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Low-Carbon Pathways in Solid Waste Management: A Systematic Review of Carbon Footprint and GHG Mitigation across Technologies and Regions

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ABSTRACT

Carbon footprinting and greenhouse gas (GHG) accounting are now widely applied to solid waste management (SWM), yet evidence remains fragmented across technologies, waste streams, and regional contexts. This systematic literature review synthesizes 50 Scopus-indexed journal articles (2017–2025) that quantify the carbon outcomes of SWM options using life-cycle assessment, carbon accounting, and sce-nario modeling. We compare methodological choices (functional units, boundaries, impact methods, avoided burdens), benchmark core treatment technologies (landfilling, incineration/WtE, composting, anaerobic digestion, mechanical-biological treatment), assess circular pathways (recycling, substitution, eco-design), and identify regionally differentiated transition archetypes shaped by governance and ener-gy-system decarbonization. Across studies, technology rankings are highly sensitive to methane dynamics, landfill gas capture and oxidation, grid emission factors, and substitution assumptions. Circular strategies frequently deliver the largest net savings when high-quality sorting and credible displacement of virgin production are achieved, while WtE benefits are context-dependent and generally increase in fossil-intensive grids. The review proposes an integrative comparison framework that links method choices to technology performance and regional pathway feasibility, providing more comparable, decision-relevant evidence for low-carbon SWM planning.

Keywords: *Solid Waste, Carbon Footprint, Life Cycle, Methane Emissions, Technologies and Regions.*

1. INTRODUCTION

Solid waste management (SWM) affects climate mainly through methane emissions from landfills and controlled sites, and fossil CO2 from thermal treatment and energy use in handling. Recent research shows landfill methane emissions vary and depend on the method used. Measurement uncertainty can change net GHG results [1], [2]. At the same time, more jurisdictions are making SWM central to climate and circular economy efforts, including incorporating it into their NDCs through waste diversion, methane control, and material recovery [3].

The academic literature has expanded rapidly in parallel with greater policy attention, highlighting the growing importance of SWM in addressing climate change. Between 2017 and 2025, studies increasingly applied life cycle assessment (LCA), carbon footprinting, and system modeling to quantify emissions and mitigation potential across treatment options. These options include landfilling, incineration/waste-to-energy (WtE), anaerobic digestion (AD), composting, mechanical-biological treatment, and material recovery [4], [5]. However, comparability remains limited, as studies differ in system boundaries (facility-only vs. system-wide), functional units (per tonne, per kWh, per capita-year), impact methods, and treatment of avoided burdens and biogenic carbon [6], [7], [8]. Evidence is also fragmented geographically, with baselines ranging from dumpsites and weak collection to engineered landfills and high-capacity residual treatment systems [9], [10].

To address these gaps and synthesize recent quantitative evidence, this review focuses on three central questions. (RQ1) Which SWM technologies and system configurations yield net emissions versus net savings across contexts? (RQ2) Which methodological choices most strongly influence reported carbon outcomes? (RQ3) Under what conditions do circular strategies outperform energy recovery or controlled landfilling in climate terms? By integrating methodological insights (Theme 1), technology performance comparisons (Theme 2), circular strategies and substitution effects (Theme 3), and regional pathways with enabling conditions (Theme 4), the review develops design principles for low-carbon SWM. These principles are aligned with the waste hierarchy and circular economy transitions.

2. METHODS

2.1 Protocol and Selection

A structured protocol was applied to a Scopus database export, yielding a curated set of 50 peer-reviewed papers on SWM climate assessment research published from 2017 to 2025. To ensure relevance, records were screened for carbon or GHG metrics and SWM technologies or systems, and retained when abstracts indicated quantitative emissions accounting (e.g., LCA, carbon footprint, methane measurement/ modeling, scenario analysis). The review focuses on carbon-related metrics (CO_2-equivalent, methane flux, mitigation potential) to enable cross-study comparison despite heterogeneity. Because outcomes and functional units are heterogeneous across studies, a meta-analysis was not attempted; instead, the review uses a thematic synthesis with structured extraction fields. Figure 1 documents the dataset-based screening flow, thus providing a clear basis for subsequent analysis.

2.2 Search Strategy

A structured literature search was conducted in Scopus, Web of Science, and ScienceDirect, complemented by Google Scholar for citation chasing. Search strings combined terms for waste streams (e.g., "municipal solid waste", "food waste", "plastic waste"), treatment options (e.g., landfill, incineration, anaerobic digestion, composting, recycling, and waste-to-energy), and climate metrics (e.g., life cycle assessment, carbon footprint, greenhouse gas, and global warming potential). The search was limited to English-language journal articles published between 2017 and 2025.

2.3 Inclusion and Exclusion Criteria

Studies were included if they: (i) were peer-reviewed journal articles; (ii) reported quantitative GHG emissions or carbon footprints for one or more SWM technologies or integrated systems; (iii) described system boundaries and a functional unit (e.g., per tonne of waste treated or per service delivered); and (iv) provided sufficient methodological detail to interpret allocation/substitution rules and key assumptions. Studies were excluded if they were non-quantitative, focused on non-solid-waste systems, reported only economic or social outcomes without GHG metrics, or lacked adequate methodological transparency.

2.4 Screening and Selection Process

After duplicate removal, titles and abstracts were screened against eligibility criteria, followed by full-text assessment. The selection process was documented using a PRISMA flow diagram (Figure 1). When screening ambiguity occurred, inclusion decisions were resolved through reviewer discussion and consensus to maintain consistency and transparency

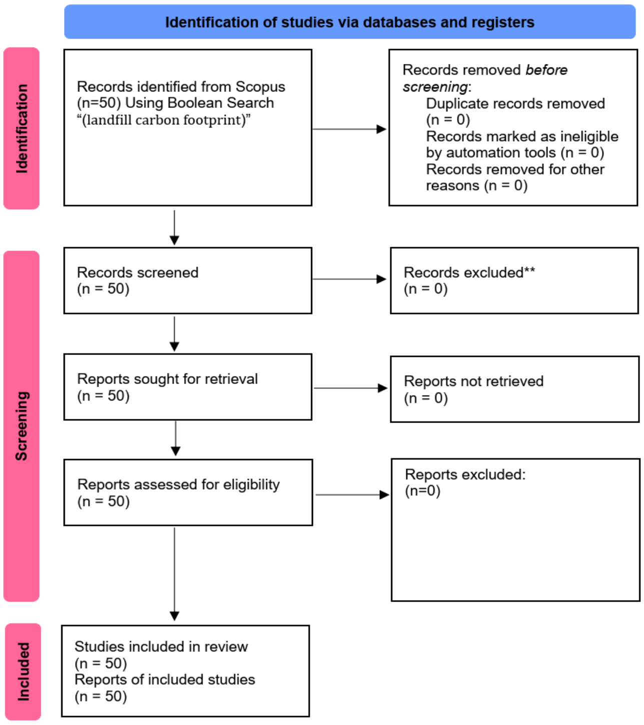

Figure 1. The PRISMA flow diagram

2.5 Screening and Selection Process

Study quality and extractability were appraised using a fit-for-purpose checklist emphasizing: clarity of goal and scope definition, functional unit selection, system boundary specification, data representativeness, treatment of co-products and recycling credits, and reporting of uncertainty/sensitivity. Given that SWM LCAs are sensitive to methodological choices, particular attention was paid to allocation and substitution approaches [11], [12] and to uncertainty treatment [13], [14], [15]. Data were extracted into a standardized template capturing study location, waste stream, technology configuration, background energy assumptions, and reported climate metrics (e.g., kg CO2-eq per functional unit).

2.6 Theoretical Framework

To interpret diverse carbon-footprint results across SWM systems, this review applies an integrated analytical framework that connects (i) the waste hierarchy and circular economy logic for prioritizing prevention, reuse, and high-quality recycling; (ii) LCA and carbon-accounting methodology (functional unit, system boundaries, and allocation/substitution); (iii) temporal dynamics in climate metrics (especially methane timing and biogenic carbon treatment); and (iv) policy and socio-technical conditions that determine whether technical mitigation potentials are realized in practice.

1. Waste Hierarchy and Circular Economy

The waste hierarchy provides the conceptual backbone for low-carbon SWM. It prioritizes prevention and reuse, followed by recycling and recovery, with disposal as a last resort. Notably, carbon performance often follows this hierarchy when avoided virgin production is properly credited and when methane is controlled in residual disposal [2], [8]. Further, circular economy principles connect SWM to climate mitigation by retaining material value and reducing demand for emissions-intensive primary production. Empirical studies on construction materials, plastics, and composites show that circular pathways can outperform residual treatment, especially when high-quality recovery and credible substitution are achieved [6], [7], [8].

2. Methane dynamics and monitoring

A distinctive feature of SWM carbon accounting is the dominance of methane from biodegradation in landfills and dumpsites. Across the reviewed literature, methane flux measurement and modeling methods materially affect emissions estimates. Techniques such as tracer methods, mobile platforms, UAV-based sensing, and flux chambers offer varying spatial and temporal resolutions and uncertainties [16], [17], [18]. Additionally, decomposition dynamics vary by waste composition, moisture, and management. For instance, wood waste decomposition and delayed emissions complicate inventory and reporting. These time-dependent processes influence climate outcomes [19].

3. Biogenic Carbon and Temporal Aspects

Carbon accounting in SWM must distinguish between fossil CO_2 and biogenic carbon flows. Temporal aspects such as delayed emissions and landfill carbon storage must also be addressed. For example, studies focusing on biodegradable plastics and bio-based materials show that climate outcomes depend on whether biogenic carbon is treated as neutral, stored, or released over time. The energy-system decarbonization context also determines the availability of substitution credits [20]. Similarly, landfill aeration and methane oxidation interventions show that management can permanently shift long-term trajectories of carbon and nitrogen emissions [21].

4. Biogenic Carbon and Temporal Aspects

SWM transitions are socio-technical. Technology performance depends on governance, financing, public behavior, infrastructure lock-in, and energy systems. Policy mapping shows heterogeneous national ambition for waste-sector mitigation. These commitments are often linked to landfill diversion, recycling expansion, and energy recovery [3]. Moreover, city- and region-level pathways are shaped by institutional capacity and economic constraints. These factors influence the feasibility of advanced facilities versus incremental improvements, such as source separation and methane capture optimization [4], [22].

3. RESULTS AND DISCUSSION

3.1 Methodological Approaches in Carbon Assessment

Across the 50 studies, three methodological families dominate: measurement/monitoring (landfill and facility methane), LCA/carbon footprinting (technology and product systems), and modeling/optimization (scenario analysis, techno-economic, and integrated systems). Methane-focused studies emphasize the importance of robust quantification methods. Downwind measurements and isotopic analysis are used to infer gas recovery efficiency. These reveal that operational performance can diverge from nominal capture assumptions [16]. Tracer-dilution approaches and atmospheric modeling highlight the wind dependence and uncertainty. This emphasizes the need for methodological transparency in emissions reporting [23]. Advances in continuous estimation and mobile/UAV platforms improve the ability to detect hotspots and quantify fugitive emissions. These advances enable regulation based on measured outcomes [18], [24], [25], [26], [27].

In LCA-oriented studies, methodological choices around boundaries and avoided burdens strongly shape reported net climate outcomes. Product and material system LCAs commonly rely on substitution credits for avoided virgin production, but results depend on assumptions about substitution ratios and the marginal displaced processes [6], [7], [8]. System-wide assessments of municipal pathways, including collection, sorting, treatment, and energy/material outputs, show that different configurations can reverse net rankings depending on whether upstream and downstream effects are included [4], [5]. Where abstracts report limited methodological detail, comparability remains constrained, underscoring the need for harmonized reporting of functional units, boundary framing, and carbon accounting conventions across SWM studies.

Table 1. Methodological Characteristics of Included Studies

Dimension	Dominant pattern across included studies	Key variants / notes	Comparability implication	Example references
Assessment approach	LCA and system/scenario modeling are the primary approaches for comparing SWM options	Carbon accounting used for city/system inventories; field measurement used for landfill CH_4 quantification; policy mapping/reviews for governance transitions	Different approaches yield different "system pictures" and uncertainty profiles	LCA: Fořt et al., 2020; Modeling: Zhang et al., 2024; Duan et al., 2021; Malakahmad et al., 2017; Ngwabie et al., 2019. Measurement: Reinelt et al., 2022; Allen et al., 2019; Riddick et al., 2018.
System boundary	Cradle-to-grave / system-level boundaries are most used for technology comparison and city pathways	Gate-to-gate boundaries occur in process-focused recycling/valorisation studies; site-scale boundaries dominate landfill methane monitoring	Boundary breadth can flip net outcomes by including/excluding upstream processes and avoided burdens	System/C2G: Fořt et al., 2020; Pizarro-Alonso et al., 2018. G2G: Zhang et al., 2020; Zhao et al., 2017. Site-scale: Reinelt et al., 2022.
Functional unit	"Per tonne of waste treated" is the prevailing FU for SWM benchmarking	Product/FU used for specific waste streams; site-year/campaign for monitoring studies; Mg used in some city models	FU choice determines what is comparable (service vs product vs monitoring intensity)	Pert: Fořt et al., 2020. Mg: Duan et al., 2021. Site-year: Taylor et al., 2018; Allen et al., 2018. Product/FU: Huang et al., 2025; Severson et al., 2025.
Impact metric & time horizon	CO_2-eq (GWP) is the headline indicator; methane is treated explicitly in landfill studies	Time horizon is critical but often under-reported in metadata/summary statements; methane-focused studies support monitoring/verification	GWP20 vs GWP100 changes rankings where CH_4 dominates (landfills, dumpsites, organics)	CH_4 quantification: Allen et al., 2018; Aghdam et al., 2018; Riddick et al., 2018. System GWP reporting: Zhang et al., 2024; Duan et al., 2021.
Avoided burdens / substitution	Avoided burdens are central to net savings claims in WtE and recycling comparisons	Energy displacement dominates WtE; material displacement dominates recycling/valorisation; integrated systems apply both; some accounting/policy papers under-specify substitution	Substitution assumptions are among the largest sources of cross-study variability	Material credits: Araña et al., 2025; Zhao et al., 2017; Zhang et al., 2020. Integrated: Fořt et al., 2020; Zhang et al., 2024.
Biogenic vs fossil carbon	Often treated implicitly (mixed waste combustion; landfill CH_4)	More explicit handling appears in studies focusing on bio-based/biodegradable	Biogenic/fossil treatment affects WtE footprints and interpretation of	Huang et al., 2025; Reinelt et al., 2022; Mohsen & Abbassi, 2020.

		materials and carbon accounting nuances	"carbon neutrality" claims	
Sensitivity / uncertainty	Key sensitivities repeatedly include landfill gas capture/oxidation, degradation kinetics, grid factors, and substitution ratios	Participation rates and separation quality are influential in system pathway studies	Explains divergent results across regions and technologies; supports robust decision-making [1], [2], [16], [18], [20], [34], [35], [36]	Methane parameters: Ta Bui et al., 2017; Liu et al., 2017; Aghdam et al., 2018. Participation: Zhang et al., 2024; Medina-Mijangos & Seguí-Amórtegui, 2021.

Source: Adapted from synthesized literature 2025

3.2 Carbon Performance of Core Treatment Technologies

Technology comparisons show that landfill methane management remains a dominant lever where biodegradable disposal is significant. Measurement and modeling studies indicate that fugitive emissions can undermine assumed gas capture performance, and that measurement-driven regulation can improve inventory reliability and targeting of mitigation [16], [25], [27]. Aeration interventions demonstrate potential for enduring reductions in carbon and nitrogen emissions, suggesting that operational retrofits can change long-term emissions trajectories [21]. In low-control contexts such as dumpsites, direct quantification shows substantial methane emissions, reinforcing the mitigation value of improved collection, cover, and controlled disposal [9].

For residual treatment, WtE and incineration performance depend heavily on energy recovery efficiency and the carbon intensity of displaced electricity or heat. Studies examining waste trade and district heating systems show that the climate footprint of combusting imported waste can be sensitive to renewable penetration and the structure of heat demand [30]. Techno-economic analyses in rapidly developing regions show that financial feasibility and policy support determine the adoption potential of energy recovery facilities [22], [37]. In municipal pathway comparisons, integrated systems combining sorting, recycling, organics treatment, and residual treatment tend to outperform disposal-only baselines, but rankings vary when assumptions about capture rates, grid factors, and waste composition change [2], [4], [5].

Table 2. GHG performance of key SWM technology pathways

Study ID / Reference	Technology / system configuration	Context (region & urban/rural)	Reported carbon footprint (as reported)	Key assumptions / sensitivities	Net climate outcome
Zhang et al., 2024	Source separation + system optimization	Shenzhen, China (urban)	0.18 t CO_2-eq (reported)	Participation rate; treatment mix; grid factors	Net saver vs baseline
Malakahmad et al., 2017	SWM scenarios (mixed portfolio)	Malaysia (urban)	−280 to 250 kg CO_2-eq/t (reported)	Portfolio shares; energy credits	Scenario-dependent
Duan et al., 2021	City pathways (integrated system)	Mexico City (urban)	−129 to −360 kg CO_2-eq/Mg (reported)	Compost/MBT mix; fossil displacement; costs	Net saver in several scenarios
Abdallah et al., 2018	WtE vs AD strategies	UAE (urban)	Carbon credits &	Energy recovery;	Context-dependent

			profitability assessed (reported)	digestate handling; separation	
Pizarro-Alonso et al., 2018	WtE with imports / system expansion	Denmark/EU (urban)	Climate footprint varies by counterfactual (reported)	Displaced fuels; boundary selection	Highly sensitive
Hannula & Reiner, 2019	WtE under renewable penetration	Finland (urban)	Lower WtE emissions under cleaner grid (reported)	Grid emission factor; efficiency	Improves with decarbonization
Liu et al., 2017	Landfill vs alternatives (model)	System-level	Methane dominates ranking (reported)	Capture rate; oxidation; k-values	Methane-critical
Reinelt et al., 2022	Fugitive methane measurement	Germany (site-scale)	Field fluxes reported	Meteorology; method choice	Uncertainty high
Aghdam et al., 2018	Methane oxidation cover performance	Landfill sites (tropical/subtropical)	Performance metrics reported	Permeability; climate	Mitigation potential
Allen et al., 2018	Mobile tracer measurement	UK landfill sites	Site emissions quantified	Wind; dispersion assumptions	Measurement-dependent
Taylor et al., 2018	Atmospheric modeling for tracer method	UK landfill sites	Wind dependence assessed	Boundary-layer parameters	Method sensitivity
Riddick et al., 2018	Continuous methane estimation	UK landfill site	Continuous estimate approach	Environmental constraints	

Source: Adapted from synthesized literature 2025

3.3 Recycling, Material Recovery, and Circular Strategies

Circular strategies frequently deliver mitigation through avoided virgin production, but evidence is conditional on recovery quality and substitution assumptions. In construction and demolition (C&D) contexts, brick and material recycling scenarios show reduced impacts when high-quality sorting and effective substitution are achieved, aligning carbon outcomes with circular performance indicators [8], [39]. For plastics, system-level scaling studies show that carbon benefits depend on collection rates, sorting contamination, and the displacement of virgin polymer production; dynamic considerations can shift rankings across different decarbonization trajectories [6]. For bio-based and biodegradable plastics, climate outcomes are highly sensitive to end-of-life pathways and grid decarbonization, reinforcing the need to differentiate strategies by material type and energy context [20].

Composite and difficult-to-recycle waste streams, such as wind turbine blades, show that circular alternatives (e.g., co-processing, recycling, or repurposing) can reduce footprints relative to disposal, but trade-offs exist between process energy use and substitution benefits [7], [40]. Materials valorization routes, such as incorporating waste plastics into construction materials, can deliver net savings when substitution is robust and when avoided production impacts outweigh processing emissions [41]. For specialized waste streams such as e-waste polymers, extraction and recovery simulations indicate potential climate benefits alongside resource recovery, but impacts depend on the solvent system and process efficiency [32].

Table 3. Climate performance of circular and recycling strategies

Study ID / Reference	Waste stream & product system	Circular strategy	Substitution assumptions	Carbon outcome (as reported)	Circularity indicators (if available)
Severson et al., 2025	Flexible plastic packaging	Recycling scale-up	Virgin polymer displaced; scenario-based ratios	Scenario-dependent (reported)	Recycling uptake/scale scenarios
Fořt et al., 2020	Mixed municipal fractions	Improved source separation	Displaced fuels/materials (explicit)	Lower GWP with better sorting (reported)	Separation rate/quality
Bertelsen & Mathiesen, 2020	Denmark (HIC)	WtE + recycling	Integrated planning reform	Optimized emissions (reported)	Coordination; planning capacity
Diez-Cañamero et al., 2023	Wind turbine blade composites	Circular alternatives	Material recovery substitutes virgin inputs	Option-dependent (reported)	Circular economy performance metrics
Huang et al., 2025	Bio-based/biodegradable materials	System strategy under decarb.	Energy mix + carbon accounting; displacement varies	Carbon footprint quantified (reported)	Linked to decarb. scenarios
Zhao et al., 2017	E-waste residues	Solvent extraction recovery	Metal recovery displaces virgin metals	CO_2-eq quantified (reported)	Recovery yield (implicit)
Zhang et al., 2020	Solvent waste	Solvent recycling	Virgin solvent displaced (explicit)	CO_2-eq quantified (reported)	Recovery yield (implicit)
Muñoz et al., 2020	Refractory industrial waste	Valorization pathways	Substitution varies by boundary	Impact depends on boundary (reported)	Material flow considerations
Araña et al., 2025	Contaminated dredged sediment	Artificial aggregates	Cement/aggregate substitution	Carbon footprint assessed (reported)	Product substitution (implicit)
Reddy et al., 2017	BOF slag in landfill covers	CO_2 sequestration	Mineral carbonation benefits	Mitigation potential (reported)	NA
Meng et al., 2019	Organic fraction conversion	Process pathways	Displaced energy/products	Scenario-dependent (reported)	NA/implicit
Sahoo et al., 2021	Fruit & vegetable waste	Energy recovery	Fossil energy displaced	Net benefit varies (reported)	NA

Source: Adapted from synthesized literature 2025

3.4 Regional Pathways, Policy Instruments, and System-Level Transitions

Regional context shapes feasible low-carbon pathways. Policy mapping shows heterogeneous national ambition for waste-sector mitigation, with commitments often emphasizing landfill diversion and recycling expansion but varying in specificity and enforcement [3]. City and regional case studies indicate that high-capacity systems in high-income contexts focus on optimizing residual treatment and circularity performance, while lower-capacity contexts can achieve large relative gains through basic collection expansion, source separation, and landfill methane control [2], [4], [5]. Humanitarian and constrained settings highlight additional barriers: refugee camp waste systems show distinct production patterns and infrastructure limitations that shape mitigation options [47]. Regulation based on measured methane emissions is emerging as an enabling instrument, potentially shifting incentives toward operational mitigation rather than assumed performance [27]. Table 4 provides a compact cross-context comparison (Table 4).

Table 4. Regional and policy contexts for low-carbon SWM pathways

Study ID / Reference	Region / country & income level	Dominant SWM system before intervention	Policy / intervention analyzed	Reported GHG impact (as reported)	Key enabling / limiting factors
Powell et al., 2018	Global	Mixed	NDC waste commitments mapping	Heterogeneous ambition (reported)	National policy coherence; monitoring
Zhang et al., 2024	China (UMIC)	Mixed; optimization needed	Source separation + system optimization	Footprint reduction (reported)	Participation; infrastructure
Kwon et al., 2023	South Korea (HIC)	Residual landfilling + high recycling	Landfill ban scenario	Large projected reductions (reported)	Regulatory strength; capacity
Király et al., 2023	Europe	Varied	Project financing mechanisms	Enables system change (reported)	Access to finance; risk allocation
Motuzienė et al., 2022	Lithuania (HIC)	Incineration expanding	Gasification/pyrolysis integration	Higher mitigation potential (reported)	R&D support; tech adoption
Hannula & Reiner, 2019	Finland (HIC)	WtE-based	Renewables integration	Lower WtE emissions (reported)	Decarbonized grid
Duan et al., 2021	Mexico (UMIC)	Mixed	Megacity system pathways	Net reductions but trade-offs (reported)	Cost; system design
Fořt et al., 2020	Finland (HIC)	Mixed	Sorting + substitution	Significant reduction (reported)	

Source: Adapted from synthesized literature 2025

Discussion

The synthesis indicates that low-carbon SWM is not determined by a single "best" technology, but by how systems manage methane, deploy circular strategies, and align residual treatment with the decarbonizing energy context. Methodologically, the strongest source of divergence is the treatment of methane and avoided burdens. Measurement and modeling studies demonstrate that fugitive emissions can vary widely across sites and time, and that assumed capture rates may misrepresent actual performance [16], [25], [50]. This implies that LCA-based comparisons that treat landfill gas capture as a fixed parameter may systematically bias rankings unless grounded in local measurement or robust uncertainty analysis.

A second cross-theme insight is that circular strategies frequently deliver net climate savings, but the magnitude depends on substitution modeling. Studies of plastics, composites, and construction materials show that avoided virgin production can dominate net outcomes, yet assumptions about substitution ratios, quality loss, and market displacement remain underreported in abstracts and vary across studies [6], [7], [8]. This methodological fragility helps explain conflicting conclusions about the relative performance of recycling versus energy recovery, particularly where the electricity grid is low-carbon or where recovered materials displace relatively clean production.

Technology performance findings highlight consistent levers: (i) landfill methane control (capture, oxidation, aeration) is critical where organics disposal is high; (ii) WtE benefits are context-dependent and sensitive to heat/electricity substitution; and (iii) integrated systems combining source separation, recycling, and organics diversion often provide robust mitigation relative to disposal-only baselines [2], [21], [30]. However, the review also suggests that focusing solely on residual treatment can yield diminishing returns in high-performing systems, whereas upstream measures that improve sorting quality, reduce contamination, and increase capture of high-impact recyclables can offer larger marginal benefits.

Regionally, the reviewed evidence aligns with a socio-technical transition view: feasible pathways depend on institutional capacity, financing, and baseline infrastructure. Policy mapping shows that national commitments vary in ambition and specificity [3], while city-scale studies show that operational measures such as source separation and support strategies can reduce footprints when aligned with local behavior and collection logistics [2]. Conversely, constrained contexts such as dumpsites and camps exhibit high emissions and limited feasible interventions without foundational governance and infrastructure improvements [9], [47].

Research gaps remain. First, many studies do not fully report comparable methodological parameters (time horizon, allocation, boundary completeness), limiting reproducibility and synthesis. Second, few papers integrate measured methane data directly into system-wide LCA comparisons, leaving a gap between monitoring literature and decision-support modeling. Third, more studies are needed on LMIC pathways where informal sectors, data scarcity, and financing constraints shape outcomes; these contexts likely offer the largest near-term mitigation gains but are underrepresented relative to high-income case studies. Finally, future work should develop standardized reporting templates for SWM carbon assessments and expand dynamic approaches that reflect energy-system decarbonization trajectories and time-dependent methane emissions.

CONCLUSIONS

This systematic review synthesizes 50 recent studies (2017–2025) on carbon footprinting and GHG mitigation in SWM across technologies and regions. Findings show that climate outcomes are primarily driven by methane dynamics and the credibility of avoided-burden accounting, with technology rankings shifting under different assumptions about gas capture, substitution, and energy grid intensity. Integrated systems combining source separation, material recovery, and organics diversion often yield net climate savings relative to disposal-oriented baselines, while WtE benefits are context-dependent and sensitive to decarbonization trajectories. Regional pathways diverge by baseline infrastructure and institutional capacity: LMIC contexts can achieve large relative mitigation through foundational improvements and methane control, whereas HIC contexts increasingly focus on optimizing residual treatment and circular policy instruments.

The review contributes a structured comparative framework linking methodological choices to pathway rankings and identifies priority gaps: harmonized reporting of system boundaries and carbon conventions, stronger integration of measured methane data into system-level assessments, and expanded evidence for LMIC transitions. These insights can support policymakers and practitioners in designing low-carbon SWM strategies aligned with circular-economy principles and local feasibility constraints.

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