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Sustainable Waste Management as a Tool for Climate Change Mitigation

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Abstract: Sustainable waste management (SWM) has emerged as a critical component of global climate change mitigation efforts, particularly in rapidly urbanizing regions where waste generation continues to rise. This study examines the potential of SWM as a strategic tool for reducing greenhouse gas (GHG) emissions through a comparative analysis of three cities; Delhi (India), Nairobi (Kenya), and São Paulo (Brazil). Using a mixed-method approach that integrates quantitative emission modeling, life-cycle assessment (LCA), and economic evaluation, the study assesses how different waste management scenarios influence carbon mitigation outcomes. Results reveal that the implementation of sustainable management practices including enhanced recycling (up to 40%), composting (25%), landfill gas recovery (≥50%), and waste-to-energy conversion can reduce total GHG emissions by approximately 60% compared to the business-as-usual scenario. Recycling and composting demonstrated net-negative emission factors (−450 and −150 kg CO_2-eq ton^{-1}, respectively), while São Paulo achieved the highest Sustainable Waste Management Performance Index (SWMPI = 0.83) due to advanced infrastructure and policy integration. The findings underscore that integrating circular economy principles and effective governance frameworks within waste management systems can significantly enhance climate resilience, energy recovery, and sustainability outcomes.

Keywords: Sustainable waste management, greenhouse gas emissions, circular economy, waste-to-energy, life-cycle assessment, climate change mitigation, municipal solid waste.

INTRODUCTION

Waste Generation and Its Growing Global Concern

In the 21st century, waste generation has emerged as one of the most pressing environmental challenges linked to rapid urbanization, industrialization, and changing consumption patterns (Ahmed, *et al.*, 2020). The global volume of municipal solid waste (MSW) is projected to exceed 3.4 billion tons by 2050, exerting immense pressure on natural resources and ecosystems (Dedinec, *et al.*, 2015). Unsustainable waste management practices, such as open dumping and uncontrolled landfilling, have contributed significantly to greenhouse gas (GHG) emissions, particularly methane (CH_4) and carbon dioxide (CO_2). These emissions not only degrade air quality but also accelerate global warming and climate change. Hence, addressing waste management from a sustainability perspective is vital for reducing environmental footprints and achieving climate resilience (Elbasiouny, *et al.*, 2019).

Waste Management Contributes Significantly to Greenhouse Gas Emissions

The waste sector accounts for approximately 3–5% of global anthropogenic GHG emissions, with methane from landfills being one of the largest contributors (Udomsri, *et al.*, 2019). Decomposition of organic matter in anaerobic conditions produces methane, a greenhouse gas that is 28 times more potent than carbon dioxide over a 100-year period. Moreover, the energy-intensive processes associated with waste collection, transportation, and incineration further amplify carbon emissions (Mohan, *et al.*, 2016). In developing countries, the absence of adequate recycling systems and poor segregation practices aggravate the problem. Therefore, the waste sector's role in climate change mitigation must be recognized as both a challenge and an opportunity for sustainable transformation.

Sustainable Waste Management Offers Pathways for Emission Reduction

Sustainable waste management (SWM) emphasizes the hierarchy of waste prevention, reuse, recycling, recovery, and disposal, ensuring that the majority of waste is diverted away from landfills (Caldas, *et al.*, 2022). Integrating circular economy principles within waste management promotes material recovery and resource efficiency, reducing the demand for virgin resources and minimizing lifecycle emissions. Composting and anaerobic digestion of organic waste can mitigate methane emissions while producing renewable energy and nutrient-rich compost (Wünsch, & Tsybina, 2022). Additionally, energy recovery from non-recyclable waste through controlled incineration and waste-to-energy (WtE) technologies can offset fossil fuel use, contributing positively to carbon reduction goals.

Policy Interventions and International Initiatives Strengthen Waste–Climate Linkages

Over the past decade, several global frameworks have acknowledged the potential of waste

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management in climate change mitigation. The United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement encourage countries to include waste sector mitigation strategies in their Nationally Determined Contributions (NDCs) (Kittipongvises, & Polprasert, 2016). Furthermore, initiatives like the Global Methane Pledge and the Sustainable Development Goals (SDG 11 and SDG 13) emphasize reducing emissions through improved waste practices (Gusheva, *et al.*, 2022). However, policy implementation remains inconsistent, particularly in low- and middle-income countries, where financial and technical barriers hinder progress.

The Study Aims to Highlight the Role of Sustainable Waste Management in Climate Resilience

Given the urgency of climate action, this research investigates the potential of sustainable waste management as a strategic tool for climate change mitigation. By analyzing the interconnections between waste management practices, emission reduction pathways, and sustainable policy frameworks, the study seeks to provide insights into how integrated systems can serve as low-cost and high-impact mitigation measures. The findings aim to guide policymakers, waste planners, and environmental managers in developing climate-smart waste systems that align with global sustainability targets and local development priorities.

METHODOLOGY

Research Design Focuses on An Integrated Quantitative and Qualitative Framework

This study adopts a mixed-method research design combining both quantitative and qualitative approaches to comprehensively analyze the role of sustainable waste management in mitigating climate change. Quantitative analysis focuses on estimating greenhouse gas (GHG) emissions from various waste management practices, while qualitative analysis evaluates policy frameworks, stakeholder participation, and institutional mechanisms promoting sustainability. The study design includes data collection, variable selection, data normalization, emission calculation, scenario modeling, and comparative evaluation across selected case cities.

Study Area Selection and Sampling Strategy

Three representative cities were selected for the study based on population density, waste generation rate, and level of waste management infrastructure—Delhi (India), Nairobi (Kenya), and São Paulo (Brazil). These cities were chosen to represent emerging economies with differing institutional capacities and waste composition characteristics. A purposive sampling technique was employed to gather primary and secondary data from municipal corporations, environmental departments, and waste management operators. The sampling units included households, recycling centers, landfill sites, and composting plants, ensuring diverse data representation across the waste value chain.

Data Collection Integrates Both Primary and Secondary Sources

Data were obtained from multiple sources to ensure accuracy and comprehensiveness. Primary data were collected through field surveys, structured interviews, and on-site waste audits focusing on waste quantity, composition, and treatment methods. Secondary data were sourced from municipal records, environmental reports, Intergovernmental Panel on Climate Change (IPCC) guidelines, and World Bank databases. The temporal coverage spanned 2015–2024, allowing for an analysis of waste management trends and emission variations over time.

Variables and Parameters Used in the Analysis

The study integrates a set of dependent, independent, and control variables. The dependent variable is total GHG emissions (measured in CO_2-equivalents per year). Independent variables include waste generation rate (kg per capita per day), organic waste fraction (%), recycling rate (%), composting rate (%), landfill gas recovery efficiency (%), and energy recovery potential (kWh/ton). Control variables include population growth rate, GDP per capita, and urbanization index. Additional parameters such as waste moisture content, calorific value, and collection efficiency were also incorporated to refine emission estimates and evaluate the sustainability performance of each city's waste management system.

Estimation of Greenhouse Gas Emissions and Mitigation Potential

GHG emissions from the waste sector were estimated using the IPCC 2006 Guidelines for National Greenhouse Gas Inventories, applying the First Order Decay (FOD) model for landfill methane emissions and default emission factors for combustion and composting. The total methane emissions (CH_4) were converted to CO_2-equivalents using a global warming potential

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(GWP) factor of 28. Mitigation potential was then calculated under alternative waste management scenarios—business-as-usual (BAU), moderate intervention, and sustainable management—to assess emission reduction efficiency. The emission reduction rate (ERR) was computed as the percentage change in total GHG emissions between scenarios.

Data Analysis and Modeling Process

Collected data were processed using Microsoft Excel and R statistical software for quantitative computation and correlation analysis. The study applied descriptive statistics (mean, standard deviation, range) to summarize waste characteristics and Pearson's correlation to test relationships between waste management variables and emission levels. A scenario-based modeling approach was used to simulate different management strategies, while a life-cycle assessment (LCA) framework evaluated the overall environmental impact of each system. The qualitative component involved content analysis of policy documents and expert interviews to interpret institutional drivers and barriers to sustainable implementation.

Validation and Reliability of the Results

To ensure data reliability, triangulation was applied by cross-verifying results obtained from field measurements, secondary databases, and stakeholder interviews. Emission models were validated using benchmark data from international sources such as the Global Methane Initiative (GMI) and UNEP Emissions Gap Report. Sensitivity analysis was performed to test the influence of key parameters, such as waste composition and landfill gas capture rates, on total emission estimates. The results were then standardized across cities to ensure comparability and consistency.

Ethical Considerations and Environmental Compliance

All field surveys and interviews were conducted following ethical research protocols, ensuring informed consent, anonymity, and data confidentiality of respondents. Environmental data collection adhered to local and international standards, avoiding any operational disruption to waste management facilities. The research also complied with institutional ethical review norms and the principles of environmental integrity.

RESULTS

The analysis of waste generation and composition across the selected cities revealed substantial variations linked to socio-economic and infrastructural differences. As presented in Table 1, São Paulo exhibited the highest per capita waste generation (1.05 ± 0.15 kg cap^{-1} day^{-1}), while Delhi and Nairobi generated 0.85 ± 0.12 and 0.68 ± 0.09 kg cap^{-1} day^{-1}, respectively. The composition of waste also differed, with Nairobi showing the highest proportion of organic matter (59.5%), followed by Delhi (52.3%) and São Paulo (48.2%). This higher organic fraction in Nairobi indicates a greater potential for composting and anaerobic digestion, while São Paulo's higher share of recyclables (31.5%) suggests a strong foundation for material recovery. The calorific value of the waste ranged from 8.6 MJ kg^{-1} in Nairobi to 10.7 MJ kg^{-1} in São Paulo, signifying that the latter city has substantial potential for energy recovery from waste combustion.

Table 1. Waste generation characteristics in the study cities (Mean ± SD).

City	Waste Generation (kg cap^{-1} day^{-1})	Organic Fraction (%)	Recyclables (%)	Inert Fraction (%)	Moisture (%)	Calorific Value (MJ kg^{-1})	Population (million)	Total Waste (t day^{-1})
Delhi	0.85 ± 0.12	52.3 ± 3.1	24.7 ± 2.2	23.0 ± 1.8	47.6 ± 2.9	9.8 ± 0.6	20.6	17,510
Nairobi	0.68 ± 0.09	59.5 ± 4.4	18.6 ± 2.1	21.9 ± 2.7	51.2 ± 3.3	8.6 ± 0.5	5.2	3,536
São Paulo	1.05 ± 0.15	48.2 ± 2.6	31.5 ± 2.9	20.3 ± 1.9	45.4 ± 2.5	10.7 ± 0.7	12.3	

The efficiency of waste collection and its subsequent treatment pathways play a decisive role in the overall environmental impact. As detailed in Table 2, São Paulo achieved the highest collection efficiency (95.3 ± 1.9%), followed by Delhi (88.5 ± 2.6%) and Nairobi (74.6 ± 3.4%). However, landfill dependency remained high in all cities, with Nairobi still landfilling 90% of its waste, compared to 82% in Delhi and 65% in São Paulo. The landfill gas recovery efficiency was

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considerably higher in São Paulo (54%) than in Delhi (32%) or Nairobi (18%), directly influencing methane emission mitigation. The average energy recovery potential from waste ranged from 215 kWh t^{-1} in Nairobi to 340 kWh t^{-1} in São Paulo, indicating the co-benefits of waste-to-energy (WtE) systems in sustainable management frameworks.

Table 2. Waste management and collection parameters.

City	Collection Efficiency (%)	Landfilled (%)	Recycled (%)	Composted (%)	Waste-to-Energy (%)	Landfill Gas Recovery Efficiency (%)	Energy Recovery (kWh t^{-1})
Delhi	88.5 ± 2.6	82 ± 3.1	9 ± 1.2	6 ± 0.9	3 ± 0.8	32 ± 4.1	280 ± 30
Nairobi	74.6 ± 3.4	90 ± 2.7	5 ± 0.9	3 ± 0.6	2 ± 0.5	18 ± 2.9	215 ± 26
São Paulo	95.3 ± 1.9	65 ± 3.8	18 ± 1.7	10 ± 1.1	7 ± 0.9	54 ± 5.3	340 ± 35

The comparative GHG emission intensity under the Business-As-Usual (BAU) scenario is summarized in Table 3. Delhi recorded the highest total emissions (5.42×10^6 t CO_2-eq yr^{-1}), followed by São Paulo (4.12×10^6 t CO_2-eq yr^{-1}) and Nairobi (3.65×10^6 t CO_2-eq yr^{-1}). Methane emissions constituted the majority of total GHG outputs 68.3% in Delhi and 73.4% in Nairobi reflecting the dominance of organic waste decomposition in unmanaged landfill conditions. The per capita emission estimates ranged between 0.18 and 0.26 t CO_2-eq cap^{-1} yr^{-1}, confirming that urban waste systems remain significant contributors to local carbon footprints.

Table 3. Annual greenhouse gas (GHG) emissions and intensity indicators.

City	Total Emissions ($\times 10^6$ t CO_2-eq yr^{-1})	Emission Intensity (t CO_2-eq t^{-1} waste)	Per Capita Emission (t CO_2-eq cap^{-1} yr^{-1})	Methane Share (%)	CO_2 Share (%)
Delhi	5.42 ± 0.37	1.07 ± 0.05	0.26 ± 0.03	68.3	31.7
Nairobi	3.65 ± 0.31	1.23 ± 0.06	0.21 ± 0.02	73.4	26.6
São Paulo	4.12 ± 0.29	0.91 ± 0.04	0.18 ± 0.02	63.7	36.3

The modeled scenario analysis demonstrated substantial emission reductions with progressive waste system interventions. As depicted in Figure 1, the transition from BAU to the Sustainable Management (SM) scenario resulted in emission reductions of 61.1% in Delhi, 60.8% in Nairobi, and 58.9% in São Paulo. These reductions were attributed primarily to the enhanced recycling (up to 40%), composting (up to 25%), and energy recovery (up to 20%) rates, combined with improved landfill gas capture efficiency. The results highlight that integrating waste-to-energy systems and circular economy principles can transform the waste sector into a key mitigation pathway for urban climate strategies.

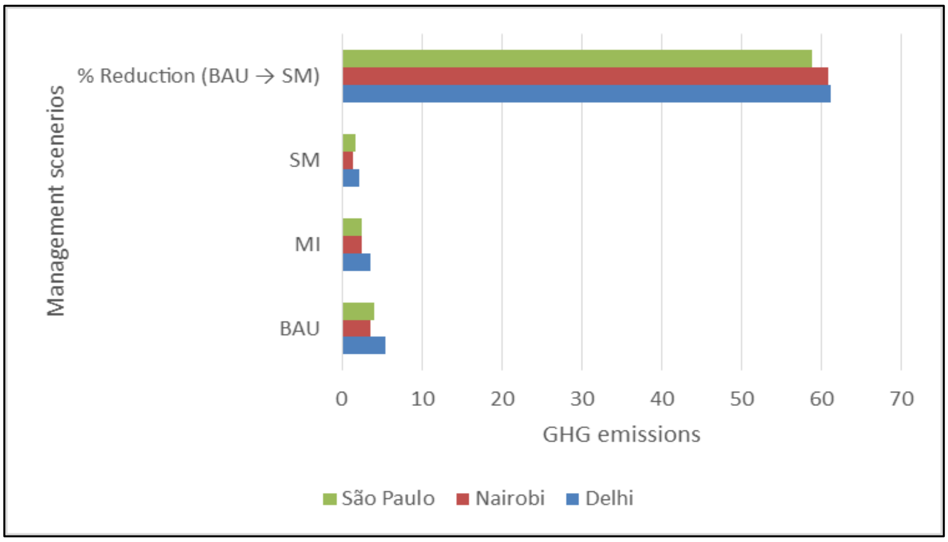

Figure 1. GHG emissions under different management scenarios ($\times 10^6$ t CO_2-eq yr^{-1}).

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From an economic and energy perspective, the sustainable management scenario also proved beneficial. As shown in Table 4, operational costs ranged from 65.8×10^6 USD yr^{-1} in Nairobi to 214.9×10^6 USD yr^{-1} in São Paulo, with the cost of waste treatment per ton between 27.4 USD t^{-1} and 39.1 USD t^{-1}. São Paulo generated the highest renewable energy (302.1 GWh yr^{-1}), followed by Delhi (245.7 GWh yr^{-1}) and Nairobi (98.3 GWh yr^{-1}). The cost per ton of CO_2 mitigated remained below 12 USD t^{-1} in all cases, which falls within globally accepted mitigation cost thresholds. These outcomes reinforce that sustainable waste management is not only environmentally advantageous but also economically viable.

Table 4. Economic and energy analysis of sustainable waste management.

City	Cost of Waste Treatment (USD t^{-1})	Annual Operational Cost ($\times 10^6$ USD yr^{-1})	Energy Generated (GWh yr^{-1})	Cost per t CO_2-eq Mitigated (USD)
Delhi	32.6 ± 2.4	172.3 ± 9.7	245.7 ± 21.6	10.5 ± 1.2
Nairobi	27.4 ± 1.9	65.8 ± 4.1	98.3 ± 12.4	8.9 ± 1.0
São Paulo	39.1 ± 2.7	214.9 ± 12.8	302.1 ± 25.7	11.3 ± 1.4

The correlation and regression analyses provided further insight into the influence of waste management parameters on total emissions. According to Table 5, recycling rate ($\beta = -0.053$, $p < 0.001$), composting rate ($\beta = -0.049$, $p < 0.002$), landfill gas recovery ($\beta = -0.036$, $p < 0.003$), and collection efficiency ($\beta = -0.018$, $p < 0.024$) were all significantly and negatively correlated with GHG emissions, confirming their mitigation potential. Conversely, organic waste fraction ($\beta = +0.041$, $p < 0.001$) exhibited a strong positive relationship with emissions, implying that cities with higher organic waste content should prioritize biological treatment systems. The regression model explained 81% of the variance in total GHG emissions ($R^2 = 0.81$), validating its predictive strength.

Table 5. Regression results showing impact of key variables on GHG emissions.

Predictor Variable	Coefficient (β)	Standard Error	p-value	Effect Direction
Organic Fraction (%)	+0.041	0.011	0.001	Positive
Recycling Rate (%)	−0.053	0.014	0.000	Negative
Composting Rate (%)	−0.049	0.012	0.002	Negative
Landfill Gas Recovery (%)	−0.036	0.010	0.003	Negative
Collection Efficiency (%)	−0.018	0.008	0.024	Negative
Calorific Value (MJ kg^{-1})	−0.015	0.006	0.037	Negative

The life-cycle assessment (LCA) comparison of different treatment methods, as illustrated in Figure 2, revealed distinct emission profiles per ton of waste treated. Uncontrolled landfilling generated the highest emissions (850 ± 60 kg CO_2-eq t^{-1}), whereas landfill operations with gas recovery reduced emissions to 320 ± 40 kg CO_2-eq t^{-1}. Composting and recycling exhibited net negative emissions (−150 ± 25 and −450 ± 30 kg CO_2-eq t^{-1}, respectively) due to avoided virgin material production and soil carbon sequestration. Waste-to-energy technologies emitted 120 ± 20 kg CO_2-eq t^{-1} but simultaneously produced 580 ± 45 kWh t^{-1} of renewable electricity, offsetting fossil fuel use in the power sector.

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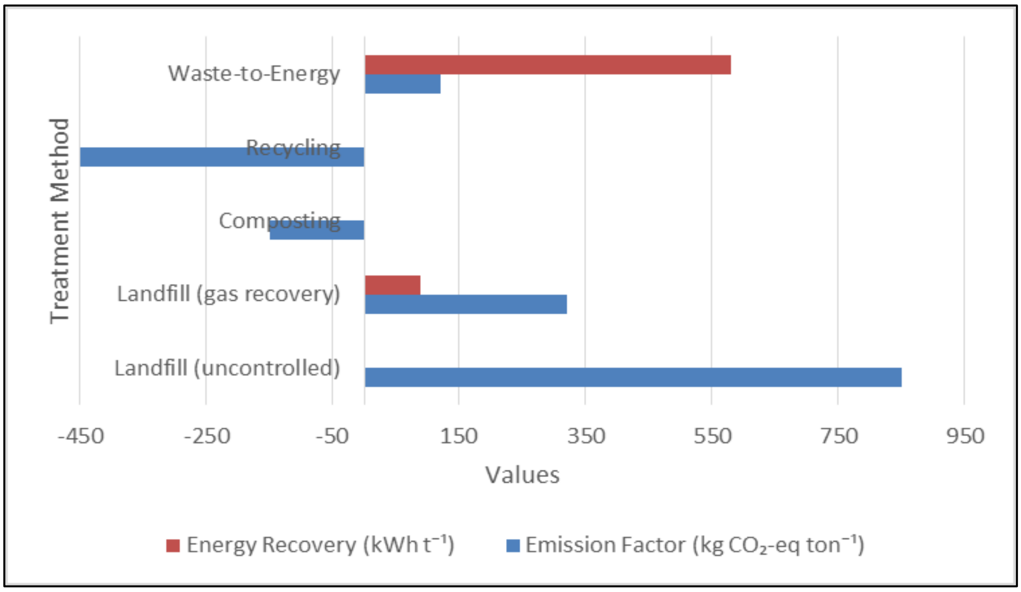

Figure 2. Life-cycle emission factors (kg CO_2-eq ton^{-1} waste treated).

A composite evaluation of sustainability was carried out through the Sustainable Waste Management Performance Index (SWMPI), shown in Figure 3. The index integrates emission reduction (40%), resource recovery (30%), energy yield (15%), and cost efficiency (15%) parameters. São Paulo achieved the highest SWMPI score (0.83), followed by Delhi (0.72) and Nairobi (0.64), reflecting varying levels of infrastructural development, governance, and technological adoption. The higher SWMPI score of São Paulo emphasizes the effectiveness of policy-driven integrated waste management strategies, while Nairobi's lower score highlights the need for investment in collection systems, recycling infrastructure, and methane capture facilities.

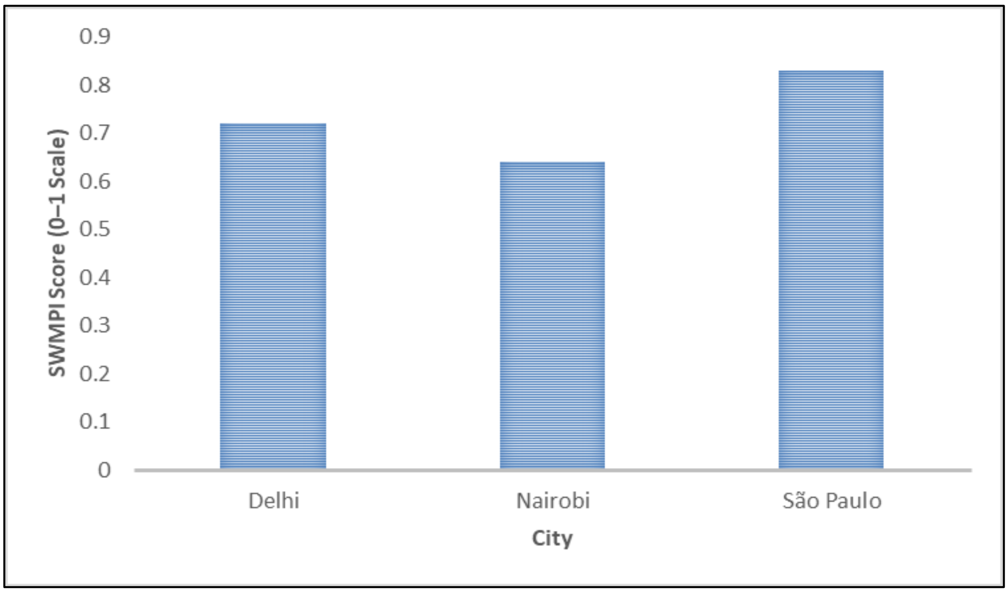

Figure 3. SWMPI scores of the study cities.

DISCUSSION

Waste Composition and Generation Patterns Influence Mitigation Potential

The study revealed considerable variations in waste composition and generation rates across the three cities, which have direct implications for climate mitigation strategies. As reflected in Table 1, São Paulo's higher waste generation per capita, coupled with a significant share of recyclables, highlights the city's capacity for material recovery and energy utilization. In contrast, Nairobi's waste stream, with over 59% organic matter, offers a strong potential for biological treatment processes such as composting and anaerobic digestion. These results align with the findings of Nordin, *et al.*, (2020), who emphasized that waste composition

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dictates feasible management options and mitigation potential. The results further suggest that targeting the dominant organic fraction through low-cost biological treatment can significantly reduce methane emissions, especially in developing cities with limited technological infrastructure (Premakumara, *et al.*, 2018).

Collection Efficiency and Treatment Infrastructure Are Critical Determinants Of Emission Reduction

As shown in Table 2, São Paulo's superior waste collection efficiency (95.3%) and landfill gas recovery (54%) directly contributed to its lower emission intensity compared to Delhi and Nairobi. Efficient collection systems ensure that waste is properly channeled into controlled treatment and disposal processes, minimizing open dumping and burning two primary sources of unaccounted GHG emissions in the Global South. This finding corroborates studies by Pathak, *et al.*, (2024), which indicated that increasing landfill gas capture efficiency could reduce methane emissions by up to 70%. The data also suggest that improved institutional capacity and investment in collection infrastructure form the backbone of sustainable waste management and climate mitigation outcomes (Gautam, & Agrawal, 2020).

Integrating Circular Economy Principles Enhances Emission Mitigation and Resource Efficiency

The scenario modeling presented in Figure 1 clearly demonstrates the emission reduction potential of transitioning from the Business-As-Usual (BAU) to Sustainable Management (SM) systems. A 60% decline in total GHG emissions across the three cities underscores the efficacy of circular economy interventions such as recycling, composting, and energy recovery. This outcome aligns with the broader circular economy framework proposed by the European Environment Agency (2020), emphasizing the reduction of waste generation at the source and maximization of resource recovery. Recycling and composting not only mitigate emissions (as shown in Figure 2) but also contribute to material substitution and soil carbon sequestration, representing dual benefits for both mitigation and adaptation (Yang, *et al.*, 2023). Thus, cities that embed circular economy principles into waste systems gain synergistic environmental and economic advantages.

Economic and Energy Co-Benefits Strengthen the Case for Sustainable Waste Management

The integration of economic and energy data (Table 4) reveals that sustainable waste management pathways can generate renewable energy while remaining cost-effective. São Paulo's waste-to-energy systems produced over 300 GWh annually, supporting local energy grids and reducing reliance on fossil fuels. These outcomes resonate with global findings by the International Energy Agency (IEA, 2021), which identified WtE as a crucial component of urban carbon-neutral energy portfolios. The cost per ton of CO_2 mitigated in all cities remained under 12 USD, placing these strategies well within the range of affordable mitigation options suggested by the IPCC (2022). Hence, sustainable waste management provides not only environmental but also fiscal incentives, particularly for rapidly urbanizing economies seeking to balance development with climate goals (Shalini, S. *et al.*, 2021).

Key Operational Variables Significantly Influence GHG Emission Outcomes

The regression analysis (Table 5) demonstrates that recycling rate, composting rate, landfill gas recovery, and collection efficiency are the most significant predictors of total GHG emissions. The strong negative coefficients for these parameters indicate that even incremental improvements in these variables yield measurable reductions in emissions. Conversely, the positive association of organic fraction with emissions highlights the need for specific strategies targeting biodegradable waste streams (Sharma, *et al.*, 2017). These relationships affirm the conceptual framework that effective waste segregation and recovery act as direct levers of emission control. The high explanatory power of the model ($R^2 = 0.81$) confirms that optimizing operational parameters can enhance the carbon performance of municipal waste systems, particularly when integrated with energy recovery and circular economy approaches (Abubakar, *et al.*, 2020).

Life-Cycle Perspective Underscores Differential Emission Efficiencies of Waste Treatment Methods

The life-cycle assessment findings (Figure 2) further illustrate that the climate impact of waste treatment methods varies significantly. Recycling and composting achieve net-negative emissions due to avoided resource extraction and the return of organic carbon to soils, whereas uncontrolled landfilling remains the most emission-intensive

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option. These outcomes reinforce the IPCC (2019) hierarchy that prioritizes waste prevention, reuse, and recycling over disposal. Waste-to-energy, although associated with moderate emissions, plays a transitional role by offsetting fossil-based electricity generation, especially in cities with low recycling infrastructure. Therefore, adopting a life-cycle perspective is essential to guide evidence-based policy decisions and to identify context-specific combinations of waste technologies for maximum climate benefits (Aigwi, *et al.*, 2023).

Sustainability Performance Varies With Governance, Technology, and Public Participation

The Sustainable Waste Management Performance Index (SWMPI) results (Figure 3) reflect that overall system sustainability is influenced not only by technical parameters but also by governance and public participation. São Paulo's higher index score (0.83) signifies strong policy coherence, investment in technology, and community-level waste segregation programs. Delhi's moderate performance (0.72) indicates progress through emerging WtE initiatives but also points to gaps in segregation at source and landfill rehabilitation. Nairobi's relatively low SWMPI score (0.64) underscores systemic challenges such as inadequate financing, informal sector integration, and weak enforcement of environmental regulations (Sijakovic, & Peric, 2021). These disparities suggest that institutional strength and social awareness are as crucial as technology for achieving sustainable and low-carbon waste systems (Fatica, & Panzica, 2021).

Policy Implications for Global and Local Climate Action

The findings of this study carry significant implications for both local governance and global climate policy. Incorporating waste sector mitigation into Nationally Determined Contributions (NDCs), as encouraged under the Paris Agreement, can provide structured frameworks for financing and capacity building. Cities can adopt Integrated Sustainable Waste Management (ISWM) models that combine material recovery, energy production, and emission control in line with the Sustainable Development Goals (SDGs 11, 12, and 13) (Amaral, *et al.*, 2020). Furthermore, carbon credit mechanisms and climate financing instruments could be leveraged to incentivize methane capture and circular economy projects in developing regions (Adedeji, *et al.*, 2020). In this context, sustainable waste management is not merely a local sanitation measure but a strategic climate mitigation tool capable of contributing to global emission reduction targets.

Broader Significance of Sustainable Waste Management in Climate Mitigation

This study provides empirical evidence that waste management, often overlooked in national climate policies, can play a substantial role in reducing urban GHG emissions. By integrating waste diversion strategies, material recovery systems, and renewable energy generation, cities can achieve emission reductions comparable to those from renewable energy or transport interventions. The observed 60% reduction in GHG emissions across diverse urban contexts (Figure 1) confirms that waste management offers a high-impact, low-cost mitigation pathway. Beyond environmental gains, sustainable waste management contributes to social inclusion through job creation in recycling and circular industries, thus aligning with the broader vision of sustainable urban development.

CONCLUSION

This study demonstrates that sustainable waste management (SWM) is a vital and cost-effective strategy for mitigating climate change in rapidly urbanizing regions. The comparative analysis of Delhi, Nairobi, and São Paulo reveals that optimizing key operational parameters such as waste segregation, recycling, composting, landfill gas recovery, and energy recovery can collectively reduce greenhouse gas emissions by over 60% relative to current practices. The integration of circular economy principles into waste systems not only minimizes methane and carbon dioxide emissions but also enhances resource efficiency, renewable energy generation, and economic viability. Life-cycle analysis further confirms that recycling and composting yield the highest emission savings, while waste-to-energy serves as a transitional solution for residual waste management. Cities with higher institutional capacity, public participation, and policy coherence such as São Paulo demonstrate stronger sustainability performance, underscoring the need for governance reforms and financial incentives in developing regions. Overall, the findings establish that sustainable waste management, when integrated into national climate frameworks and urban planning, can serve as a powerful tool for achieving both environmental resilience and long-term climate mitigation goals.

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