https://doi.org/10.64211/oidaijsd190807

Enhancing Municipal Solid Waste Sustainable Management Through the Concept of Urban Symbiosis: A Literature Review

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OIDA International Journal of Sustainable Development, Ontario International Development Agency, Canada.
ISSN 1923-6654 (print) ISSN 1923-6662 (online) www.oidaijsd.com
Also available at https://www.ssrn.com/index.cfm/en/oida-intl-journal-sustainable-dev/

Abstract: This study investigates how the concept of urban symbiosis can enhance Municipal Solid Waste (MSW) reduction and promote more sustainable waste management practices in urban environments. With growing urbanization and resource inefficiency, urban symbiosis offers an integrated approach by encouraging collaboration, waste-to-resource conversion, and circularity among urban stakeholders. The aim of this study is to understand the evolution, application, and potential of urban symbiosis in addressing MSW challenges. Adopting a systematic literature review (SLR) methodology and guided by the PRISMA framework, this study examines 69 peer-reviewed journal articles published between 2015 and 2025 across databases Scopus, Web of Science, and ScienceDirect. The analysis combines thematic review and bibliometric mapping using VOSviewer to identify publication trends, geographical distribution, and key research clusters. Findings reveal a growing but still limited body of research, with dominant approaches including eco-industrial parks, community-based resource sharing, and infrastructure redesign. Despite the promise, the adoption of urban symbiosis faces barriers such as policy constraints, lack of awareness, and coordination challenges. The study also highlights the contribution of urban symbiosis to several Sustainable Development Goals (SDGs), particularly in areas of responsible consumption and sustainable cities. By identifying research gaps and outlining practical strategies, this study emphasizes the importance of integrated planning and policy support to scale urban symbiosis practices. From a practical perspective, it offers valuable insights for policymakers, urban planners, and environmental managers aiming to build more sustainable and circular cities.

Keywords: Urban Symbiosis; Municipal Solid Waste (MSW); Sustainable Waste Management; Sustainable Development Goals (SDGs)

Introduction

The amount of MSW generation has increased dramatically due to the world's rapid urbanization and changing consumption patterns (Saja et al., 2021a). Cities in all round the world are under pressure to manage waste sustainability due to the population density, limited space available and need to mitigate negative impact on the environment(Kaza et al., 2019). Still in many countries waste management relies on the traditional practices such as landfilling and incineration which cause many drawbacks such as health and environment risk, as landfill cause groundwater contamination, land degradation and methane emission(Kaza et al., 2019). These outdated waste management practices have also resulted in high operational costs for cities lacking sufficient financial reserves, thereby imposing significant economic burdens(Blair & Mataraarachchi, 2021). Developing countries are not the only ones facing these challenges, but also high-income countries also face similar challenges of growing per capita waste generation, complex waste stream and inadequate recycling systems (Agamuthu & Babel, 2023a). Without appropriate long-term solutions in place waste management systems will remain ineffectively (Awino & Apitz, 2024). Those improper approaches highlight a critical gap in practice, the absence of integrated, circular methods that address waste generation, reduction and recovery as a part of a lager urban system (Kotyal, 2023).it is becoming clear that conventional linear MSW management strategies are no longer viable in response to growing environmental demands and urban resource restrictions (Kotyal, 2023).

In this background, urban symbiosis presents a comprehensive and viable strategy for addressing the challenges of MSW management. Rooted in the principles of industrial symbiosis, urban symbiosis encourages collaboration among corporations, governments and communities to exchange materials, energy and by products in ways that optimise resource efficiency and reduce waste (Nugroho et al., 2025). These strategies allow cities to transform disposing waste to circulating resources and it reduces dependency on landfills and providing positive economic and environmental outcomes (Edmond et al., 2025). Urban symbiosis offers global sustainability goals by engaging innovation, enhancing urban resilience, and advancing circular economy practices. However, its application in the management of MSW is still limited and poorly address area (Wilson et al., 2012). Many cities currently lack the institutional coordination, regulatory frameworks, and infrastructure needed to implement such integrated initiatives (Nugroho et al., 2025). This demonstrates how crucial it is to understand urban symbiosis as a strategy for controlling and minimising MSW. It is crucial to understand how waste may be more successfully incorporated into urban system to address today's waste problems and build more sustainable, efficient and connected cities(Edmond et al., 2025).

MSW generation and trends

Municipal solid waste (MSW) comprises both biodegradable and non-biodegradable materials generated from households, commercial establishments, institutions, and industries within municipal boundaries(Kaza et al., 2019). The nature and scale of MSW generation and management practices vary significantly across regions due to differences in population density, urban form, socio-economic conditions, environmental regulations, cultural practices, and institutional capacity (Saja et al., 2021). Rapid urbanisation has further intensified pressure on existing infrastructure and public services, making MSW management a critical challenge for cities worldwide(Asian Development Bank, 2009).

Globally, MSW generation continues to rise, driven primarily by population growth, urban expansion, and changing consumption patterns. Although the global average waste generation rate appears moderate, substantial disparities exist between regions, reflecting variations in income levels, lifestyles, and economic structures(Kaza et al., 2019). High-income regions are generally characterised by higher per capita waste generation associated with consumption-intensive lifestyles, while low- and middle-income regions generate lower per capita waste but face increasing total waste volumes due to rapid population growth and urbanization (United Nations Environment Programme, 2024). This imbalance places disproportionate pressure on cities with limited financial and technical capacity, exacerbating environmental and public health risks.

Regional differences are also evident in MSW composition. Organic waste, particularly food and garden waste, dominates waste streams in low- and middle-income regions, largely due to dietary habits and limited packaging consumption(United Nations Environment Programme, 2024). In contrast, high-income regions generate a greater proportion of recyclable materials such as paper, cardboard, plastics, metals, and glass, reflecting advanced consumption systems and industrialised supply chains. These variations in waste composition highlight the inadequacy of uniform waste management strategies and underscore the need for region-specific, integrated approaches that consider material recovery potential.

Ineffective MSW management remains a significant concern, particularly in rapidly urbanising regions. Poorly managed waste contributes to environmental pollution, greenhouse gas emissions, and deteriorating urban living conditions, directly affecting public health and quality of life(Dawar et al., 2025). Sustainable MSW management, therefore, plays a vital role in resource conservation, emission reduction, and the transition towards circular urban systems(Neto et al., 2024). Understanding regional waste generation patterns is essential for designing adaptive strategies that align waste flows with local socio-economic and environmental contexts.

Municipal Solid Waste Management Practices and Challenges

Municipal Solid Waste Management (MSWM) refers to the systematic process of waste collection, transportation, treatment, and final disposal aimed at minimising adverse environmental and health impacts(Kumar et al., 2020). Effective MSWM is a fundamental component of urban planning and sustainable development, as it supports environmental protection while enabling economic growth (Mian et al., 2017). However, MSWM systems remain highly uneven across regions, with developing countries facing persistent challenges related to institutional capacity, financial constraints, and data availability.

One of the most critical challenges in MSWM is the lack of reliable and comprehensive data, particularly in many Asian and developing countries, which limits evidence-based planning and policy formulation(Agamuthu & Babel, 2023). Economic constraints further complicate waste management, as waste collection alone accounts for a substantial proportion of total MSWM costs in most countries (Agamuthu & Babel, 2023).As waste quantities continue to rise, especially in South Asian nations, these challenges threaten the long-term sustainability of existing MSWM systems.

Waste collection represents the most visible and essential municipal service within MSWM. While door-to-door collection is widely adopted globally, collection coverage remains uneven, particularly between urban and rural areas (Kaza et al., 2019). In regions with limited or irregular collection services, households often resort to open dumping, burning, or informal disposal practices, leading to severe environmental degradation and health risks. Improving waste collection coverage is therefore a prerequisite for reducing pollution and enhancing urban liveability, particularly in lower-income regions.

Disposal practices further reveal systemic inefficiencies in MSWM systems. Open dumping and landfilling remain the dominant disposal methods worldwide, especially in low-income regions, while sustainable treatment options such as composting, anaerobic digestion, and material recovery are underutilised (Kaza et al., 2019). This reliance on linear disposal pathways reflects a missed opportunity to recover value from waste and reduce environmental burdens. The continued dominance of unsustainable disposal methods highlights a structural gap in transitioning from conventional waste management to resource-oriented systems. Although existing literature provides extensive insights into MSW generation trends, composition, and management practices, most studies adopt a fragmented or sector-specific perspective. Current MSWM approaches largely focus on collection efficiency and disposal technologies, with limited emphasis on systemic integration across urban sectors. This gap is particularly evident in rapidly urbanising regions, where increasing waste volumes coincide with constrained resources and weak institutional coordination.

Urban symbiosis

Urban symbiosis is a cooperative relationship between various urban actors (such as households, commercials, and institutions) that entails the exchange of resources and services for the benefit of both parties to increase resource efficiency and water efficiency and promote sustainability (Yatawatta, 2023). The concept was the equivalent of the concept of Industrial Symbiosis: "Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products (Mulder, 2016). As an extended concept of urban symbiosis, investigates synergies in urban and industrial areas by converting MSWinto industrial space and using industries to supply living resources, such as waste heat and hot water (Sun et al., 2017).

The concept of Urban Symbiosis for MSW reduction and management

Population expansion and urbanization increases MSW day by day and it become a threat to urban development in all around the world. The take make dispose traditional linear waste management systems are becoming less sustainable and increases the negative impact on environment. Urban symbiosis is the one of potential remedy which reimagining cities (Kellner, 2021). The concept of urban symbiosis is one possible solution. Urban symbiosis, which has its roots in industrial ecology and circular economy concepts, is based on reimagining cites as interconnected ecosystems where waste, energy, materials and resources continuously flow among stakeholders including, municipalities, industries, homes, and service providers (Momirski et al., 2021).

Urban symbiosis convert waste into useful inputs for other industries such as for local enterprises urban farms, organic waste from food markets can be converted into compost and Biagas. Similarly, construction and demolition waste can be used for infrastructure projects reducing demand for landfills and virgin materials (Kaza et al., 2019). To create efficient, closed-loop municipal waste management systems, collaboration and resource sharing are essential (Momirski et al., 2021). Urban symbiosis places a strong insistence on integrated waste management strategies that plan waste collection, recycling, and treatment. When residential areas are connected to near by commercial or industrial zones, flow of waste are more efficient (Fraccascia, 2018). Using recycling hubs, stakeholders can increase material recovery while lowering processing and transportation expenses and achieve efficient waste to resource networks(Oberoi, 2020). It is important that co locations of those facilities near to the manufacturing hubs or residential areas to efficient energy recovery and material reuse which strengthens the urban symbiosis (Fraccascia, 2018), such as composting and anaerobic digestion systems, can convert biodegradable waste into fertiliser or renewable energy, waste to energy plants can supply electricity and heat to nearby users and material recovery facilities can provide recycled inputs for manufacturers enhancing sustainability and local economies (Oberoi, 2020).

Technology is essential to urban symbiosis cause with digital platforms and intelligent waste management systems can guarantee the real time monitoring, effective resource matching and transparency. To adopt this kind of technology it is important to have cooperation between communities, private companies and municipalities to build supportive infrastructure and governance processes (Kellner, 2021). By integrating waste as a resource urban symbiosis offers transformative approach to regenerative urban systems by managing municipal waste to foster sustainable and circular cities for the future (Mulder, 2016).

Methodology

This study adopted a Systematic Literature Review (SLR) methodology to examine the evolution of the urban symbiosis concept in relation to Municipal Solid Waste (MSW) management and reduction. The SLR approach was selected to ensure a transparent, structured, and reproducible process while minimizing bias and identifying existing research gaps. The review was guided by two primary research questions: (1) What is the current state of research on urban symbiosis in MSW management and reduction? and (2) What key themes, strategies, and research gaps exist in this domain. Prior to the literature search, a structured review protocol was developed to outline the study objectives, define the research questions, select the databases (Scopus, ScienceDirect, Web of Science), specify the keyword search strategy, and set clear inclusion and exclusion criteria to enhance methodological rigor. The review process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A comprehensive search was conducted in three major peer-reviewed databases, namely Scopus, ScienceDirect, and Web of Science, which were selected due to their extensive academic coverage. The search was limited to titles, abstracts, and keywords using the search string: TITLE-ABS-KEY ((“municipal waste” OR “municipal solid waste” OR “MSW management” OR “MSW reduction”) AND (“urban symbiosis”)). The initial search yielded 188 articles. After removing duplicates, 175 articles remained for title and abstract screening. The inclusion criteria limited studies to peer-reviewed journal articles published in English between 2015 and 2025, focusing specifically on urban symbiosis in MSW management and reduction, with accessible full texts and clear methodological descriptions. Studies were excluded if they were duplicates, non-peer-reviewed documents (such as conference abstracts, editorials, book reviews, reports, and theses), publications in languages other than English, articles published outside the selected time frame, or studies that addressed MSW management without linking it to urban symbiosis or discussed industrial symbiosis without an urban context. Following title and abstract screening, 98 articles were shortlisted for full-text assessment. After evaluating the full texts for relevance, methodological quality, and direct applicability to urban symbiosis in MSW management and reduction, 69 articles were finally selected for detailed analysis. The final sample size of 69 studies is considered appropriate given the relatively recent emergence of the urban symbiosis concept within MSW research, which limits the volume of available literature while still providing sufficient depth for comprehensive thematic synthesis. The selected studies were critically appraised for conceptual clarity and methodological robustness, and relevant data were systematically extracted. To address the research questions, both thematic analysis and bibliometric analysis were employed. Thematic analysis was used to identify recurring patterns, strategies, and research gaps, while bibliometric analysis using VOS viewer was conducted to generate keyword co-occurrence and research network visualizations. The integration of qualitative thematic interpretation and quantitative bibliometric mapping, combined with clearly defined inclusion and exclusion criteria, enabled a comprehensive understanding of research trends, thematic developments, and conceptual patterns in urban symbiosis for MSW management and reduction.

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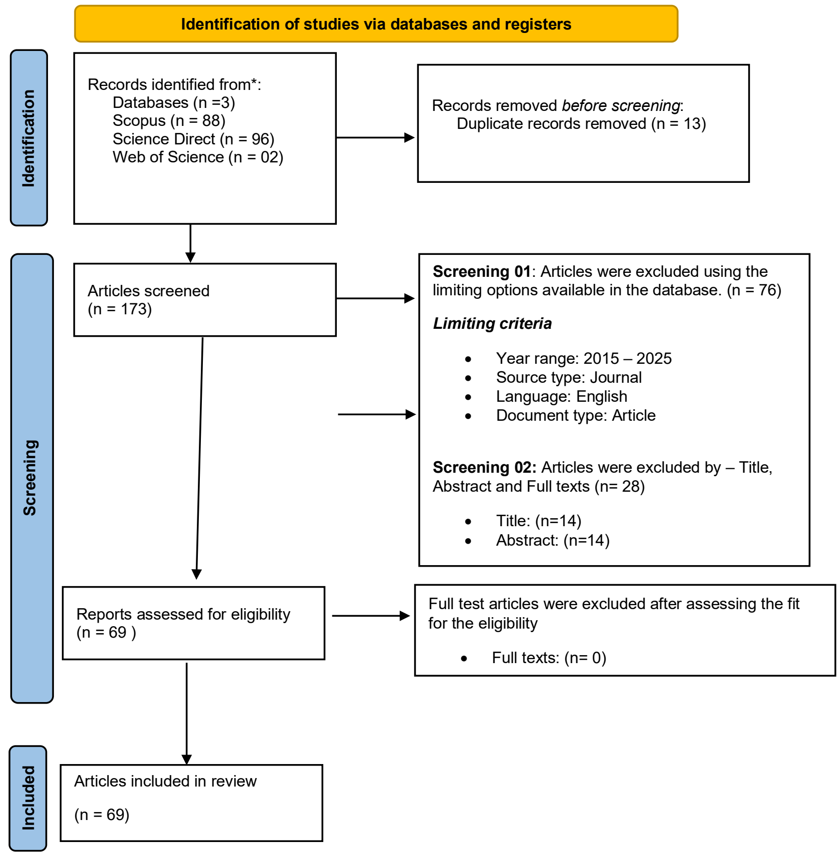
Figure 1: PRISMA guideline-based SLR procedure



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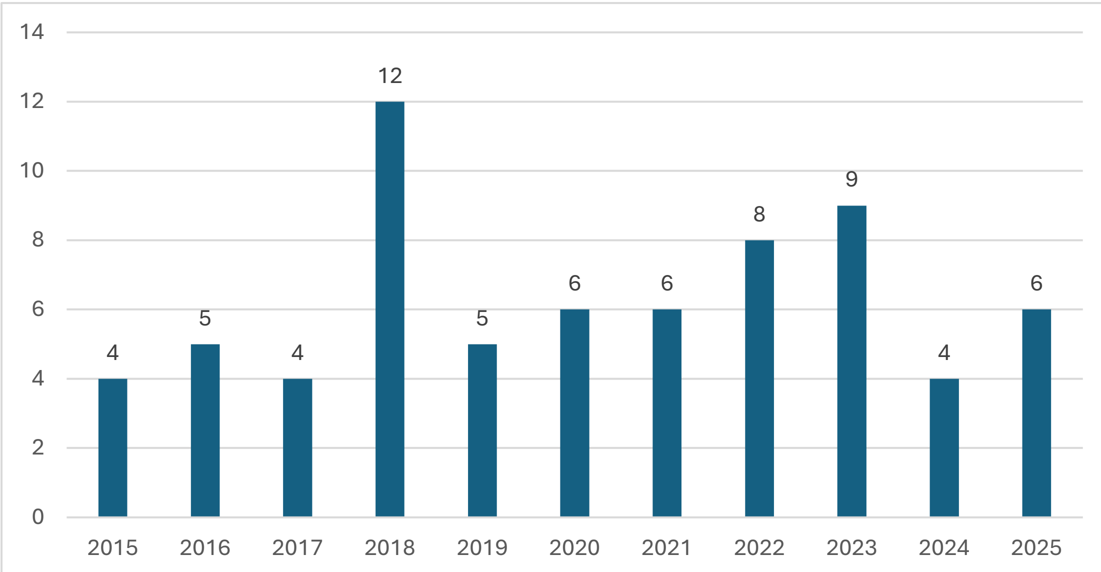
Results

Current state of research

Figure 2: Trendline publication year



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The publishing trend on urban symbiosis for MSW management and reduction over the past decade has shown a generally increasing trend with fluctuations. There was a period of noticeable growth in publications in 2018 which had the most publications (12 articles) by year over the entire decade. It was then followed by a period of moderate stability, and then further upward surges through 2022 and 2023. While there was mild decrease in 2024, there has already been an upward publication trend in 2025 which is still ongoing. This marks that the academic output consumption of the topic is very much sustained and still growing over the decade. Overall, the trend shows sustained and growing academic attention on the subject over the fictitious decade, but importantly the topic is growing quickly into an important area of scholarship**.**

Table 1: Major sources of publication

Journal and Quartile	Number of Articles
Journal of Cleaner Production (Q1)	20
Resources, Conservation and Recycling (Q1)	14
Sustainability (Switzerland) (Q1)	4
Waste Management (Q1)	4
Ecological Modelling (Q1)	3
Environmental Science and Pollution Research (Q1)	2
Renewable and Sustainable Energy Reviews (Q1)	2

Source: Created by the authors

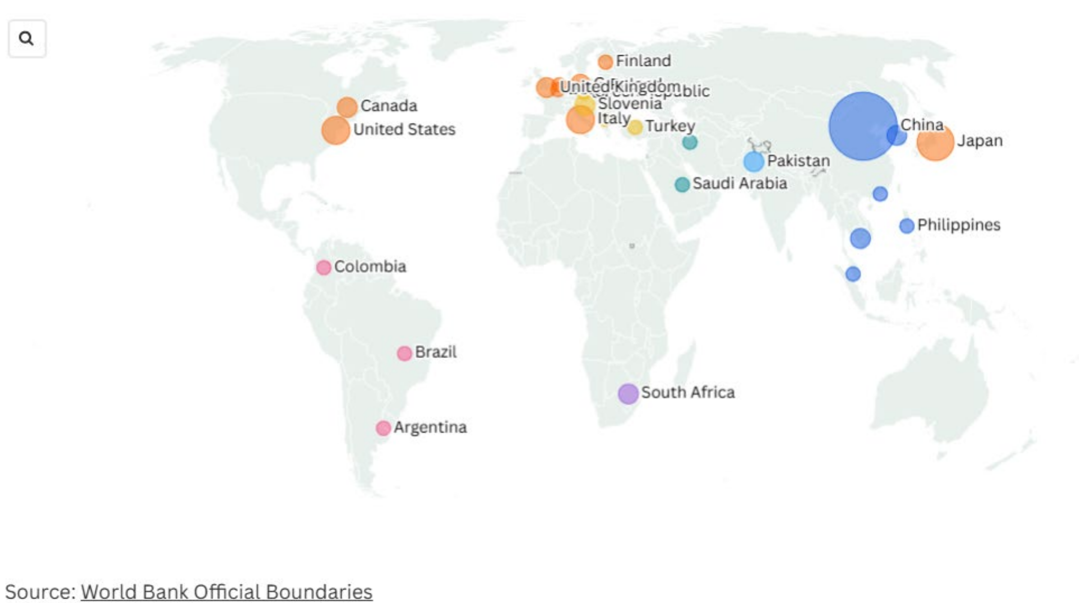
The Journal of Cleaner Production has the most articles published (20) in the field of adopting urban symbiosis for the reduction and management of municipal solid waste. This journal is known for its concentration on cleaner production, sustainability, and resource efficiency across sectors including the waste management industry. The total number of publications in Resources, Conservation and Recycling was 14, which also indicates a strong focus on the sustainable use of materials and linear and circular economy. A closer look at journals like Sustainability (Switzerland) and Waste Management shows they both have a lesser amount of papers published (n = 4) on recycling and treatment technologies they cover across a wide range of sustainability topics. Ecological Modelling published three articles, which include a systems modelling perspective relevant to ecological and environmental reflection. In addition, Environmental Science and Pollution Research and Renewable and Sustainable Energy Reviews, both published two articles, including interdisciplinary perspectives on environmental sustainability, energy systems, and pollution management. These journals are largely, if not all, high-impact journals specializing in sustainability, environmental science, and resource management.

Table 2: Research context

Category	**Countries**	**Number of Articles**
Asia	China (24), Hong Kong (1), India (1), Japan (7), Malaysia (1), Pakistan (2), Philippines (1), South Korea (2), Taiwan (1)	40
Africa	South Africa (2)	2
America	Argentina (1), Brazil (1), Canada (2), Colombia (1), United States (4)	9
Europe	Belgium (1), Czech Republic (1), Finland (1), Germany (2), Italy (4), Macedonia (1), Netherlands (1), Poland (1), Saudi Arabia (1), Slovenia (2), South Africa (2), United Kingdom (2), Turkey (1)	18
Oceania	None	0

Source: Created by the authors

Figure 3: Distribution of the reviewed studies by publication country



Source: Created by the authors

Table 02 shows the number of continents studied and other important counts, with more papers in Asia (40) compared to the rest of the continents. China has the highest number of papers (24), Japan has 7 publications. This indicates a significant research effort in the Asian region. Europe had the next highest number of publications (18), specifically Italy, Germany, Slovenia, and the UK. The Americas contributed 9 articles with representatives from the United States and Canada contributing the majority. Africa had the lowest representations, with South Africa only producing 2 articles and Oceania provided no articles. The findings suggest a geographic bias in research efforts with disproportionate representation from Asia particularly China. Other continents and regions appear to be under-researched.

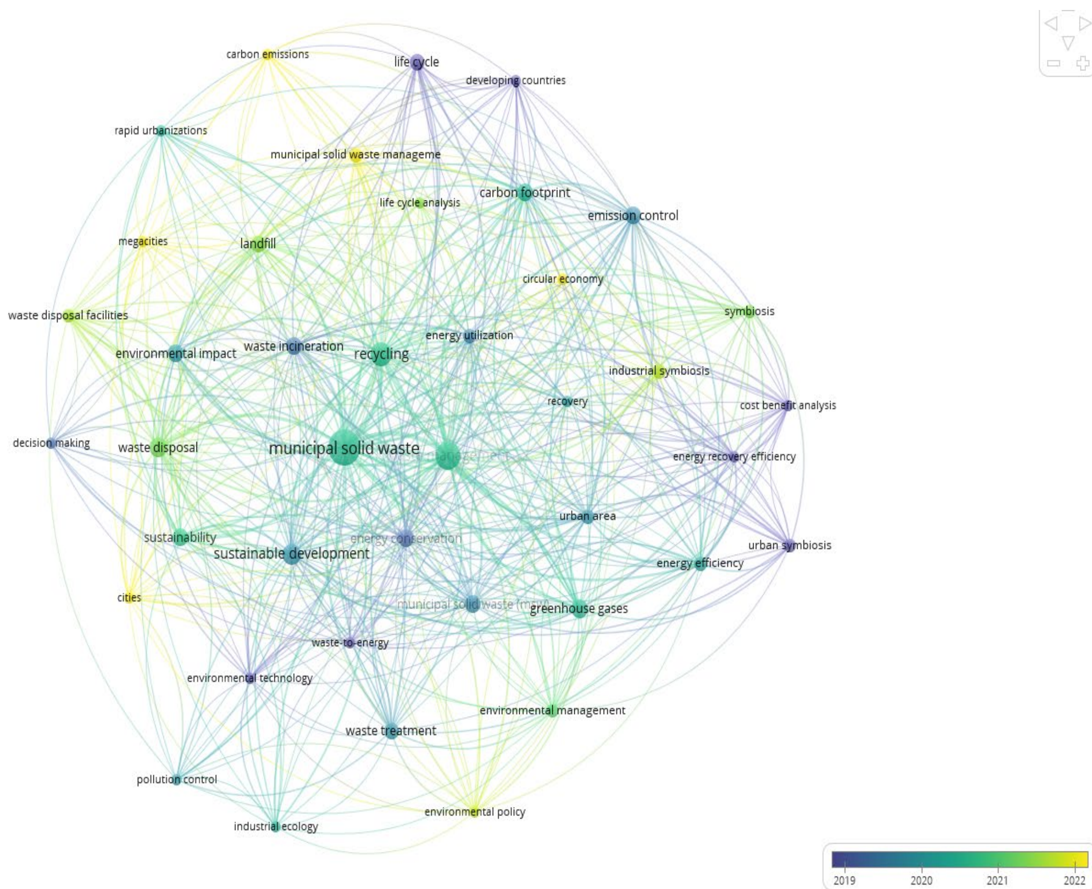
The figure 8 depicts the interconnectedness of countries publishing on urban symbiosis for MSW reduction. Larger nodes (China) reflect a greater amount of publication output; China is connected to the United States, Japan, South Korea, and other countries, as they represent the hub of publication output. The thicker the line, the stronger the collaborative research effort. Regional clusters like, Malaysia–UK–Canada, and Japan–South Korea–Denmark do suggest some degree of international collaboration. This network shows that global research on urban symbiosis remains highly product focused, since most connections are limited to urban symbiosis researchers based in the same countries as the focal point for this study, which indicates that more diverse and global collaboration is needed in urban symbiosis research.

Figure 4: Interconnection of publishing countries

Source: Created by the authors

An analysis of the keyword co-occurrence visualization reveals the interconnectedness of key concepts related to MSW(MSW) management. The central term, *municipal solid waste*, dominates the network, indicating its foundational role in the field. Closely linked terms such as *sustainable development*, *recycling*, *waste-to-energy*, and *greenhouse gases* demonstrate the core research themes, particularly focusing on sustainability, environmental impact, and resource recovery. The strong links between *waste treatment*, *energy utilization*, and *landfills* highlight concerns regarding pollution control and efficient resource use. These connections reflect a broader shift toward integrating MSW strategies with climate mitigation and energy production efforts. The map also shows a cluster of terms including *urban symbiosis*, *industrial symbiosis*, *circular economy*, and *symbiosis*, representing growing interest in collaborative, systemic approaches to waste management. These concepts underscore the importance of material reuse and closed-loop systems in reducing waste and promoting sustainability. Terms such as *developing countries*, *rapid urbanization*, and *megacities* point to the geographic and socio-economic contexts shaping waste management research, particularly in regions facing significant urban growth. Governance-related terms like *decision-making*, *cost-benefit analysis*, and *environmental policy* suggest a focus on regulatory frameworks and economic considerations in implementing effective MSW solutions.

Figure 5: Mapping of keyword co-occurrence in research



Source: Created by the authors.

The color gradient from dark blue (2019) to yellow (2022) reflects the temporal evolution of research themes. Newer terms like *urban symbiosis*, *energy recovery efficiency*, and *emission control* indicate emerging interests in efficiency, integration, and environmental performance. Additionally, the presence of keywords such as *life cycle*, *carbon footprint*, and *environmental technology* highlights the incorporation of assessment tools and innovations to optimize waste systems. Overall, the visualization portrays a transition from traditional disposal-focused methods to holistic, circular, and smart waste management strategies aligned with sustainability goals**.**

Urban symbiosis approaches for MSW reduction and management

Waste to resource conversion

Waste to resource conversion is urban waste management approach which transform invaluable waste materials and by products to valuable inputs or raw materials to reintegrate or repurposed in production cycle (Grimmel et al., 2024). The goal of waste to resource conversation is to minimize waste, maximize the resource efficiency and closing materials loops to reduce environmental impact (Sun et al., 2017). By integrating innovative technologies and processes urban industries can convert MSW into various kind of raw materials, by products, energy and resources. This mitigate the MSW issues such as landfill and fulfil the need of raw material extractions (Siwawa, 2024). Recycling is one of the most common method used in waste to resource process (Fujii et al., 2016). Where recyclable

MSW materials such as glass, metal and plastic are collected, processed and used in manufacturing to reduce the volume of waste send to the landfill for instance, one of the earliest most successful applications is the Eco-Town program in Japan (Afshari et al., 2018). This promotes integrated waste management by converting waste into raw materials. The Eco-Town program also focuses on developing innovative recycling industries through voluntary initiatives and governmental support, particularly in cities with ageing infrastructures. The program resulted in extending the life of existing landfill sites and revitalizing local industries (Afshari et al., 2018). Composting is another method for waste to resource conversion (Smitha et al., 2024). Organic waste such as kitchen and garden waste can convert to compost for the use of urban farming and landscaping cause rich nutrients in compost enrich the soil (Ali et al., 2018). More sophisticated methods, such as waste to energy (WTE) technology and anaerobic digestion, use biological processes to transform organic waste into biogas (Yin et al., 2024). Fossil fuel can be replaced by this biogas as a green energy source for heating or electricity power (Fujii et al., 2016).

Converting waste into resources has many benefits. Environmentally, it lessens the amount of waste that is dumped in landfills which reduce the problems that landfills cause such as leachate contamination and methane emissions (Sun et al., 2020). Additionally, it lowers carbon emissions and preserves natural ecosystems by reducing the need for virgin materials (G. Zhang et al., 2025). This approach can save waste disposal costs while generating income from waste driven products, new markets and green jobs (W. Dou et al., 2024).it contribute to cleaner cites, encourage responsible consumption and stimulate the development of green technologies, making it an essential part of sustainable urban development (Appio et al., 2019).

Eco industrial parks

Eco industrial parks recognized as a strategic evolution in urban and industrial planning, EIPs are strategically planned zones where different industries co located to facilitate waste to resource conversation through symbiotic relationship to promote sustainable development (Huang et al., 2019). The concept of EIPs is firm in industrial symbiosis where the waste or by products of one industry used as the raw materials for another enabling circular economy model(Guo et al., 2016). These parks are arranged spatially to optimize material and energy flows among industries, simulating an ecological system where nothing is wasted (Anastasovski, 2023). For example, Envi Grow Park in Finland's Forssa region incorporates waste-to-energy technologies, such as waste demolition centers and recycling units, to convert residual waste into energy or secondary materials(Uusikartano et al., 2022). EPIs significantly reduced environmental footprint of urban industrial activities by combining complementary industries (Dong et al., 2016). This enhances the waste minimization by transforming traditional waste landfill into a valuable input(Bibri & Krogstie, 2021). Additionally, EPIs generate revenue streams from waste-based products and encourage economic benefits by reducing energy cost and raw material cost within industries (Guo et al., 2016). These parks can infuse innovation by exploring new ways to repurpose materials, creating a platform for green technologies and circular economy practices(Kim et al., 2018).

Community based resource sharing

Community based resource sharing is a socially grounded strategy for managing and reducing MSW (Yin et al., 2024). This approach uses shared values, local cooperations and behavioural change to promote sustainability (L. Zhang et al., 2024). Community based resource sharing focusses on motivating communities to actively engage in waste prevention, segregation, reuse and circular sharing networks within the framework of urban symbiosis. This approach promotes community involvement, grassroots efforts and shared accountability instead of heavily rely on the industry or infrastructure initiatives(Kuznetsova et al., 2019). Resource sharing programs like neighbourhood recycling centers, tool libraries, second hand market, food sharing networks and community composting serve as the essentials of this concept (Shi et al., 2023). Households are enabled to identify recyclable, compostable, and reusable products before they enter the general waste stream by promoting waste segregation at the source (Ali et al., 2018). The amount and quality of materials that can be recovered and reintegrated into urban material flow are greatly increased by this method. Furthermore, hared resource systems reduce the unnecessary consumption by providing access without ownership to the sharing system (Yin et al., 2024). This is especially advantageous in dense urban entities which have limited space(Ali et al., 2018). Community based resource sharing reduces the need for virgin resources and contribute to remove large amount of waste from landfill and it encourages local green marketplaces and cost savings for both individuals and communities (Silverman et al., 2020). This approach strengthens and unites communities by fostering cooperation and common objectives. These programs educate and raise public awareness and encourage long term changes in consumer behaviour (Afshari et al., 2018). Therefore, community-based resource sharing improves resilient, low waste urban ecosystems that directly support the larger objectives of urban symbiosis by establishing citizens as important player in the circular economy(Zając & Avdiushchenko, 2020).

Urban infrastructure designs

To effectively reduce and manage MSW through urban symbiosis, urban infrastructure design is essential (Fei et al., 2021). This strategy places a strong emphasis on integrating sustainable practices into the structural and operational framework of cities, from public infrastructure and utility networks to housing developments and transportation systems (Dong et al., 2017). Instead of treating waste management as separate service, Urban infrastructure design incorporates waste management into city's basic systems, enabling circular flows of energy, materials, and resources. Decentralized waste collection and treatment facilities in neighbourhoods is one of the best planning approaches (Kuznetsova et al., 2019). This includes modular recycling stations in residential buildings, underground pneumatic waste collection and rooftop composting systems (Fan et al., 2021). Additionally, using special chutes or smart bins that direct recyclables, organic and landfill waste into the proper streams, building and districts can be planned to promote waste segregation at the source (Dong et al., 2016). These design features promote efficient pollution management, resource efficiency, and waste minimization. And, its reduce the environmental effects and logistical cost related to waste transportation (Fei et al., 2021). Urban infrastructure makes waste processing systems more dependable and efficient, which increase communities' ability to withstand disruptions and it encourages residents to adopt sustainable habit by making them easier to understand and adopt (Aver et al., 2023) . Furthermore, well-planned infrastructure makes circular economy models more scalable, enabling cities to expand in a sustainable manner (Vernay & Mulder, 2016). Urban landscape becomes dynamic ecosystems where waste is controlled and repurposed when infrastructure is constructed with material flows in mind .

Digital symbiosis platforms

Digital symbiosis platforms are novel technologies that simplify MSWM with urban sustainability. These platforms provide intelligent networks that use digital interface and real time data to link authorities, companies, individuals and service providers. Using technologies like IoT, AI, blockchain and GIS can live tracking, predictive analytics, and effective coordination of waste related activities for effective MSWM (Siwawa, 2024). Smart bins with sensors monitoring contamination and fill levels which reduce the fuel consumption and optimize the collection routes (Dong et al., 2016). Cities should make proactive preparations by using AI powered tools that can predict waste surged during events (Shah et al., 2020). Blockchain improves recycling and reuse and encourage to implement rewarding systems for appropriate waste management (Mancini et al., 2021). Additionally, these tools reduce need of waste disposal by connecting resource users and producers together (Tröger et al., 2023) . These platforms promote data driven decision making which increase the operational efficiency and reduce the emission (Kuznetsova et al., 2019). Due to circular value chains can minimize the disposal costs and people gain transparency and tools that promote heathier behaviours (Tsai et al., 2020). Digital platforms essentially accelerate the transition to smart, connected, and zero waste urban ecosystems(Chin et al., 2023).

Policy driven symbiosis

Policies are the legislative foundation. Therefore, policy driven symbiosis is needed for integrating sustainability and urban symbiosis into MSWM (Mondal & Kitawaki, 2025). This strategy makes sure that waste reduction and circular behaviours are institutionalised across all the sectors through regulations, incentives and governance structures (Zeller et al., 2019). Mandatory waste segregation rules that encourage recycling and legislations required to establish for proper MSWM. Governments can play a huge role in establishing regulations that promote waste minimization, recycling and industrial cooperation (Sellitto et al., 2025). Support mechanism such as subsidises or tax incentives, further encourage urban industries and municipalities to participate in symbiosis initiatives that reduce MSW (Boom Cárcamo & Peñabaena-Niebles, 2022). Green investment cab be strengthened vis carbon credits, which can promote low emission technologies(Chu et al., 2023). Policies facilitate system accountability, performance monitoring and strengthen the coordination across industries (Mondal & Kitawaki, 2025). This has long term structural benefits such as clear regulations lower the risk for firms and investors and consistency make possible long term environmental objectives and smart infrastructure development (Dong et al., 2016). Policy driven symbiosis positions sustainable waste management as a pillar of future ready urban development by turning it to a standard (Ohnishi et al., 2018).

Table 3: Summary of benefits of urban symbiosis approaches

Benefits		Waste to Resource	Eco-Industrial Parks	Community Resource Sharing	Urban Infrastructure Designs	Digital Symbiosis Platforms	Policy-Driven Symbiosis
Environmental	Reduced landfill waste	●	●	●			●
	Lower greenhouse gas emissions	●	●		●		●
	Resource efficiency	●	●	●		●	●
	Pollution control		●		●		●
	Energy recovery from waste	●	●				
	Circular economic support	●	●	●	●	●	●
	Biodiversity protection				●		●
Economical	Cost savings on raw materials	●	●	●		●	
	Job creation	●	●	●	●	●	●
	Economic resilience		●		●	●	●
	New revenue streams	●	●			●	
	Reduced municipal waste management cost	●		●		●	●
	Market development for recyclables	●	●				●
Social	Community empowerment			●			●
	Increased public awareness	●	●	●	●	●	●
	Improved public health	●		●	●		●
	Enhanced urban liveability			●	●		●
	Educational opportunities		●	●		●	
	Collaboration and innovation culture		●	●	●	●	●

Sources - (Grimmel et al., 2024),(Sun et al., 2017),(Siwawa, 2024), (Fujii et al., 2016),(Afshari et al., 2018), (Smitha et al., 2024), (Ali et al., 2018),(Yin et al., 2024),(Sun et al., 2020),(G. Zhang et al., 2025),(W. Dou et al., 2024),(Appio et al., 2019). (Huang et al., 2019), (Guo et al., 2016),(Anastasovski, 2023),(Uusikartano et al., 2022),(Dong et al., 2016),(Bibri & Krogstie, 2021),(Kuznetsova et al., 2019) ,(Shi et al., 2023),(Silverman et al., 2020),(Zając & Avdiushchenko, 2020),(Fan et al., 2021),(Aver et al., 2023),(Vernay & Mulder, 2016),(Siwawa, 2024),(Shah et al.,

2020),(Mancini et al., 2021),(Tröger et al., 2023),(Tsai et al., 2020),(Chin et al., 2023),(Mondal & Kitawaki, 2025),(Zeller et al., 2019),(Sellitto et al., 2025),(Boom Cárcamo & Peñabaena-Niebles, 2022),(Chu et al., 2023) ,(Ohnishi et al., 2018).

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Barriers and strategies of adopting urban symbiosis to MSW reduction and management

Urban symbiosis offers promising approach for sustainable MSW reduction and management approaches, but its implementation faces different barriers. Understanding these barriers will help to develop strategies to overcome those barriers and promote urban symbiosis in MSW management. Technological constraints are one of the main barriers to implement urban symbiosis. The advanced technologies like pyrolysis, anaerobic design and automated material recovery system are need to adopt urban symbiosis and in most countries these technologies are still not available (Sellitto et al., 2025). To address this barrier governments can invest in research and development and promote international technology transferring to make these technologies are more accessible (Dong et al., 2016). Furthermore, due to inadequate infrastructure and lack of data, the integration of digital tools such as IoT enable waste bin, AI power sorting, or urban metabolism modelling remain underdeveloped (Tröger et al., 2023). By creating open-source platforms to share urban data and introducing pilot project to test these digital tools can be mitigate this issue and improve the planning and integration (Paes et al., 2019). Smooth resource exchange is often restricted by technological incompatibilities between systems, such as outdated waste treatment plants or non-standardized waste collection systems (Yasar et al., 2023). This can overcome by standardising waste collecting procedure, ensuring the interoperability between systems and upgrading the outdated infrastructures. Without advanced technology, it is difficult to design and maintain the complex, interconnected networks that relies upon urban symbiosis. Initiatives for urban symbiosis frequently encounter financial and economic barriers that restrict their potential for growth and stakeholder appeal(Afshari et al., 2018). Many governments and private investors find the high initial capital investment required to establish eco industrial parks, decentralised waste processing hubs, or digital symbiosis platforms unaffordable(Ndou & Rampedi, 2022). Government can mitigate this barrier by introducing green bonds, low interest loans and public and private partnership to mitigate financial risk (Kim et al., 2018). Furthermore, financial commitment is discouraged by circular waste initiatives unclear profitability and lengthy payback periods (Yang & Yang, 2022). Developing transparent business models and demonstrating long term lifecycle savings can help investors to access to the circular initiatives (Tröger et al., 2023). Circular models find it difficult to compete with traditional waste management techniques in the absence of sufficient subsidies, tax breaks, or green investment incentives (W. Dou et al., 2024). Implementing supportive policies like tax breaks, subsidies or carbon credits can make symbiotic models more competitive (Sellitto et al., 2025). Furthermore, unstated expenses like those for system maintenance, operation, or training can put a burden on municipal budgets and deter adoption (Yang & Yang, 2022). By including those cost at the early stage of financial planning can mitigate this issue and municipalities can seek for operational grant or funds(Y. Dou et al., 2018).

Another major barrier to implement urban symbiosis is social and cultural resistance. Decentralised recycling, community-based sharing, and waste segregation all depend on public engagement, but many people are resistant to behavioural changes because of rooted habits or lack of knowledge (Paes et al., 2019). Public education and awareness programmes can foster community participation and change behaviour(Appio et al., 2019). Symbiotic concepts like sharing, reuse, and cooperative consumption may clash with cultural values that support private ownership, convenience, or disposability (Ndou & Rampedi, 2022). To address this should use cultural appropriate design and initiate urban symbiosis approaches that align with local values which highlight the economic and community benefits (Sun et al., 2020). Additionally, because of alleged aesthetic or health issue, local may be against the construction of trash infrastructure next to their homes (Yin et al., 2024). To improve the community acceptance can involve communities in planning, using well design and ordor controlled facilities which will also reduce the health risk (Yin et al., 2024). Without public support and cultural alignment, even the most technically sound urban symbiosis models might not succeed (Tsai et al., 2020). Practically speaking, operation and logistic issues usually interfere with implementing urban symbiosis plans. Contamination from improper waste segregation at the source cause the low-quality resources that can be recovered or reuse (Licastro et al., 2024). To address this issue can establish regulations for waste separation and segregation polices and use the clear labelling and user awareness (Chu et al., 2023). Collection systems are frequently fragmented and poorly coordinated and cause for inefficient systems in waste handling. By developing centralised waste management platforms with proper collection schedules this can be mitigate (Li et al., 2024). Additionally, the siloed nature of urban planning procedures limits the integration of waste, energy, transportation, and housing systems that are essential for symbiosis (Fujii et al., 2016). To promote systematic collaboration can practice the integrated planning frameworks (Sellitto et al., 2025). A shortage of skilled personal and institutional capacity and maintain symbiotic infrastructure further limits the long-term performance and functionality (Grimmel et al., 2024). By arranging training programmes and awareness programmes can be improve the skills (Chin et al., 2023).

The implementation of symbiotic infrastructure is challenging because it needs unique spatial and environmental constraints. To locate decentralise treatment units, community recycling centres and composting facilities in densely populated cities is hard due to the limited amount of available land (Paes et al., 2019). As a solution can use spaces like rooftops, parking area and brownfields for modular designs (Appio et al., 2019). However, if not adequately managed, poorly planned resource exchanges may present environmental hazards including leachate, emission or order (Fei et al., 2021). Therefore, environmental risk assessment should be conducted and can be use advanced technologies for treatments and odor control(Licastro et al., 2024). The systemic cooperation required urban symbiosis. Many existing policies and regulations are rooted in linear models of waste disposal and lack of supportive legislation or enforcement mechanisms leads to weak implementation and restrict circular or symbiotic initiatives (Mancini et al., 2021). Government can update regulations to support circular economy principles, set clear recycling and reuse mandates and establish multi-stakeholder governance platforms to provide strong regulatory background (Sellitto et al., 2025).

Table 4: Barriers and strategies of adopting urban symbiosis to MSW reduction and management

Barrier Category	**Specific Barriers**	**Strategies to Overcome**
Technical Barriers	Limited access to advanced technologies (e.g., pyrolysis, anaerobic digestion)	Promote R&D and facilitate international tech transfer
	Inadequate infrastructure and urban data	Launch pilot projects and open-source urban data platforms
	Technological incompatibility across systems	Upgrade outdated infrastructure and standardize systems for interoperability
Economic Barriers	High initial capital investment	Introduce green bonds, low-interest loans, and PPPs
	Uncertain profitability and long payback	Develop clear business models with lifecycle cost analysis
	Lack of subsidies or tax incentives	Offer subsidies, tax relief, and green investment incentives
	Hidden costs (O&M, training, etc.)	Include full costs in financial planning
Social Barriers	Resistance to behavioral change and lack of awareness	Conduct awareness campaigns, gamification, and educational programs
	Cultural values opposing reuse and sharing	Align messaging with local values and showcase economic/community benefits
	Public opposition to waste infrastructure	Engage communities and design aesthetically acceptable facilities with buffers
Operational Barries	Poor waste segregation and contamination	Enforce source separation laws and clear labeling

	Fragmented and inefficient collection systems	Create centralized collection platforms and harmonized schedules
	Siloed urban planning	Establish integrated planning frameworks
	Lack of skilled personnel	Develop training programs and technical certifications
Enviorenmntal Barriers	Limited urban land for facilities	Utilize underused spaces (rooftops, brownfields) with modular designs
	Risk of pollution (leachate, emissions, odor)	Conduct environmental risk assessments and use advanced control technologies
Regykatory Barriers	Outdated linear-model policies	Update regulations to support circular economy principles
	Weak enforcement mechanisms	Set clear recycling/reuse mandates
	Lack of inter-agency collaboration	Establish multi-stakeholder governance platforms

Sources - (Sellitto et al., 2025),(Dong et al., 2016),(Tröger et al., 2023),(Paes et al., 2019),(Yasar et al., 2023),(Afshari et al., 2018),(Ndou & Rampedi, 2022),(Kim et al., 2018),(Yang & Yang, 2022),(W. Dou et al., 2024),(Sellitto et al., 2025),(Yang & Yang, 2022),(Y. Dou et al., 2018)(Y. Dou et al., 2018) ,(Paes et al., 2019),(Appio et al., 2019),(Ndou & Rampedi, 2022),(Sun et al., 2020),(Yin et al., 2024),(Tsai et al., 2020),(Licastro et al., 2024),(Chu et al., 2023),(Li et al., 2024),(Fujii et al., 2016),(Grimmel et al., 2024),(Chin et al., 2023),(Paes et al., 2019),(Appio et al., 2019),(Fei et al., 2021),(Licastro et al., 2024),(Mancini et al., 2021).

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Contribution of Urban Symbiosis to Achieving Sustainable Development Goals (SDGs)

Urban symbiosis promotes integrated methods to resource optimisation and MSW(MSW) reduction, which greatly aids in the achievement of several Sustainable Development Goals (SDGs). In terms of the environment, policies such as waste-to-resource conversion, eco-industrial parks, and policy-driven symbiosis improve resource efficiency and pollution control (SDG 12: Responsible Consumption and Production), decrease greenhouse gas emissions (SDG 13: Climate Action), and lessen reliance on landfills (SDG 11: Sustainable Cities). In terms of economics, urban symbiosis fosters economic resilience and the growth of the recyclables market (SDG 9: Industry, Innovation, and Infrastructure) while supporting circular economies through cost reductions, job creation, and new revenue sources (SDG 8: Decent Work and Economic Growth). On the social front, digital platforms and community resource sharing promote inclusive innovation and liveable urban settings (SDG 11), empower citizens, enhance public health, and increase environmental awareness (SDG 3: Good Health and Well-Being; SDG 4: Quality Education). The advancement of a more sustainable, circular, and resilient urban future is greatly aided by urban symbiosis, which aligns social, economic, and environmental benefits.

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Table 5: Contribution of Urban Symbiosis to Achieving Sustainable Development Goals (SDGs)

Benefit Category	Specific Benefits of Urban Symbiosis	SDGs	Goal Description
Environmental	Reduced landfill waste	**SDG 11**	Sustainable Cities and Communities
	Lower greenhouse gas emissions	**SDG 13**	Climate Action
	Resource efficiency	**SDG 12**	Responsible Consumption and Production
	Pollution control	**SDG 12**	Responsible Consumption and Production
	Energy recovery from waste	**SDG 13**	Climate Action
	Circular economic support	**SDG 12**	Responsible Consumption and Production
	Biodiversity protection	**SDG 15**	Life on Land
Economic	Cost savings on raw materials	**SDG 12**	Responsible Consumption and Production
	Job creation	**SDG 8**	Decent Work and Economic Growth
	Economic resilience	**SDG 8**	Decent Work and Economic Growth
	New revenue streams	**SDG 8**	Decent Work and Economic Growth
	Reduced municipal waste management costs	**SDG 11**	Sustainable Cities and Communities
	Market development for recyclables	**SDG 9**	Industry, Innovation and Infrastructure
Social	Community empowerment	**SDG 11**	Sustainable Cities and Communities
	Increased public awareness	**SDG 4**	Quality Education
	Improved public health	**SDG 3**	Good Health and Well-Being
	Enhanced urban livability	**SDG 11**	Sustainable Cities and Communities
	Educational opportunities	**SDG 4**	Quality Education
	Collaboration and innovation culture	**SDG 9**	Industry, Innovation and Infrastructure

Source: Created by the authors

Discussion

The rapid increase in MSW(MSW) generation resulting from urbanization, industrialization and consumerism presents a significant challenge to sustainable, global urban development. The literature demonstrates that typical MSW Management (MSW) systems are not keeping up with waste generation globally and particularly in developing countries. The studies demonstrate that MSW systems have failed to implement paradigm shifts from conventional linear-based approach that collects, transports, and disposes. Typical MSW systems are linear based and lead to an unsustainable system because of negative externalities that lead to environmental pollution, lost recoverable resources, and adverse health impacts. The need for transition to circular and integrated approaches has resulted in some interest in approaches like Urban Symbiosis (US).

Inspired by the principles of industrial ecology, Urban Symbiosis has a systemic approach to ensure that the waste and by-products of one entity become the inputs of another. The reviewed studies provide evidence that urban symbiosis offers a sound framework toward solid waste management (decreasing waste) because it supports resource circulation, cooperation and collaboration among stakeholders and solid waste management technology. Of particular interest is that urban symbiosis increases the efficiency of solid waste management because it closely integrates waste treatment with urban infrastructures and industrial processes.

The idea behind Urban Symbiosis for MSW reduction and management is especially exciting because in a networked ecosystem, municipalities, industries and communities can be coordinated together. The studies suggest that such integration helps with converting waste into resources, decentralizing waste processing, and utilizing existing infrastructure efficiently. However, the action continues to be sporadic and often limited to pilot projects or efficient resource use environments with favourable governance and economic conditions.

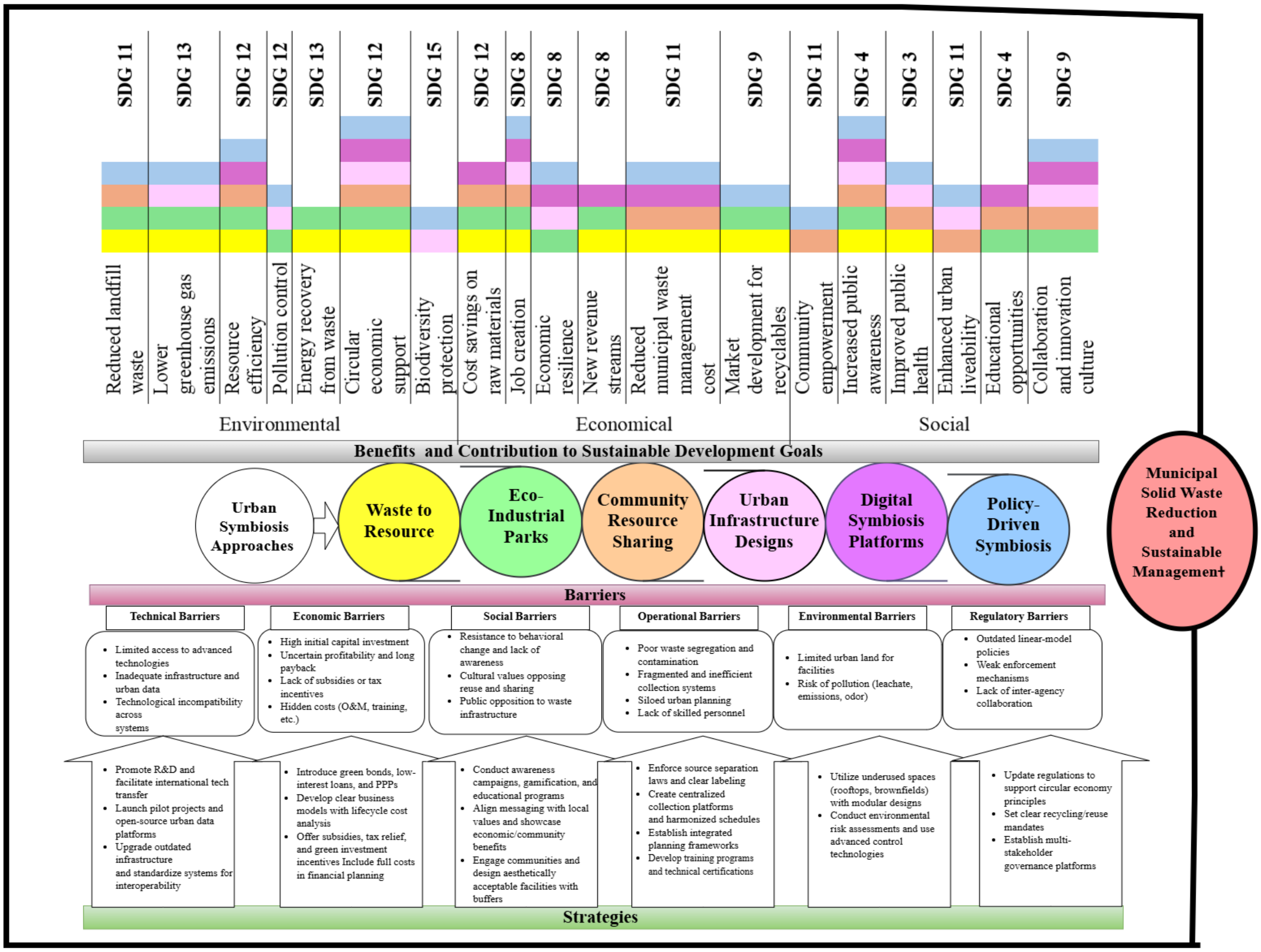
There are several types of urban symbiosis methods that have been identified in the literature. For example, Eco-Industrial Parks (EIPs) as a way of exchanging resources industrially, Community-Based Resource Sharing (CBRS) that focus on local reuse and recycling, Digital Symbiosis Platforms (DSPs) that match waste producers to those that want to use it via real time data, and finally, Symbiotic Urban Infrastructure (SUI) that places waste management as part of urban planning. With the number of varied methods, most studies only look at technological or case-specific aspects with little examination of why socio-political, economic, and institutional settings must be considered for the sake of wider scalability.

The barriers to urban external symbiosis are evidently complex. Most important barriers include fragmentation of policy frameworks, lack of institutional alignment, limited data and monitoring systems, poor public engagement, and absence of enabling infrastructures. While recommendations are made, such as policy incentives, stakeholder engagement, digitalization, and public-private partnerships, there has been a documented misalignment between theory and practice, particularly in low-and middle-income and rapidly urbanizing regions.

Another key area worth exploring is the potential of urban symbiosis to support the Sustainable Development Goals (SDGs). The literature confirms that the act of urban symbiosis supports multiple SDGs, including Goal 11 (Sustainable Cities), Goal 12 (Responsible Consumption and Production), and Goal 13 (Climate Action), related to reducing emissions, reducing waste, and building resilience in cities. Nevertheless, the contributions to these SDGs are often qualitative and anecdotal, highlighting the need for standardized assessment and indicators to quantify the impact of urban symbiosis on SDG targets.

Despite the increasing levels of interest, whether academic, institutional or market-driven, the overall literature remains underdeveloped in the scientific, holistic, and contextual understanding and practice of urban symbiosis for MSW minimization approaches in complex contexts in varying socio-economic and geographical conditions. Most of the literature focuses on either high-income countries or industrial applications; when limited observations of MSWapproaches exist, specifically in developing urban areas, further availability of literature transformation potential is limited. Current research has also lacked technical, institutional, and social comprehension of how urban symbiosis processes occur, especially research informed by policy analysis and stakeholder behaviour testing of existing alternative technologies existing. Consequently, the goal of this research is to articulate this gap and provide a synthesis of urban symbiosis processes that could be applied to MSWminimization and management. The intention of this research is to structuralize it with a framework to align all the technical, institutional, and social dimensions that would allow urban symbiosis to make practical, applicable, and reliable similar constructions in different urban contexts. In doing so the research ultimately adds to sustainable practices in MSWM and contributes to the wider goals of both sustainable MSWM and sustainable development goal (SDG) implementation.

Figure 6: Framework for Utilize Urban Symbiosis Approaches to MS Reduction and Sustainable Management



Source: Created by the author

The framework provides a comprehensive guide to MSWReduction and Sustainable Management through Urban Symbiosis Approaches. It includes elements like benefits aligned with Sustainable Development Goals (SDGs), six urban symbiosis approaches (with barriers assessed under categories and counter-measures), and assessment of benefits of strategies grouped by the environment, economy, and society linked visually with each urban symbiosis approach (as colour coded). The framework links benefits to urban symbiosis approaches and provide examples of contributions specifically for environmental, economic, and social benefits. The framework shows the relationships between approaches, showing how the components when combined can synergistically address adversities within each issue category (technical, economic, social, operational, environmental, and regulation). This framework shows how, by developing specific approaches to overcome barriers, urban symbiosis can ultimately contribute to the mitigation of MSWand support Sustainable Waste Management aligned with global sustainability goals.

Implications

Policy and Governance

Urban symbiosis demands integrated policy approaches to bring waste management in line with urban development, environmental, and industrial policies. Governments must create an enabling environment with the necessary regulations, incentives, and cross-sector coordination. A clear delineation of institutional roles and stakeholder partnerships are important in overcoming disparate waste management approaches.

Urban Systems and Infrastructure

Incorporating symbiotic concepts within urban systems can support waste and resource circulation. Urban systems and infrastructure (e.g., eco-industrial zones, decentralised treatment assets, logistics) should be developed so that circularity is facilitated. Long-term resilience and sustainability will rely on urban systems being integrated within the workforce and organizational structures.

Technology and Community Engagement

Digital platforms can harness internet of things (IoT) capabilities and artificial intelligence (AI), to help monitor waste flows and facilitate coordination between stakeholder groups. However, communities need to be active participants going forward. Increased public awareness, proactive behaviour and inclusive engagement will be essential supports for advancing local initiatives such as sharing resources, household recycling programmes etc.

Research and Capacity Building

Empirical studies are required to assess the operational efficacy of urban symbiosis and MSWM. Development of standardized tools to assess urban outcomes and contribution to SDGs has the potential to streamline future assessments. Furthermore, capacity building through training and knowledge share will assist cities in developing and deploying situationally-relevant and effective strategies for urban symbiosis.

Conclusion

Urban Symbiosis provides an opportunity to rethink the ways cities might reduce and manage municipal solid waste, by harnessing and enhancing interconnected resource flows, cross-sector collaboration and excellent circular economic practices. Overall, this literature review indicates that, although there is significant potential for a variety of mechanisms - from eco-industrial parks to digital platforms - to support urban symbiosis, their implementation may be limited by policy, institutional, technological and behavioural hindrances. This research contributes to knowledge by reviewing how we currently understand urban symbiosis strategies and identifying the barriers and enablers to effective urban symbiosis as a component of MSWM. Relatedly, we call for a holistic perspective on urban symbiosis that considers urban infrastructure, governance, collective community participation, and sustainability objectives. In conclusion, urban symbiosis is not just a technical solution but a partial structural reframing of the way cities deal with waste and resources. To align urban symbiosis with sustainable development and circular economy objectives, cities can advance towards zero-waste targets, improving resource efficiencies as well as creating urban spaces that are resilient and liveable for future generations.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that would influence this paper.

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