Chandani, G.G.N. and Karunarathna, A.S.W., 2025. Urban symbiosis in municipal solid waste management and reduction: Insights from a bibliometric review. In: Waidyasekara, K.G.A.S., Jayasena, H.S., Wimalaratne, P.L.I. and Tennakoon, G.A. (eds). *Proceedings of the 13th World Construction Symposium*, 15-16 August 2025, Sri Lanka. pp. 1431-1444. DOI: https://doi.org/10.31705/WCS.2025.107. Available from: https://ciobwcs.com/papers/

URBAN SYMBIOSIS IN MUNICIPAL SOLID WASTE MANAGEMENT AND REDUCTION: INSIGHTS FROM A BIBLIOMETRIC REVIEW

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ABSTRACT

Municipal solid waste (MSW) output has escalated to critical levels due to the fast expansion of urban populations and industrial activity. This poses serious risks to environmental sustainability due to resource inefficiencies, greenhouse gas emissions, and increased landfilling. By encouraging interorganisational cooperation and resource sharing among urban systems to improve waste reduction and material recovery, urban symbiosis presents a viable remedy. The purpose of this study is to investigate how urban symbiosis might enhance MSW management through a thorough bibliometric analysis. The study analyses patterns of international collaboration, evaluates the topic's development, and identifies the most significant sources and authors. 50 journal articles published between 2015 and 2025 were analysed using a bibliometric approach. Systematic keyword searches were used to retrieve relevant articles from Scopus. To find research hotspots, top journals, top authors, and country-by-country contributions, a manual content analysis was used. Collaboration networks and keyword co-occurrence maps were created using VOS viewer software. While the concept of urban symbiosis has been increasingly applied in the context of industrial ecology and circular economy, existing literature remains fragmented with limited cross-sectoral integration. Most studies focus on isolated case applications without exploring broader synergies or long-term sustainability outcomes. This study presents a consolidated body of knowledge that documents the historical and thematic development of urban symbiosis in MSW management. The findings serve as a valuable resource for researchers, urban planners, and policymakers seeking to advance resilient and resource efficient urban waste systems.

Keywords: *Municipal Solid Waste (MSW); Municipal Solid Waste Management (MSWM); Urban Symbiosis.*

1. INTRODUCTION

The global generation of MSW has increased dramatically because of the rapid urbanization of the world and changing patterns of consumption (Saja et al., 2021). Cities are particularly under pressure to contain waste sustainably given the limited space available, the density of the population, and the need to mitigate negative impacts on the environment. The management of waste continues to follow decades old practices such

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as landfilling and incineration which pose serious risks to the environment and to health (Kaza et al., 2018). Incinerating waste releases gas and contributes to air pollution along with creating greenhouse gases, while landfills lead to the decaying of land, groundwater contamination, and methane emissions. These methods also incur high operational costs that cities do not have in reserve, posing extensive financial hurdles (Blair & Mataraarachchi, 2021).

In many developing counties, a large part of municipal waste is uncollected and dumped inappropriately leading to steadily increasing urban pollution and worsening public health (Agamuthu & Babel, 2023). Developing countries are not the only ones facing challenges of growing per capita waste generation, intricate waste streams, and inadequate recycling systems; high earning countries also face similar challenges. Without appropriate long-term resolutions in place, systems that work in silos remain ineffective (Awino & Apitz, 2024). The lack of integrated, circular strategies that address waste generation, reduction, and recovery as part of a larger urban system is a crucial gap in practice and research that is highlighted by this disjointed approach (Kotyal, 2023). Considering growing environmental pressures and urban resource constraints, it is becoming increasingly apparent that traditional linear waste management models are no longer practical (Kotyal, 2023).

Considering this, urban symbiosis presents a viable and comprehensive substitute. Urban symbiosis, which has its roots in industrial symbiosis, promotes cooperation between communities, businesses, and governments to exchange materials, energy, and byproducts in ways that maximize resource efficiency and minimize waste (Nugroho et al., 2025). Cities can shift from disposing of waste to circulating resources thanks to these synergies, which decreases their reliance on landfills while producing benefits for the economy and environment (Edmond et al., 2025). By encouraging innovation, strengthening urban resilience, and promoting circular economy practices, urban symbiosis supports global sustainability goals. Its use in municipal solid waste management is still restricted and poorly understood, though (Wilson et al., 2012). The infrastructure, institutional coordination, and policy frameworks necessary to execute such integrated approaches are still lacking in many cities (Nugroho et al., 2025). This emphasises how important it is to comprehend urban symbiosis as a method for managing and reducing MSW. To solve today's waste issues and create more sustainable, effective, and connected cities, it is imperative to investigate how it can be more effectively integrated into urban systems (Edmond et al., 2025). Therefore, the main objective of this study is to analyse international research trends, key contributors, collaboration networks, and thematic developments related to urban symbiosis in the context of MSW management, to identify research gaps and inform future strategies for resilient and resource efficient urban waste systems.

2. LITERATURE REVIEW

2.1 URBAN SYMBIOSIS

Urban symbiosis is a cooperative interaction between diverse urban actors (such as homes, businesses, and institutions) that involves the exchange of resources and services for the mutual advantage of both parties to maximize resource efficiency, water efficiency, and sustainability (Yatawatta, 2023). The concept was equivalent to the concept of Industrial Symbiosis. "Industrial symbiosis engages traditionally separate

industries in a collaborative approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products" (Mulder, 2016). As an extension of urban symbiosis, studies synergies between urban and industrial areas by turning municipal solid waste into industrial space and employing industries to supply living resources, such as waste heat and hot water (Sun et al., 2017).

2.2 THE CONCEPT OF URBAN SYMBIOSIS FOR MUNICIPAL SOLID WASTE REDUCTION AND MANAGEMENT

Municipal solid waste (MSW) is waste collected by local municipalities. The main part of MS comes from households, but waste from commerce and trade, offices and institutions are also included in municipal solid waste (Cvetković et al., 2014). Its main components include kitchen waste, wastepaper, waste plastic, waste fabric, scrap metal, scrap glass, and scrap furniture (Zhao, 2021). The increasing amount of MSW brought on by population expansion, urbanization, and shifts in consumer behaviour is posing a significant threat to urban areas worldwide. The take-make-dispose paradigm of traditional linear waste management systems is becoming less and less sustainable (Kellner, 2021). One potential remedy is the idea of urban symbiosis. Reimagining cities as interconnected ecosystems where waste, energy, materials, and resources continuously flow among stakeholders including municipalities, industries, homes, and service providers is the foundation of urban symbiosis, which has its roots in industrial ecology and circular economy ideas (Momirski et al., 2021).

Urban symbiosis transforms waste into valuable inputs for other sectors. Compost and biogas can be produced from organic waste from food markets for local businesses or urban farming. In a similar vein, construction and demolition waste can be recycled for infrastructure projects, which lessens the need for virgin materials and landfills (Kaza et al., 2018). Working together and pooling resources is essential to developing effective, closed-loop systems (Momirski et al., 2021). Urban symbiosis for municipal solid waste management (MSWM) emphasises integrated approaches that coordinate collection of waste, recycling, and treatment. Waste streams are more efficient when residential regions are connected to adjacent commercial or industrial zones (Fraccascia, 2018). Recycling hubs that serve a variety of stakeholders can reduce processing and transportation costs while increasing material recovery. Composting and anaerobic digestion systems are examples of waste-to-resource networks that can transform biodegradable trash into fertilisers or renewable energy, boosting regional economies and sustainability (Oberoi, 2020).

Strategic facility co-location strengthens urban symbiosis. Locating waste treatment plants near manufacturing hubs or residential areas enables efficient energy recovery and material reuse. Waste-to-energy plants can supply electricity and heat to nearby users, while material recovery facilities provide recycled inputs for manufacturers, creating economic and environmental benefits (Fraccascia, 2018). Technology plays a critical role in urban symbiosis, with smart waste management systems and digital platforms ensuring real-time monitoring, transparency, and efficient resource matching. Collaboration among municipalities, private enterprises, and communities is essential to developing supportive infrastructure and governance mechanisms (Kellner, 2021). By integrating waste as a resource into regenerative urban systems, urban symbiosis offers a transformative approach to municipal waste management, fostering sustainable and circular cities for the future (Mulder, 2016).

3. RESEARCH METHODOLOGY

This study applied a bibliometric analysis approach to explore the relationship between urban symbiosis and municipal waste reduction and management. Bibliometric analysis offers a quantitative method for examining research trends, key contributors, and emerging themes within a specific field, enabling a structured understanding of scholarly development over time. To gather relevant literature, the Scopus database was selected due to its broad indexing of peer-reviewed journals across scientific disciplines. The search was conducted using the combined keywords "municipal waste reduction," "urban symbiosis," and "waste management", with the following query: TITLE-ABS-KEY (“municipal waste" OR "municipal solid waste" OR "municipal solid waste management" OR "municipal solid waste reduction" AND "urban symbiosis”).

The timeframe for this search spanned from 2015 to 2025, ensuring coverage of a complete decade of academic research on the topic. The initial search returned 81 records, which were then screened for relevance. Articles were filtered by publication year and refined to include only journal articles, reducing the number to 54. A final language filter was applied to retain only publications in English, resulting in a dataset of 50 articles that served as the basis for the analysis. The selected articles were analysed using two primary bibliometric indicators. First, keyword co-occurrence was examined to uncover dominant themes and conceptual interconnections across the dataset. Second, publication distribution was evaluated to track changes in research output over time, as well as to identify the most active journals, prolific authors, and leading countries contributing to the field. These indicators provided a comprehensive view of how scholarly attention to urban symbiosis in the context of municipal waste management has developed over the years.

4. RESULT AND DISCUSSION

The paper's main study findings are presented in this section on two main areas: (i) outcomes of bibliometric analysis, and (ii) industrial symbiosis for municipal solid waste reduction and management. The bibliometric analysis identified the most influential publications, authors and south Asian countries in the field of industrial symbiosis, highlighting the growing interest in this area of research.

4.1 OUTCOME OF BIBLIOMETRIC ANALYSIS

The primary stage in gathering information about the involvement of urban symbiosis in municipal solid waste reduction and management was a systematic study based on Scopus. Bibliometric analysis was performed on the data acquired between 2015 and 2025. The outcomes were categorized into four main headings: (i) evolution of the number of journal articles published, (ii) leading journals that published articles related to industrial symbiosis and municipal solid waste reduction and management (iii) analysis of the leading authors in this field, and (iv) analysis of leading south Asian countries of journals that published articles on the topic. This analysis offers insightful information about the patterns and trends in this field of study, emphasizing the increasing interest in the concept of industrial symbiosis to reduce and manage municipal solid waste.

4.2 GROWTH OF JOURNAL PUBLICATIONS ON URBAN SYMBIOSIS FOR MUNICIPAL SOLID WASTE REDUCTION AND MANAGEMENT

A total of 50 papers published between 2015 and 2025 were examined in this review, which concentrated on the involvement of urban symbiosis in municipal solid waste management and reduction. Figure 1 shows the evolution of the number of journal articles published on this topic in the Scopus database. According to the database, there were just 01 articles published in 2015; and by 2016 it has been increased to 4 articles. This early growth may reflect the emergence of global interest in sustainable urban planning and resource efficiency following the 2015 Paris Agreement and the adoption of the UN Sustainable Development Goals (SDGs) (United Nations, 2015). According to the analysis there were no any articles in 2017. however, the number of publications peaked in 2018 with total 9 articles as illustrate in the figure. This spike likely reflects increased global discourse on circular economy principles, along with a growing push for sustainable urban development policies in both developed and developing countries (Geissdoerfer et al., 2017). In 2019 and 2020 there were 3 and 4 articles published, respectively. grew to 6 sources in 2021 before being lowered to 3 articles in 2022. The marginal output during these years may be linked to broader research disruptions and shifting priorities due to the COVID-19 pandemic, which affected many research activities worldwide (Miki et al., 2020). But the following years showed a strong recovery, with 7 publications each in both 2023 and 2024. In 2025, the output slightly decreased to six. Overall, the data reveals a pattern of fluctuating research productivity with a general upward trend in publications on urban symbiosis in municipal solid waste reduction and management from 2015 to 2025, highlighting renewed consistency and growth in publication output. This resurgence could be driven by increasing policy mandates for sustainable cities, greater public awareness of climate resilience, and advances in digital tools for symbiotic urban design. Overall, the data reflects a fluctuating but generally upward trajectory in research activity. The trend highlights increasing academic and practical interest in the role of urban symbiosis for MSW reduction, especially considering global sustainability challenges and policy shifts over the past decade.

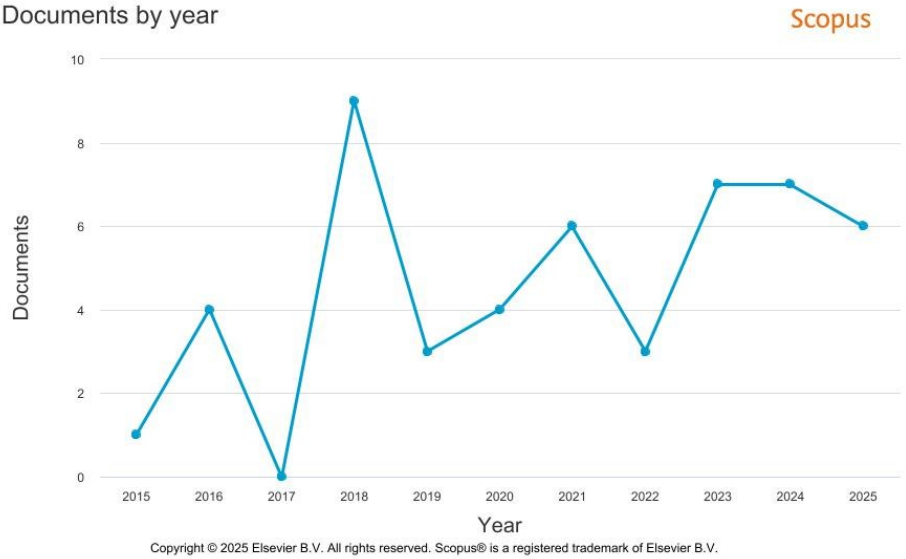

Figure 1: Publication distribution through 2015-2025
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4.3 LEADING JOURNALS PUBLISHED URBAN SYMBIOSIS IN MUNICIPAL SOLID WASTE REDUCTION AND MANAGEMENT

Nowadays, concept of urban symbiosis is considered a novel idea, with only a limited number of journals dedicated to publishing research on the topic. The top journals that published papers on urban symbiosis in municipal solid waste management and reduction between 2015 and 2025 are shown in Figure 2. The data shows that over the period, the Journal of Cleaner Production published the most papers (nine) on this subject. Resources, Conservation and Recycling, Sustainability (Switzerland), Environmental Science and Pollution Research, Science of the Total Environment, Waste Management are some more prestigious journals that have published a significant number of articles.

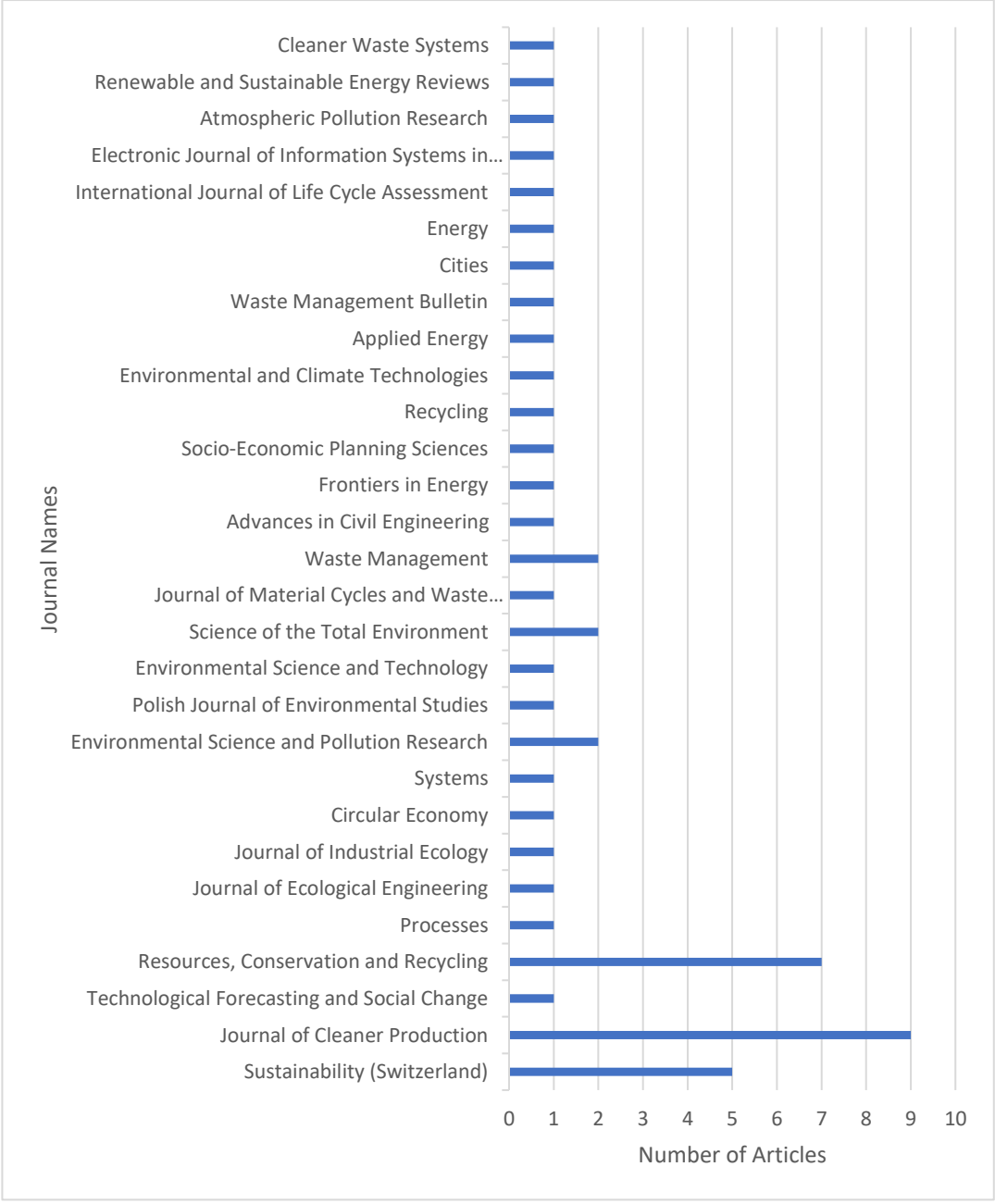

Figure 2: Leading journals that published most articles
Source: Produced by authors from data retrieved from Scopus®

This dominance of journals such as the Journal of Cleaner Production and Resources, Conservation and Recycling reflects the interdisciplinary nature of urban symbiosis, which intersects sustainability science, environmental engineering, and industrial ecology. These journals have a strong emphasis on life cycle thinking, circular economy models, and integrated approaches to environmental management which align closely with the principles of urban symbiosis (Geissdoerfer et al., 2017).

Furthermore, the prominence of these journals suggests that the academic community increasingly recognizes the role of urban symbiosis in addressing complex urban waste challenges. High-impact journals in environmental science and waste management, such as Science of the Total Environment and Waste Management, have published studies that frame urban symbiosis as a scalable, systems-based solution for sustainable city infrastructure (Dong et al., 2016).

The fact that relatively few journals contribute to this research body also indicates that urban symbiosis is still an emerging subfield. Its presence in established journals hints at growing legitimacy and relevance, potentially forecasting wider adoption in policy, planning, and urban innovation discourse in the coming years.

4.4 LEADING AUTHORS IN CONCEPT

The prominent authors who have aided in urban symbiosis in municipal solid waste management and reduction are showcased in Figure 3. According to a Scopus data study, Fujii M published the most publications (seven) and author Geng Y published six papers on this topic between 2015 and 2025. Both authors Dong H and Fujita T published five articles. Ohnishi, S. and Sun, L. have each contributed 4 publications, reflecting a consistent output in the field. Dong, L. follows with approximately 3 articles, while Li, Z., De Clercq, D., and Liu, J. each have published two articles in Scopus and have all made noteworthy contributions.

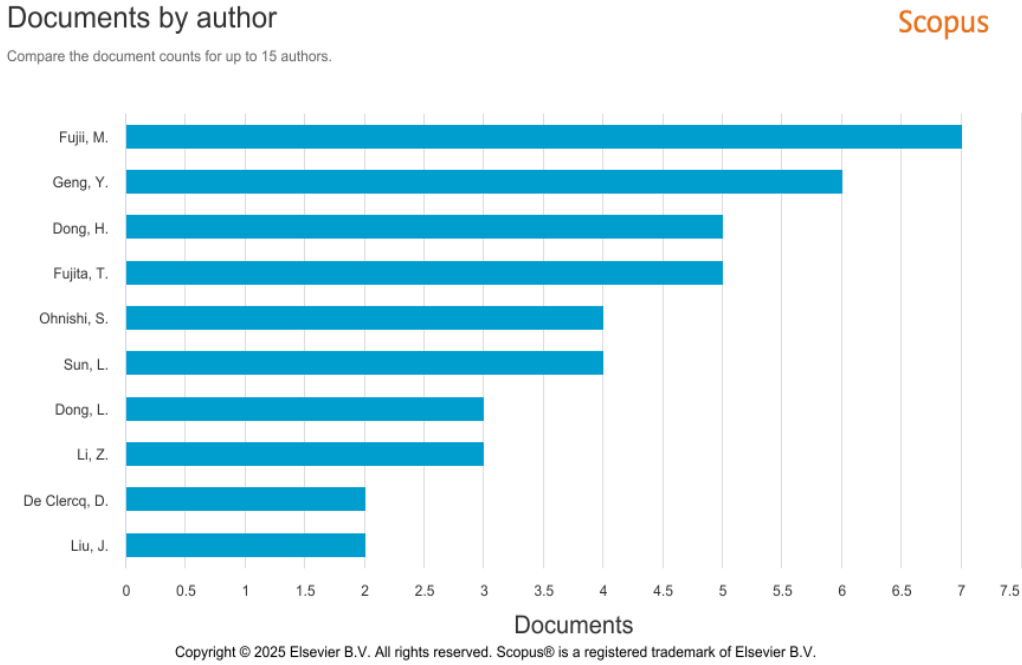

Figure 3: Leading authors in the field
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4.5 PUBLICATIONS BY COUNTRY OR TERRITORY

The uppermost journal countries that have contributed the most articles regarding urban symbiosis in municipal solid waste management and reduction during the span of years from 2015 to 2025 are represented in Figure 4. Figure 4 displays the situation that China and Japan published the most articles regarding the combination of urban symbiosis, municipal solid waste management and reduction among the countries which published from 2015 to 2025. The Italy and United State America came in third place as country that produced a journal on urban symbiosis in municipal solid waste management. Along with the Czech Republic, Pakistan, Poland, Slovenia, South Africa and United Kingdom are the other significant countries that takes journal articles on urban symbiosis and municipal solid waste management as the major topic.

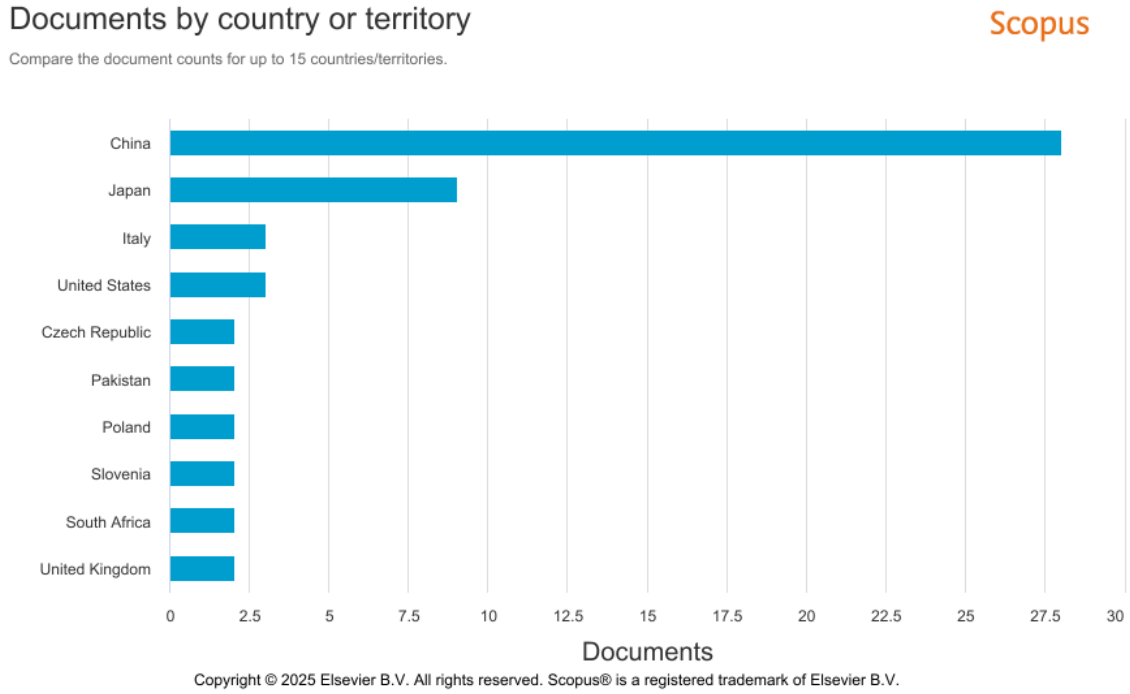

Figure 4: Documents by countries
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4.6 MAPPING OF THE KEY WORDS OCCURRENCE IN RESEARCH

A total of 29 keywords were retrieved from the 50 articles using VOSviewer software. The selection of these keywords was based on their occurrence in a minimum of four publications. The frequency of a keyword in a document reflects its overall scope, while cooccurrence highlights how often two keywords appear together in a title, abstract, or keyword list. The findings of this study depict Figure 5. The illustration shows the frequency of co-occurring terms in the publications through the size of nodes. The thickness of the linking lines represents the strength of relationships. The proximity of nodes in the figure shows a strong linkage between them. According to the visual network map, these keywords may be categorised into four clusters.

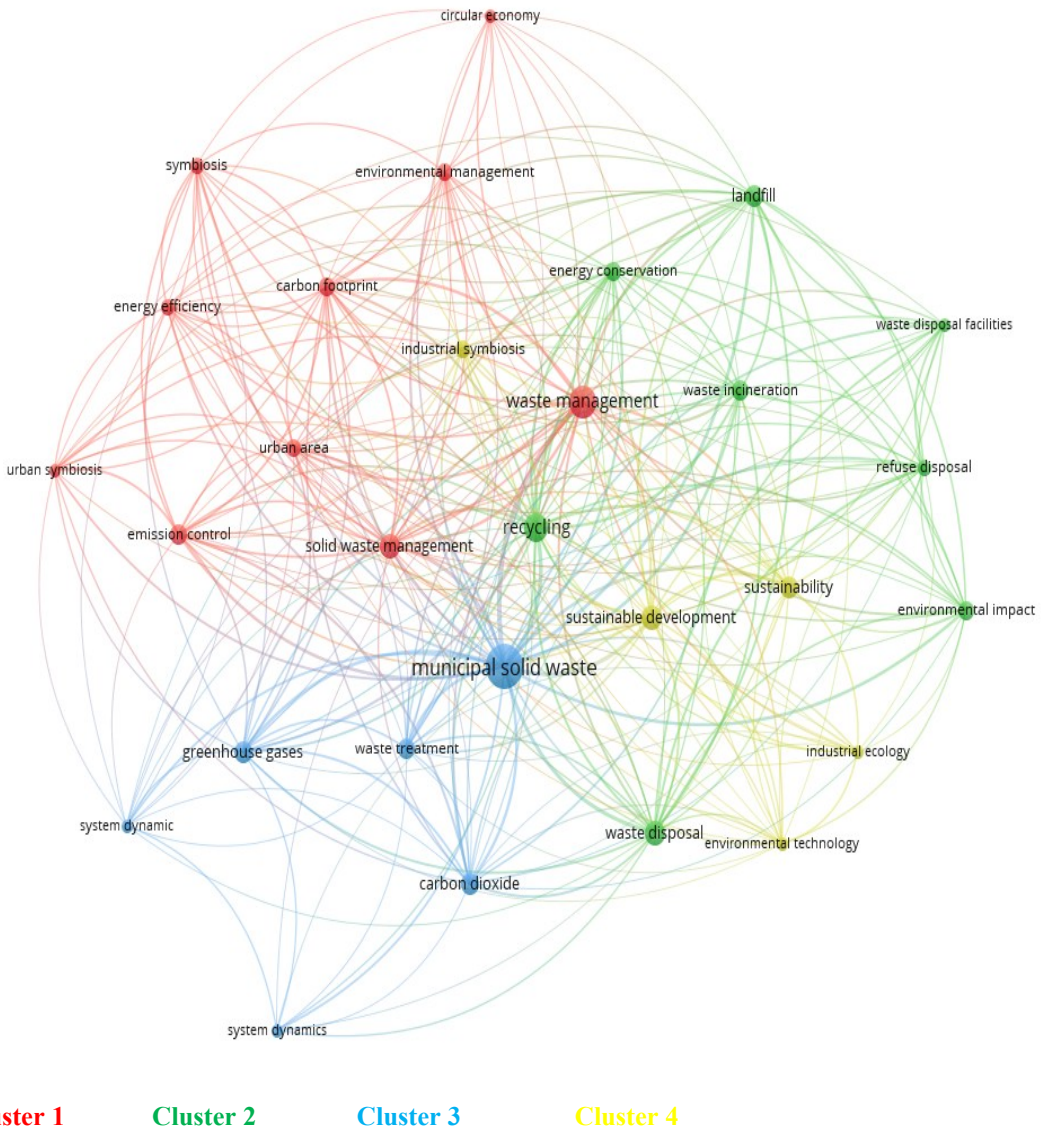

Figure 5: Key words occurrence analysis

According to Figure 5, The co-occurrence network diagram reveals four distinct thematic clusters within the field of waste management and sustainability, each represented by different colours. The cluster 1 (red) emphasizes systems thinking and resource optimization, highlighting concepts such as circular economy, symbiosis (both urban and industrial), energy efficiency, and emission control. These terms reflect a strategic approach to minimizing environmental impact through integrated environmental management. The cluster 2 (green) canters around traditional waste disposal methods, including landfill, incineration, and refuse facilities. This group of terms captures the infrastructure focused, end-of-pipe solutions that are still widely employed in many waste management systems today. The cluster 3 (blue) shifts focus toward the scientific and quantitative assessment of waste related impacts, featuring terms like municipal solid waste, greenhouse gases, carbon dioxide, and system dynamics. This cluster underscores

the importance of modelling and analysing emissions and environmental consequences associated with waste. Finally, the cluster 4 (yellow) aligns closely with the broader goals of sustainability, incorporating terms such as sustainable development, industrial ecology, environmental technology, and environmental impact. This cluster reflects a holistic and interdisciplinary approach aimed at embedding sustainability principles within waste management strategies. Collectively, these clusters illustrate the multidimensional nature of municipal solid waste management research, encompassing technical, environmental, economic, and systemic perspectives.

4.7 ADOPTING URBAN SYMBIOSIS FOR MUNICIPAL SOLID WASTE REDUCTION AND MANAGEMENT

The concept of urban symbiosis is central to the study, where the interactions between urban waste management and industrial processes can lead optimize waste management and resources to reduced environmental impacts and enhanced resource efficiency between various sectors. Examples of successful urban symbiosis include using waste heat from industrial processes for district heating and repurposing solid waste as fuel in energy intensive industries (Tröger et al., 2023).

Recent journal articles suggest that adopting the concept of urban symbiosis can be an effective approach to manage and reduce municipal solid waste in urban areas. To enhance urban symbiosis, several strategic approaches can be implemented. As example, prioritizing the recycling of materials such as slag, fly ash, and scrap steel is crucial for maximizing resource savings and reducing CO2 emissions (Lu et al., 2020). This approach should be complemented by fostering integration between urban waste management and industrial resource needs, allowing for efficient exchanges of by products and waste (Kuznetsova et al., 2019). Furthermore, a recent review by Dong et al. (2016) highlighted the potential of urban symbiosis for municipal solid waste management in China. According to the study, to promote resource efficiency and reduce waste outputs, a symbiosis network designed that connects multiple industries and urban areas to facilitate the exchange of materials and waste. Moreover, identifying and implementing waste reuse initiatives coupled with establishing energy recovery systems to harness waste energy from industrial processes, will significantly reduce reliance on fossil fuels while enhancing overall energy efficiency (Taouahria, 2024).

Urban symbiosis presents numerous benefits in the realm of waste management, fundamentally transforming how waste is perceived and utilized. One of the primary advantages is the reduction of greenhouse gas emissions, as utilizing municipal solid waste as a resource can significantly lower emissions by converting waste into energy or valuable products, thus decreasing reliance on landfills and fossil fuels(Dong et al., 2016). Additionally, urban symbiosis promotes efficient resource use by allowing waste from one process to serve as raw material for another, optimizing material consumption and minimizing waste generation (Sun et al., 2020). utilize both fossil and recycled resources, allows for better optimization of existing industrial facilities (Smith et al., 2015). This not only helps in reducing waste but also in maximizing the efficiency of resource use, leading to a more sustainable industrial ecosystem (Sun et al., 2020). The financial implications of converting waste into energy or products, enhancing economic viability and creating new business opportunities through synergies between different waste-to-energy or waste-to-product systems (Fei et al., 2021). Urban symbiosis can be tailored to fit the specific socioeconomic conditions of different cities. cities with varying waste

management practices and economic situations, allowing for localized strategies that can effectively address waste management challenges (Fujii et al., 2016). By integrating waste management into industrial processes, urban symbiosis contributes to the development of sustainable practices that align with global efforts to reduce carbon emissions and promote low-carbon industries (Fei et al., 2021). Lastly, effective waste management through urban symbiosis can lead to improved public health outcomes by reducing risks associated with waste accumulation and enhancing sanitation efforts in urban areas (Berg et al., 2018). Overall, urban symbiosis offers a comprehensive approach to waste management that addresses environmental concerns while promoting economic growth and community well-being (Dong et al., 2016).

Implementing urban symbiosis faces several significant barriers. One major challenge is the insufficient infrastructure in many cities, particularly in Africa, where inadequate public service management and failing systems limit the effectiveness of urban symbiosis initiatives(Tsai et al., 2020). Additionally, the high costs associated with advanced waste treatment technologies pose a financial barrier, especially in developing regions, preventing the adoption of necessary systems for resource recovery (Chin et al., 2023). The excessive generation of waste further complicates matters, as existing MSWM infrastructure often struggles to manage increasing volumes, leading to environmental issues like plastic waste leakage. Moreover, the lack of holistic approaches to monitoring and managing MSWM on a global scale makes it difficult to establish effective urban symbiosis frameworks that require coordinated efforts across various sectors (Appio et al., 2019). There is also a limited body of research and knowledge on MSWM in a circular economy, which hinders the identification of best practices and indicators essential for successful implementation. The complexity of integrating various types of materials and operations poses a challenge. Urban symbiosis requires the seamless integration of different flows, including materials and energy, which can be difficult to achieve(Sun et al., 2018). Finally, regional disparities in research output, with areas like Africa and North America having fewer studies compared to Europe and Asia, create additional barriers to effectively implementing urban symbiosis in less-studied regions (Tsai et al., 2020). These challenges underscore the complexities involved in fostering urban symbiosis and highlight the need for targeted strategies to overcome them.

5. CONCLUSIONS

In recent years, there has been a growing interest in the concept of urban symbiosis for municipal sloid waste management and reduction. The results of this bibliometric analysis show a significant increase in publications that address this intersection, especially between 2017 and 2025. This indicates that there is an increasing need to find long-term solutions to reduce the negative environmental effects of urbanization and infrastructure. Prominent journals have become important venues for sharing research on this subject, suggesting that the academic community is working together to increase knowledge and comprehension in this area. Furthermore, nations like China, Japan, and Italy have contributed significantly to the body of knowledge on the concept urban symbiosis for MSWM. The concept of urban symbiosis offers significant potential to enhance waste reduction, resource recovery, and circularity in urban systems by promoting inter industry collaboration and material exchange. By optimizing flows of energy, materials, and information across sectors, urban symbiosis supports more resilient, efficient, and sustainable urban environments. However, challenges persist in

achieving widespread implementation, including regulatory barriers, lack of infrastructure, high cost of waste treatment technologies, and the need for stronger cross-sectoral coordination. Overcoming these challenges will require interdisciplinary collaboration, supportive policy mechanisms, and targeted investment in scalable symbiotic solutions. In conclusion, urban symbiosis holds substantial promise in reshaping municipal solid waste management practices. Continued innovation, stakeholder engagement, and policy alignment are essential to fully realize its transformative potential in building sustainable cities for the future.

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