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REVIEW ARTICLE

Review of waste management and life cycle assessment studies in megacities

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ABSTRACT

This study reviews existing Life Cycle Assessment (LCA) studies on municipal solid waste (MSW) management in megacities to evaluate their comprehensiveness and identify key research gaps. For this purpose, the Web of Science (WoS)and Science Direct databases were used. The findings reveal that while LCA studies provide valuable insights into the environmental and economic impacts of municipal solid waste management (MSWM) strategies, they predominantly focus on greenhouse gas (GHG) emissions and environmental concerns, with limited consideration of social, health, and policy aspects. Additionally, research primarily examines specific waste fractions such as food and packaging waste, whereas significant waste streams like hazardous waste and e-waste remain underexplored. Studies are largely city-specific, lacking cross-city comparisons that would facilitate broader generalizations. From an environmental perspective, MSWM strategies significantly impact global warming potential (GWP), acidification, nutrient enrichment, and net carbon emissions, with landfills and incineration being the most analyzed treatment methods.

However, alternative technologies, including advanced recycling and circular economy approaches, receive less attention. Economic assessments are also scarce, with limited studies evaluating the financial sustainability of MSWM strategies. Furthermore, research on megacities in developed countries is limited due to well-established waste management systems, strict regulations, and data accessibility challenges. Similarly, studies on lower-middle-income megacities are hindered by data scarcity, funding constraints, and weak regulatory frameworks. To enhance LCA research on MSWM, future studies should incorporate broader sustainability dimensions, address underexamined waste streams, and increase research coverage in both developed and lower-middle-income megacities. Expanding the analysis to include advanced waste treatment technologies, cross-city comparisons, and standardized LCA frameworks will support informed decision-making and more effective waste management policies.

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INTRODUCTION

The global waste production rate is increasing, around the world, with an estimated that the world produces 2.24 billion tons of solid waste generated per day in 2020. Annual waste generation is expected to rise to 3.88 billion tons by 2050. People living in developing countries, particularly in low-income regions, are more severely affected by unsustainably managed waste compared to those in developed countries. In low-income countries, over 90% of waste is often dumped in unregulated landfills or open burned. These practices have severe consequences for human health and environment. Poorly managed waste contributes to the spread of diseases and global climate change through methane emissions [1].

Megacities, generally defined as metropolitan areas with a total population of more than 10 million, are among the most affected by inappropriate waste management in both developed and developing countries. Rapid growth rates, new forms of spatial population density, and the presence of both formal and informal economies are key factors that distinguish megacities from global cities. These urban centers face extreme environmental challenges and threats that can have severe adverse effects on human health. In this context,

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effective waste management is increasingly critical for the long and medium-term sustainability of megacities [2].

As resource limitations and pollution-related diseases have become more apparent, waste management has gained importance, especially with advancing technology and increased environmental awareness. Integrated solid waste management (ISWM) has emerged from these developments. ISWM can be defined as the selection of appropriate techniques, technologies, and management plans for a specific waste management system, provided that all economic and social requirements are met [3]. In this context, LCA, a tool used to evaluate the environmental performance of products throughout their life cycle, provides a holistic perspective. It used to assess the environmental impacts of various waste management options, encompassing all processes from waste collection to disposal. An LCA study consists of four main stages which are: defining the goal and scope, conducting an inventory analysis, assessing environmental impacts, and interpreting the results. Waste management policies are not uniform but depend on local factors such as geography, infrastructure and regulations [4], [5]. LCA helps policymakers and waste management professionals make informed decisions to minimize environmental impacts and move toward more sustainable waste management practices.

GOAL AND SCOPE DEFINITION

This study aims to review publications on waste management and Life Cycle Assessment (LCA) in megacities to analyze the comprehensiveness of existing LCA studies on municipal solid waste (MSW) management and identify key gaps in their coverage. Additionally, this study aims to answer the following question: What are the common environmental and economic impacts of MSWM strategies in megacities based on LCA studies? To achieve this objective, megacities were analyzed based on their numbers, population, income levels, and waste management practices. For this purpose, literature reviews were carried out using the Web of Science (WOS) and Science Direct databases.

Megacities

Megacities are a product of continuous urbanization, typically defined as metropolitan areas with a total population of more than 10 million people. They stand apart from global cities due to their rapid growth [2]. According to [6], there are 32 megacities in the world, each with a population exceeding 10 million. Of these, 29 are located in developing countries, while only three of the megacities including Tokyo, Osaka (Japan) and Paris (France) are in developed countries. Furthermore, megacities are categorized into three groups based on income levels. These groups are high-income (developed) countries, upper-middle-income and lower-middle-income and (developing) countries (Table 1).

Municipal Solid Waste Management (MSWM) in Megacities

Currently, 4.9 million Mg/d of MSW, including 2.6 million Mg/d of organic waste, is generated worldwide. Of this, 0.59 million Mg/d of MSW (0.3 million Mg/d of organic waste) is generated in megacities. These waste generation values accounts for 12% of global waste production and 11.5% of global organic waste production [7].

MSW generation and disposal rates vary according to the income levels of countries. High-income countries generate 34% of the world's waste, upper-middle-income and lower-middle-income countries generate 32% and 29%, respectively, while low-income countries produce 5% of global waste. Open dumping is the most common waste disposal method in megacities located in lower-middle-income countries, while landfilling is the primary disposal method in megacities located in upper-middle-income (developing) countries. In contrast, megacities located in high-income countries focus on recovering materials through recycling and composting, and they generate energy through incineration (Table 2) [8].

Table 1. Classification of megacities by income levels [6]

High-Income (Developed) Countries	
Paris	France
Tokyo, Osaka	Japan
Upper Middle-Income (Developing) Countries	
Buenos Aires	Argentina
Sao Paulo, Rio De Janeiro	Brazil
Shanghai, Beijing, Chongqing, Tianjin, Guangzhou, Shenzhen	China
Bogota	Colombia
Mexico City	Mexico
Lagos	Nigeria
Lima	Peru
Moscow	Russia
Bangkok	Thailand
Istanbul	Türkiye
Lower Middle-Income (Developing) Countries	
Dhaka	Bangladesh
Kinshasa	Democratic Republic of Congo
Cairo	Egypt
Delhi, Hyderabad, Mumbai, Kolkata, Bangalore, Chennai	India
Jakarta	Indonesia
Karachi, Lahore	Pakistan
Manila	Philippines

Table 2. MSW disposal methods by income levels [6]

Countries by Income Levels	Open Dumping	Landfill	Recycling	Composting	Incineration	Other Advanced Disposal
				%		
High-Income	2	39	29	6	22	2
Upper Middle-Income	30	54	4	2	10	-
Lower Middle-Income	66	18	6	10	-	-

MATERIAL AND METHODOLOGY

This study reviews publications on waste management and Life Cycle Assessment (LCA) in megacities to analyze the comprehensiveness of existing LCA studies on municipal solid waste (MSW) management and identify key gaps in the literature. Additionally, it examines the common environmental and economic impacts of MSWM strategies in megacities based on LCA studies. The literature review was conducted in five stages using the Web of Science (WoS) and ScienceDirect databases.

In the first phase of the literature review, scientific publications related to Solid Waste Management (SWM) in megacities were sourced from the WOS database. Initially, sources were gathered using the keyword 'Solid Waste Management.' Subsequently, the search was refined by combining the keywords 'Solid Waste Management' and 'Megacity.' In the next stage, the keyword 'Municipal Solid Waste Management' was employed, followed by a combined search using the keywords 'Municipal Solid Waste Management'' and 'Megacity'. The third step involved integrating the 'Life Cycle Assessment' keyword into the literature review. The 'Life Cycle Assessment' keyword was applied in conjunction with 'Solid Waste Management' and 'Municipal Solid Waste Management' separately for megacities." Finally, LCA studies on MSWM in megacities were searched for in the Science Direct database.

REVIEW OF WASTE MANAGEMENT AND LIFE CYCLE ASSESSMENT (LCA) PUBLICATIONS IN MEGACITIES

Waste Management Publications in Megacities

In the first stage of the literature review, scientific publications on Solid Waste Management (SWM) in megacities were searched using the Web of Science (WOS) database. Initially, a source using only the keywords “Solid Waste Management” resulted in 6,892 studies. Following this, a more specific search combining the keywords “Solid Waste Management” and “Megacity” in the topic category yielded 22 studies.

In the second step of the search, the keyword “Municipal Solid Waste Management” was used, identifying a total of 1,740 studies. When the keywords, “Municipal Solid Waste Management” and “Megacity” were searched together, 4 studies were found. Upon detailed review, it was determined that only 4 of these studies were directly related to SWM in megacities, and these studies were the same as those identified in the search on MSWM in megacities (Table 3).

The first study on SWM in megacities was conducted in 2014. It examined the performance of public-private partnerships for household solid waste collection in Lagos, Nigeria [10]. Another study [11] critically explored how value appreciation from informal MSWM contributes to green neoliberalism and inclusive development in Lagos, Nigeria. The study by [12] aimed to investigate the current MSWM situation in Shanghai to advance existing MSWM research.

In Mexico City, fossil energy use, GHG emissions, resource recovery, and economic costs of the current MSWM and five alternative scenarios were evaluated by [13] to compare their performance and identify more sustainable MSWM practices for the megacity.

Table 3. Solid waste management (SWM) and municipal solid waste management (MSWM) publications in megacities [9]

Keywords	Publication Number
Solid Waste Management	6,892
Solid Waste Management + Megacity	4
Municipal Solid Waste Management	1,740
Municipal Solid Waste Management + Megacity	4

Life Cycle Assessment (LCA) Publications on Waste Management in Megacities

The search process was conducted using the Web of Science (WOS) and Science Direct databases. Initially, the keyword “Life Cycle Assessment” yielded 42,049 publications. The search was then refined by adding the keywords “Solid Waste Management” and “Municipal Solid Waste Management” to “Life Cycle Assessment”. This resulted in 635 LCA publications related to SWM and 296 publications related to MSWM (Table 4).

Next, the keyword “Megacity” was included in the search, yielding only one LCA publication related to SWM [13], which did not include an LCA process. Finally, a more specific search was conducted using “Life Cycle Assessment” and “Megacity” along with “Municipal Solid Waste Management”, which again resulted in only one LCA publication [13], the same study found in the SWM category. In conclusion, no LCA studies on SWM or MSWM in megacities were identified in the searches conducted in the WOS database. Aside from these findings, no studies were found when searching for the keywords “Life Cycle Assessment”, “Integrated Solid Waste Management”, and “Megacity” together in the WOS database.

In the second phase of the search process, the Science Direct database was used for a more detailed search. This search identified 18 LCA studies on MSWM in megacities which are listed according to their publication dates (Table 5).

Table 4. Number of life cycle assessment (LCA) publications on waste management [9]

LCA	Publication Number
Life Cycle Assessment	42,049
Life Cycle Assessment + Megacity	22
Life Cycle Assessment + Solid Waste Management	635
Life Cycle Assessment + Solid Waste Management + Megacity	0
Life Cycle Assessment + Municipal Solid Waste Management	296
Life Cycle Assessment + Municipal Solid Waste Management + Megacity	0

Life cycle assessment methodology is used to evaluate the environmental impacts of various disposal methods, including landfilling, composting, and biological treatment of simply biodegradable fractions of MSW in Sao Paulo City, Brazil [15]. Another study [16], analyses GHG emissions from landfill sites in Chennai megacity. Current and potential MSW management patterns were assessed in Tianjin megacity concerning GHG emissions using Life cycle assessment methodology [17].

Similarly, global warming potential (GWP) of various municipal waste management options is evaluated in Delhi megacity, India, using Life cycle assessment methodology [18]. Life cycle assessment and Multi-Criteria Decision Analysis (MCDA) techniques are harmonically combined to manage food waste from households in the megacity of Rio de Janeiro as a case study [19].

The Life cycle assessment method was applied to determine the most environmentally sustainable source-separated packaging waste collection system in Istanbul, Türkiye [20]. Additionally, another study [21] compared the environmental impacts of three management alternatives for the organic fraction of municipal solid waste in Rio de Janeiro using the Life cycle assessment method.

An emergy Life cycle assessment analysis of MSWM for Beijing was conducted in study [22], which analyzed four MSW collection and treatment strategies. Future food waste management alternatives were evaluated in Istanbul using Life cycle assessment [23].

Existing and alternative municipal packaging waste management systems were analyzed in the Maltepe district of Istanbul in terms of environmental and social impacts using Life cycle assessment method [24]. Life cycle assessment methodology (LCA) and Life Cycle Inventory (LCI) were applied to determine net carbon emissions during the treatment of food waste and residual waste collected from 2,365 families in three pilot communities in the Putuo district of Shanghai, China [25].

Table 5. Life cycle assessment (LCA) publications on municipal solid waste management (MSWM) in megacities [14]

	Megacities	References	Parameters	Waste Type/Process
1	Sao Paulo	[15]	Global warming, acidification, and nutrient enrichment	Simply biodegradable fraction of MSW
2	Chennai	[16]	GHG emissions	Landfill sites
3	Tianjin	[17]	GHG emissions	Current and possible MSWM strategies
4	Delhi	[18]	GWP	MSWM strategies
5	Rio de Janeiro	[19]	Environmental impacts	Food waste management
6	Istanbul	[20]	Environmental impacts	Packaging waste management
7	Rio de Janeiro	[21]	Environmental impacts	Three MSWM alternatives for organic fraction of MSW
8	Beijing	[22]	Total emergy use	MSWM strategies
9	Istanbul	[23]	Environmental impacts	Food waste
10	Istanbul	[24]	Environmental impacts	Packaging waste management
11	Shanghai	[25]	Net carbon emissions	Food waste and residual waste
12	Shanghai	[26]	GHG emissions	MSW Disposal Process Scenarios
13	Beijing	[27]	Energy recovery efficiency, LCC and benefit, GHG emissions	MSW Disposal Process Scenarios
14	Delhi	[28]	Environmental and economic impacts	Current MSWMS
15	Shanghai	[29]	GHG emissions	MSW incineration plant
16	Shanghai	[30]	Environmental impacts	Food waste
17	Shenzhen	[31]	Environmental and economic impacts	Organic waste management in Eco-industrial park
18	Kinshasa	[32]	GHG emission and costs	MSW strategies

Variations in GHG emission patterns from waste disposal processes in Shanghai were examined from 2005 to 2015 [26]. The study combined the IPCC-recommended method with a bottom-up method approach for detailed GHG emission estimations.

In another study conducted in Beijing, energy recovery efficiency, life cycle cost (LCC), benefits, and GHG emissions, were analyzed using Life cycle assessment methodology [27]. The environmental and economic impacts of the current waste management system in Delhi were analyzed using the Gabi 17.00 software for Life cycle assessment method [28].

The GHG emissions of an MSW incineration plant in Shanghai were evaluated with Life cycle assessment [29]. LCA was also used to determine the environmental impacts of food waste in Shanghai, China between 1986 and 2020 in the other study [30].

Finally, Life cycle assessment was applied for the environmental management of an eco-industrial park in Shenzhen city, which includes a food waste anaerobic digestion plant, an animal carcass disposal center, a fecal composting plant, and a wastewater treatment plant for synergistic organic waste treatment [31].

Based on the search results from the WOS database, only 4 studies on SWM and MSWM in megacities were found. All of these studies were conducted in upper middle income countries, and no LCA studies on SWM or MSWM in megacities were identified.

A detailed search in the Science direct database revealed 18 LCA studies (Table 5) on waste management in megacities. Of these, three studies which referenced as [16], [18], and [28] were conducted in the megacities in Chennai and Delhi in India, a lower-middle income country. One study [32] was conducted in the megacities of Kinshasa in Democratic Republic of Congo, also a lower middle income country. The remaining 14 studies (Table 5) were carried out in megacities in Brazil, China, Türkiye, and India, all of which are upper middle income countries. Notably, no LCA studies on waste management in megacities located in developed countries were found. As observed from the LCA publications, only specific aspects of waste management, such as biowaste, packaging waste, and food waste, have been studied in megacities. Among these publications, 6 studies which referenced as [17], [18], [22], [26], [27], and [32] focused on current and alternative MSWM systems, but they primarily analyzed only GWP, GHG, and energy production.

CONCLUSION

This study reviewed existing Life Cycle Assessment (LCA) studies on municipal solid waste (MSW) management in megacities to assess their comprehensiveness and identify key research gaps. The findings indicate that while LCA studies on MSWM strategies in megacities provide valuable insights into environmental and economic impacts, several limitations remain.

The existing studies predominantly focus on greenhouse gas (GHG) emissions and environmental impacts, with fewer addressing broader sustainability aspects such as social, health, and policy implications. Additionally, most studies analyze specific waste fractions, such as food waste, packaging waste, and biodegradable MSW, while other significant waste streams, including hazardous waste and e-waste, receive limited attention. Moreover, research on MSWM strategies often centers on individual megacities without cross-city comparisons, making it difficult to generalize findings across different urban contexts.

From an environmental perspective, the reviewed studies highlight that MSWM strategies significantly influence global warming potential (GWP), acidification, nutrient enrichment, and net carbon emissions. Landfills and incineration plants are frequently analyzed, but alternative waste treatment technologies, such as advanced recycling systems and circular economy approaches, remain underexplored. The economic impacts of MSWM strategies have been evaluated in only a few studies, such as those in Delhi, Shenzhen, and Kinshasa, suggesting the need for further research into the cost-effectiveness and financial sustainability of waste management solutions in megacities.

Additionally, this study demonstrates that a notable gap in the literature is the lack of LCA studies on waste management in megacities located in developed countries. Furthermore, although certain cities in lower-middle-income countries, like Chennai, Delhi, and Kinshasa, have been included in some studies, the majority of research comes from upper-middle-income nations such as Brazil, China, Türkiye, and India. LCA studies on waste management in megacities of developed countries are limited due to several factors. These include well-established waste management systems, strict regulatory frameworks, and the assumption that existing practices are already sustainable. Additionally, data accessibility issues, research prioritization toward emerging environmental challenges, and the complexity of waste streams make conducting LCA studies more challenging. LCA studies on waste management in megacities of lower-middle-income countries are limited due to data scarcity, insufficient funding, and a focus on immediate waste management challenges rather than environmental assessments. The dominance of informal waste sectors, weak regulatory frameworks, and limited research capacity further hinder the feasibility of conducting LCA studies.

To enhance LCA studies on waste management in megacities, future research should expand its scope to include social, health, and economic impacts while addressing neglected waste streams like hazardous waste and e-waste. Increasing studies in developed and lower-middle-income countries requires better funding, data accessibility, and research infrastructure. Exploring advanced waste treatment technologies, such as circular economy approaches and waste-to-energy solutions, can improve sustainability assessments. Standardized LCA frameworks and cross-city comparative analyses will help generalize findings and identify best practices. Additionally, strengthening data collection systems, fostering collaborations, and evaluating the cost-effectiveness of MSWM strategies will support informed decision-making and more effective waste management policies.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest with any individual, institution, or organization in the preparation, evaluation, or publication of this study.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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