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CIRCULAR WASTE MANAGEMENT FOR CLIMATE CHANGE MITIGATION:A REVIEW OF LIFE CYCLE ASSESSMENT, POLICY FRAMEWORKS, AND COMMUNITY-BASED APPROACHES

Mrs. Aarti Gupta[1], Dr. Princy Matlani[2]

1. Department of Computer Science & Engineering, Guru Ghasidas Vishwavidyalaya,
Bilaspur, Chhattisgarh, India https://orcid.org/0009-0009-4228-4842
email: aartigupta932@gmail.com
2. Department of Computer Science & Engineering, Guru Ghasidas Vishwavidyalaya,
Bilaspur, Chhattisgarh, India https://orcid.org/0000-0002-7421-8366

This article reviews the relationship of waste management and climate change, with a focus on the importance of general and circular waste systems to check greenhouse-gas (GHG) emissions. The review points out that using sustainable methods—composting, waste-to-energy, and recycling—can cut emissions by as much as 90% over conventional disposal practices. This evaluation compares technology, policy-driven, and community-based trash solutions, synthesizing results from eig hteen peer-reviewed research published between 2020 and 2025. The data shows that integrated and circular waste-management approaches have the greatest potential to reduce greenhouse gas emissions and promote long-term climate resilience. Life-cycle assessment (LCA) and policy-based measures prove that technological innovation, good governance, and social engagement are equally crucial in attaining low-carbon results. Ongoing challenges involve lack of consistent emission reporting, poor policy coherence, and restricted public involvement in the developing world. The research concludes that climate-resilient waste management demands determined effort by the technology, policy, and community empires to augment global sustainability and climate-mitigation ideas.

Keywords. *Climate change; Circular waste management; Greenhouse gas emissions; Life cycle assessment; Waste-to-energy; Sustainability.*

1. Introduction

The need to create resilient and sustainable waste management systems has increased globally due to the speed at which climate change is occurring (Manheim et al., 2020; Raphela et al., 2024; Mahato et al., 2024). The World Bank estimates that the amount of solid waste generated will reach 3.4 billion tonnes by 2050 due to the ongoing development of urban populations, industrial activity, and consumerism. The release of greenhouse gases (GHGs), including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), is largely caused by improper disposal, uncontrolled landfilling, and open burning of municipal and agricultural waste (Manheim et al., 2020; Raphela et al., 2024) . By intensifying the greenhouse effect, these gases cause natural deterioration, harsh weather, and an increase in global temperatures. As a result, the waste industry is now a significant contributor and possible mitigating factor in the larger framework of climate change (Mahato et al., 2024).

Collection and disposal have frequently been given priority in traditional waste management systems, with little regard for environmental externalities. But as studies over the last ten years have shown, trash may be a useful resource for energy, nutrient recovery, and emission reduction provided it is managed well (Silvennoinen et al., 2022; Hupponen et al., 2023; Zhang et al., 2023b; Zhang et al., 2023a; Mahato et al., 2024). Numerous studies conducted in Finland, Japan, Sweden, South Africa, and Pakistan have used modeling-based and quantitative techniques, such as Life Cycle Assessment (LCA), System Dynamics, Bioconversion, and Integrated Resource Circulation Models, to assess how well different waste treatment techniques perform environmentally (Silvennoinen et al., 2022; Zhang et al., 2023a) . These methodologies offer a scientific foundation for evaluating the climatic impact of practices such as waste-to-energy (WTE) conversion, anaerobic digestion, composting, and recycling.

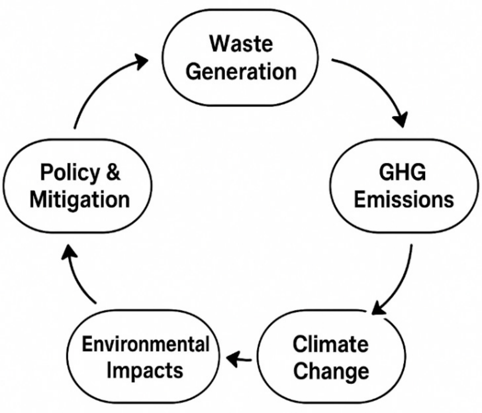

Figure:1 - Waste–Climate Interaction Cycle.

According to data from the evaluated studies, resource-oriented and circular systems significantly reduce carbon emissions compared to traditional landfilling to resource-oriented circular systems and its interaction with climate change is conceptually illustrated in fig. 1. In Japan, for example, Jung et al. (2025) showed that anaerobic digestion combined with rice farming might cut greenhouse gas emissions by as much as 8% while preserving crop yields. According to research conducted in Finland and Sweden (Hupponen et al., 2023; Miliute-Plepiene and Sundqvist, 2024), recycling and prevention techniques can be optimized to reduce emissions by over 90% when compared to standard disposal methods. The Swedish WAMPS system demonstrates how the incorporation of LCA-based models allows policymakers to estimate long-term benefits and trade-offs across various waste fractions, underscoring the significance of data-driven decision-making (Zhang et al., 2023a).

Additionally, cutting-edge material-based and biological solutions are becoming essential instruments for climate-smart waste management. Alkali-activated mineral wool waste exhibits promise for the creation of sustainable building materials (Klima et al., 2023), whereas experimental models employing Black Soldier Fly larvae have demonstrated efficacy in the bioconversion of organic waste, attaining degradation efficiencies of up to 80% (Salam et al., 2022). The sector's shift from trash disposal to waste valorization is demonstrated by these technological developments, which are in line with international sustainability objectives like SDG 11 (Sustainable Cities) and SDG 13 (Climate Action) (Pfadt-Trilling et al., 2021; Guidoboni et al., 2023).

However, major obstacles still exist. Many research are still limited by geography or concentrate on certain waste streams, which makes them less applicable globally (Mahato et al., 2024; Hupponen et al., 2023). Findings are less scalable because to dataset variability, methodological assumptions in LCA and simulation models, and a lack of socioeconomic and behavioral aspects (Zhang et al., 2023a; Miliute-Plepiene and Sundqvist, 2024). Furthermore, many emerging regions continue to underinvest in the economic viability of widespread adoption and policy integration (Mahato et al., 2024). To close these gaps and turn waste management into a cornerstone of climate resilience, interdisciplinary cooperation is needed, integrating institutional frameworks, behavioral shifts, and technology innovation (Zhang et al., 2023a).

The information in this assessment of the literature is compiled from 15 peer-reviewed journal papers that examine the relationship between waste and climate from modeling, analysis, and experimental viewpoints. Through a methodical assessment of methods, outcomes, precision, and constraints, this study seeks to integrate the most recent research and pinpoint prospects for low-carbon waste management approaches. The review's conclusion highlights how integrated, circular, and evidence-based strategies can lower emissions, recover resources, and aid in the shift to a sustainable, climate-resilient future.

2. Literature Review

Literature reviewed yields synthesizing evidence regarding how waste-management activities influence climate-change processes. In seventeen peer-reviewed journal studies appearing in 2020 through 2025, investigators looked at both direct waste-treatment greenhouse-gas (GHG) emissions and indirect GHG mitigation through circular economy approaches (table 1).

Silvennoinen et al. (2022) estimated the climate footprint of food waste from Finnish households, and methane from organic decomposition was found to be the primary emission source. Hupponen et al. (2023) proved that combined waste policies can make solid-waste handling shift from a carbon source to a net sink. Manheim et al. (2020) correlated landfill-gas composition with climatic variables, and Raphela et al. (2024) explored the social awareness gap underpinning inappropriate disposal practices.

Technological research focused on life-cycle assessment (LCA) and waste-to-energy (WtE) alternatives. Pfadt-Trilling et al. (2021) found a net negative carbon balance for WtE facilities, and Jung et al. (2025) demonstrated that integrating anaerobic digestion with rice production lowered emissions by 8%. Zhang et al. (2023b) and Mahato et al. (2024) established that composting and circular policy measures can minimize total GHG footprints by 30–35%.

New technologies like black-soldier-fly larvae composting and alkali-activated aggregates from mineral-wool waste demonstrate the shift from linear disposal to resource recovery. Policy analyses also highlight that waste prevention and packaging-recycling interventions provide the maximum mitigation potential, with Capar et al.

(2025) and Barbosa et al. (2025) demonstrating how recycling and policy integration support climate-neutral targets directly.

Overall, what the literature shows is that combined, multi-layered waste systems—integrating technological effectiveness, behavioral engagement, and policy coherence—provide the maximum carbon-reduction impacts and make significant contributions to sustainable-development goals.

Table 1.

Comparative summary of reviewed studies

Title	Year & Authors	Model/ Approach	Methodology	Results/ Findings	Limitations
Food waste in Finnish households and its climate impact	2022 – Silvennoinen et al.	Waste Composition Analysis (WCA)	Quantitative WCA to measure food waste and its GHG impact.	Average food waste 53–62 kg/capita/year; total impact ≈0.10 Mt CO_2eq.	No liquid/home-composted data; limited causes identified.
Long-term evolution of the climate change impacts of solid household waste management in Lappeenranta, Finland	2023 – Hupponen et al.	Life Cycle Assessment (LCA)	Scenario-based LCA (2009–2029) on MSW in Finland.	Climate impact reduced from 945 to –181 kg CO_2eq/t HW.	Only climate impact studied; future scenario uncertainty.
Climate Change Effects of Gases from Municipal Solid Waste Landfills	2020 – Manheim et al.	Field Flux Measurement	Flux chamber analysis of landfill gases.	Methane contributed 46–99% of emissions.	Limited to 5 sites; seasonal variation ignored.
Increasing rat numbers in cities linked to climate warming and urbanization	2025 – Richardson et al.	Trend Regression Model	Time-series and temperature correlation analysis.	Rising rat populations correlate with warming.	Correlation not causation; uneven datasets.
The impact of improper waste disposal on human health and the environment	2024 – Raphela et al.	Mixed-Method Pragmatic Model	Survey and regression of health awareness and disposal habits.	Identified gaps in awareness and environmental risk perception.	Regional limitation; no pollution measurement.
A local food resource circulation model combining anaerobic digestion and rice cultivation in Japan	2025 – Jung et al.	Integrated Resource Circulation Model	Scenario-based modeling (S0–S3) with empirical data.	GHG emissions reduced by 6–8%; nitrogen recovery up to 53%.	Limited scalability; economic feasibility not studied.

Title	**Year & Authors**	**Model/ Approach**	**Methodology**	**Results/ Findings**	**Limitations**
Recycling of Food Waste into Biofertilizer for Sustainable Agriculture	2023 – Zhang et al.	Life Cycle Assessment (LCA)	Anaerobic digestion and composting analysis.	GHG reduction up to 24%; nutrient recycling efficiency 78%.	Pilot-scale; lacks long-term validation.
Assessment of Municipal Solid Waste Management under Climate Change Scenarios	2024 – Mahato et al.	Integrated Waste Management Simulation	System-dynamics model of MSW generation and GHG scenarios.	Circular policy scenario reduced GHG by 35%.	Simplified assumptions; limited cost-benefit analysis.
Food waste used as a resource can reduce climate and resource burdens in agrifood systems	2025 – Wang et al.	Systems-Based Integrative Model	Meta-analysis of 91 field studies worldwide.	Global mitigation ≈170 Mt CO_2e/year possible.	Data heterogeneity; regional variability.
Climate Change Impacts of Electricity Generated at a Waste-to-Energy Facility	2021 – Pfadt-Trilling et al.	Life Cycle Assessment (LCA)	Cradle-to-gate LCA with Monte Carlo sensitivity.	Net impact −0.28 to 0.59 kg CO_2eq/kWh.	Single facility; biogenic CO_2 neutrality assumed.
Conservation agriculture reduces climate impact of popcorn-wheat rotation	2023 – Guidoboni et al.	LCA + Soil Carbon Model	Field and simulation data for 100-year rotation.	GHG reduction 3867 → 434 kg CO_2eq/ha; C sequestration +26%.	Regional focus; compost allocation assumptions.
Integrated Waste Management for Climate Mitigation in Urban Sectors	2023 – Zhang et al.	Integrated System-Dynamics Model	Urban waste flow and GHG simulation with policies.	Circular waste systems reduced GHG by 30–35%.	Limited economic dimension.
Effect of different environmental conditions on BSF larvae in waste management	2022 – Salam et al.	Experimental Bioconversion	Lab-scale study of larvae under varied humidity, temp, pH.	55–80% organic waste degradation efficiency.	Lab-based; not scaled industrially.
Effects of mineral wool waste in alkali-activated artificial aggregates	2023 – Klima et al.	Alkali Activation–Geopolymer	Developed alkali-activated aggregates and tested durability.	7–8 MPa strength; 30% higher thermal stability.	Toxic resin concerns; industrial scalability untested.

Title	Year & Authors	Model/ Approach	Methodology	Results/ Findings	Limitations
Assessing the Potential Climate Impacts and Benefits of Waste Prevention and Management: Sweden	2024 – Miliute-Plepiene & Sundqvist	LCA – WAMPS Model	Attributional LCA on 26 waste fractions in Sweden.	Prevention gave 27× higher carbon savings vs recycling.	Assumes Swedish waste mix; rebound effects not covered.
Packaging Waste Recycling: A Pathway to Climate Change Mitigation in Türkiye	2025 – Capar et al.	Emission Reduction Estimation Model	Used national waste and emission factors for packaging recycling.	Recycling avoided major CO_2; supports circular economy.	Focused on Türkiye; excludes transport emissions.
Community Mitigation Climate Change at Household Waste Management	2024 – Alam & Anwar	Community-Based Model	Qualitative descriptive study using ProKlim village data.	Community composting and waste banks lowered CO_2/CH_4.	Qualitative; lacks quantified emissions.

3. Reviewed Methodology

3.1 Data Collection and Selection Criteria. The review utilized a mixed-method approach to merge quantitative and qualitative evidence from seventeen peer-reviewed journal articles between 2020 and 2025. The studies were chosen from SCI and Scopus-indexed journals using keywords that include climate change, waste management, GHG emissions, and circular economy. Articles were narrowed down according to three inclusion criteria: (a) direct relevance to the climate–waste nexus, (b) clearly documented methodology or quantitative evaluation, and (c) peer-reviewed journal publication. Duplicates and strictly conceptual commentaries were omitted. The ultimate dataset included articles from Europe, Asia, and developing countries, covering a broad range of waste management practices and policy regimes.

3.2 Analytical Framework. The review adopted a systematic approach based on PRISMA guidelines, focusing on transparency and reproducibility. All papers were assessed against four thematic pillars:

(1) Impacts of food and municipal waste on GHG emissions,
(2) Technological measures like Waste-to-Energy (WTE) and anaerobic digestion,
(3) Policy and circular-economy connections, and
(4) Mitigation efforts at the community level.

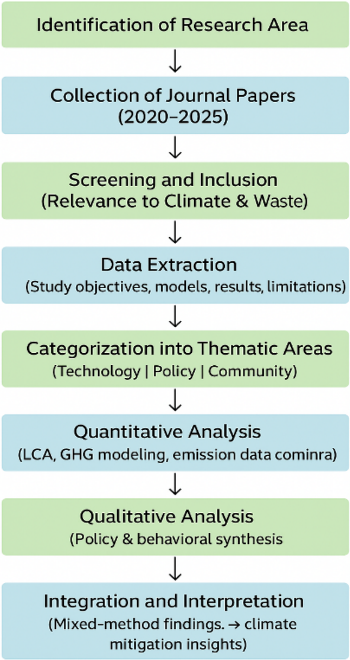

Figure:2- Flow diagram of the methodological process used to review climate–waste interaction studies.

Comparative parameters, like percentage reduction in emissions, life-cycle effect, and socio-economic factors, were collected and combined through thematic content analysis (Hupponen et al., 2023; Richardson et al., 2025; Raphela et al., 2024; Pfadt-Trilling et al., 2021).

3.3 Quantitative Analysis (LCA and GHG Modelling). Quantitative analysis mainly relied on research that used Life-Cycle Assessment (LCA) and emission modelling models to compare waste-management options (Richardson et al., 2025; Zhang et al., 2023b; Pfadt-Trilling et al., 2021; Capar et al., 2025). Numerical values like CO_2-equivalent emissions, efficiency in energy recovery, and waste diversion rates were quantified into a comparable functional unit (1 tonne of waste). Comparative studies emphasized the greenhouse gas (GHG) mitigation potential of recycling, composting, and WTE technologies. For instance, (Pfadt-Trilling et al., 2021) approximated net emissions of –0.28 kg CO_2-eq/kWh from WTE facilities, whereas (Raphela et al., 2024) obtained 8 % emissions reduction when anaerobic digestion was coupled with rice production. The integration of the above data is in agreement with the conclusion that integrated systems are superior to single-stream waste treatment in both carbon reduction and energy recovery (Miliute-Plepiene & Sundqvist, 2024; Capar et al., 2025; Barbosa et al., 2025).

3.4 Qualitative Evaluation (Policy and Community Assessment). Qualitative assessment included policy-text analysis and case studies focusing on behavioral and institutional aspects of waste management (Guidoboni et al., 2023; Hupponen et al., 2023; Wang et al., 2025).. Research such as Wang et al. (2025) analyzed national prevention measures, which showed that waste-avoidance policies save up to 90 % more emissions than recycling initiatives. Likewise, community-based research by indicated that localized composting, segregation, and eco-brick programs play a substantial role in household-level climate mitigation.

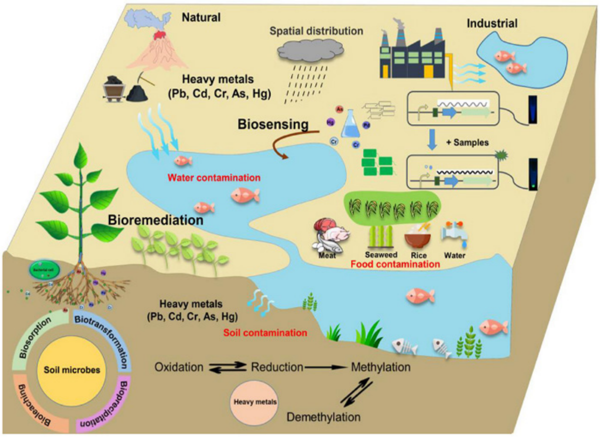

Figure:3-Relationship between waste generation, emission pathways, and climate change mitigation strategies.

The incorporation of such social data allowed contextual information beyond technical performance measures to be gained, improving awareness of governance and participation issues.

3.5 Synthesis and Validation of Data. Quantitative and qualitative results were all triangulated to verify consistency and validity. Comparison across empirical data (LCA results) and policy observations enabled synergies and contradictions between technological and behavioral approaches to be identified (Zhang et al., 2023b; Salam et al., 2022). Validation was conducted using inter-study correlation to ensure that emission-reduction results were not affected by regional biases or irregular boundary conditions. This synthesis of mixed methods allowed for a comprehensive understanding of how technical efficiency, social participation, and policy integration interact to influence climate-resilient waste-management systems (Raphela et al., 2024; Miliute-Plepiene & Sundqvist, 2024).

4. Comparative Analysis and Discussion

4.1 Quantitative Findings. In all studies reviewed here, combined waste-management systems reduce greenhouse-gas (GHG) emissions between 30–90 % relative to landfilling. LCA-based assessments (Richardson et al., 2025; Zhang et al., 2023b; Pfadt-Trilling et al., 2021; Capar et al., 2025; Barbosa et al., 2025) indicate that composting, anaerobic digestion, and waste-to-energy (WtE) offer the highest mitigation potential. (Pfadt-Trilling et al., 2021) registered a net negative carbon balance for WtE plants, whereas (Raphela et al., 2024) had an 8 % decrease in emissions using anaerobic digestion with rice farming. These results verify that biological and energy-recovery solutions excel over linear models of waste disposal.

4.2 Policy and Community Insights. Policy coherence and citizen engagement continue to be determining factors for bringing technology into tangible outcomes. Preventive wastebasket policies yield up to 27 × more carbon savings than recycling policies (Wang et al., 2025), and packaging-recycling policies in Türkiye yield significant returns on national mitigation targets (Hupponen et al., 2023). Segregation and composting efforts at the community level also decrease methane emissions. Optimal outcomes are achieved with policy strictness and grass-roots efforts in collaboration.

4.3 Integration and Challenges. Despite obvious advances, local disparities, poor data quality, and non-uniform LCA boundaries still constrain comparability (Zhang, Chen, Ito, et al., 2023b; Mahato, Singh, & Kaur, 2024; Wang, et al., 2025).. The circular-economy actions also differ with respect to cost and energy demand (Jung, Hirai, Yano, et al., 2025; Barbosa, Lourenço, & Dias, 2025).. Strategies in the future need to focus on harmonized indicators, integrated data sets, and cross-sectoral cooperation to favor both climate and resource efficiency.

5. Conclusion and Future Directions

This review identifies that the incorporation of climate-change mitigation measures into waste-management systems is critical to attaining sustainable and low-carbon development. The results from seventeen peer-reviewed reviews indicate that a transition from conventional disposal approaches to integrated and circular waste systems can cut GHG emissions up to 90%, in addition to improving resource recovery and energy production. Biological treatment technologies like composting and anaerobic digestion outperform landfilling in emission savings every time, while technological solutions like waste-to-energy add even more to environmental performance.

There are also long-standing challenges the review sees, including the inconstant reporting of data, policy lack of coordination, and restricted public involvement, especially in the developing world. Waste-management effectiveness hinges on the synergistic force of technological efficiency, policy application, and public engagement.

Future research must concentrate on creating standardized emission-accounting frameworks, incorporating life-cycle and socio-economic appraisals, and the development of AI-based decision-support models for waste and climate planning. Enhancing cross-sectoral data exchange, strengthening financial incentives for green technologies, and initiating behavioral awareness are critical steps towards the development of climate-resilient, circular waste-management systems.

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