ENVIRONMENTAL REPORTS

Review Article
ISSN: 3041-556X
Journal homepage: https://er.researchfloor.org/

Circular Economy as an Alternative to Waste Burning: A Comparative Review of Municipal Solid Waste Management in Sweden and Bengaluru, India

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Citation: Vasant G Kulkarni and T. S. Harsha (2026). Circular Economy as an Alternative to Waste Burning: A Comparative Review of Municipal Solid Waste Management in Sweden and Bengaluru, India. *Environmental Reports; an International Journal*.
DOI: https://doi.org/10.51470/ER.2026.8.2.38

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Received 15 April 2026 | Revised 12 May 2026 | Accepted 16 June 2026 | Available Online July 14 2026

ABSTRACT

Municipal solid waste (MSW) management is a major environmental and economic challenge for rapidly urbanising cities. Conventional waste management practices, including landfilling and open burning, contribute to greenhouse gas emissions, environmental degradation, and resource depletion. In contrast, circular economy approaches promote waste prevention, reuse, recycling, and resource recovery, thereby transforming waste into an economic resource. This review synthesises published literature and government reports to compare municipal solid waste management systems in Sweden and Bengaluru, India. The review examines waste generation, segregation, recycling efficiency, waste-to-energy technologies, biogas production, landfill diversion, governance, and economic performance. Sweden demonstrates an advanced circular economy model characterised by near-complete landfill diversion, extensive recycling, waste-to-energy facilities, and strong policy enforcement. Bengaluru, despite comprehensive policy frameworks, continues to experience challenges related to inadequate segregation, high transportation costs, landfill dependency, and periodic waste burning. Based on the comparative analysis, this review proposes decentralised ward-level recycling centres and biomethanation facilities as practical strategies for improving resource recovery and reducing waste burning. The review concludes that adaptation of circular economy principles offers Bengaluru an economically viable and environmentally sustainable pathway for municipal solid waste management.

Keywords: *Circular economy, Municipal solid waste, Waste-to-energy, Recycling, Biomethanation, Sweden, Bengaluru, Resource recovery.*

1.0 Introduction

Municipal solid waste (MSW) management has become one of the foremost environmental and sustainability-challenges of the twenty-first century. Accelerated urbanization, population growth, industrial development, and changing consumption patterns have led to a continuous increase in the quantity and complexity of municipal waste generated worldwide. Current estimates indicate that global MSW generation exceeds 2 billion tons annually and is expected to increase substantially by 2050, placing enormous pressure on urban infrastructure, natural resources, and public health. Conventional waste management practices, particularly landfilling and open burning, remain prevalent in many developing regions despite their well-documented environmental impacts, including greenhouse gas emissions, air and soil pollution, groundwater contamination, and the loss of potentially recoverable materials. These challenges have intensified the need for sustainable waste management strategies that minimize environmental impacts while maximising resource efficiency [1].

The circular economy (CE) has emerged as a promising framework for addressing these challenges by shifting waste management from a linear "take-make-dispose" model towards a regenerative system based on waste prevention, reuse, recycling, material recovery, and energy generation.

In contrast to conventional waste disposal approaches, the circular economy views waste as a valuable resource capable of generating economic, environmental, and social benefits. Numerous studies have highlighted that integrating recycling, composting, biomethanation, and waste-to-energy technologies within a circular economy framework can significantly reduce landfill dependency, conserve natural resources, lower greenhouse gas emissions, and contribute to renewable energy production [2,3].

Among countries that have successfully implemented circular economy principles, Sweden is widely recognized as an international benchmark for sustainable municipal solid waste management. Its integrated system combines source segregation, extended producer responsibility, advanced recycling technologies, waste-to-energy facilities, and anaerobic digestion for biogas production, resulting in the diversion of almost all municipal waste from landfills. Strong policy support, effective governance, public participation, and continuous technological innovation have enabled Sweden to transform municipal waste into a valuable economic and energy resource, demonstrating the practical benefits of adopting circular economy principles at the national level.[4]

In contrast, rapidly urbanising cities in developing countries continue to face significant challenges in implementing circular waste management systems.

Bengaluru, one of India's fastest-growing metropolitan cities, generates approximately 6,000–7,000 tons of municipal solid waste daily and has experienced persistent challenges related to incomplete source segregation, inadequate recycling infrastructure, high transportation costs, landfill dependence, and periodic waste burning. Although national policies such as the Solid Waste Management Rules, 2016 have established a regulatory framework promoting segregation, recycling, and scientific waste processing, implementation remains inconsistent because of institutional, financial, and behavioural constraints. Consequently, much of the municipal waste management system continues to operate within a predominantly linear framework, limiting opportunities for resource recovery and circular resource utilization. [5,6,7]

A growing body of literature has independently examined Sweden's circular economy achievements and the operational challenges associated with municipal solid waste management in Indian cities. However, comparatively few review studies have synthesised evidence from these contrasting contexts to identify transferable practices, contextual limitations, and opportunities for adapting successful circular economy strategies to rapidly urbanising cities such as Bengaluru. Comparative reviews are particularly valuable because they facilitate the identification of policy instruments, governance mechanisms, technological interventions, and community participation models that can support the transition from disposal-oriented waste management to resource-efficient circular systems. Therefore, this review synthesises published literature and government reports to compare municipal solid waste management systems in Sweden and Bengaluru through the lens of the circular economy. The review examines key indicators, including waste generation, source segregation, recycling efficiency, waste-to-energy utilization, biogas production, landfill diversion, governance frameworks, and economic performance. Drawing upon the comparative evidence, the review discusses the applicability of decentralized community-based waste management approaches, including ward-level recycling centers and bio-methanization plants, as practical alternatives to waste burning. By identifying context-specific lessons from Sweden's experience, this review aims to provide evidence-based recommendations that can support Bengaluru's transition towards a more resilient, resource-efficient, and sustainable municipal solid waste management system.[8,9]

2.0 Review Methodology

2.1 Review Design

This review employed a comparative narrative review approach to synthesis published evidence on municipal solid waste (MSW) management practices in Sweden and Bengaluru, India. The review was based exclusively on secondary sources and aimed to critically evaluate and compare the two waste management systems through the lens of the circular economy. The methodology comprised four sequential stages: literature identification, study selection, data extraction, and comparative synthesis.

2.2 Literature Search Strategy

A comprehensive literature search was undertaken using major scientific databases, including Scopus, Web of Science, PubMed, and Google Scholar, together with reports from recognised national and international organisations.

Institutional publications were retrieved from the European Commission, Organisation for Economic Co-operation and Development (OECD), United Nations Environment Programme (UNEP), World Bank, Swedish Environmental Protection Agency, Bruhat Bengaluru Mahanagara Palike (BBMP), Ministry of Housing and Urban Affairs (MoHUA), and the Government of India. The search was restricted to publications published between 2010 and 2024 to capture recent advances in circular economy policies, waste management technologies, and urban governance.

The search strategy combined keywords and Boolean operators, including *"municipal solid waste"*, *"circular economy"*, *"waste-to-energy"*, *"biogas"*, *"resource recovery"*, *"recycling"*, *"Sweden"*, *"Bengaluru"*, and *"India"*.

2.3 Eligibility Criteria

Studies were selected based on predefined inclusion and exclusion criteria to ensure the relevance and quality of the reviewed literature.

Inclusion criteria comprised:

2.3.1 Peer-reviewed research articles;
2.3.2 Government policy documents and technical reports;
2.3.3 Publications from recognised international organisations (e.g., UNEP, OECD, European Commission, and World Bank);
2.3.4 Case studies examining municipal solid waste management, circular economy practices, recycling systems, waste-to-energy technologies, or biomethanation in Sweden or Bengaluru.

Exclusion criteria included:

2.3.5 Studies focusing exclusively on industrial, hazardous, biomedical, or construction waste;
2.3.6 Publications unrelated to municipal solid waste management;
2.3.7 Articles lacking adequate methodological detail or reliable statistical information.

2.4 Data Extraction and Synthesis

Relevant information from the selected literature was extracted and organised into a comparative framework. The principal indicators examined included municipal waste generation, source segregation, recycling rates, waste-to-energy utilisation, biogas production capacity, landfill dependency, prevalence of open burning, governance mechanisms, public participation, and economic performance. Information relating to operational expenditure, resource recovery, and revenue generation was also compiled where available.

The extracted data were synthesised thematically and presented in comparative tables to facilitate systematic evaluation of similarities and differences between Sweden and Bengaluru. Rather than performing a quantitative meta-analysis, the review adopted a qualitative evidence synthesis approach to integrate findings from diverse study designs and institutional reports.

2.5 Analytical Framework

The comparative analysis was guided by the principles of the waste hierarchy prevention, reuse, recycling, recovery, and disposal and the broader circular economy framework.

Sweden was considered a reference case representing a mature circular economy model, while Bengaluru served as an example of a rapidly urbanizing city undergoing transition towards more sustainable waste management practices.
The literature was critically analysed across four thematic dimensions:

2.5.1 Resource efficiency: waste generation, source segregation, recycling performance, and landfill diversion;
2.5.2 Technological interventions: adoption of waste-to-energy systems, biomethanation, and resource recovery technologies;
2.5.3 Governance and policy: legislative frameworks, institutional arrangements, and implementation mechanisms supporting circular economy practices; and
2.5.4 Socio-economic aspects: operational costs, economic returns, citizen participation, and the contribution of the informal recycling sector.
The synthesis of these thematic dimensions enabled the identification of transferable practices from Sweden's circular economy model and informed recommendations for strengthening decentralized and resource-efficient municipal solid waste management in Bengaluru.

3.0 Discussion: Comparative Insights into Circular Municipal Solid Waste Management in Sweden and Bengaluru

The comparative review of municipal solid waste (MSW) management systems in Sweden and Bengaluru highlights both shared policy objectives and substantial differences in implementation, infrastructure, and overall performance. Although both jurisdictions recognize the importance of sustainable waste management and have established regulatory frameworks promoting source segregation, recycling, and environmentally sound disposal, their outcomes differ considerably because of variations in governance, technological capacity, financial investment, and public participation.

3.1 Common Policy Objectives and Institutional Approaches

Both Sweden and Bengaluru have adopted policies aligned with the principles of sustainable waste management, emphasizing source segregation, recycling, resource recovery, and the reduction of landfill disposal. Municipal authorities in both regions are responsible for waste collection, transportation, and processing, while waste-to-energy and bio-methanization facilities are employed to manage non-recyclable and biodegradable waste fractions. In addition, public awareness campaigns and community participation initiatives have been introduced to encourage waste segregation and environmentally responsible disposal practices. These common objectives reflect a growing global commitment to reducing greenhouse gas emissions, improving resource efficiency, and advancing circular economy principles.[2,6,7,10]

3.2 Differences in Waste Management Performance

Despite similarities in policy intent, the effectiveness of implementation varies markedly between the two systems. Sweden has developed a mature circular economy model supported by stringent landfill bans, extended producer responsibility legislation, and advanced waste processing infrastructure.
As a result, nearly all municipal solid waste is diverted from landfills, with recycling and energy recovery rates approaching 99%. Integrated waste-to-energy facilities and large-scale anaerobic digestion plants further enable efficient recovery of energy and valuable resources from residual waste streams.[4,8]
In contrast, Bengaluru continues to experience significant operational challenges. Although the city generates approximately 6,000–7,000 tons of municipal solid waste daily, only about 50–60% is effectively processed. Inadequate source segregation, limited recycling infrastructure, high transportation costs, and continued reliance on landfills and occasional waste burning reduce the overall efficiency of the waste management system. Consequently, a substantial proportion of municipal expenditure is allocated to waste collection and transportation, leaving comparatively limited investment for recycling, resource recovery, and technological innovation.[5,6]

3.3 Economic Implications of Circular Economy Practices

The review also highlights substantial differences in the economic performance of the two waste management systems. Sweden treats municipal waste as an economic resource capable of generating revenue through recycling, district heating, electricity generation, and biogas production. Advanced waste-to-energy technologies enable electricity generation at comparatively lower production costs, while efficient resource recovery contributes to strong economic returns. Available evidence indicates that Sweden recovers approximately ₹150–200 for every ₹100 invested in municipal solid waste management.[1]
Conversely, Bengaluru continues to operate predominantly within a linear waste management model in which waste is largely regarded as a disposal burden rather than a recoverable resource. Electricity generation costs remain relatively high, and the city recovers only about ₹3–5 for every ₹100 invested in waste management. This disparity reflects the continued emphasis on collection, transportation, and disposal rather than investment in decentralised recycling, biomethanation, and resource recovery infrastructure.[7]

3.4 Infrastructure and Community Participation

The comparison further illustrates significant differences in technological infrastructure and citizen engagement. Sweden generates almost twice the quantity of municipal waste compared with Bengaluru (approximately 12,328 tonnes/day versus 6,000–7,000 tonnes/day), yet achieves significantly higher recycling and landfill diversion rates. Less than 1% of Sweden's municipal waste is disposed of in landfills, whereas approximately 10–20% of Bengaluru's waste continues to be landfilled or openly dumped.[5]
Infrastructure capacity also differs substantially. Sweden operates 32 waste-to-energy plants with a combined electricity generation capacity of approximately 342 MW, alongside nearly 300 biogas plants producing an estimated 170–220 tons of compressed biogas per day. Bengaluru, in comparison, currently operates a single waste-to-energy plant with a capacity of approximately 11.5 MW and six bio-methanization plants producing between 5 and 25 tons of biogas per day.[4,5]
Public participation represents another critical differentiating factor. Sweden has achieved consistently high levels of compliance with source segregation and recycling through sustained environmental education, economic incentives, and well-established producer responsibility programmes.

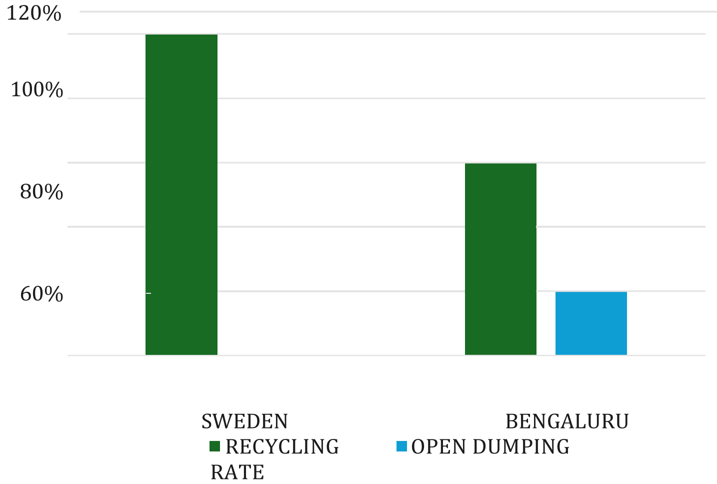
Bengaluru, however, continues to experience inconsistent segregation practices, limited public awareness, and variable community participation, all of which reduce the efficiency of downstream recycling and resource recovery processes.[2,3,6,7]

3.5 Implications for Transitioning Bengaluru towards a Circular Economy

The findings of this review suggest that Bengaluru can substantially improve its municipal solid waste management system through the adoption of decentralized circular economy strategies rather than relying solely on centralized collection and disposal systems. Establishing ward-level Community Waste Recycling Centres(CWRCs), expanding biomethanation facilities for biodegradable waste, strengthening enforcement of sourcesegregation, and integrating the informal recycling sector into formal waste management systems would improve resource recovery while reducing transportation costs, landfill dependence, and greenhouse gas emissions.[10]

Furthermore, economic incentives for waste segregation, repair, reuse, and recycling, together with increased investment in decentralized infrastructure and public awareness programmes, could accelerate the transition towards a more resource-efficient urban waste management system. Although Sweden's model cannot be directly replicated because of differences in socio-economic and institutional contexts, its core principles of circular resource utilization, technological innovation, and community participation provide valuable guidance for rapidly urbanizing cities such as Bengaluru.[3]

Overall, the comparative evidence demonstrates that Sweden has successfully established a mature circular economy in which municipal solid waste is transformed into a source of energy, revenue, and environmental value. Bengaluru, by contrast, continues to operate within a predominantly linear system characterized by disposal-oriented practices. Adapting key elements of Sweden's circular economy framework through decentralized infrastructure, improved governance, and greater stakeholder participation offers a practical pathway for reducing waste burning, increasing resource efficiency, and achieving long-term environmental and economic sustainability.



Parameter	Sweden	Bengaluru, India
Waste management approach	Circular economy based	Collection and disposal based
Daily MSW generation	~12,328 tonnes/day	~6,000–7,000 tonnes/day
Per capita waste generation	~1.27 kg/person/day	~0.5 kg/person/day
Recycling rate	~99%	~50–60%
Landfill/Open dumping	<1%	10–20%
Waste-to-energy plants	32 operational plants	1 operational WtE plant (Bidadi)
Electricity from incineration	~342 MW	~11.5 MW
Biogas plants	280–300 plants	6 plants
Recycling capacity	~12,000 tonnes/day (~99%)	~4,100 tonnes/day (~60%)
Biogas production	170–220 tonnes/day CBG/LNG	5–25 tonnes/day
Cost of electricity generation	₹3.8–5.7 per unit	~₹7.08 per unit
Landfill policy	Combustible waste banned from landfill since 2002; organic waste banned since 2005	Landfills still used for residual waste
Waste import	Imports waste from other European countries and generates revenue through energy recovery	Does not import waste
Transportation	Minimal due to efficient segregation and decentralized recovery	High transportation cost due to centralized collection
Economic focus	Waste treated as a valuable resource	Major expenditure on collection and transportation
Public participation	High compliance with segregation and recycling	Segregation compliance remains inconsistent
Repair and reuse policy	Tax incentives for repair of bicycles, shoes and household appliances encourage reuse	Limited incentives for repair and reuse
Innovation	Plastic waste used in engineering projects such as artificial islands and advanced circular economy initiatives	Limited large-scale circular economy innovations

The comparative analysis reveals substantial structural, technological, and economic differences between the municipal solid waste (MSW) management systems of Sweden and Bengaluru. Sweden has established a mature circular economy framework characterized by advanced waste-processing infrastructure, stringent landfill regulations, and high levels of resource recovery. In contrast, Bengaluru continues to operate predominantly within a linear waste management model that emphasizes collection and disposal over material and energy recovery.

Although Sweden generates approximately twice the quantity of municipal solid waste as Bengaluru (approximately 12,328 tons/day compared with 6,000–7,000 tonnes/day), it achieves an overall resource recovery rate of nearly 99%, with less than 1% of waste being disposed of in landfills. Conversely, Bengaluru recycles only about 50–60% of its municipal waste, while an estimated 10–20% continues to be directed to landfills or open dumping sites. These differences are largely attributable to disparities in waste-processing infrastructure. Sweden operates 32 waste-to-energy (WtE) facilities with a combined electricity generation capacity of approximately 342 MW, in addition to nearly 300 biogas plants producing 170–220 tons/day of compressed biogas. By comparison, Bengaluru has only one WtE facility with an installed capacity of 11.5 MW and six bio-methanization plants producing approximately 5–25 tons/day of biogas. [4,8,9]

Economic performance further differentiates the two systems. Sweden's waste management model demonstrates greater cost efficiency, generating electricity at an estimated cost of ₹3.8–5.7 per unit while recovering approximately ₹150–200 for every ₹100 invested through energy generation and material recovery. In contrast, Bengaluru incurs a higher electricity generation cost of approximately ₹7.08 per unit and recovers only ₹3–5 for every ₹100 invested, indicating that financial resources are primarily allocated to waste collection and transportation rather than value recovery. Furthermore, Sweden exhibits consistently high public participation in source segregation, recycling, and reuse, supported by robust policy instruments, public awareness programmes, and economic incentives. Bengaluru, however, continues to experience inconsistent segregation practices, limited public participation, and comparatively lower levels of technological innovation in resource recovery.[11,12]

Overall, the comparison indicates that Sweden has successfully transitioned to a circular economy in which municipal solid waste is treated as a valuable resource for material recovery and renewable energy production. In contrast, Bengaluru remains largely dependent on aDisposal-oriented approach. Strengthening decentralized recycling systems, expanding bio-methanization capacity, enhancing source segregation, and implementing policy incentives for recycling and reuse could substantially reduce landfill dependency, improve economic returns, and facilitate Bengaluru's transition towards a more sustainable and resource-efficient circular economy.

4.0 Conclusion

The reviewed literature demonstrates that effective municipal solid waste (MSW) management is strongly influenced by governance frameworks, technological infrastructure, economic instruments, and public participation. Sweden represents a well-established circular economy model in which stringent landfill restrictions, integrated recycling systems, waste-to-energy technologies, and sustained citizen engagement have enabled high levels of resource recovery and minimal landfill disposal. The Swedish experience illustrates how coordinated policy implementation and long-term investments in infrastructure can transform municipal waste into a valuable source of materials and renewable energy.

In contrast, the literature indicates that Bengaluru's MSW management system continues to be characterized by challenges associated with incomplete source segregation, inadequate decentralized processing capacity, high collection and transportation costs, and continued reliance on landfills. Although several national and municipal policies promote sustainable waste management, implementation gaps, limited technological integration, and inconsistent public participation have constrained the transition towards a circular economy.

The comparative evidence suggests that decentralized waste processing, improved segregation at source, integration of the informal recycling sector, and greater investment in material and energy recovery are among the key strategies consistently identified in the literature for improving urban waste management performance. Furthermore, economic incentives, public awareness initiatives, and supportive regulatory mechanisms are recognised as essential components for enhancing recycling rates and reducing landfill dependency.

Overall, this review highlights that the transition from a linear to a circular waste management system requires an integrated approach that combines policy coherence, technological innovation, institutional capacity, and behavioural change. While Sweden's waste management model reflects context-specific socio-economic and institutionalconditions, its underlying principles of resource efficiency, circularity, decentralization, and stakeholder participation provide valuable insights for rapidly urbanizing cities such as Bengaluru. Future research should focus on evaluating the long-term environmental, economic, and social impacts of decentralized waste management systems, assessing the scalability of circular economy interventions in developing-country contexts, and identifying policy mechanisms that can accelerate sustainable urban waste management.

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