romania, Singapore, and Slovakia. The United Kingdom maintains co-authorships with Bangladesh, Finland, Ireland, Norway, Qatar, Sweden, and Turkey. China already has partnerships with Denmark, Hong Kong, Iran, Pakistan, South Korea and Taiwan. The smallest representation was Latvia, Argentina, and Algeria, both with only six publications, and Iraq, with five publications. Brazil is among the countries with the largest number of partners, with Portugal and Iraq.

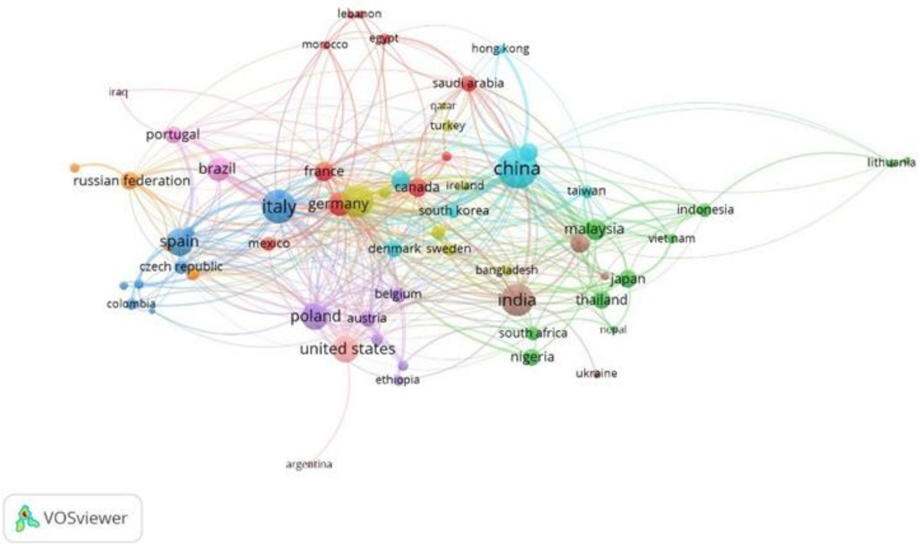

Figure 1. Co-authorship between countries

3.1.2 Analysis of publications by country

For the analysis of publications by country, the ten most representative countries were highlighted. Table 1 presents the ten countries with the highest number of publications and citations in the analyzed period. It is observed that the country with the highest representation is China, with 159 documents. With the lowest number, Malaysia appears with only 45 publications.

Interestingly, despite having a smaller volume of documents, certain countries substantially impact citations. The United Kingdom notably outpaces Italy in citations, signifying considerable influence despite a potentially smaller number of publications. Likewise, the United States surpasses Spain in citations, highlighting its significant impact despite presenting a smaller number of documents.

Table 1. Publications by countries

Countries	Documents	Citations
China	159	3,271
Italy	111	2,782
United Kingdom	107	3,207
India	104	1,593
Spain	74	1,621
Poland	72	806
United States	70	2,622
Germany	56	1,087
Brazil	53	630
Malaysia	45	1,357

The results presented in Table 1 may be attributed to the advancements in programs and policies aimed at recovering urban solid waste in these countries. China, for instance, has implemented effective waste management policies, such as reducing the influx of imported waste in industries [4]. Additionally, the country has enacted measures to curtail waste generation. In January 2020, the National Development and Reform Commission (NDRC) imposed a new prohibition on the use of non-degradable plastic products, encompassing plastic bags, single-use plastics, and packaging materials [9].

Another highlight is Italy, which, despite being considered one of the largest waste generators among European Union countries, presents itself as one of the most advanced in waste management in recent years [23]. This was confirmed by several factors, such as the low rate of waste production per capita, which remained at 0.499 kg in 2019 and has remained stable since 2010, when it was 0.5 kg. Material recovery is another aspect that has driven the country to stand out in waste management, reaching 29% in 2019. The country is advancing in efficiency in energy recovery from waste. Furthermore, recycling reached an impressive level in 2020 [23].

The United Kingdom (UK) has advanced waste management based on policies designed to manage the entire waste chain. Management is based on the control of waste disposal activities, which includes prevention and recovery [24]. The nations of the United Kingdom are already actively involved through existing measures or ongoing work to take forward the commitments made in their respective waste management strategies. For example, England adopted a package of measures and legislative proposals to boost sustainable growth, the Resources and Waste Strategy (RWS), which among its objectives is to define the preservation of material resources, minimize waste, promote resource efficiency, and move towards a circular economy. The RWS forms part of the UK Government's commitment to the 25 Year Environment Plan. In a similar vein, Wales has set out a series of targets to drive circularity based on the RWS [25].

India confronts considerable environmental challenges linked to the generation of waste and the insufficient collection, transportation, treatment, and disposal of waste, particularly in the realm of solid waste management (SWM). India has 17.5% of the world's population and is the second most populous country [26]. The surge in population, especially the urban sprawl, is turning solid waste management (SWM) into a major issue in India. [26]. However, the country has advanced in waste prevention policies. The Central Pollution Control Board (CPCB) and the State Pollution Control Board Committees are responsible for transmitting environmental policies in addition to pollution control.

They are also responsible for reporting on central and state government controls. These institutional bodies can present measures for the formulation of a national policy regarding the collection and disposal of urban solid waste [27].

Spain, the second largest country in the European Union (EU), still needs help in terms of waste management, as 52% of waste is still landfilled or recycled [28]. However, the country has promoted advances in waste management. In 2020, Spain approved the Spanish Circular Economy Strategy to 2030 "España Circular 2030" [29], including proposals to promote a sustainable and decarbonized economy with efficient waste management. The Spanish Strategy is characterized by an innovative model with guidelines for sustainable production and consumption that aims to significantly extend the life cycle of products, materials and resources in the economy. With a proposal for the present and the future, it prioritizes the reduction of waste generation, maximizing the usefulness and useful life of various components, emphasizing a sustainable and efficient use of resources [29]. Another step towards a sustainable economy was the approval of the law on waste and contaminated soil in 2022. This law proposes guidelines in line with the Recovery and Resilience Plan for 2022-2023.Among its actions, the plan emphasizes the improvement of waste management techniques towards the circular economy [28, 29].

In Poland, waste management has significantly transformed its practices. There has been a notable shift from landfilling waste to prioritizing its recovery, mainly through municipal facilities, waste composting centres, recycling facilities, and thermal waste treatment plants. In 2019, 56% of the total waste collected in the country was sent for recovery [30]. The research shows that material recycling was 25%, composting 9%, and incineration with energy recovery 23%. Waste sent to landfills was 43%. However, the thermally processed municipal waste level in Poland has increased significantly. In 2019, approximately 23% of waste was sent for recovery through thermal processing [30].

The United States (USA) represents 4% of the world's population and is considered the most significant economy [31]. This may be associated with the fact that it is the largest waste producer and faces challenges in its elimination. According to data from the United States Environmental Protection Agency (EPA), the amount of municipal solid waste (MSW) generated in 2018 was 292.4 million tons, of which 69.0 million tons were recycled and 24.9 million tons composted. Approximately 17.7 million tons of food were recovered through alternative methods. Energy recovery accounted for 34.6 million tons, while 146.2 million tons of MSW were sent to landfills [31].

Germany leads in municipal waste recycling with a rate of 67%, surpassing other EU countries [32]. The country has implemented efficient strategies and policies for waste management, relying on advanced recycling and thermal treatment methods through waste incineration. Germany is a pioneer in implementing the European Waste Framework Directive, emphasizing the waste hierarchy. This hierarchy prioritizes waste prevention as the focus, followed by preparation for reuse, recycling, various forms of recovery, and environmentally friendly disposal [4].

Brazil has been prominent in research, although there are challenges to overcome for the country to achieve its environmentally correct waste disposal goals, as a large volume is still being sent to landfills. According to the 2022 Solid Waste Panorama, 81.8 million tons of waste was produced, corresponding to 224 tons per day. Around 61% of urban solid waste collected is sent to landfills, disposing of 46.4 million tons [33]. However, initiatives such as the "Zero Waste" program, introduced by the Ministry of the Environment in 2019, stand out. Its objective is to contribute to the closure of landfills in the country [33]. In 2022, the country established its National Solid Waste Plan (Planares), aiming to promote integrated and responsible waste management, focusing on the circular economy. The plan was designed for the period up to 2040 [34].

Malaysia faces challenges in managing urban solid waste, resulting from the consequences of population growth reflected in increased waste production. With a per capita production of 1.17 kg/capita/day, domestic waste accounts for approximately 65% of the total solid waste generated in the country [35]. Another issue in Malaysia concerns the disposal of waste in landfills, which are mostly not suitable for recovering waste. However, the recycling rate in Malaysia has shown improvements over the years, rising from 10.5% in 2013 to 31.5% in 2021 [35]. Energy recovery from waste is being actively implemented, with three landfills already equipped with landfill gas recovery (LFG) systems, showcasing the country's advances in waste management [36].

3.1.3. Analysis of the author's keywords co-occurrence

For the analysis of keywords, the ones most used by the authors were considered. The keywords were separated into nine clusters according to the main keyword or the one with the highest number of occurrences. Out of a total of 3,328 keywords with at least 5 occurrences, 149 met this criterion. However, "municipal solid waste," "waste management," and "circular economy" stood out as the most prominent keywords. This analysis enables us to identify the relationship between keywords, denoted by their proximity. It's observable that "municipal solid waste" and "circular economy" appear most close, suggesting that many studies direct their analysis to this focus.

It is also possible to observe that the keyword "anaerobic digestion" is directly linked to "food waste", indicating studies that aim to solve the issue of urban waste, as these types constitute the largest production volume. Furthermore, "landfill" is close to "disposal", as numerous studies use both terms when defining waste treatment processes. This association is like the relationship between "waste to energy" and "pyrolysis", as well as "waste collection" with "waste generation", as illustrated in Figure 2.

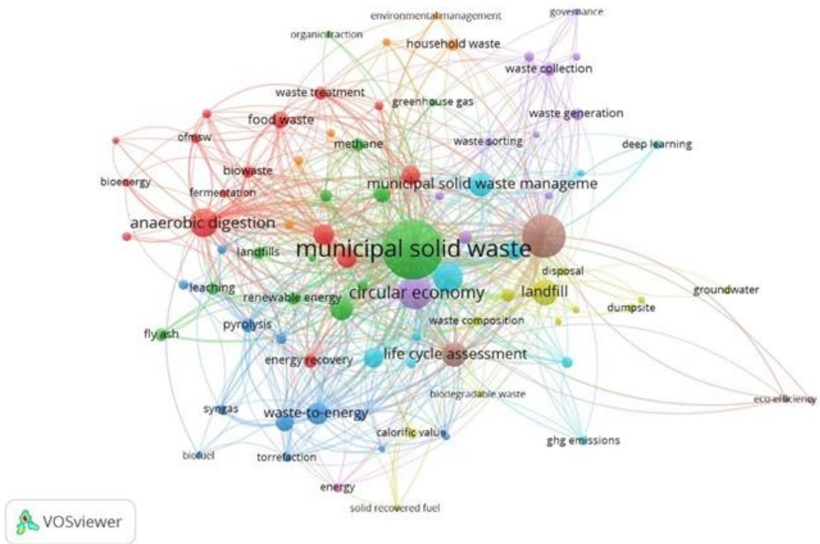

Figure 2. Author keywords co-occurrence

In Table 2, the main keywords are presented by number of occurrences. It is observed that "urban solid waste" was the one that had the greatest representation, followed by "waste management" and "circular economy". The keywords with the lowest number, with at least 5 occurrences "waste recovery", "biofuel", "eco-efficiency", "biodegradable waste" and "solid recovered fuel", which may be related to the fact that most research considers the waste not only directed to energy production but to several applications, depending on the type of waste and need.

The results demonstrate that urban solid waste and its management are directly linked to the circular economy, given the issues surrounding the problem of waste and its negative impacts. These topics are currently widely publicized due to their significant relevance in meeting the need for waste recovery solutions. This urgency arises from the adverse environmental impact of waste, which contributes to soil, water, and air pollution and increases greenhouse gas emissions.

In this context, the circular economy approach emerges with a sustainable waste management proposal. It focuses on a dynamic waste prevention and elimination process that covers the entire life cycle, from producing a product to its environmentally correct disposal.

Table 2. Authors Keyword Occurrences

Authors Keywords	N. of Occurrences
Municipal solid waste	311
Waste management	165
Circular economy	96
Recycling	74
Anaerobic digestion	69
Landfill	58
Life cycle assessment	55
Incineration	44
Waste-to-energy	41
Biogas	38

Based on the timeline of the analysis period, as shown in Figure 3, it is possible to observe that the studies were concentrated between 2020 and 2021 and that the keywords most used by the authors are waste management and circular economy, reaffirming the results that the majority of research deals with the issue of waste and the need to move towards a sustainable economic model that is based on clean environmental technologies, focused on the circularity of production processes.

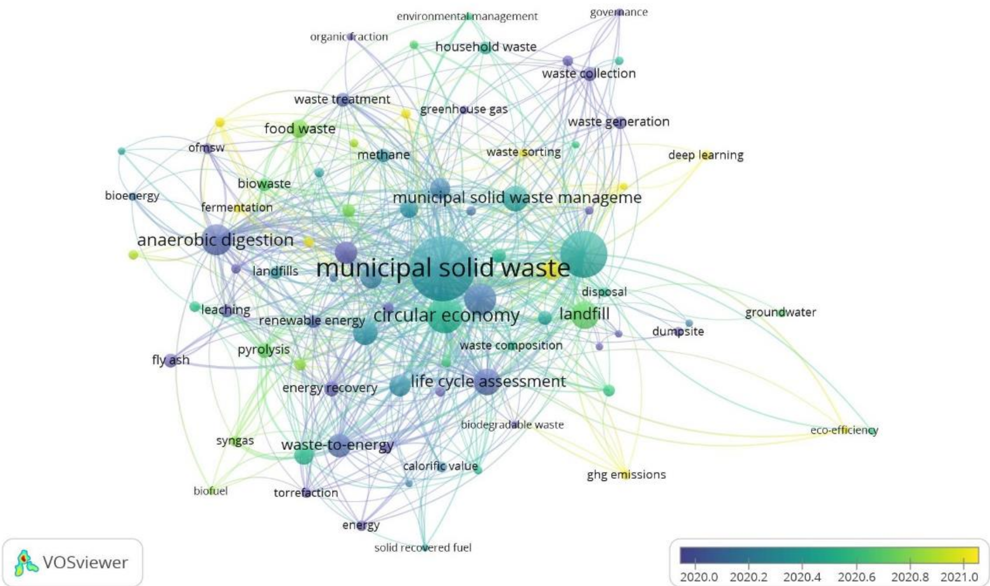

Figure 3. Author keywords overlay visualization.

3.2. Systematic Literature Review

The Systematic Literature Review was conducted by selecting identified research. Initially, 1,473 studies were identified, and following the exclusion criteria, 250 were removed in the subsequent stage, restricting the selection to 1,223 publications, including articles and reviews from 2018 to 2022. The final selection criteria involved the identification of the top ten most cited researchers in the English language. As described in the PRISMA diagram, Figure 4:

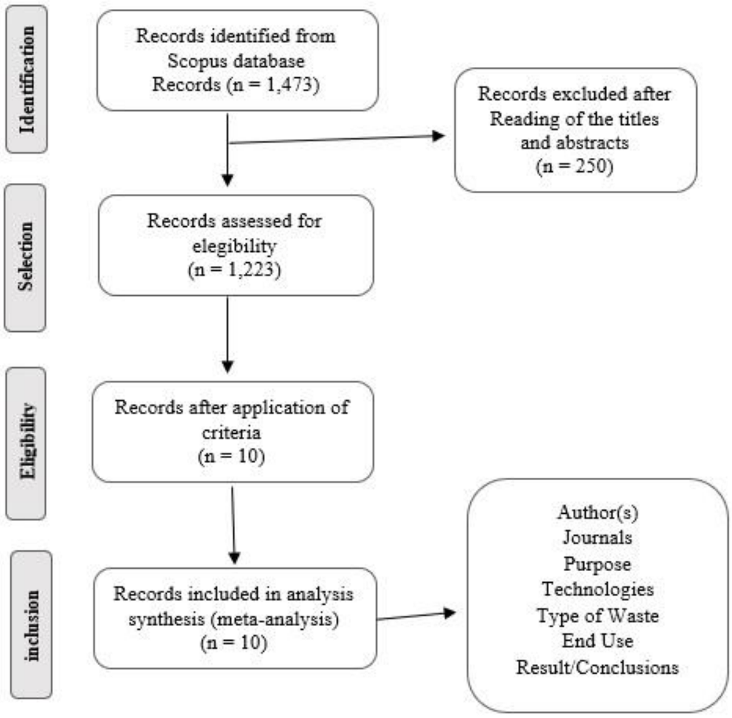

Figure 4. PRISMA diagram records identified from the Scopus database.

To present the information from the ten publications included in the analytical synthesis, the abstract of the information was organized accordingly. Table 3 is divided into four sections: authors, journals, research objectives, and main conclusions of the studies. Table 4 displays the identified technologies, types of waste, and their final uses. Emphasizing the importance, it should be noted that due to the exclusion criteria used in the article selection process, publications from 2023 were not included. This exclusion is justified by the data collection period during which only a few studies were available in the research database used.

Table 3: Main characteristics and results of the articles selected.

Authors	Journals	Purpose	Results/Conclusions
[37]	Humanities and Social Sciences Communications	To examine the possibility of improving the granularity of country-level plastic waste generation data using reasonable assumptions based on population density and affluence.	Advances in technology, consumer product design, and behaviour patterns may change the per capita GDP-consumption relationship and conversion rates of waste to mismanaged plastic waste (MPW).
[38]	Egyptian Journal of Petroleum	To determine the stakeholders' action/ behaviour that has a role in solid waste management and to analyze different factors that affect the system.	Biodegradation of MSW according to time is an essential factor that governs the amount of recyclable material, particularly the organic contents.
[39]	Science	To propose an evidence-based global strategy that includes practical, measurable interventions aimed at reducing plastic pollution	Further innovation in resource-efficient and low-emission business models, reuse and refill systems, sustainable substitute materials, waste management technologies, and effective government policies are needed.

Table 3: Main characteristics and results of the articles selected. Continued

Authors	Journals	Purpose	Results/Conclusions
[40]	Environmental Management	To review the challenges of scaling up Polyhydroxyalkanoates (PHA) production by utilizing waste streams as a carbon source, with emphasis on the feasibility of the alternatives.	Choosing the right waste stream is critical to guarantee a consistent and sufficient supply.
[41]	Science of the Total Environment	To give an overview of a selection of recycling/recovery technologies for the management of air pollution control residues (APCr) and fly ashes (FA) generated in municipal solid waste incineration (MSWI).	European societies desire better management of APCr/FA and care that not only provides safe final disposal of this hazardous waste but also recovers secondary raw materials from this anthropogenic resource.
[42]	Science of the Total Environment	To present a global backdrop of MSW management during the COVID-19 outbreak and to examine various aspects of MSW management.	Effective management of municipal solid waste stands as a essential public health service necessitating urgent attention from authorities both during and after the COVID-19 pandemic.
[43]	Journal of Cleaner Production	Support practitioners and policymakers from diverse backgrounds in devising future strategies and interventions aimed at encouraging household waste separation behaviour.	Targeted communication and educational programs that involve the community and present sorting wastes as a social norm are crucial for the establishment of a recycling culture Accompanied by environmental alterations and economic incentives.
[44]	Science of the Total Environment	To provide a detailed life cycle investigation of different WtE Technologies life cycle assessments (LCA) using two sets of data: theoretical analysis and case studies of large-scale commercial plants.	The diversity in MSW and the various purification methods for syngas are the primary obstacles affecting the present WtE systems based on pyrolysis and gasification.
[45]	Resources, Conservation & Recycling	To investigate the co-integration the relationship between MSW, recycling, economic growth, carbon emissions, and energy efficiency, using quarterly data from 1990 to 2017.	The research validates a single-directional connection from MSW, recycling to economic growth, carbon emissions, and energy efficiency. These results imply that any policy intervention linked to MSW recycling yields substantial economic growth and alterations in carbon emissions.
[46]	Environmental Research Letters	Apply compositional Bayesian regression to generate initial estimates of historical and projected waste production (1965–2100) categorized by their composition and management methods. This includes assessing the associated environmental impacts in all countries	The per capita waste production is linked to per capita income; richer developed countries continue to produce the most waste. Fundamentally, given current trends, it was estimated that waste production will continue to rise with unsustainable treatments.

Next, Table 4 presents the waste recovery technologies identified in the selected studies, along with the waste types and their end uses. Subsequently, the analytical synthesis of the systematic review is presented.

Table 4: Technologies, type waste and end use of the articles selected.

Authors	Technologies	Type Waste	End Use
[37]	Recycling of plastic waste and technologies to prevent escape from land-based sources into the ocean.	Plastic waste	Not specified
[38]	Organic solid-state fermentation (SSF)	Organic waste	To produce succinic acid, used in medicine production, plastics, and laundry detergents
[39]	Recycling	Plastic Waste (microplastic)	Not specified
[40]	Polyhydroxyalkanoates (PHA) production	. Industrial by-products and/or waste streams, i.e., agriculture feedstock, waste plant oils, or wastewater	Polyhydroxyalkanoates (PHA), biopolymers, or organic plastics
[41]	Recycling/recovery technologies	Pollution control residues (APCr) and fly ashes (FA) from Municipal solid waste incineration (MSWI), hazardous waste	Lightweight aggregates, glass-ceramics, cement, recovery of zinc, rare metals, and salts
[42]	Thermal treatment (waste to energy) with an energy recovery facility	Municipal solid waste (MSW)	Not specified
[43]	Recycling	Household waste.	Not specified
[44]	Thermal conversion (pyrolysis, gasification, incineration)	Municipal solid waste (MSW)	Waste-to-energy (WtE)
[45]	Recycling	Municipal solid waste (MSW)	Not specified
[46]	Not specified	Municipal solid waste (MSW	Not specified

3.2.1 Research areas records included in analysis synthesis.

This section presents the analytical synthesis of the studies included in the systematic review. The points analyzed were the research objectives, the technologies identified, the variety of types of waste, and the final application given to the waste.

3.2.1.1 Research purpose

The selected research covers several areas focused on waste treatment, considering its types, appropriate technology, and final disposal. This shows that the combination of processes allows for more effective use of waste through adequate final disposal, preventing it from being sent to landfills and mitigating adverse environmental impacts.

The first study discusses the importance of plastic as a crucial material in the economy and its presence in various products. However, the increase in plastic waste has adverse effects on the environment. The study aimed to investigate the possibility of refining the specifics regarding plastic waste generation on a national scale, using reasonable assumptions based on population density and GDP. As described in the study, plastics used mainly for packaging have a short useful life, contributing significantly to their disposal as waste. The authors project that, given the current growth rate, plastic production is expected to double in the next 20 years, consequently leading to increased waste production [37].

The second study aimed to determine the stakeholders' actions or behaviour that have an essential role in solid waste management and to analyze different factors that affect the system. The analysis encompassed municipal solid waste across 22 developing countries, spanning over thirty urban areas across four continents. The authors assert that solid waste management poses the most significant challenge to authorities in small and large cities in developing countries. They cite associated factors, including high costs and a need for a comprehensive understanding of the various factors influencing the entire waste handling system [38].

In the third study, researchers examined plastic pollution with a focus on solutions. The aim was to propose an evidence-based global strategy that includes practical, measurable interventions to reduce plastic pollution. To gauge the potential impact, the authors created the Plastics-to-Ocean (P2O) model, an ordinary differential equation (ODE) model that tracks plastic flow through representative systems. This model assesses plastic pollution from municipal solid waste, microplastics, and four primary sources of microplastics. It was utilized to identify crucial stocks and flows in land-based plastic pollution across the entire municipal solid waste (MSW) value chain [39].

The fourth study assessed advancements in polyhydroxyalkanoate (PHA) production through waste recovery. It aimed to review the challenges associated with scaling up PHA production using various waste streams such as agricultural feedstock, waste plant oils, or wastewater as carbon sources. The study emphasized assessing the feasibility of these alternatives and identifying the most promising options for scaling up. The authors highlighted multiple processes for waste stream recovery and using resulting by-products in industries [40].

The circular economy approach was presented in the fifth study. The objective was to identify the best technologies available for recovering solid waste and avoiding its disposal in landfills. The authors provided an outline of several recycling and recovery technologies designed to deal with waste and air pollution control (APCr) and fly ash (FA) produced in municipal solid waste incineration (MSWI), both of which are considered hazardous waste. Six case studies were presented and discussed: recycling of lightweight aggregates, glass-ceramics, cement, recovery of zinc, rare metals, and salts [41].

The sixth study investigated municipal solid waste (MSW) management during the global COVID-19 pandemic. It provided a global overview of MSW management practices during this period, examining different aspects such as waste types, their generation, and their impact on MSW management. The discussion delved into identifying disease transmission parameters related to solid waste handling, the consequences of the surge in medical waste on existing municipal waste treatment and disposal systems, and the resulting impacts [42].

The seventh study also presented the circular economy approach with drives in household waste separation. Its objective was to assist practitioners and policymakers from diverse fields in developing future strategies and interventions to promote this behaviour. The authors argue that embracing a circular economy necessitates the active engagement of the public in waste management, including pre-sorting waste at home. They highlighted that active public involvement in separating and managing municipal solid waste systems (MSWMS) can significantly enhance the quantity and quality of recyclable waste [43].

The eighth study aimed to investigate the life cycle of various Waste-to-Energy (WtE) technologies and explore how existing WtE methods could transition toward more environmentally sustainable technology. The authors presented a life cycle assessment (LCA) approach utilizing two sets of data: a theoretical analysis of seven multistage WtE systems encompassing thermal conversion methods like pyrolysis, gasification, incineration, and energy utilization through steam cycles, gas/CC turbines, and combustion engines, along with case studies from large commercial plants [44].

The ninth study aimed to evaluate the economic and environmental impacts of recycling domestic solid waste (MSW) in the United States, with a focus on achieving sustainable development. Its primary objective was to assess how MSW recycling affected environmental quality, economic growth, and the intricate relationships among MSW recycling, economic growth, carbon emissions, and energy efficiency in the United States. The study utilized quarterly data covering the period from 1990 to 2017, encompassing more than two decades of analysis. The study offered a comprehensive view through autoregressive modelling by examining the correlations between these variables throughout this period [45].

The tenth study aimed to produce estimates of national waste production levels, categorized by composition and treatment, on a worldwide scale. This involved utilizing Bayesian regression analysis to examine both past and future periods (1965–2100). The authors implemented a three-stage framework to gauge waste trends and their effects. Firstly, a waste type matrix was constructed, followed by regression analysis involving the total waste and waste per capita plotted against the Gross Domestic Product (GDP) per capita. Finally, combined projections were derived from these regressions [46]

These studies have stood out for presenting innovative proposals for managing urban solid waste. They represent advances in research aimed at reducing plastic pollution and ocean contamination, as referenced in [37,39]. Studies emphasize efforts to find solutions for a circular economy [41,43], covering waste management from product planning throughout its life cycle [44], and raising awareness among consumers [43] about disposal adequate disposal of domestic waste residues [45]. Research highlights efforts in waste management and recovery in several areas, reflecting a growing concern about environmental issues associated with waste and how it has been seen as a valuable raw material.

3.2.1.2 Identified Technologies

Among the articles analyzed, out of the ten selected for the systematic review, a variation in the technologies presented in the studies was observed. Recycling was highlighted as an alternative to address the issue of plastic waste. Additionally, other technologies were identified, such as standardizing technologies to prevent leakage from land-based sources into the ocean [37], municipal solid waste recycling, and solid-state organic fermentation (SSF) of food waste [38]. Moreover, the studies explored the recovery of waste streams for PHA production [39], recycling and recovery technologies for managing APCr and FA generated in MSW [41], thermal treatment (transforming waste into energy) with recycling from energy recovery facilities [41; 43], and thermal conversion [44]. These findings illustrate the diversity of technologies utilized in waste recovery and the advancements made over time in the quest for effective waste management and treatment solutions.

3.2.1.3 Types of Wastes

The types of waste identified in the chosen studies present a significant diversity, presenting different forms of treatment and potential for use. According to the studies analyzed, plastic waste is the main contributor to marine pollution [37, 39]. Urban solid waste, organic waste (industrial, agricultural, and domestic), and plastic waste [38]. Furthermore, industrial byproducts and/or waste streams were categorized into agri-food, non-agri-food industrial, food, urban waste treatment plants, and synthetic substrates. This range extends to agricultural raw materials, waste vegetable oils or wastewater [40], hazardous waste from APCr and FA in MSW [40], municipal solid waste (MSW) together with hazardous biomedical waste [42], and waste household [43]. The identification of these different types of waste highlights the need to value them, considering their potential as raw materials or for energy production.

3.2.1.4 End Use

The final disposal methods applied to various types of waste, as per the studies examined, exhibit considerable diversity. These methods encompass several strategies: the recycling of plastic waste and municipal solid waste [37], the repurposing of organic waste to generate biogas [38], and the production of Polyhydroxyalkanoates (PHA) using waste as a source of organic matter. PHA is an alternative to fossil fuel-based plastics derived from petroleum, a finite natural resource [40].

Advancements in Municipal Solid Waste Incineration (MSWI) treatment, aligned with the principles of a circular economy, involve the recovery of Air Pollution Control residues (APCr) and Fly Ash (FA), offering diverse applications [41]. These applications are driven by manufacturing products based on their physical and chemical properties, focusing on ceramic materials, glass-ceramics, and cement. Additionally, alternative uses include secondary building materials, geotechnical applications, zeolite-like materials, adsorbents, thermal energy storage materials, biogas enhancement, CO2 sequestration, stabilization/solidification agents, embankment fill materials, landfill cover, and alkali. There's also an exploration into the recovery of specific materials like zinc, precious metals, phosphorus, copper, rare earth metals, and salts [41]. Moreover, waste-to-energy (WtE) processes are also being considered [44].

3.2.1.5 Main Results and Conclusions of the Studies

In the study conducted by [37] to explore the feasibility of refining the granularity of plastic waste generation data at a national level, using reasonable assumptions based on population density and GDP, the authors concluded that there are significant advances in discussions on the waste treatment and its use, whether through reintroduction into production processes as raw material or through recycling. Furthermore, technological advances, consumer product design, and behavioural changes have the potential to alter the GDP-per capita consumption correlation, along with waste-to-usable materials (MPW) conversion rates [37].

When discussing waste management as one of the biggest challenges to the environment, to analyze the behaviour of all those involved in the process, the study by [38] concluded that, among other problems, inadequate waste management causes changes in ecosystems, including air, water and soil pollution, thus representing a real threat to human health. The authors reinforce that studies indicate that communities close to municipal solid waste (MSW) facilities have lower birth weights, increased congenital anomalies, and certain types of cancer. Furthermore, the growing volume of solid waste imposes substantial financial pressure on municipal budgets. This is a consequence of several factors, such as population growth, rapid urbanization, a prosperous economy, and improved living standards, that have notably increased the rate, volume, and quality of municipal solid waste generated. These factors influence the degradation of MSW and the recyclable content, especially the organic components, over time [38].

In the study by [39] to propose a strategy to reduce plastic pollution, the conclusion was that the problem of plastic pollution requires advanced innovation in resource-efficient and low-emissions business models, reusable systems, sustainable alternatives, and waste management technologies. The authors reinforce that this requires a successful global strategy and understanding of various mitigation potentials that are essential to reduce plastic pollution significantly. The study results also indicate that urgent and coordinated actions that combine pre- and post-consumption solutions that can reverse the growing trend of environmental plastic pollution are needed [39].

Focusing on advances in the production of Polyhydroxyalkanoates (PHA) through waste recovery, the study by [40] concluded that, in the production of PHA, the selection of the correct waste stream is crucial to ensure a consistent and adequate supply, ensuring thus the efficiency of the process. Consequently, the integration of PHA (polyhydroxyalkanoates) production into various operations, such as wastewater treatment plants, hydrogen production, or biodiesel plants, becomes not only feasible but also highly advantageous. This integration can improve implementation through the efficient use of materials using flexible processes [40].

To identify the best recycling and recovery technologies aimed at dealing with waste and air pollution control (APCr) and fly ash (FA), APCr/FA, produced in the incineration of municipal solid waste (MSW), both considered waste [41], argue that efficient management is essential in European societies to ensure the safe disposal of hazardous waste and its use as secondary raw materials. The study examined six cases, each involving two proposals: three related to product manufacturing and three involving the recovery of metals and salts. The decision about choosing technology is crucial and must be based on reliable information. The authors conclude that establishing a network of competent individuals or institutes for the recovery of APCr/FA secondary raw materials would improve the use of these resources and contribute to a more circular economy [41].

In their analysis of waste management during the COVID-19 pandemic, [42] argue for the critical role of municipal solid waste management as a fundamental public health service. During this crisis, it has become increasingly evident that rapid and efficient waste treatment is essential. The authors reinforce the urgent need for sustained attention from government bodies, not only during the pandemic but also in its aftermath. They emphasize the potential dangers arising from incorrect waste treatment during this period, which requires proactive measures to mitigate risks. Furthermore, the authors advocate a comprehensive assessment that covers the entire management process, from collection to disposal, to institute measures that protect public health [42]

Intending to help professionals and policymakers from different areas in developing strategies and interventions promoting the separation of domestic waste towards the circular economy [43] concluded that social factors influence this process, significantly shaping individuals' actions in waste management practices. Furthermore, he highlighted the need for active and effective public participation in separating and managing municipal solid waste systems (RSGMS). For the author, the interconnection between urban areas highlights the need for strategic and coordinated initiatives to understand, encourage, and develop these environmentally conscious behaviours [43].

In their study to carry out a life cycle analysis on waste-to-energy (WtE) technologies, according to life cycle analysis (LCA) [44], they concluded that the search for better energy recovery and Sustainable waste management practices has led to significant attention on WtE technologies. However, challenges arise from the diverse composition of municipal solid waste (MSW) and the methods involved in syngas purification in pyrolysis/gasification-based WtE systems. The comprehensive procedure involves pre-treatment, thermal conversion, product utilization, and waste management. As a result, improving process efficiency requires advances in plant efficiency [44]

When evaluating the economic and environmental effects of recycling household municipal solid waste (MSW) in the United States, aiming to achieve sustainable development based on causality analyses [45], identified not only a two-way correlation between energy efficiency and greenhouse gas emissions but also the interaction between energy efficiency and economic growth, as well as the link between economic growth and carbon emissions. Their study elucidates a crucial unidirectional relationship: from MSW recycling initiatives to promoting economic growth, reducing carbon emissions, and increasing energy efficiency. This perception implies that any policy intervention that encourages MSW recycling significantly influences environmental quality, particularly in terms of pollution reduction and economic growth [45].

In research carried out by [46] to evaluate the global scale of waste production, analyzing its composition and treatment methods through correlation analysis, the authors concluded that developed countries tend to generate greater amounts of waste consistently. According to the study, if current consumption and disposal practices persist, an increase in waste production is expected in the coming years. It also predicts that this increase will follow an unsustainable pattern, mainly regarding waste disposal in landfills [46]. This perception of the correlation between the economic situation and waste production proposes critical reflections on environmental issues. It requires an urgent reconsideration of waste management strategies on a global scale.

3.3 Advances and Challenges in Waste Management

The studies analyzed reveal a notable surge in waste treatment strategies, emphasizing proper disposal methods like recycling and transformation into raw materials for production. This shift aligns with the principles of the circular economy, aiming to prevent incorrect waste disposal. However, achieving these goals necessitates significant changes and the development of efficient solutions, which have shown promising advancements.

Various technological models have emerged within the realm of waste management and treatment, all centered around the circular economy concept. For instance, processes such as Polyhydroxyalkanoates (PHA) production utilize waste streams as carbon sources, exploring multiple feasible alternatives and applications [40]. Additionally, technologies for managing air pollution control residues (APCr) and fly ashes (FA) generated from municipal solid waste incineration (MSWI) are being refined [41].

In parallel, methodologies for assessing sustainability and performance in waste treatment have evolved, employing tools like Life Cycle Assessment (LCA) [43]. This multifunctional approach measures the environmental impact of products or services across their life cycles, focusing on resource use, production, and final disposal [47]. Thus, LCA is considered an important evaluation tool in production processes, given its ability to evaluate the entire cycle, which allows the impacts to be assessed, especially in the final phase, during disposal.

Advancements toward a circular economy also involve innovative concepts like biorefineries, aiming to convert biomass into high-value products and energy with minimal environmental impact [48]. Additionally, the rise of ecological parks or industrial eco-parks (EIPs) fosters collaborative relationships among industries to promote waste reuse, recycling, and pollution reduction [49]. These processes centered on the concepts of ecological economy and the principles of circular economy are considered innovative in promoting circularity throughout the production process chain.

However, despite these advancements, challenges persist, particularly concerning societal awareness and behavioural changes in waste separation practices. This awareness varies across regions, necessitating strategic actions and policies to understand influential factors and foster greater public awareness of these crucial issues [43].

IV. CONCLUSIONS

In summary, it was identified that the theme has been discussed in different areas that develop research aiming to resolve the waste issue. Various practical and efficient proposals have emerged, targeting substantially reducing improperly disposed waste. The studies scrutinized through systematic review and bibliometric analysis depict the status of waste management and treatment technologies, underscoring the advancements in this field. These developments highlight the theme's relevance, emphasizing the imperative for effectively tackling waste-related problems and their environmental impacts.

In the bibliometric analysis, the articles were analyzed considering publications by country, co-authorship between countries, and co-occurrence of the author's keywords. This analysis showed that China stands out, followed by Italy and the United Kingdom, with the most publications. Co-authorship between countries showed that Italy has the highest number of partnerships with Spain, Chile, Colombia, Czech Republic, Ecuador, Romania, Singapore, and Slovakia. The results show these countries' efforts in recent years to waste management.

The examination of the authors' keywords revealed the primary ones to be "municipal solid waste," "solid waste management" and "circular economy." This outcome highlights the research's emphasis on waste management, encompassing various processes from planning to ultimate disposal, aimed at preventing inappropriate waste disposal and reducing environmental impacts. The study chronology concentrates on the years 2020 and 2021, particularly highlighting waste management within the circular economy framework. This result makes it possible to understand the interconnection of these concepts and the evolution of research focusing on efficient waste management towards the circular economy.

In the Systematic review through the PRISMA model, ten articles were analyzed. The analysis of the ten most cited research, based on some criteria such as authors, areas and proposals of the research, identified technologies, types of residues, final use, and main conclusions of the studies, demonstrated that the issue of municipal solid waste involves different areas. It revealed the utilization of diverse technologies in waste treatment and the progression towards integrated processes involving advanced technologies like Polyhydroxyalkanoates (PHA) production. Additionally, it highlighted recycling or recovery technologies for managing air pollution control residues (APCr) and fly ashes (FA) produced during municipal solid waste incineration (MSWI).

The studies also focused on waste management before, during, and after the COVID-19 pandemic, presenting the management process, impacts, and challenges identified, such as care in managing hospital waste and the responsibility of companies in this process, in addition to also raising awareness among the population regarding the separation and correct disposal of waste because of the severe risks of contamination that these can cause, both to people's health and the environment.

Studies indicate that waste treatment technologies contribute to the correct destination and avoid its improper destination, strongly direct the transition from the linear to the circular economy and overcome the challenges of implementing comprehensive EC policies in a post-COVID-19 era. Therefore, it is hoped that the results of this paper can contribute to new research, expanding the scope of discussions around the issue of solid waste and the need for environmentally correct solutions and more studies to be directed to this theme.

Regarding the limitations of the research, this is due to having its data obtained from a single source (Scopus); however, we understand that this does not invalidate its relevance and contribution to the theme. In respect to future research, it is suggested that other databases be included.

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Declaration of Competing Interest

The authors have no relevant financial or non-financial interests to disclose, and there are no conflicts of interest among the authors.

References

[1]. Yang, M. et al. (2023). “Circular economy strategies for combating climate change and other environmental issues.” Environmental Chemistry Letters (2023) 21:55–80. https://doi.org/10.1007/s10311-022-01499-6

[2]. Díaz-Villavicencio, G.; Didonet, S. R.; Dodd, A. (2017). “Influencing factors of eco-efficient urban waste management: evidence from Spanish municipalities.” Journal of Cleaner Production. http://dx.doi.org/10.1016/j.jclepro.2017.07.064

[3]. Melaré, A. V. S; González, M. S.; Faceli, K.; Casadei, V. (2016) Technologies and decision support systems to aid solid-waste management: a systematic review. Waste Management. http://dx.doi.org/10.1016/j.wasman.2016.10.045

[4]. Silva, V. P. M.; Capanema, L. X. de L. (2019. "Public policies in solid waste management: compared experiences and challenges for Brazil." In: BNDES Set (2011 a 2019), Rio de Janeiro, Sanitation Edition; v. 25, n. 50, p. 153-200.

[5]. Kaza, S. et al. (2018). "What a Waste 2.0: a global snapshot of solid waste: management to 2050." World Bank. Available from: https://openknowledge.worldbank.org/entities/publication/d3f9d45e-115f-559b-b14f-28552410e90a. Accessed 02 Fev 2021.

[6]. Kumar, A.; Agrawal, A. (2020). "Recent trends in solid waste management status, challenges, and potential for the future Indian cities – A review." Current Research in Environmental Sustainability 2; http://dx.doi.org/10.1016/j.crsust.2020.100011.

[7]. "Climate Action Goals and Planning-San Francisco (2021)." Available from: https://sfgov.legistar.com/View.ashx?M=F&ID=9703162&GUID=BC303056-BA32-44E0-B005-78F73B7FA7FF. Accessed 14 June 2023.

[8]. United States Environmental Protection Agency (EPA) (2023). "Zero Waste Case Study: San Francisco." Available from: https://www.epa.gov/transforming-waste-tool/zero-waste-case-study-san-francisco. Accessed 14 June 2023.

[9]. Lee, et al. (2020). "Sustainable waste management for zero waste cities in China: potential, challenges and opportunities." Clean Energy, 2020, Vol. 4, No. 3, 169–201. https://doi.org/10.1093/ce/zkaa013.

[10]. Local Governments for Sustainability (ICLEI). (2021). "Building new partnerships for circular economy in Kawasaki." https://circulars.iclei.org/update/building-new-partnerships-for-circular-economy-in-kawasaki/. Accessed 14 June 2023

[11]. Adami, L. & Schiavon, M. (2021). "From Circular Economy to Circular Ecology: A Review on the Solution of Environmental Problems through Circular Waste Management Approaches." Sustainability 2021, 13, 925. https://doi.org/10.3390/su13020925.

[12]. Campitelli, A. & Schebek, L. (2020). "How is the performance of waste management systems assessed globally? A systematic review." Journal of Cleaner Production 272 (2020) 122986. https://doi.org/10.1016/j.jclepro.2020.122986.

[13]. Vinti, G. et al. (2021). "Municipal Solid Waste Management and Adverse HealthOutcomes: A Systematic Review." Int. J. Environ. Res. Public Health 2021, 18, 4331. https://doi.org/10.3390/ijerph18084331.

[14]. Cano, N. S. de S.L.; Iacovidou, E. & Rutkowski, E. W. (2022). "Typology of municipal solid waste recycling value chains: A global perspective." Journal of Cleaner Production 336 (2022) 130386. https://doi.org/10.1016/j.jclepro.2022.130386.

[15]. Lamé, G. (2019). "Systematic literature reviews: an introduction." International Conference on Engineering Design, Aug 2019, Delft, Netherlands. pp.1633-1642. https://doi.org/10.1017/dsi.2019.169.

[16]. Mizrahi, et al. (2018). "A systematic review of the socioeconomic factors that Influence how marine protected areas Impact on ecosystems and Livelihoods". Society and Natural Resources: https://doi.org/10.1080/08941920.2018.1489568.

[17]. Okoli, C. A. (2015). "Guide to Conducting a Standalone Systematic Literature Review." Communications of the Association for Information Systems, Vol. 37, Article 43. https://doi.org/10.17705/1CAIS.03743.

[18]. Bergstrom, J. C.; Taylor, L. O. (2006). "Using meta-analysis for benefits transfer: Theory and practice." Ecological Economics. 2006, 60 351 – 360. doi: 10.1016/j.ecolecon.2006.06.015.

[19]. Galvão, T. F. & Pansani, T. S. A. (2015). "Key items for reporting systematic reviews and meta-analyses: the PRISMA recommendation." Epidemiologia e Serviços de Saúde, v.24, n 2, p. 335-342. https://dx.doi.org/10.5123/S1679-49742015000200017.

[20]. Soares, L., Ihler, J. & Boloy, R. (2020) "Bibliographic review manual: use of bibliometrics through VOSviewer." GEEMAT – CEFET/RJ, Brazil.

[21]. Verborgh, R.& Wilde, M. D. (2013). "Using OpenRefine." Packt Publishing: Birmingham – Mumbai, UK. Ebook.

[22]. Oliveira, J. O. et al (2019). "Bibliometric Method for Mapping the State-of-the-Art and Identifying Research Gaps and Trends in Literature: An Essential Instrument to Support the Development of Scientific Projects." In book: Scientometrics Recent Advances..DOI: http://dx.doi.org/10.5772/intechopen.85856.

[23]. Statista Research Department (2021). "Volume of municipal solid waste generated per capita in Italy from 2010 to 2019 (in kilograms per inhabitant), 2021". Available from: https://www.statista.com/statistics/682495/per-capita-municipal-solid-waste-generatedinitaly/#:~:text=The%20average%20Italian%20generated%20over,kilograms%20per%20inhabitant%20since%202010. Accessed 15 April 2022.

[24]. Araya, M.N. (2018). "A Review of Effective Waste Management from an EU, National, and Local Perspective and Its Influence: The Management of Biowaste and Anaerobic Digestion of Municipal Solid Waste." Journal of Environmental Protection, 9, 652-670. https://doi.org/10.4236/jep.2018.96041.

[25]. Department for Environment, Food and Rural Affairs (DEFRA) (2021). "Waste Management Plan for England". Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/ attachment_data/file/955897/waste-management-plan-for-england-2021.pdf. Accessed 6 June 2023.

[26]. Kumar, S. et al. (2017). "Challenges and opportunities associated with waste management in India." R. Soc. open sci.4: 160764. http://dx.doi.org/10.1098/rsos.160764.

[27]. Gour, A.A. and S.K. Singh, S.K. (2023). "Solid Waste Management in India: A State-of-the-Art Review." Environ. Eng. Res. 2023; 28(4): 220249. DOI: https://doi.org/10.4491/eer.2022.249.

[28]. European Commission. (2022). "Spain-Report 2022-". Available from: https://commission.europa.eu/system/files/2022-05/2022-european-semester-country-report-spain_en.pdf. Accessed 13 Dez 2023.

[29]. Ministry for Ecological Transition and Demographic Challenge (MITECO). (2021). "I Circular Economy Action Plan-2021-2023- Spanish Circular Economy Strategy". Available from: https://www.miteco.gob.es/content/dam/miteco/es/calidad-y-evaluacion-ambiental/publicaciones /planaccion economia_circular2021_2023_tcm30-534717.pdf. Accessed 13 Dez 2023.

[30]. Poniatowska, A. Kisiel, M. & Panasiuk, D. (2021). "Municipal Waste Management in Poland Compared to Other European Union Countries." Studia Ecologiae Et Bioethicae, 19(4), 85–95. https://doi.org/10.21697/seb.2021.19.4.07.

[31]. United States Environmental Protection Agency (EPA) (2020) "National Overview: facts and figures on materials, wastes and recycling." Available from: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/nationaloverviewfactsandfiguresmaterials#:~:text=Of%20the% 20MSW%20generated%2C%20approximately,were%20managed%20by%20other%20methods. Accessed 20 Fev 2021.

[32]. Weghmann, V. (2023). "Waste Management in Europe. Europen Public Service Union." Available from: https://www.epsu.org/sites/default/files/article/files/Waste%20Management%20in%20 Europe _EN_1.pdf. Accessed 06 June 2023.

[33]. Brazil. Ministry of the Environment (2021). "600 dumps deactivated less than a year after sanction of the Sanitation Framework." Available from: https://www.gov.br/mma/pt-br/assuntos/noticias/600-lixoes-desativados-menos-de-um-ano-apos-sancao-do-marco-do-saneamento. Accessed 16 May 2021.

[34]. Abrelpe. "Solid Waste in Brazil Panorama (2022)". Available from: https://abrelpe.org.br/download-panorama-2022/. Accessed: 01 June 2023.

[35]. Ng, K.S., Yeoh, L., Iacovidou, E., Wan Ab Karim Ghani, W.A. & Yamaguchi, A. (2023). "Towards Sustainable Municipal Solid Waste Management in Malaysia." University of Oxford and Brunel University London. Funded by the UK Natural Environment Research Council (NE/R012938/1). Available from: https://eng.ox.ac.uk/media/12832/towards-sustainable-municipal-solid-waste-management-in-malaysia.pdf. Accessed 06 June 2023.

[36]. Tang, Y. Y., Tang, K. H. D., Maharjan, A. K., Abdul Aziz, A., & Bunrith, S. (2021). "Malaysia Moving Towards a Sustainability Municipal Waste Management." Industrial and Domestic WasteManagement,1(1),26-40. https://doi.org/10.53623/idwm.v1i1.51.

[37]. Lebreton, L. & Andrady, A. (2019). "Future scenarios of global plastic waste Generation and disposal." Palgrave Communications, 5:6 https://doi.org/10.1057/s41599-018-0212-7.

[38]. Abdel-Shafy, H.I. & Mansour, S.M.M. (2018). "Solid waste issue: Sources, composition, disposal, recycling, and valorization." Egyptian Journal of Petroleum 27 (2018) 1275–1290. https://doi.org/10.1016/j.ejpe.2018.07.003.

[39]. Lau, W.W.Y., et al. (2020). "Evaluating scenarios toward zero plastic pollution." Science 2020 Sep 18;369 (6510):1455-1461. https://doi.org/10.1126/science.aba9475.

[40]. Santiago Rodriguez-Perez, S.; Serrano, A.; Pantion, A. & Alonso-Fariñas, B. (2018). "Challenges of scaling-up PHA production from waste streams. A review." Journal of Environmental Management 205 (2018) 215e230. https://doi.org/10.1016/j.jenvman.2017.09.083.

[41]. Quina, M.J. (2018). "Technologies for the management of MSW incineration ashes from gas cleaning: New perspectives on recovery of secondary raw materials and circular economy." Science of the Total Environment 635 (2018) 526–542. https://doi.org/10.1016/j.scitotenv.2018.04.150.

[42]. Kulkarni, B. N. & Anantharama, V. (2020). "Repercussions of COVID-19 pandemic on municipal solid waste management: Challenges and opportunities." Science of the Total Environment 743 (2020) 140693. https://doi.org/10.1016/j.scitotenv.2020.140693.

[43]. Knickmeyer, D. (2020). "Social factors influencing household waste separation: A literature review on good practices to improve the recycling performance of urban areas." Journal of Cleaner Production 245 (2020) 118605. https://doi.org/10.1016/j.jclepro.2019.118605.

[44]. Dong, J. et al. (2018). "Life cycle assessment of pyrolysis, gasification and incineration waste-to-energy technologies: Theoretical analysis and case study of commercial plants." Science of the Total Environment 626 (2018) 744–753. https://doi.org/10.1016/j.scitotenv.2018.01.151.

[45]. Razzaq, A.A.; Sharif, A.; Najmi, A.; Tseng, ML.; Ming K. & Lim, M.K. (2021). "Dynamic and causality interrelationships from municipal solid waste recycling to economic growth, carbon emissions and energy efficiency using a novel bootstrapping autoregressive distributed lag." Resources, Conservation & Recycling 166 (2021) 105372. https://doi.org/10.1016/j.resconrec.2020.105372.

[46]. Chen, D.MC et al. (2020). "The world's growing municipal solid waste: trends and impacts." Environmental Research Letters 15 (2020) 074021. https://doi.org/10.1088/1748-9326/ab8659.

[47]. Moretti, C. et al. (2020). "Reviewing ISO Compliant Multifunctionality Practices in Environmental Life Cycle Modeling". Energies, 2020; 13, 3579; https://doi.org/10.3390/en13143579.

[48]. Demichelis, F., Piovano, F., & Fiore, S. (2019). "Biowaste Management in Italy: Challenges and Perspectives". Sustainability 2019, 11, 4213. https://doi.org/10.3390/su11154213.

[49]. Abu-Qdais, H.A. & Kurbatova, A. I. (2022). "The Role of Eco-Industrial Parks in Promoting Circular Economy in Russia: A Life Cycle Approach". Sustainability 2022, 14, 3893. https://doi.org/10.3390/su14073893.

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