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Sustainable Circular Economy–Based Waste Management: A Systematic Review and Integrative Framework for Triple-Bottom-Line Outcomes

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ABSTRACT

This PRISMA 2020–aligned systematic review synthesizes a Scopus-indexed corpus spanning 2017–2026 on sustainable circular economy (CE) municipal/solid waste management systems (MSWMS) and their triple-bottom-line (TBL) outcomes. From 333 records, 90 studies met eligibility criteria and were mapped using bibliometric science-mapping (Bibliometrix/Biblioshiny and VOSviewer) and full-text evidence-to-framework synthesis. Within the included corpus, the evidence base is concentrated in recycling/material recovery, organics valorization, and residual management, while prevention and reuse remain under-studied. The review identifies four recurring mechanisms through which CE strategies are associated with outcomes: (i) substitution, (ii) leakage reduction, (iii) market formation/value creation, and (iv) inclusion/legitimacy. An integrative framework and eight evidence-informed propositions (P1–P8) outline boundary conditions and help explain variation in performance across contexts. Using a multi-level perspective (MLP), regime factors, financing/cost recovery, infrastructure readiness, enforcement, market maturity, and data/monitoring emerge as prominent moderators, while niche technology reliability and landscape-level participation norms further condition outcomes. Robustness checks indicate that the relative prominence of the core mechanisms remains broadly stable across quality and method subsets, but social outcomes are operationalized least consistently, pointing to a focused research agenda on social metrics and upstream CE levers.

1. INTRODUCTION

Municipal solid waste (MSW) has become a defining sustainability challenge because its impacts accumulate across environmental integrity, public health, and local economic resilience. Recent global re-assessments estimate that MSW generation in 2019 likely ranged from 2.3–3.1 billion tones and could rise to 2.89–4.54 billion tones by 2050, while "almost one-third of the total MSW generated is not collected," and much of what is collected is not managed according to sound practices [1]. This combination of scale and systemic service gaps drives persistent pollution, avoidable greenhouse-gas emissions, and unequal exposure to health risks, making waste management not only a technical service problem, but a governance and development problem.

Within this context, the circular economy (CE) is increasingly framed as a transition pathway for reorienting waste systems away from end-of-pipe disposal toward value retention, resource productivity, and system redesign. Geissdoerfer et al. [2] defined CE as "a regenerative system in which resource input and waste, emission, and energy leakage are minimized," highlighting that circularity is pursued by slowing, closing, and narrowing material and energy loops rather than focusing solely on downstream recycling. For the waste sector, this implies reconfiguring upstream design choices, collection and sorting architectures, market incentives for secondary materials, and institutional arrangements that determine whether waste becomes a recoverable resource stream or an unmanaged externality.

However, CE is not interpreted or operationalized consistently across the waste-management literature. Kirchherr et al. [3], reviewing 114 definitions, observed that CE is "most frequently depicted as a combination of reduce, reuse and recycle activities," while the need for broader systemic shift is often underemphasized. Complementing this definitional dispersion, Korhonen et al. [4] argued that the research content of CE can be "superficial and unorganized," appearing as a collection of disparate ideas rather than a coherent analytical lens. This conceptual variability matters because it reduces comparability across studies and makes it harder to convert evidence into implementable pathways for cities and service providers.

A sustainability-oriented CE agenda therefore requires evaluation criteria that explicitly address trade-offs and distributional effects, not only material recovery. In practice, CE-for-waste studies often emphasize environmental outcomes (e.g., diversion, emissions), while social outcomes, occupational safety, procedural justice, inclusion of informal actors, and community well-being, are less consistently measured and synthesized [5]. Consistent with this concern, Elia et al. [6] concluded that "the social dimension of sustainability is currently the most neglected in Circular Economy assessment," and highlighted heterogeneity and weak standardization in assessment approaches. For MSW systems, where frontline work conditions, community acceptance, and livelihood impacts can shape feasibility and legitimacy, this asymmetry in evidence limits both scholarship and policy design.

These issues reveal a synthesis gap with direct implications for both research and implementation in municipal/solid waste management systems (MSWMS). First, evidence is dispersed across technological options, governance instruments, and business-model initiatives, frequently reported without a shared causal logic that explains how specific CE strategies generate triple-bottom-line (TBL) outcomes [3, 4]. Second, the same intervention can yield different outcomes depending on contextual moderators such as market demand for secondary materials, institutional capacity for source separation and enforcement, financing constraints, and the role of informal collection and sorting networks [1, 5]. At the same time, conceptually adjacent waste studies are not always directly anchored in municipal systems, which makes a clearly bounded MSWMS-focused synthesis especially important.

While multiple reviews exist, they tend to cover adjacent, but incomplete, pieces of the puzzle. Reviews on CE assessment emphasize methodological fragmentation and the persistent neglect of social dimensions, but typically do not translate findings into waste-system transition mechanisms and actionable pathways [6]. Reviews dedicated to the social aspects of CE map social impact categories and measurement challenges across sectors, yet are not anchored to MSW system design choices and governance constraints that shape real-world waste outcomes [5]. Meanwhile, waste-focused sustainability reviews frequently concentrate on life-cycle tools (e.g., LCSA) and catalog impact categories across case studies, but do not integrate CE strategies, enabling conditions, and contextual moderators into an explanatory model for TBL performance [7]. Within this more specific MSWMS boundary, this study addresses that gap by developing an integrative framework that links CE strategies to (i) underlying mechanisms, (ii) enabling and constraining conditions, and (iii) environmental, social, and economic outcomes, while explicitly accounting for context-dependent variation.

Accordingly, this study conducts a systematic review of sustainable CE-based MSWMS with a focus on TBL outcomes and the pathways connecting CE strategies to environmental, social, and economic performance. The review is confined to studies directly relevant to MSWMS, including integrated system-wide analyses and major municipal waste fractions where these are examined within municipal solid-waste arrangements. We synthesize: (i) the portfolio of CE strategies examined in MSWMS (prevention, reuse, recycling, organics valorization, and residual treatment within integrated systems), (ii) enablers and barriers across governance, infrastructure, and markets, (iii) mechanisms through which strategies translate into outcomes, and (iv) the moderators that help explain variation across contexts [2, 6]. Wastewater, sewage, and sludge systems are outside the scope of this review.

The remainder of the paper details the review protocol and selection procedure, reports descriptive and thematic findings, introduces the proposed integrative framework, and concludes with implications for research design, policy mixes, and implementation priorities for sustainable circular waste systems.

2. CONCEPTUAL BACKGROUND

2.1 Conceptual clarity and scope: From "circularity" to sustainable circular waste systems

CE has rapidly diffused into waste-management scholarship, yet its meaning remains uneven across studies, creating ambiguity about what is being implemented, measured, and compared. Kirchherr et al. [3] showed that CE is "most frequently depicted as a combination of reduce, reuse and recycle activities," while the systemic shift implied by CE is often underemphasized. In the same vein, Korhonen et al. [4] cautioned that the "scientific and research content of the CE concept is superficial and unorganized," implying that CE can become a bundle of loosely connected ideas unless anchored by explicit boundaries and evaluative criteria. To keep the synthesis coherent and policy-relevant, this review adopts a sustainability-first framing: CE-based waste management is treated as a socio-technical transition evaluated through TBL outcomes. In this review, the analytical boundary is restricted to MSWMS and to studies directly relevant to municipal waste-system design, operation, or governance. The scope is MSWMS, primarily non-hazardous municipal/household waste and similar commercial waste streams managed within municipal systems, covering upstream interfaces (products/consumption affecting waste generation), collection and source separation, sorting and material recovery, biological and thermal treatment pathways, and final disposal. Studies addressing broader waste domains were considered only where their evidence was clearly embedded in, or directly transferable to, municipal solid-waste arrangements; they were not intended to redefine the core scope of the review. Wastewater, sewage, and sludge systems are outside the scope. This boundary is intended to ensure that the core synthesis, descriptive patterns, and framework development remain anchored in the MSWMS-focused evidence base rather than in broader waste-system literatures.

2.2 Operational definitions: Circular economy and sustainability as analytical anchors

To minimize definitional drift, we adopt Geissdoerfer et al.'s [2] definition of CE as "a regenerative system in which resource input and waste, emission, and energy leakage are minimized," achieved by "slowing, closing, and narrowing" loops through strategies such as reuse, repair, remanufacturing, and recycling. This definition is paired with their definition of sustainability as the balanced integration of economic performance, social inclusiveness, and environmental resilience, directly motivating a TBL lens. Together, these anchors prevent "circularity" from being reduced to downstream recycling rates and ensure that "success" must be justified across environmental, social, and economic dimensions.

To explain why similar circular strategies, yield different TBL outcomes across settings, this review uses a socio-technical transitions lens, specifically the multi-level perspective (MLP), as an organizing backbone. In MSW transitions, landscape pressures (e.g., urbanization, climate/resource pressures) interact with regime structures (infrastructure lock-in, incumbent routines, regulatory capacity) and niche innovations (new separation systems, reuse platforms, EPR schemes, valorization technologies). Iyamu et al. [8] explicitly characterized MSWMS transition through the three MLP levels, "landscape pressures, regimes, and niche innovations", supporting the use of MLP to structure intervention types, enabling conditions, and context dependence.

2.3 Circular strategies in municipal/solid waste management systems: A structured taxonomy of value-retention options

The central reason CE evidence becomes hard to integrate is that studies often mix interventions without a shared taxonomy. Reike et al. [9] observed that the CE "revival" has been "accompanied by controversies and confusions," motivating a structured view based on resource value-retention options. Complementarily, Morseletto [10] proposed an actionable mapping lens using "10 common circular economy strategies" (e.g., recover, recycle, reuse, reduce, rethink, refuse) to scrutinize targets and avoid narrow, partial operationalization.

Translated into MSWMS, this review organizes strategies as: (i) prevention and demand reduction (e.g., packaging redesign, pricing/consumption shifts); (ii) reuse systems (refill/repair/secondhand logistics); (iii) recycling and material recovery (source separation, MRF performance, quality upgrading); (iv) organics valorization (composting, anaerobic digestion, bio-based products); and (v) residual management (controlled treatment and sanitary disposal to reduce leakage). This hierarchy supports consistent comparison across heterogeneous studies and clarifies where evidence concentrates (often recycling) versus where it remains thinner (prevention/reuse and social outcomes).

2.4 Triple-bottom-line outcomes: Indicators, trade-offs, and measurement pitfalls

A TBL lens is essential because CE interventions can generate trade-offs (e.g., higher diversion but higher household costs) and distributional effects (who benefits, who pays, who bears risk). Environmental outcomes typically include reduced emissions/pollution, resource conservation, and reduced leakage. Economic outcomes include cost-effectiveness, revenue stability, and value creation from secondary materials. Social outcomes include health and safety, inclusion, procedural fairness, and community well-being/acceptance. Haupt and Hellweg [11] highlighted that mass-based circularity indicators (e.g., recycling rates) are widely used, but "fail to cover the environmental perspective", a key motivation for CE transitions. Moreover, CE-sustainability assessments frequently under-represent social dimensions: Elia et al. [6] concluded that "the social dimension of sustainability is currently the most neglected in Circular Economy assessment," alongside methodological heterogeneity. These limitations justify a synthesis approach that tracks not only "how circular" systems appear, but whether circular strategies translate into demonstrable TBL outcomes.

To prevent "social" from becoming a rhetorical add-on, this review operationalizes social outcomes into codeable categories: (1) decent work and occupational health & safety (exposure, injuries, protections); (2) inclusion and livelihood security (participation of informal/vulnerable groups, income stability); (3) procedural justice and stakeholder participation (voice, transparency, accountability); and (4) community well-being and acceptance (health, nuisance, trust). Padilla-Rivera et al. [5] noted that "there has been no agreement to measure" CE transition effectiveness "particularly those that affect society," underscoring the need for explicit social coding in CE syntheses. This framing is consistent with social-inclusion scholarship arguing that CE must expand beyond material loops: Souza Piao et al. [12] stated that "circular economy has to devote more attention to social inclusion" to fully support sustainable development.

2.5 Mechanisms and conditions: How circular economy strategies produce (or fail to produce) triple-bottom-line outcomes

This review treats the CE–TBL relationship as mechanism-based: strategies influence outcomes through identifiable pathways whose strength depends on enabling conditions. Resource efficiency and substitution. Improved separation, sorting, and quality upgrading increase secondary material usability, enabling substitution of virgin inputs and associated environmental benefits. Yet substitution and life-cycle impacts may be misrepresented when evidence relies on mass-based circularity metrics alone [2, 11]. Leakage reduction and risk control. Reliable collection, controlled treatment, and safe disposal reduce open dumping/burning and exposure pathways, linking CE transitions to public health and local environmental quality. Regime capacity (institutions, enforcement, infrastructure lock-in) shapes feasibility and effectiveness, as anticipated by MLP dynamics [8]. Circular strategies can create economic value through circular services (repair/reuse), secondary material markets, and organics valorization; however, performance is moderated by price volatility, financing, and policy credibility. Targets and instruments can steer transitions but remain partial if focused narrowly on recovery/recycling [10]. Inclusive circular transitions can improve legitimacy and continuity of recovery systems, while exclusion can undermine both social outcomes and system performance. For example, Valencia et al. [13] argued that "implementing a circular economy… can be the opportunity to include waste pickers and other informal workers" within a regenerative model, illustrating how inclusion can be a core condition for "sustainable circularity" in MSW contexts.

2.6 Context moderators and bridge to the integrative framework

The same CE strategy can produce different TBL outcomes across settings due to moderators such as governance capacity, waste composition (organics vs plastics), urban density/logistics, maturity of secondary-material markets, and labor structure (formal vs informal). A transitions lens expects heterogeneity because system change depends on aligned developments across technologies, institutions, markets, and user practices [8]. Higher-order value-retention strategies (prevention/reuse/repair) are expected to offer stronger TBL potential than recycling-only approaches because they align with CE's loop-slowing/value-retention logic [2]. Policy mixes and targets are expected to strengthen strategy-to-mechanism links, but targets limited to recovery/recycling may fail to promote CE comprehensively [10]. Social safeguards (decent work, inclusion, procedural justice) are expected to improve transition legitimacy and implementation stability, increasing the likelihood of positive social outcomes and potentially reinforcing environmental/economic performance through higher participation [12, 13]. Finally, because mass-based circularity indicators can omit environmental impacts, impact-oriented assessment is expected to yield more reliable TBL inference and make trade-offs more visible [11].

3. METHODS

3.1 Review design and reporting standard

This study conducted a systematic literature review (SLR) combined with an evidence-to-framework synthesis to develop an integrative model of sustainable CE–based MSWMS and their TBL outcomes. The review was designed a priori with explicit scope boundaries, eligibility rules, appraisal criteria, and synthesis logic, and it is reported in accordance with the PRISMA 2020 statement to ensure transparency and reproducibility across identification, screening, eligibility assessment, and inclusion [14].

3.2 Information source and search strategy

A single-database search was performed in Scopus using an advanced query applied to TITLE–ABS–KEY. The search string combined three concept blocks: (i) CE-related terms, (ii) MSWMS-related terms, and (iii) TBL/sustainability assessment terms, with explicit exclusions for wastewater/sewage/sludge. Results were restricted to journal sources, final publication stage, document types “article” and “review,” and English language. The Scopus query applied the temporal filter PUBYEAR > 2016 AND PUBYEAR < 2026. At the time of data extraction, however, the export included two records indexed as 2026; these records were retained in the analytical dataset. Accordingly, the reviewed corpus is reported consistently as spanning 2017–2026 throughout the revised manuscript. The full query is provided verbatim in Table A1b, and the search setup is summarized in Table A1. To complement the descriptive profiling of the evidence base, bibliometric performance indicators and science-mapping analyses were generated from the same Scopus export using Bibliometrix (Biblioshiny, R) and VOSviewer [15]. The exported fields included full records and cited references. Keyword harmonization (e.g., singular/plural, spelling variants, acronyms) was performed using a thesaurus file prior to mapping. Co-occurrence (keywords), co-citation (sources/references), and collaboration networks (countries/authors) were visualized using association-strength normalization, with minimum-occurrence thresholds reported alongside each map. These bibliometric outputs were used to describe the structure and thematic patterning of the included Scopus-indexed corpus and to inform the subsequent evidence-to-framework synthesis; they were not intended to imply exhaustive coverage of the wider field beyond the reviewed sample.

3.3 Eligibility criteria (scope and inclusion/exclusion rules)

Eligibility criteria were pre-specified to enforce a tight boundary around MSWMS and sustainability outcomes. Studies were included if they:

1) addressed CE strategies directly within MSWMS or within clearly municipal solid-waste arrangements (e.g., prevention, reuse, recycling/material recovery, organics valorization, residual management), and
2) reported or discussed environmental, social, and/or economic outcomes under an explicit sustainability/TBL framing or through sustainability assessment/indicator approaches.

To preserve scope consistency, studies from broader waste domains were included only when their empirical focus, system boundary, or governance setting was clearly embedded in MSWMS; conceptually adjacent but non-municipal waste studies were not intended to form part of the core synthesis. Studies were excluded if they focused on wastewater/sewage/sludge, addressed waste domains not clearly aligned with MSWMS, were not peer-reviewed journal articles/reviews, were not in English, or were not retrievable in full text for synthesis. The complete inclusion/exclusion criteria and rationale are provided in Table A2.

3.4 Study selection process and PRISMA flow

Search results were exported from Scopus and screened in stages aligned with PRISMA 2020. As shown in Figure 1, the search identified 333 records. Prior to screening, 8 records were removed as ineligible by automation tools; no duplicates were recorded (n = 0), and no records were removed for other reasons (n = 0). The remaining 325 records proceeded to title/abstract screening, where 80 were excluded. A total of 245 reports were then sought for retrieval. Of these, 150 reports were not retrieved in usable full-text form. The remaining 95 reports were assessed for eligibility. At the eligibility stage, 3 reports were excluded due to wrong document type (not article/review), and 2 were excluded because the full text was not in English. The final included set comprised 90 studies. Report-not-retrieved and full-text exclusion categories and counts are documented in Table A3. Methodological guidance recommends explicit documentation of review decisions and exclusion rationales to reduce bias and enable auditability; therefore, reasons for exclusion were recorded using standardized categories at the retrieval and full-text eligibility stages. To maintain internal consistency, the same PRISMA category definitions and counts were applied throughout Figure 1, the main text, and the appendix tables.

3.5 Methodological quality appraisal

To avoid treating all evidence as equally reliable, methodological quality appraisal was conducted using a transparent, mixed-method–friendly rubric (Table A4) adapted to the diverse designs expected in CE–waste research (e.g., LCA-based assessments, modelling studies, case studies, and policy analyses). Criteria covered clarity of aim, boundary specification, methodological appropriateness, data transparency, robustness/validation, limitations/bias, and the substantive measurement of environmental, social, and economic outcomes. The rubric is conceptually aligned with the Mixed Methods Appraisal Tool (MMAT) 2018, which is widely used for appraising heterogeneous evidence bases in mixed-studies reviews. Quality scores were used to weight confidence and support sensitivity checks, rather than to exclude studies mechanically (thresholding rules and usage are specified in Table A4b). This approach is consistent with contemporary review practice that treats appraisal as a tool for interpreting confidence in synthesized claims.

3.6 Data extraction and coding scheme

A standardized extraction template was developed to ensure consistent capture of constructs required for the integrative framework. Extracted data fields included: study context and scale; waste stream and system boundary; circular strategies; enabling conditions and barriers (governance, infrastructure, markets/finance, coordination/data, behavior/acceptance); mechanisms (substitution, leakage reduction, market formation/value creation, inclusion/legitimacy); and TBL outcomes (indicators and effect direction where stated). The complete extraction form (fields, operational definitions, and data types) is provided in Table A5. Qualitative and mixed evidence was coded using a structured codebook (Table A6). In particular, the social pillar was operationalized into codeable categories, decent work/OHS, inclusion and livelihoods, procedural justice/participation, and community wellbeing/acceptance, to prevent social impacts from being treated as incidental narrative (Table A7). For thematic organization and cross-study pattern identification, the coding and synthesis followed established guidance for thematic analysis as a rigorous approach to constructing meaning patterns across a dataset.

3.7 Evidence synthesis and integrative framework development

Synthesis proceeded in two linked layers:

1) Descriptive mapping summarized the distribution of evidence across years, journals, contexts, methods, waste streams, and CE strategies (bibliographic fields are compiled in Table A8).
2) Evidence-to-framework thematic synthesis translated coded findings into higher-order constructs and relationships linking strategies → enabling conditions/barriers → mechanisms → TBL outcomes, with context moderators used to explain heterogeneity rather than being treated as noise.

To operationalize framework building, relationships were consolidated into propositions (P1–P8) and documented via an evidence matrix linking each relationship to supporting studies and boundary conditions (Table A9). This proposition-based, integrative approach is increasingly used in high-impact reviews to move beyond descriptive summaries and to generate testable, transferable models grounded in the evidence base.

3.8 Robustness and bias considerations

Robustness checks were pre-specified to assess whether conclusions and framework relations were sensitive to evidence quality, context, waste stream, and method family. Planned checks and reporting formats are provided in Table A10. This reflects best practice in systematic reviewing: when meta-analysis is infeasible due to heterogeneity, reviewers should still demonstrate analytic discipline through transparent sensitivity and robustness assessments. A key limitation is that the evidence base is constrained by database indexing and filter choices (e.g., journal-only and the implemented OA constraint). Where feasible, future iterations can complement database searching with structured citation chasing to broaden coverage and reduce retrieval bias; recent work has shown that transparent citation chasing can efficiently expand evidence capture beyond keyword search results.

4. RESULTS

4.1 Study identification and selection (PRISMA 2020)

As summarized in Figure 1 (PRISMA 2020 flow diagram), the database search identified 333 records. Prior to screening, 8 records were removed as ineligible by automation tools, while no duplicates were detected (n = 0) and no records were removed for other reasons (n = 0). The remaining 325 records were screened at the title/abstract level, resulting in the exclusion of 80 records that did not meet the review scope. A total of 245 reports were then sought for retrieval. Of these, 150 reports were not retrieved in usable full-text form. The remaining 95 reports were assessed for eligibility. At this stage, 3 reports were excluded due to document-type mismatch (i.e., not articles or reviews), and 2 reports were excluded because the full text was not in English. After applying all eligibility criteria, 90 studies were retained for the final synthesis.

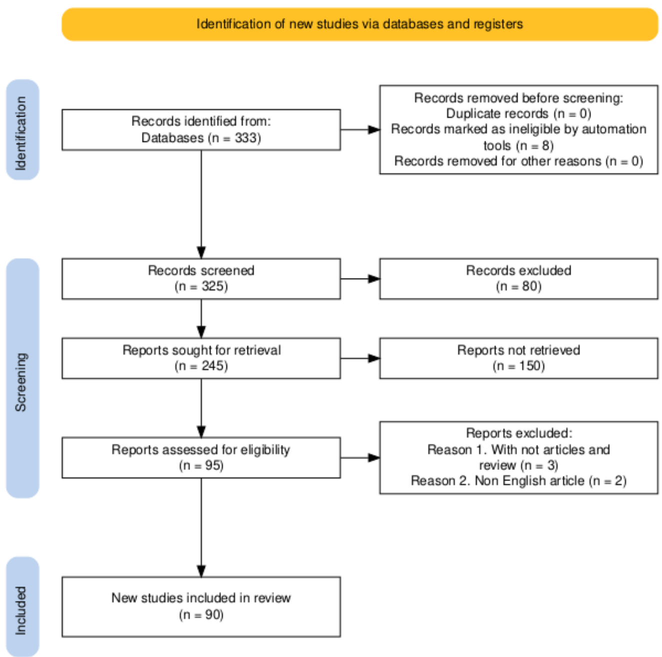

Figure 1. PRISMA flow chart

4.2 Bibliometric snapshot and science mapping

To contextualize the evidence base, we conducted a compact bibliometric assessment of the 90 included Scopus-indexed studies using Bibliometrix/Biblioshiny for performance indicators (growth and sources) and VOSviewer for science mapping (keyword co-occurrence structure and temporal dynamics) [16]. This bibliometric layer is descriptive and is used to situate the SLR and inform the subsequent evidence-to-framework synthesis. Within the included corpus, the annual production trend (Figure 2) shows a low publication volume during 2017–2020 (2–4 papers/year), followed by sustained growth from 2021 onward and a marked increase in

2025 (41 papers). The smaller count in 2026 (2 papers) should be interpreted cautiously, as it likely reflects partial-year/indexing timing within the exported corpus rather than a substantive decline in publication activity. These trends are presented as descriptive features of the reviewed Scopus-indexed sample, not as exhaustive indicators of the wider field.

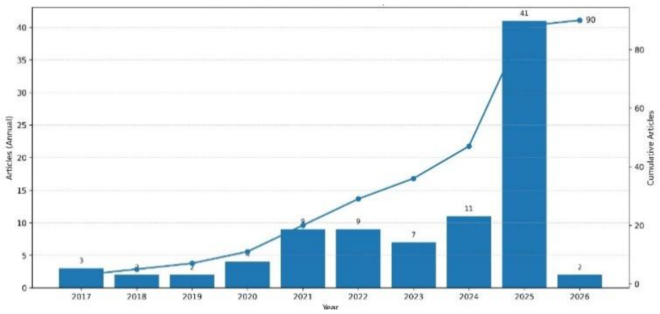

Figure 2. Annual scientific production of included studies

The outlet distribution indicates a concentrated publication pattern (Figure 3). Sustainability (Switzerland) is the dominant source (25 papers), followed by a long tail of journals contributing smaller numbers (typically 2–3 papers each). To complement productivity counts with impact descriptors, Table 1 reports source-level indicators (e.g., h-index, total citations, and starting year within this dataset) generated in Bibliometrix/Biblioshiny, which helps avoid interpreting volume alone as quality. These source patterns are reported to characterize the included evidence base rather than to imply field-wide source dominance beyond the reviewed sample.

Keyword co-occurrence mapping was performed in VOSviewer using an occurrence threshold of ≥ 3, yielding a network of 35 terms (Figures 4-6). The network and density views (Figures 4-5) reveal a tightly connected conceptual core anchored by "circular economy" (59 occurrences; total link strength, TLS = 172), "waste management" (42; TLS = 156), and "sustainability" (33; TLS = 113). Pairwise links further confirm strong coupling between CE ↔ waste management (link strength = 31) and CE ↔ sustainability (23), suggesting that, within the included sample, CE is predominantly framed as a sustainability-oriented transformation of waste systems rather than a stand-alone efficiency agenda.

Beyond the core, the map separates into several coherent thematic neighborhoods. One cluster emphasizes MSW and decision/policy orientation (e.g., municipal solid waste, decision making, policy making), another emphasizes assessment and impacts (e.g., environmental impact, life cycle assessment, valorization), and a third emphasizes resource recovery and related risk/economic lenses (e.g., recycling, environmental economics, risk assessment). The temporal overlay (Figure 6) indicates a more recent emphasis on SDG-aligned framing (sustainable development goals, average publication year = 2025) and waste-to-energy-related terms (average publication year ≈ 2024.7), pointing to increasing attention to policy alignment and residual-treatment pathways in recent publications within the reviewed corpus.

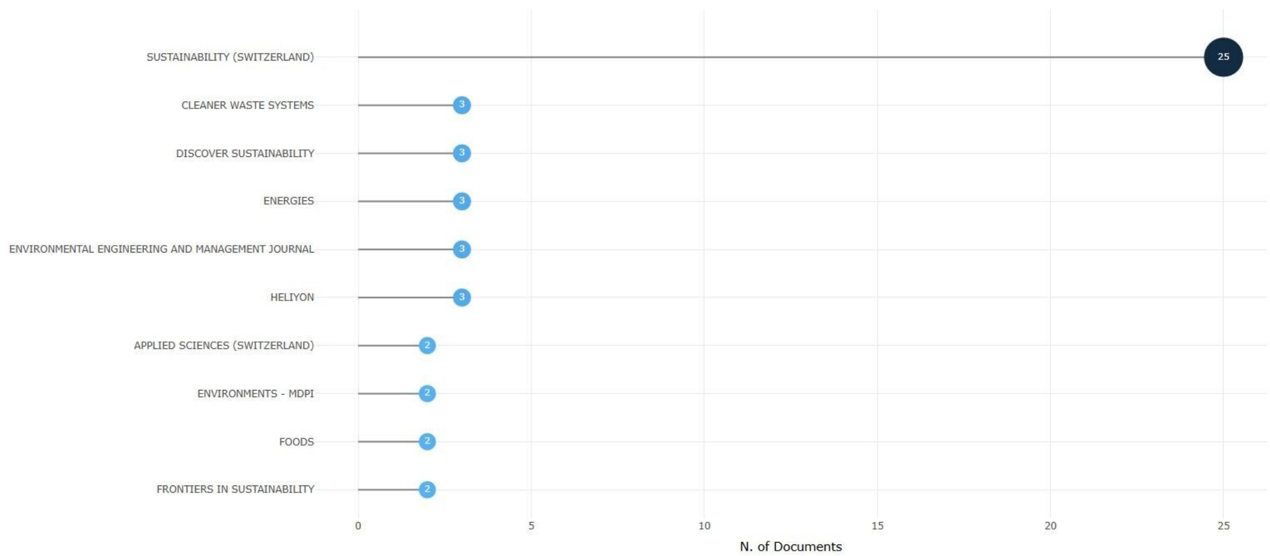

Figure 3. Most relevant sources by number of documents

Table 1. Source impact metrics of leading journals

Journal (Source)	NP	TC	h-index	g-index	m-index	PY_start
Sustainability (Switzerland)	25	772	12	25	1.2	2017
Energies	3	31	3	3	0.5	2021
Heliyon	3	26	3	3	0.6	2022
Recycling	2	65	2	2	0.222	2018
Foods	2	29	2	2	0.5	2023
Applied Sciences (Switzerland)	2	29	1	2	0.143	2020
Environments – MDPI	2	27	2	2	0.667	2024
Frontiers in Sustainability	2	19	2	2	0.4	2022
ACS Environmental Au	1	243	1	1	0.25	2023
Brazilian Journal of Operations and Production Management	1	12	1	1	0.167	2021

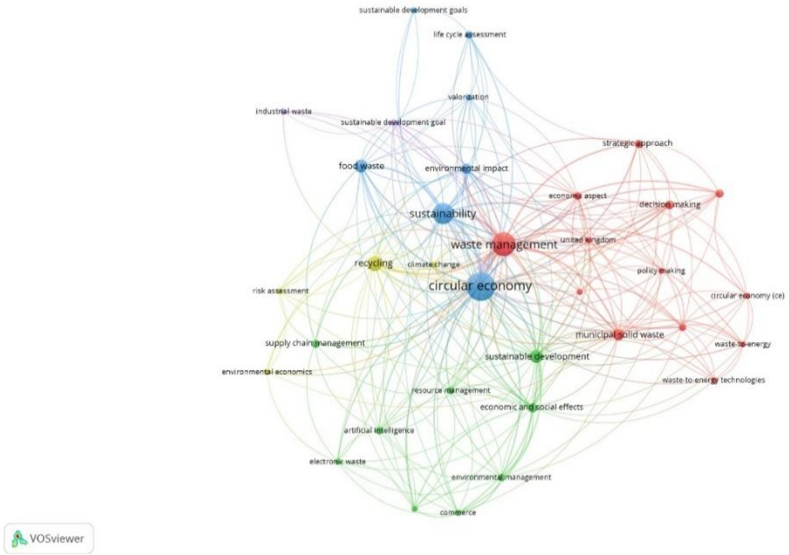

Figure 4. Keyword co-occurrence network visualization

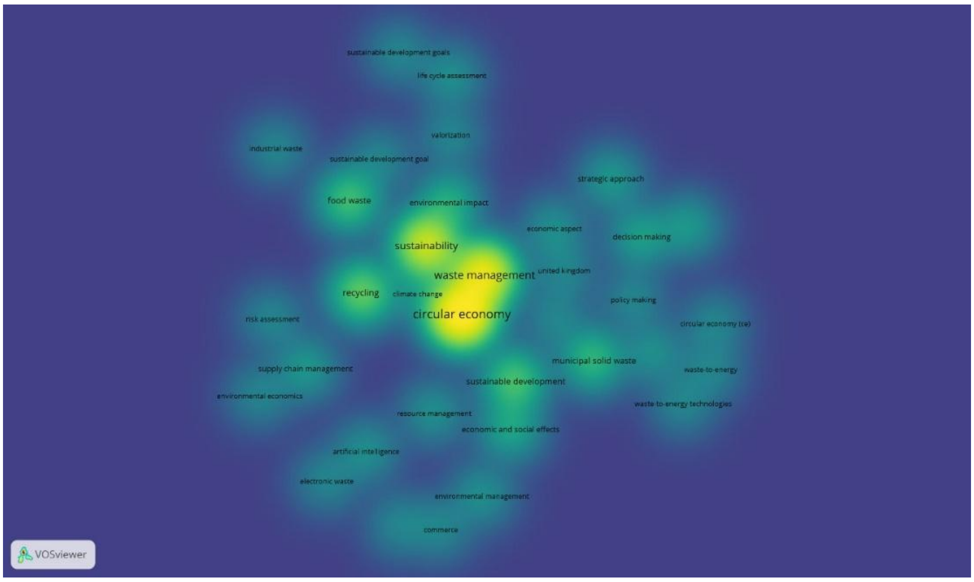

Figure 5. Keyword co-occurrence density visualization

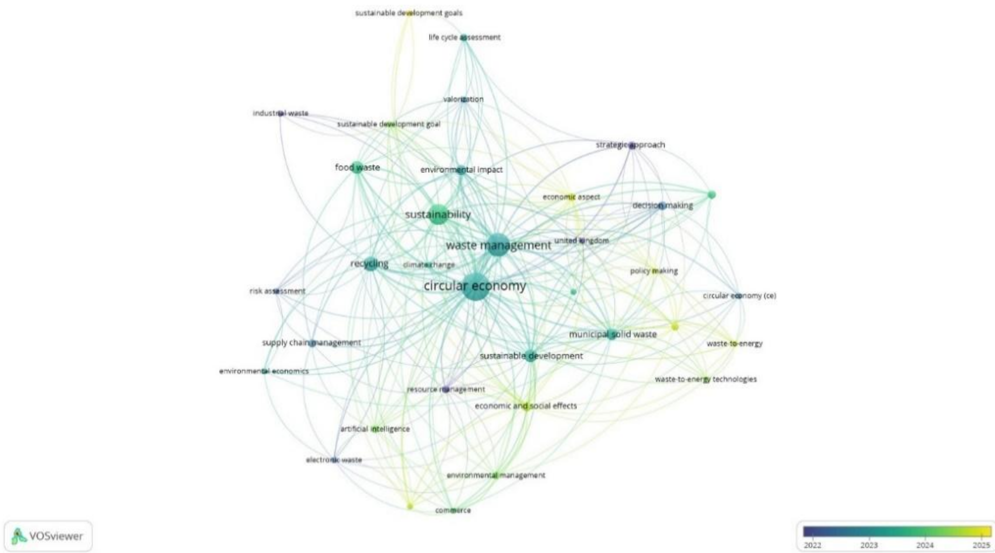

Figure 6. Keyword co-occurrence overlay visualization by average publication year

4.3 Evidence base at a glance

The review synthesizes 90 peer-reviewed journal articles and reviews captured from Scopus within the defined time window. The evidence base is heterogeneous in study setting, waste-stream focus, system boundary, and methodological approach, reflecting the multi-dimensional nature of CE transitions in waste systems. To preserve concision in the main text while ensuring full auditability, the complete study-level descriptors (authors, year, outlet, study setting, waste stream, boundary/stage, and method family) are reported in Table A11.

As shown in Figure 7, within the included corpus, organics/food waste and general/system-wide framings account for the largest shares of the evidence base, followed by plastics-focused studies. Additional studies address mixed MSW, WEEE/e-waste, construction and demolition (C&D) waste, and a small number of industrial-waste contexts. To preserve scope consistency, these conceptually adjacent cases were retained only where they informed interpretation of MSWMS and were not used to redefine the core MSWMS focus of the review [17-19]. This uneven stream coverage is analytically important: it shapes which TBL indicators are most frequently measured and where the evidence base remains thin for stream-specific social outcomes [20-23].

Figure 8 indicates that most studies take a multi-stage or system-wide boundary, often spanning more than one stage of the waste hierarchy. Among stage-focused studies, the evidence is concentrated in recycling/material recovery and waste-to-energy/thermal pathways, followed by reuse, with comparatively fewer studies centered on prevention/upstream measures, collection/separation, organics treatment/valorization as a primary stage focus, or landfill/final disposal. This boundary pattern matters for synthesis because system-wide studies tend to emphasize governance, infrastructure, and economic feasibility, while stage-specific studies more often report operational indicators and technology-specific environmental performance.

The method-family distribution (Figure 9) shows a mixed evidence base led by policy/institutional analyses, life cycle assessment (LCA), and decision-support/MCDA approaches, complemented by optimization/modelling studies that explore scenario trade-offs. Behavioral survey/SEM and qualitative stakeholder designs appear less frequently than policy, assessment, and decision-oriented approaches, which has implications for how robustly the social pillar is operationalized and measured across the corpus.

Taken together, these descriptive results indicate a reviewed corpus that is method-diverse and increasingly active over time, but still concentrated in system-wide or multi-stage framings, organics/food waste and general MSW applications, and selected recovery-oriented pathways. Coverage remains comparatively thinner for prevention-focused studies, landfill/disposal, and several stream-specific social-outcome analyses, patterns that motivate the subsequent quality appraisal and mechanism-based synthesis.

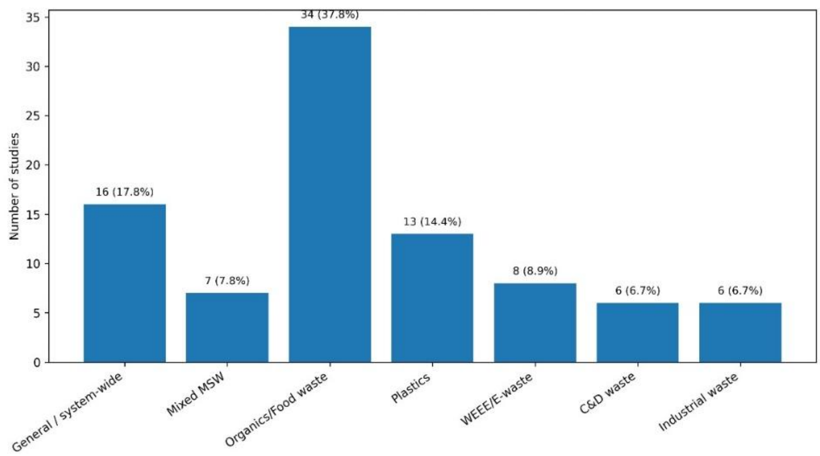

Figure 7. Distribution of waste-stream focus across the included studies (n = 90)

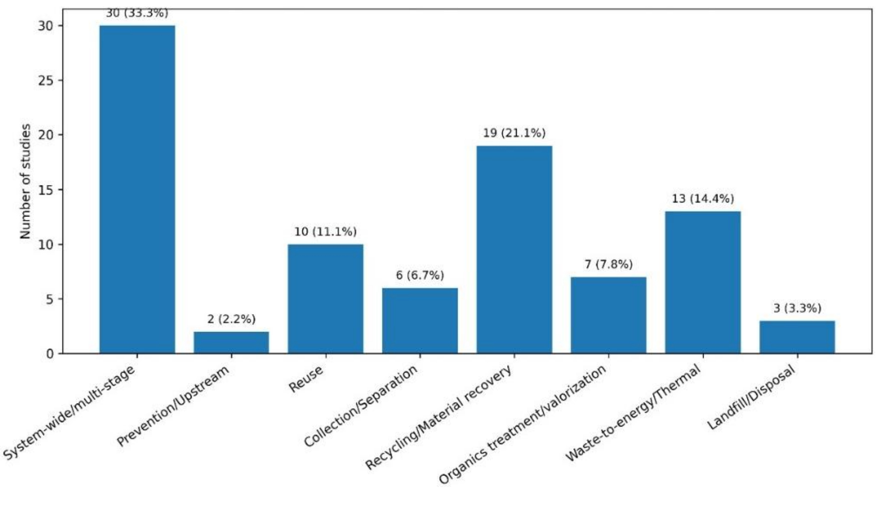

Figure 8. Distribution of system boundary/stage focus across the included studies (n = 90)

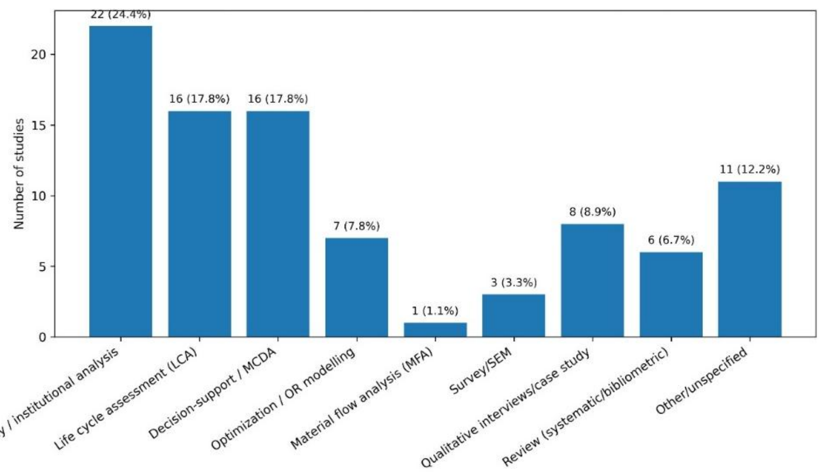

Figure 9. Method-family composition of the included studies (n = 90)

4.4 Methodological quality appraisal

Methodological quality appraisal was applied across the 90 included studies using the rubric reported in the Methods (Appendix A4), with appraisal used to qualify confidence in synthesized relations rather than to exclude evidence mechanically. Table 2 summarizes quality levels by method family. Overall, the evidence base is dominated by Moderate-quality studies (44/90; 48.9%), followed by High-quality (29/90; 32.2%) and Low-quality (17/90; 18.9%) studies.

Quality profiles differ by method family. Within the reviewed corpus, LCA-based assessments show the highest share of High-quality studies (56.2%), reflecting more frequent reporting of methodological structure and robustness elements. Optimization/OR modelling and decision-support/MCDA studies also exhibit comparatively higher shares of High-quality papers (42.9% and 37.5%, respectively), while policy/institutional analyses are more commonly appraised as Moderate (63.6%) with a smaller High-quality share (27.3%). Review papers are largely Moderate, consistent with their reliance on reporting and synthesis discipline rather than primary empirical validation.

Across the corpus, three recurring appraisal weaknesses affect confidence in the synthesized evidence. First, explicit boundary specification is unevenly reported relative to the diversity of designs, which reduces comparability across studies. Second, robustness/validation reporting appears less consistently than core results reporting, limiting confidence in magnitude claims when studies rely on scenario assumptions [24, 25]. Third, while limitations/bias are frequently acknowledged, data transparency varies, particularly in qualitative/policy and mixed-method contributions [26-29]. These patterns are therefore used to qualify the interpretation of later mechanism-based findings and to motivate the robustness/sensitivity checks reported below, rather than to invalidate lower-scoring studies mechanically.

4.5 Coverage of circular economy strategies in municipal/solid waste management systems

Table 3 summarizes how the included studies operationalize CE action in MSWMS and how evidence coverage is distributed across strategy clusters. Two complementary coverage indicators are reported: (i) primary focus, capturing the dominant strategy emphasis within each study, and (ii) mentioned across studies, capturing strategies that are discussed or evaluated as part of broader systems framing (multi-label). This distinction is important because many papers reference multiple CE options while empirically evaluating only one core pathway.

Across the corpus, the evidence base is heavily concentrated in recycling/material recovery as the primary focus (40 studies; 44.4%), consistent with the field's dominant orientation toward closing material loops through collection, sorting, and secondary-material production. Recycling/material recovery is also the most widely discussed strategy overall (59 studies; 65.6%), indicating that it functions as the conceptual anchor of CE–waste scholarship even when not the main evaluation target. Residual management (e.g., waste-to-energy and other controlled residual pathways) forms the second-largest primary emphasis (20 studies; 22.2%) and is discussed in 38 studies (42.2%), suggesting that residual handling remains a prominent, though more contested, component of CE-oriented MSW transitions [30-32].

Table 2. Quality appraisal summary by method family (n = 90)

Method Family	N	High	Moderate	Low	High (%)	Mean Score (0–7)
Policy / institutional analysis	22	6	14	2	27.3	4.77
Life cycle assessment (LCA)	16	9	6	1	56.2	5.44
Decision-support / Multi-Criteria Decision Analysis (MCDA)	16	6	8	2	37.5	4.81
Optimization / Operations Research (OR) modeling	7	3	3	1	42.9	5.29
Material flow analysis (MFA)	1	0	0	1	0	3
Survey / Structural Equation Modeling (SEM)	3	1	1	1	33.3	4.33
Qualitative interviews/case study	8	3	3	2	37.5	4.5
Review (systematic/bibliometric)	6	1	4	1	16.7	4.33
Other/unspecified	11	0	5	6	0	3.55
Overall	90	29	44	17	32.2	4.7

Table 3. Circular economy strategy taxonomy and evidence coverage across included studies (n = 90)

CE Strategy Cluster	Operational Scope (Summary)	Representative Interventions (Examples)	Primary Focus, n (%)	Mentioned Across Studies, n (%)
Prevention	Upstream waste avoidance and design/policy measures that reduce waste generation and improve circularity before materials enter the waste stream.	Source reduction; eco-design/design for disassembly; green/circular procurement; pay as you throw (PAYT) strategy; extended producer responsibility (EPR) / product stewardship.	7 (7.8%)	19 (21.1%)
Reuse	Strategies that extend product/service life by maintaining products in use with minimal reprocessing.	Repair/refurbishment; remanufacturing; reuse centers; deposit–return systems; sharing/rental models.	9 (10.0%)	28 (31.1%)
Recycling/Material recovery	Collection, separation, and processing that returns materials to productive use as secondary resources.	Source separation; sorting/sorting / materials recovery facility (MRF); mechanical (and, where relevant, chemical) recycling; material recovery from mixed material recovery from mixed municipal solid waste (MSW).	40 (44.4%)	59 (65.6%)
Organics valorization	Valorization pathways for the organic fraction of MSW to generate products and energy while closing nutrient/carbon loops.	Composting; anaerobic digestion/biogas; digestate/biofertilizer use; organic fraction of municipal solid waste (OFMSW) management.	13 (14.4%)	25 (27.8%)
Residual management	Management of residual waste fractions not feasibly prevented/reused/recycled, prioritizing controlled treatment and recovery where applicable.	Waste-to-energy/thermal treatment; Refuse-Derived Fuel (RDF) / co-processing; controlled landfill with gas capture; residual handling and risk control.	20 (22.2%)	38 (42.2%)

In contrast, upstream strategies are comparatively less represented as focal evaluations. Organics valorization appears as the primary strategy in 13 studies (14.4%) and is mentioned in 25 studies (27.8%), reflecting the importance of managing the organic fraction through composting and anaerobic digestion but also indicating that organics is often embedded within broader system narratives rather than evaluated as a stand-alone CE lever. Reuse is the primary focus in only 9 studies (10.0%), despite being mentioned in 28 studies (31.1%), implying that reuse is frequently acknowledged as a priority but is less often implemented and assessed through rigorous outcome measurement. Prevention, arguably the highest-value CE strategy in the waste hierarchy, shows the lowest primary coverage (7 studies; 7.8%) and is mentioned in 19 studies (21.1%), underscoring a persistent evidence gap at the upstream end of MSWMS [28, 33, 34].

A brief linkage to the descriptive coding further indicates that recycling-focused studies most often align with material recovery stages and are frequently associated with plastics-oriented applications, whereas organics valorization studies cluster around OFMSW contexts and treatment/valorization stages; residual-management studies are commonly tied to thermal/WtE pathways. These distributional patterns provide the empirical basis for later sections that trace strategy → mechanisms → TBL outcomes and specify where evidence is currently strongest versus underdeveloped.

4.6 Enablers and barriers for circular economy implementation

This subsection synthesizes the enabling conditions and barriers reported across the included studies, coded from full texts into five implementation domains: governance, infrastructure, markets/finance, coordination/data, and behavior/acceptance. To keep the main Results concise while maintaining transparency, the ranked theme list with operational definitions and counts is provided in Table A12.

Cross-cutting pattern. Across domains, the most frequently reported themes are not "single-sided": they are often described as enablers were present and functional, but as constraints where weak or absent (hence "mixed" polarity in Table A12). This is particularly evident for financing, policy frameworks, collection systems, and public engagement, areas where studies repeatedly stress that implementation success depends on the strength and coherence of the supporting system rather than on the technical viability of a single CE option [35, 36].

Governance conditions (rules, capacity, enforcement). Governance-related factors are pervasive. A policy/regulatory framework is referenced in 84 studies, typically as a necessary foundation for CE–MSW reforms, but frequently accompanied by implementation gaps (mixed framing). Enforcement and compliance are highlighted in 52 studies, reflecting recurrent concerns about weak enforcement capacity, limited monitoring, and persistent illegal dumping. EPR/producer responsibility appears less frequently (20 studies), indicating that upstream responsibility mechanisms remain less embedded in the MSWMS-focused evidence base than downstream recovery strategies, consistent with the lower primary coverage of prevention-oriented CE strategies reported earlier [8, 13].

Infrastructure conditions (collection, sorting, treatment capacity). Infrastructure emerges as a dominant operational determinant. Collection coverage and logistics are discussed in 81 studies, often linking service coverage, routing capacity, and collection reliability to downstream material quality and system performance. Treatment capacity (composting/AD/WtE and related infrastructure) is discussed in 68 studies, reflecting the recurring emphasis on adequate throughput capacity and stable operational performance to avoid leakage back to disposal. Source separation and sorting capacity is referenced in 51 studies, commonly tied to contamination rates, MRF availability, and the feasibility of high-quality recycle streams [37-39].

Markets and finance (viability, incentives, end-markets). The most ubiquitous economic constraint is financing and investment feasibility, discussed in 86 studies, capturing capital/operational cost burdens, cost recovery limitations, and investment risk. Economic incentives and instruments (fees, subsidies, PAYT, fiscal tools) appear in 57 studies and are frequently framed as enabling instruments when aligned with behavioral and market realities [40-42]. However, even where incentives exist, market demand and offtake for recycles remains a recurrent fragility (30 studies), pointing to price volatility and end-market uncertainty as persistent bottlenecks in closing loops [17, 27, 30, 43].

Coordination/data (systems intelligence and collaboration). Evidence repeatedly underscores that CE implementation requires information and coordinated action [25, 44]. Data availability and monitoring systems are referenced in 68 studies, typically emphasizing the need for reliable waste-flow data, tracking/traceability, and monitoring to support planning and performance management [45]. Stakeholder collaboration and partnerships are discussed in 54 studies, including public–private arrangements and multi-stakeholder governance, often positioned as enabling conditions for scaling collection, sorting, and recovery markets [8, 32].

Behavior and acceptance (participation, legitimacy). Behavioral and social conditions are consistently present in the corpus. Public awareness and education appear in 75 studies, and participation/sorting behavior in 71 studies, reflecting widespread recognition that source separation and program adherence are decisive for material quality and system outcomes [33]. Social acceptance/NIMBY is less frequently explicit (26 studies) but remains salient for siting and operating treatment facilities, indicating that legitimacy and procedural fairness can become binding constraints even when technical and economic conditions are favorable [8, 13].

4.7 Triple-bottom-line outcomes and indicator patterns

Across the 90 included studies, TBL outcome reporting is stronger for environmental and economic dimensions than for the social pillar. Based on full-text indicator coding, economic outcomes are reported in 72 studies (80.0%) and environmental outcomes in 69 studies (76.7%), while social outcomes appear in 52 studies (57.8%). Only 34 studies (37.8%) explicitly cover all three pillars (Econ–Env–Soc), whereas 21 studies (23.3%) focus on Econ–Env only. Social-only evidence is rare (1 study; 1.1%), and a small subset remains not specified (3 studies; 3.3%), underscoring that "TBL" is often invoked even when operationalization is partial [46, 47].

Indicator use is also concentrated in a narrow set of metrics. The most frequently reported categories are Cost/efficiency (54 studies; 60.0%) and Revenue/value creation (48; 53.3%) for the economic pillar, and Energy use/production (49; 54.4%) plus GHG/Climate (32; 35.6%) for the environmental pillar. Environmental impacts are commonly expressed through process or scenario metrics (e.g., net energy recovery, emission reductions, or LCA-derived impact categories), while economic assessments frequently rely on CAPEX/OPEX, unit costs (e.g., cost per ton), and financial feasibility outputs. Beyond these "core" indicators, Pollution/leakage appears in 26 studies (28.9%), often reflecting concerns about open dumping, uncontrolled emissions, and local contamination risks.

The social pillar shows the greatest fragmentation in both indicator choice and measurement depth. The most common social category is OHS/health & safety (33 studies; 36.7%), but it is frequently operationalized via risk proxies or descriptive assessments rather than standardized, comparable metrics. Other social indicators are much less frequent: Wellbeing/acceptance (15; 16.7%), Inclusion/livelihoods (14; 15.6%), and Justice/participation (9; 10.0%). Employment outcomes are explicitly quantified in only 7 studies (7.8%). Overall, the pattern suggests that while social impacts are often discussed, they are less consistently measured, limiting cross-study comparability and weakening inference about social trade-offs relative to environmental and economic gains. A complete taxonomy of indicator categories and typical operationalizations is provided in Table A13.

4.8 Mechanism-based synthesis

This subsection consolidates the integrative, mechanism-based logic emerging from the 90 included studies by tracing how CE strategies in MSWMS are associated with TBL outcomes through a limited set of repeatable causal mechanisms. synthesis organizes evidence around four mechanisms that recur across study designs and settings: (i) substitution, (ii) leakage reduction, (iii) market formation/value creation, and (iv) inclusion/legitimacy. The mechanism evidence matrix (counts, dominant strategy linkages, pillar coverage, and quality distribution) is provided in Table A10, while the aggregated flow structure is visualized in Figure 10.

Within the reviewed corpus, market formation/value creation is the most frequently evidenced mechanism (60/90 studies; 66.7%). Here, CE strategies are linked to TBL effects by converting "waste" into tradable inputs (secondary materials, energy, compost/digestate), strengthening end-markets (offtake stability, price signals), and enabling business-model viability. The evidence links this mechanism most strongly to recycling/material recovery and residual management as primary strategy foci (Table A14). Outcome coverage under this mechanism is consistently broad: within studies evidencing market formation, economic outcomes are near-universal (e.g., cost efficiency, revenues, feasibility), while environmental outcomes (e.g., reduced emissions and resource savings) are typically reported in parallel, and social outcomes appear when market formation is coupled with governance or inclusion design (e.g., labor conditions, participation, affordability). Mechanistically, economic gains arise through cost recovery (lower net system costs, higher value capture) and through risk reduction (greater predictability for investment and operations). Environmental gains often follow when market formation increases recovery rates and displaces virgin production, but the direction and magnitude depend on boundary choices and the extent to which market demand is stable rather than speculative [48].

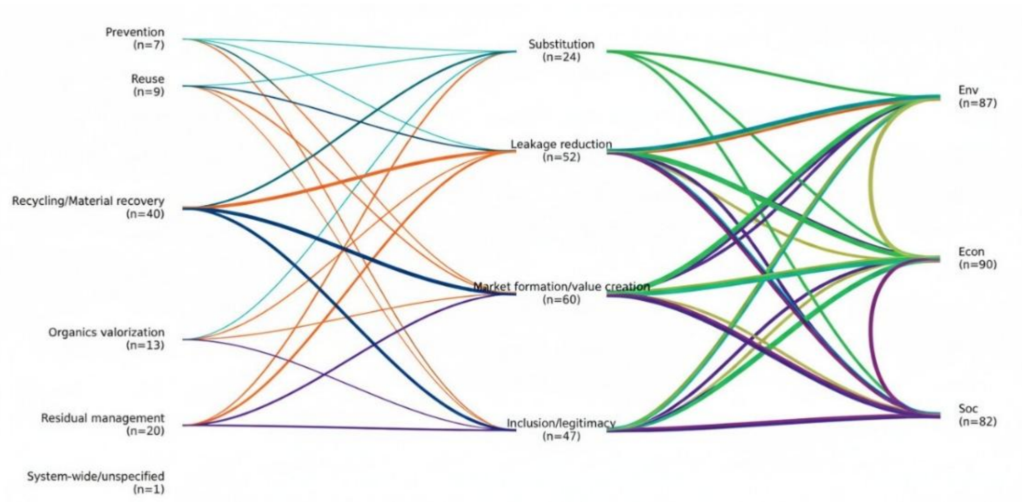

Figure 10. Strategy → mechanism → TBL outcome flow

Leakage reduction is the second most prevalent mechanism (52/90; 57.8%), and it captures the system's capacity to reduce losses of materials and externalities to the environment (open dumping, uncontrolled disposal, littering, unmanaged organics, and diffuse emissions). This mechanism is especially prominent in studies emphasizing recycling/material recovery and residual management, where improved collection coverage, source separation, controlled treatment, and disposal control reduce "leakage pathways" and improve environmental performance. In the mapped evidence, leakage reduction is strongly associated with environmental outcomes (e.g., diversion, reduced local pollution and climate-relevant emissions) and is frequently paired with economic outcomes through avoided costs (clean-up, health risks, landfill expansion) and improved operational efficiency. Social outcomes also appear frequently under leakage reduction, but typically as co-benefits (reduced nuisance impacts, improved community conditions) rather than as systematically measured endpoints, an imbalance that echoes the broader indicator patterns reported earlier [49].

Inclusion/legitimacy appears in 47/90 studies (52.2%) and functions as the "social-operational" mechanism that stabilizes implementation: strategies appear more likely to translate into sustained performance when participation is credible, benefits are perceived as fair, and institutions can maintain social license. Evidence for this mechanism is visible where CE strategies require household separation behavior, where siting and operation of facilities raise acceptance concerns, and where informal-sector integration shapes both material recovery performance and equity outcomes. The mapped evidence indicates that inclusion/legitimacy is commonly co-present with both market-formation and leakage-reduction logics (Figure 10), which is consistent with the idea that participation and legitimacy are not "add-ons" but operational prerequisites for high-performing recovery systems. When inclusion is designed explicitly (e.g., stakeholder engagement, fair role allocation, improved working conditions), social outcomes are more likely to be measured and reported; when it is not, social impacts are often noted qualitatively, with weaker comparability across studies.

Substitution is less frequently coded as an explicit mechanism (24/90; 26.7%), but it is conceptually central: environmental and economic benefits often depend on whether recovered outputs meaningfully displace virgin materials and conventional energy. Substitution is most visible in studies where LCA-type logic or scenario modelling makes displacement assumptions explicit. In such studies, substitution tends to produce aligned TBL gains (lower emissions, reduced resource depletion, improved cost performance when markets exist), but it is also where results are most sensitive to modelling choices (e.g., substitution ratios, energy mix, contamination and yields). This explains why substitution appears less often as an explicit narrative mechanism in non-assessment papers even when it implicitly underpins CE rationale.

Two synthesis implications follow. First, across the included studies, a recurrent pathway involves recovery-oriented strategies activating market formation and leakage reduction, with these patterns appearing more durable where inclusion/legitimacy conditions are met (Figure 10). Second, where studies report tensions among TBL outcomes, the tension often arises between mechanisms rather than within one mechanism; for example, market formation (economic viability) without inclusion (legitimacy) can trigger resistance, while leakage reduction without market formation can create cost burdens that undermine continuity. These mechanism linkages provide the backbone for the integrative framework and the propositions developed in the next subsection and discussion.

4.9 Contextual moderators (Multi-Level Perspective lens)

An MLP-informed reading of the evidence shows that regime-level conditions are the most frequently reported moderators of circular MSWMS performance (Figure 11, Table A15). The most frequently tagged moderators are financing & cost-recovery conditions (n = 85), infrastructure readiness (collection–sorting–treatment) (n = 79), and policy stability & enforcement strength (n = 78), each reported with a largely contingent (mixed) direction, enabling when robust, but constraining when fragmented, underfunded, or weakly enforced. Two further regime moderators appear consistently: data availability & monitoring/traceability (n = 66) and governance capacity & institutional coordination (n = 61), both often discussed as prerequisites for scaling and for avoiding performance slippage (e.g., leakage, contamination, or cost overruns). Beyond regime conditions, a niche-level moderator, technology maturity & operational reliability (n = 65), is frequently referenced in relation to treatment and recovery performance, while landscape-level pressures are less often operationalized explicitly, even though participation norms & acceptance are repeatedly cited (n = 51) and broad external pressures (e.g., climate targets, commodity price dynamics, crises) appear in a smaller subset (n = 30).

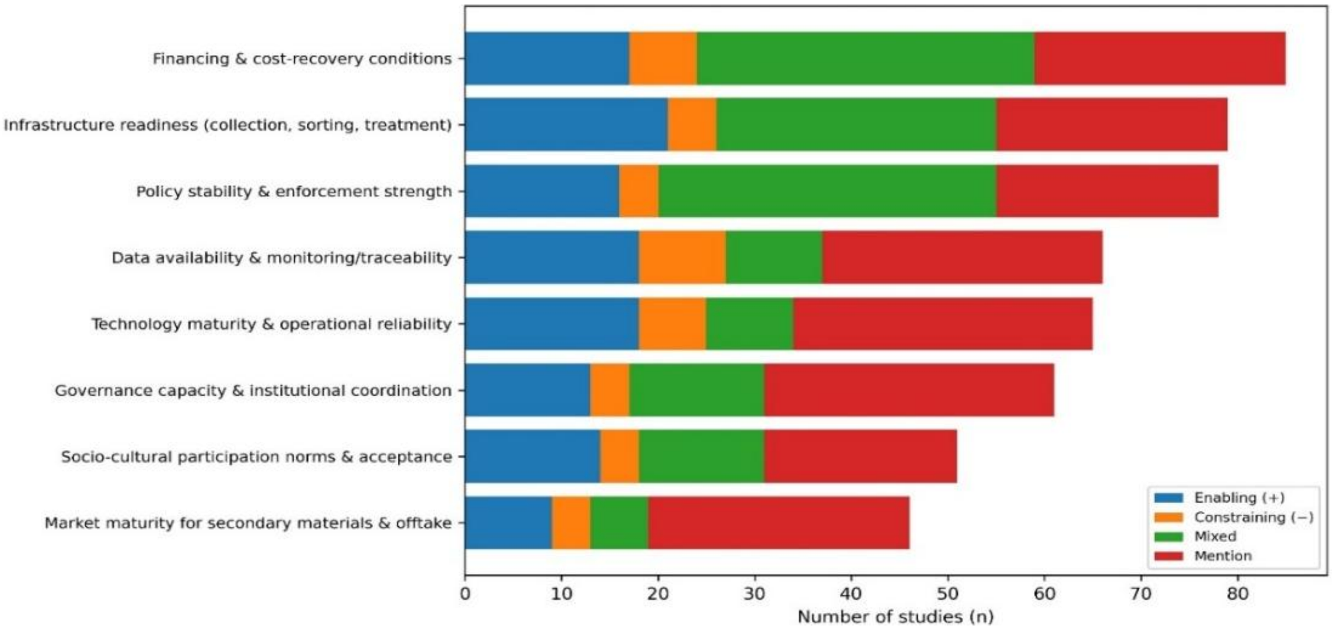

Figure 11. Key contextual moderators and direction of influence (Multi-Level Perspective (MLP) lens; n = 90)

Mechanistically, these moderators shape outcomes by selectively amplifying, or throttling, the four recurrent mechanisms mapped in this review. Across most moderator categories, the strongest co-occurrence is with market formation/value creation and leakage reduction (Table A15), indicating that system performance depends not only on technical options, but on whether end-markets, cost recovery, and operational capacity sustain recovery pathways while reducing uncontrolled disposal. Financing, market maturity, and data systems mainly condition market formation/value creation, which in turn most directly affects economic viability and the durability of recovery chains; infrastructure readiness and enforcement strength most directly condition leakage reduction, with downstream sensitivity in environmental outcomes (diversion, emissions, local impacts) and indirect effects on system costs [50, 51]. By contrast, inclusion/legitimacy becomes the decisive mechanism where participation, acceptance, and informal-sector structure are salient (e.g., source separation adherence, facility siting, workforce conditions): when inclusion is designed into governance and service models, social benefits and program continuity are more likely; when not, resistance and non-compliance weaken both leakage reduction and market formation. Taken together, these moderators explain why nominally similar CE strategies can yield different TBL patterns across settings and justify making "context" explicit in the integrative propositions [41].

4.10 Integrative framework and propositions

Figure 12 presents the final integrative framework developed from the evidence-to-framework synthesis. The model is structured as a transferable, evidence-informed explanatory chain in which CE strategy bundles in MSWMS are linked to outcomes through a limited set of repeatable mechanisms, conditional on implementation domains and contextual moderators. In the framework, strategies (prevention, reuse, recycling/material recovery, organics valorization, and residual management) do not "produce" TBL outcomes directly; rather, they operate through enabling conditions and barriers (governance, infrastructure, markets/finance, coordination/data, and behavior/acceptance) that activate, or weaken, four evidence-based mechanisms: substitution, leakage reduction, market formation/value creation, and inclusion/legitimacy. Outcomes are expressed in the environmental, economic, and social pillars, with the model explicitly allowing non-mutually exclusive effects (a single study or intervention can activate multiple mechanisms and outcomes).

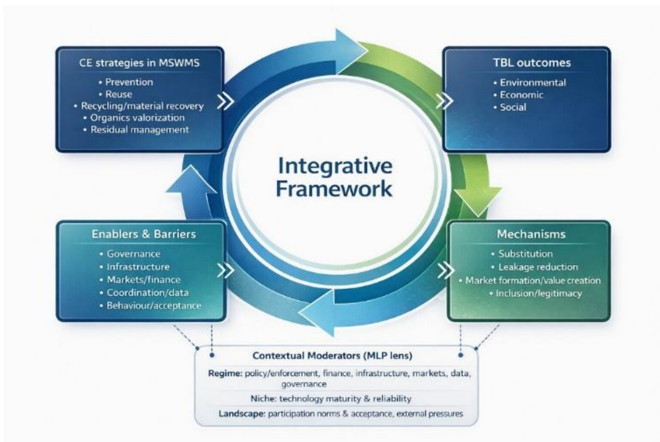

Figure 12. Integrative framework linking CE strategies, enabling conditions, mechanisms, and their TBL outcomes

A core implication is that performance is system-dependent: recovery-oriented strategies dominate the evidence base, but their realized benefits hinge on the integrity of upstream and enabling subsystems. For example, recycling/material recovery is most often associated with improved environmental performance when it reduces leakage and/or produces credible substitution (secondary materials displacing virgin production), but this relationship is bounded by collection coverage, separation/sorting quality, and stable end-markets [52]. Similarly, organics valorization appears more likely to yield joint environmental–economic gains when treatment capacity, feedstock quality, and offtake for compost/digestate/biogas are in place [49]. Residual-management pathways appear to contribute primarily through leakage reduction, but their viability is sensitive to policy stability, financing, technology reliability, and local legitimacy. Across strategies, market formation/value creation frequently mediates economic outcomes through cost recovery and market stabilization; inclusion/legitimacy appears especially important where participation, informal-sector dynamics, and siting acceptance determine whether systems function as designed [53].

The framework embeds an explicit MLP moderator layer to explain heterogeneity. Regime-level conditions (policy/enforcement, finance/cost recovery, infrastructure readiness, market maturity, data systems, and governance coordination) are the most frequently identified contextual conditions influencing whether strategies can scale and sustain leakage reduction and market formation. Niche-level factors (technology maturity and operational reliability) are pivotal for treatment-intensive pathways. Landscape-level pressures (participation norms/acceptance and external shocks) shape legitimacy and adoption dynamics and can amplify or undermine system performance. Based on these mappings, eight propositions (P1–P8) are specified as empirically testable relationships with stated boundary conditions and support levels reported in Table A16. These support levels are intended to summarize relative support within the reviewed corpus, rather than to imply definitive causal confirmation. Together, Figure 12 and the proposition set move the review beyond descriptive cataloguing by providing a transferable model that can be operationalized in future empirical work (e.g., comparative case designs, causal models, or configuration-based analyses) to test when and why CE strategies are more likely to be associated with TBL outcomes in MSWMS [23, 35].

4.11 Robustness and evidence gaps

Sensitivity checks indicate that the main synthesis signals are largely robust to reasonable restrictions of the evidence base (Table A17). First, the dominance of recovery-oriented strategies (especially recycling/material recovery) persists when restricting the dataset to higher-quality studies, suggesting that the headline mapping is not driven by low-quality outliers. Second, the same leading mechanism, market formation/value creation, remains most prevalent across quality subsets and stream-typed subsets, reinforcing the interpretation that economic viability (cost recovery, offtake stability, value capture) is a cross-cutting driver of CE performance in MSWMS. Third, the most frequently reported contextual constraint/enabler continues to be financing & cost-recovery conditions, indicating that fiscal design and sustained funding are consistently treated as binding regardless of study type.

Two sensitivities are substantive and should be treated as informative rather than problematic. (i) In high-quality-only subsets, the relative balance across pillars becomes less skewed, implying that stronger designs tend to operationalize a broader outcome set. (ii) In stream-focused subsets the strategy mix shifts in predictable directions (e.g., plastics- vs organics-dominant), confirming that conclusions about "which strategy dominates" should be read as system-wide evidence-weighted rather than stream-invariant.

Evidence gaps remain concentrated in three areas (Table A18):

1) Upstream CE strategies (prevention and reuse) are comparatively underrepresented, producing thin evidence for system-level impacts and scalability conditions.
2) Social operationalization is shallow: inclusion/livelihood and justice metrics are rarely measured consistently across strategy clusters, and OHS measurement is sporadic.
3) Context reporting is uneven: many studies discuss barriers, but fewer specify boundary conditions in a way that supports transferability testing (e.g., comparable finance parameters, enforceability, and data-system maturity).

5. DISCUSSION

This PRISMA-aligned systematic review synthesizes 90 Scopus-indexed studies to explain how CE strategies in MSWMS are associated with TBL outcomes. The key contribution is the integrative, evidence-informed framework that moves beyond listing strategies by specifying (i) implementation domains (governance, infrastructure, markets/finance, coordination/data, behavior/acceptance), (ii) four recurring mechanisms (substitution, leakage reduction, market formation/value creation, inclusion/legitimacy), and (iii) contextual moderators using an MLP lens to explain heterogeneity across settings [54]. In other words, CE strategies do not "deliver sustainability" automatically; they appear more likely to do so when domain conditions activate the relevant mechanisms. The results align with the broader CE literature in two ways. First, CE is commonly framed around reduce–reuse–recycle and system-level loop closure [3], and the evidence base in MSWMS remains strongly concentrated on downstream recovery pathways rather than upstream prevention/reuse [23, 30, 41, 42]. Second, the persistent under-measurement of social outcomes mirrors the conceptual critique that CE definitions and applications often privilege economic and environmental aims while treating social equity as secondary [2, 3]. Our synthesis adds specificity for MSWMS: social performance is not merely "missing data," but in the reviewed corpus frequently appears to hinge on whether inclusion/legitimacy is designed into service models and governance arrangements [55-57].

The proposition set helps explain why similar interventions can yield different outcomes. Recovery-focused strategies most consistently operate through leakage reduction and substitution, and are more often associated with environmental improvements when collection–sorting–treatment chains are reliable (P1–P3). Economic performance is repeatedly mediated by market formation/value creation (P4): without stable offtake and cost-recovery instruments, recovery can become financially fragile and prone to regression. Where participation, siting, and labor conditions matter, inclusion/legitimacy appears especially important (P5). This is consistent with evidence that integrating informal recycling can improve system performance and livelihoods but requires deliberate policy design to manage trade-offs in working conditions and governance. Finally, moderators mapped with the MLP lens show that regime conditions (finance, enforcement, infrastructure, data systems, coordination) are the most frequently identified constraints and enabling conditions, while niche factors (technology maturity/reliability) are pivotal for treatment-intensive options (P6–P8) [54, 58].

A practical implication is sequencing. Cities should prioritize "system enablers" before scaling technical options: (1) secure financing and cost recovery and clarify mandates; (2) upgrade collection and sorting infrastructure and performance monitoring; (3) develop end-markets/offtake and procurement standards for recovered outputs; and (4) institutionalize inclusion and legitimacy via stakeholder participation, grievance handling, and fair integration of informal workers where relevant. This sequencing is suggested by the mechanism-based patterns observed in the reviewed corpus: without finance and data, market formation and leakage reduction are unstable; without legitimacy, participation and compliance collapse, undermining both environmental and economic gains.

Table A18 indicates four priorities: (i) stronger causal designs and transparent boundary assumptions (especially for prevention/reuse impacts), (ii) standardized and explicit operationalization of social indicators (OHS, livelihoods, justice/participation), (iii) comparative studies that treat moderators as measurable conditions rather than narrative context, and (iv) mixed-method syntheses that integrate quantitative assessments with governance and behavior evidence, supported by rigorous appraisal for heterogeneous designs [59, 60]. Taken together, these priorities reinforce that the proposed framework and propositions should be read as a transferable, evidence-informed basis for future testing rather than as definitive, field-wide confirmation.

6. LIMITATIONS AND FUTURE RESEARCH

6.1 Limitations

This review followed a transparent systematic approach and PRISMA-aligned reporting, yet several limitations should be acknowledged when interpreting the evidence maps, mechanism synthesis, and propositions. The evidence base was built from a single bibliographic database (Scopus) and restricted to English-language journal articles and reviews within the specified time window. While Scopus provides broad coverage, any single-database strategy risks indexing bias (field- and region-specific under coverage) and may under-represent practice-oriented or locally published work that is influential in MSWMS policy implementation. Similarly, the journal-only filter likely reduces noise but may exclude technically relevant grey literature (e.g., municipal reports, feasibility studies, and practitioner evaluations), which can be important for implementation domains such as financing, operations, and enforcement.

Although screening and eligibility were conducted systematically, full-text accessibility can introduce bias if certain regions, publishers, or subfields are less accessible. Where full texts cannot be retrieved, the synthesis may over-weight more accessible outlets and topics, which can distort the apparent distribution of strategies, methods, and outcomes. The included studies vary widely in design (assessment modelling, case studies, surveys/behavioral research, policy analyses) and in outcome operationalization. As a result, meta-analysis is not feasible, and the synthesis necessarily emphasizes directional and mechanism-based patterns rather than pooled effect sizes. This is a structural limitation of many CE–waste literatures, where inconsistent functional units, system boundaries, and substitution assumptions complicate direct comparison across contexts. Consequently, findings should be read as evidence-weighted relationships rather than universal effect magnitudes.

Quality appraisal was conducted to avoid treating all evidence as equally reliable, using a mixed-studies-friendly rubric conceptually aligned with MMAT. However, any appraisal involves judgement, and "quality" can manifest differently across method families (e.g., robustness/validation in modelling vs. credibility/transferability in qualitative work). To minimize exclusion bias, appraisal was used to inform support assessments and sensitivity checks rather than to remove studies mechanically, yet the support levels assigned to the propositions remain contingent on how methodological robustness is operationalized within the reviewed corpus. The evidence-to-framework synthesis relies on structured coding. Even with a codebook and standardized fields, there is unavoidable interpretive risk when translating heterogeneous narratives into common constructs (strategies, mechanisms, moderators). In particular, the social pillar suffers from definitional and measurement ambiguity in CE applications, meaning that "social outcomes" are not always comparable across studies. Thus, pillar coverage should be interpreted as explicit operationalization frequency, not as definitive absence of social impacts in practice.

Science mapping outputs depend on choices regarding field selection (author keywords vs. Keywords Plus), normalization, thresholds, and clustering parameters. Although the review used established tools, co-occurrence networks and overlays can be sensitive to preprocessing decisions (e.g., synonym unification, stemming, and minimum occurrence thresholds). Therefore, bibliometric visualizations should be treated as descriptive heuristics that complement, rather than substitute for, full-text synthesis. The integrative framework and propositions (P1–P8) are designed to be transferable, but they remain proposition-based and should be regarded as evidence-informed hypotheses grounded in the included sample, not as validated causal laws. Contextual moderators were mapped with an MLP lens, yet the literature itself often reports context narratively rather than as measurable parameters. This limits stronger inference about moderator effect sizes and interaction structures.

6.2 Future research directions

The evidence gaps and robustness patterns motivate a focused research agenda that strengthens causal inference, improves indicator comparability, and tests boundary conditions explicitly.

1) Shift upstream: Prevention and reuse. The evidence remains recovery-heavy. Future work should quantify prevention/reuse impacts using credible counterfactuals (e.g., natural experiments, policy rollouts, longitudinal tracking) and examine rebound effects and distributional impacts.
2) Standardize TBL measurement and social metrics. The field needs more consistent social operationalization (OHS, livelihoods, inclusion, justice/participation), alongside clearer environmental and economic boundary assumptions. A minimum reporting set for MSWMS CE studies,

functional units, boundary stages, substitution ratios, financing assumptions, and equity indicators, would materially improve comparability.

3) Test propositions (P1–P8) with designs that identify mechanisms. Empirical studies should test the framework using approaches suited to complex systems: configurational methods (e.g., comparative case designs), structural modelling for mechanism pathways, and system dynamics/agent-based modelling where feedbacks and behavior are central. Importantly, studies should measure mechanism activation (e.g., market stabilization, leakage reduction indicators, legitimacy/acceptance metrics), not only end outcomes.
4) Moderator-explicit, cross-context comparisons. Given the dominance of regime constraints (finance, enforcement, infrastructure, data), future research should treat moderators as measurable conditions (e.g., tariff design, enforcement capacity proxies, monitoring maturity) and estimate how they condition strategy–outcome relationships across cities and regions.
5) Integrate informal sector and justice into CE design. Where informal recovery is significant, research should evaluate governance models that improve livelihoods and safety without reducing system performance. Justice-oriented assessments should move from narrative mention to explicit measurement and policy evaluation.
6) Strengthen evidence ecosystems. Expanding beyond single-database capture (multi-database searches, structured citation chasing, and multilingual coverage) would reduce indexing bias and improve representativeness, especially for rapidly evolving policy and practice contexts. Taken together, these directions position the proposed framework and propositions as a basis for cumulative empirical refinement rather than as a closed or final account of CE performance in MSWMS.

7. CONCLUSION

This PRISMA-aligned systematic review synthesized 90 Scopus-indexed studies on sustainable CE–based MSWMS to explain how CE strategies are associated with TBL outcomes. The review shows that the evidence base remains strongly concentrated on downstream recovery pathways, particularly recycling/material recovery, organics valorization, and residual management, while upstream strategies (prevention and reuse) are comparatively underrepresented. Across the literature, environmental and economic outcomes are more frequently operationalized than social outcomes, indicating a persistent measurement imbalance that limits claims about equity and wellbeing in CE transitions. The review's central contribution is an integrative, mechanism-based framework that clarifies why similar CE interventions may be associated with heterogeneous outcomes across contexts. Rather than assuming direct effects from strategies to sustainability, the synthesis identifies four recurring mechanisms, substitution, leakage reduction, market formation/value creation, and inclusion/legitimacy, that mediate outcomes and define boundary conditions for success. Results indicate that market formation/value creation and leakage reduction are the most frequently evidenced pathways within the reviewed corpus, while inclusion/legitimacy appears especially important where participation, informal-sector dynamics, and social acceptance shape implementation durability. These findings reinforce that CE performance is system-dependent and contingent on implementation domains (governance, infrastructure, markets/finance, coordination/data, and behavior/acceptance) and on contextual moderators consistent with a MLP.

From a practical standpoint, the findings suggest that cities should prioritize enabling conditions before scaling technical options. Financing and cost-recovery design, adequate collection and sorting infrastructure, reliable monitoring and data systems, and stable end-markets for recovered outputs are repeatedly treated as key enabling or constraining conditions. In parallel, policy packages should institutionalize legitimacy and inclusion, through stakeholder participation, procedural fairness, and context-appropriate integration of informal actors, to prevent compliance failures and resistance that can undermine both leakage reduction and market formation. Finally, the review advances an empirically testable agenda through propositions (P1–P8) that specify how strategies, mechanisms, and moderators interact. Future research should (i) strengthen evidence on prevention and reuse with causal designs and credible counterfactuals, (ii) standardize TBL operationalization, especially social indicators such as OHS, livelihoods, and justice, and (iii) test moderator-explicit configurations across cities to identify which combinations of governance, finance, infrastructure, and market conditions reliably deliver TBL gains. By making mechanisms and boundary conditions more explicit, this review offers a transferable, evidence-informed foundation for future work on designing, evaluating, and scaling CE-based MSWMS reforms that are more likely to be environmentally effective, economically viable, and socially legitimate.

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APPENDIX

Table A1. Search protocol and screening summary

Item	Value
Database	Scopus
Search field	Title-Abstract-Keywords (TITLE-ABS-KEY)
Time window (query)	**2017-2026 analytical corpus; query used PUBYEAR > 2016 AND PUBYEAR < 2026**
Source type	Journals only (SRCTYPE = j)
Open Access filter	Publisher full gold (OA = publisherfullgold)
Publication stage	Final (PUBSTAGE = final)
Document types	Article and Review (DOCTYPE = ar OR re)
Language	English
Records identified (databases)	n = 333
Records removed before screening - duplicates	n = 0
Records removed before screening - ineligible by automation	n = 8
Records screened	n = 325
Records excluded (title/abstract)	n = 80
Reports sought for retrieval	n = 245
Reports not retrieved	**n = 150**
Reports assessed for eligibility	**n = 95**
Reports excluded (**full-text eligibility**)	**n = 5**
Studies included in review	n = 90
Note on year alignment	At the time of data extraction, the Scopus export included 2 records indexed as Year = 2026. These records were retained in the analytical dataset; accordingly, the reviewed corpus is reported consistently as spanning 2017-2026 in the revised manuscript.

Table A1b. Scopus search string

Source	Search String (Verbatim)
Scopus	TITLE-ABS-KEY (("circular econom*" OR circularit*) AND ("waste management" OR "municipal solid waste" OR "solid waste" OR MSW) AND ("triple bottom line" OR TBL OR (environment* W/3 social W/3 economic)) AND (indicator* OR metric* OR performance OR impact* OR assessment OR evaluat*)) AND NOT TITLE-ABS-KEY (wastewater OR sewage OR sludge) AND PUBYEAR > 2016 AND PUBYEAR < 2026 AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (OA , "publisherfullgold")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English"))

Table A2. Eligibility criteria

Criteria	Inclusion	Exclusion	Rationale/Notes
Year	2017-2026 analytical corpus	Before 2017	The Scopus query used PUBYEAR > 2016 AND PUBYEAR < 2026; at data extraction, two records indexed as 2026 were retrieved and retained. The revised manuscript therefore reports the corpus consistently as spanning 2017-2026.
Document type	Article and Review	Conference papers/proceedings, editorials/notes, books, book chapters, other non-peer-reviewed items	
Source type	Journals	Books, trade publications, book series, conference proceedings	
Publication stage	Final	Article in press	
Language	English	Non-English	
Full text for synthesis	Full text retrievable in usable form	Not retrieved in usable full-text form	Applied at the retrieval stage prior to full-text eligibility assessment.

Table A3. Exclusion reasons

PRISMA Stage	Exclusion Reason	Operational Definition	Count
Retrieval stage	Reports not retrieved	Full text could not be accessed/retrieved in usable form for analysis.	150
Full-text eligibility stage	Reason 1. Wrong document type (not article/review)	Full text was retrieved, but the document type did not meet the review protocol.	3
Full-text eligibility stage	Reason 2. Non-English article	Full text not in English.	2
	Total excluded at full-text eligibility		5

Table A4. Quality appraisal rubric

Criterion	What to Assess	Scoring Guide (0/1/2)
Clear aim and research question(s)	Study states explicit aim and/or research questions aligned with methods and results.	0 = unclear/absent; 1 = partially stated; 2 = clearly stated and consistent
Context and system boundary clarity	Defines waste stream (MSW/solid waste), system boundary (collection-sorting-treatment-disposal), and context.	0 = unclear; 1 = partially defined; 2 = clearly defined
Method appropriateness	Design fits the research aim (e.g., LCA/LCSA for impacts; case study for governance; modelling for scenarios).	0 = misaligned; 1 = partially aligned; 2 = well aligned
Data transparency and reproducibility	Data sources, assumptions, and key parameters are reported sufficiently for replication/audit.	0 = poor; 1 = partial; 2 = transparent
Validity/robustness	Sensitivity analysis, validation, triangulation, or robustness checks are reported where relevant.	0 = none; 1 = limited; 2 = adequate
Bias and limitations	Explicit discussion of limitations and potential biases (data, scope, assumptions).	0 = absent; 1 = limited; 2 = clear and appropriate
Environmental outcome measurement quality	Environmental indicators are appropriate (e.g., GHG, energy, pollution) and methods are explained.	0 = weak/unclear; 1 = partial; 2 = strong
Social outcome measurement quality	Social outcomes are measured/discussed beyond superficial mention (e.g., OHS, inclusion, justice).	0 = absent; 1 = limited; 2 = substantive
Economic outcome measurement quality	Economic outcomes are measured/discussed (costs, value creation, jobs, financing) with clarity.	0 = absent; 1 = limited; 2 = substantive
Conclusion plausibility	Conclusions follow logically from evidence and acknowledge uncertainty/context-dependence.	0 = weak; 1 = moderate; 2 = strong

Table A4b. Quality scoring rules

Item	Specification
Total score calculation	Sum item scores; maximum = 20.
Quality tier (recommended)	High ≥ 16; Medium 12-15; Low ≤ 11.
Use of quality scores	Use for confidence weighting and sensitivity checks; do not exclude mechanically unless protocol specifies

Table A5. Data extraction template

Field Group	Field	Operational Definition	Data Type
Bibliographic	ID	Unique study identifier (S1-S90).	Text
Bibliographic	Authors; Year; Title; Source title; DOI	Standard reference fields exported from Scopus.	Text
Context	Country/region; income setting (optional)	Study setting and geographic coverage.	Text
Context	Scale	City/municipal, regional, national, facility/system.	Categorical
Waste scope	Waste stream	MSW/mixed solid waste/plastics/organics/other solid waste within MSWMS.	Categorical (multi-label)
Waste scope	System boundary	Stages covered: upstream prevention; collection; separation/sorting; treatment/valorization; disposal.	Categorical (multi-label)
Circular strategies	Prevention/Reduce	Upstream waste prevention, eco-design, PAYT, avoidance measures.	Binary/notes
Circular strategies	Reuse/Repair	Refill, repair, reuse logistics, sharing systems.	Binary/notes
Circular strategies	Recycling/Material recovery	Source separation, MRF, recycling, material recovery and quality upgrading.	Binary/notes
Circular strategies	Organics valorization	Composting, anaerobic digestion, bio-based products.	Binary/notes
Circular strategies	Residual management	Controlled treatment and sanitary disposal to reduce leakage.	Binary/notes
Enablers/Barriers	Governance	Policy mix, EPR, standards, enforcement, institutional coordination.	Text (coded)
Enablers/Barriers	Infrastructure/Technology	Collection coverage, sorting/treatment capacity, technology readiness.	Text (coded)

Enablers/Barriers	Markets/Finance	Secondary market demand, price volatility, investment and financing.	Text (coded)
Enablers/Barriers	Data/Coordination	Monitoring, traceability, stakeholder collaboration.	Text (coded)
Enablers/Barriers	Behaviour/Acceptance	Participation, trust, acceptance (incl. NIMBY).	Text (coded)
Mechanisms	Substitution	Secondary materials displace virgin inputs; depends on quality and demand.	Text (coded)
Mechanisms	Leakage reduction	Reduced dumping/burning/pollution pathways.	Text (coded)
Mechanisms	Market formation/value creation	Stable demand/standards; new circular services and value.	Text (coded)
Mechanisms	Inclusion/legitimacy	Decent work and inclusion improve legitimacy/participation and system stability.	Text (coded)
Outcomes (Environmental)	Indicators and direction	GHG, energy, pollution, diversion etc; effect direction (positive/negative/mixed).	Text
Outcomes (Social)	Indicators and direction	OHS, inclusion, justice, wellbeing; effect direction.	Text
Outcomes (Economic)	Indicators and direction	Cost/benefit, revenue, jobs, value added; effect direction.	Text
Quality appraisal	Quality tier	High/Medium/Low based on Table A4_meta thresholds.	Categorical
Key findings	One-sentence takeaway	Concise main conclusion relevant to CE-MSWMS-TBL pathways.	Text

Table A6. Thematic coding framework

Category	Sub-Code	Definition
Circular strategies	Prevention/Reduce	Reduce waste generation at source (eco-design, PAYT, avoidance).
Circular strategies	Reuse/Repair	Extend product/packaging life via reuse, refill, repair systems.
Circular strategies	Recycling/Recovery	Recover materials through separation, sorting, MRFs, recycling; improve recyclate quality.
Circular strategies	Organics valorization	Valorize organics via composting/AD/bio-products.
Circular strategies	Residual management	Manage residuals with controlled treatment and sanitary disposal to reduce leakage.
Enablers	Governance	Policy mix, EPR, standards, enforcement, institutional capacity.
Enablers	Infrastructure/Technology	Collection coverage; sorting/treatment capacity; technology readiness.
Enablers	Market/Finance	Demand for secondary materials; price stability; financing and investment.
Enablers	Data/Coordination	Monitoring, traceability, stakeholder coordination and collaboration.
Enablers	Behavior/Acceptance	Household/firm participation; awareness; acceptance and NIMBY dynamics.
Mechanisms	Substitution	Secondary materials displace virgin inputs; depends on quality and markets.
Mechanisms	Leakage reduction	Reduced dumping/burning and environmental leakage.
Mechanisms	Value creation	New revenue streams and circular services; improved cost-effectiveness.
Mechanisms	Legitimacy/Inclusion	Decent work, inclusion and procedural justice improve legitimacy and stability.
Outcomes	Environmental	Emissions/pollution reduction; resource conservation; diversion.
Outcomes	Social	OHS; inclusion/livelihoods; procedural justice; wellbeing/acceptance.
Outcomes	Economic	Costs, revenues, jobs, investment, value added.
Moderators	Context	Governance capacity; waste composition; market maturity; urban form; informality.

Table A7. Social outcome dimensions

Social Outcome Dimension	Operational Definition	Typical Indicators/Proxies
Decent work & occupational health and safety (OHS)	Safe and dignified working conditions along the waste value chain.	Exposure, injuries, PPE access, formal protections, training.
Inclusion & livelihoods	Inclusion of informal/vulnerable groups and livelihood stability.	Income stability, formalization, access to programs/benefits, participation of waste pickers.
Procedural justice & participation	Fair decision-making processes and meaningful stakeholder participation.	Transparency, accountability, voice, consultation, grievance mechanisms.
Community wellbeing & acceptance	Impacts on residents and community acceptance of facilities/practices.	Health complaints, nuisance/odour, trust, NIMBY, perceived fairness.

Table A8. Overview of included studies

ID	Authors	Year	Title	Source Title
S1	Md Fauadi, M.H.F.M.; Anuar, N.I.; Kurniawati, D.A.; Nur Rosyidi, C.N.; Abdullah, L.; Muhamad Damanhuri, A.A.M.; Jian, T.S.	2026	Recent advances in multi-criteria decision-making approaches for circular supply chains: A comprehensive review	Multidisciplinary Reviews
S2	Kokane, P.; Shete, G.; Handore, K.; Jakhar, R.; Styszko, K.	2026	Waste-to-Energy in India: A Decompositional Analysis	Applied Sciences (Switzerland)
S3	Esposito, L.; Accardo, F.; Prandi, B.; Tedeschi, T.	2025	How food wastes can be converted into new products: European legislation and analysis of enzymatic hydrolysis	New Biotechnology

S4	Pambudi, N.F.; Samarakoon, S.M.S.M.K.; Simatupang, T.M.; Ratnayake, R.M.C.; Mulyono, N.B.	2025	Risk management for the circular economy business model sustainability of reduce, reuse, and recycling in plastic waste management	Discover Sustainability
S5	Gangwar, P.; Narain, A.; Saini, A.; Mitra, D.; Karmakar, R.; Assefa, A.	2025	Sustainable approaches to solar photovoltaic waste management under environmental uncertainty	Discover Environment
S6	Chandra, N.P.; Subashini, R.	2025	Mapping the landscape of sustainable development in the pharmaceutical industry a bibliometric analysis	Discover Sustainability
S7	Ghoneim, M.M.; Halabya, A.; Moussa, O.M.; Hassan, A.A.	2025	An empirical assessment of material waste drivers and sustainability strategies in Egypt's construction sector	Discover Sustainability
S8	Anokye, K.	2025	Black Soldier Fly Larvae as a circular solution for organic waste management and sustainable livestock feed in Ghana	Cleaner Waste Systems
S9	Bokor, B.	2025	Legal analysis of the EU regulatory framework on circular economy and sustainability principles in plastic food packaging	Cleaner Waste Systems
S10	Battiston, E.; Ren, J.; Mazzi, A.	2025	Sustainable circularity performance indicators to optimize waste management at company level	Sustainable Futures
S11	Yu, H.; Zahidi, I.; Chow, C.M.; Madsen, D.Ø.	2025	Preliminary evaluation of mining area sustainability using multi-criteria decision-making methods	Environmental Sciences Europe
S12	Baseri, S.	2025	An attractive path to use of green resources for production of antibacterial and antioxidant wool yarns	Scientific Reports
S13	Zervoudi, E.K.; Christopoulos, A.G.; Niotis, I.	2025	Food Waste and the Three Pillars of Sustainability: Economic, Environmental and Social Perspectives from Greece's Food Service and Retail Sectors	Sustainability (Switzerland)
S14	Sedliačiková, M.; Kostúr, M.; Osvaldová, M.	2025	Proposing Green Growth Indicators for Enterprises in the Woodworking and Furniture Industry	Forests
S15	Polman, D.	2025	Policymaking for circular urban food systems: A systematic literature review of policy instruments and governance arrangements	Regional Science Policy and Practice
S16	Zseni, A.; Horváth, A.; MacHer, G.Z.; Sipos, D.; Pécsinger, J.	2025	Using Multivariate Statistical Analysis for Examining the Relationship between Food Waste Generation and Socio-economic Factors	Journal of Sustainable Development of Energy, Water and Environment Systems
S17	Makan, A.; Salama, Y.; Mamouni, F.Z.; Makan, M.	2025	Towards Zero-Waste Cities: An Integrated and Circular Approach to Sustainable Solid Waste Management	Sustainability (Switzerland)
S18	Weerakoon, T.G.; Zvirgzdins, J.; Geipele, S.; Wimalasena, S.; Drukis, P.	2025	Integrating Circular Economy (CE) Principles into Construction Waste Management (CWM) Through Multiple Criteria Decision-Making (MCDM)	Sustainability (Switzerland)
S19	Ogwu, M.C.; Hills, C.E.; Pietrosemoli, S.	2025	The Piggy Solution: Harnessing Food Waste for Sustainable Hog Farming	Global Challenges
S20	Derse, O.; Göçmen, E.G.	2025	EVALUATION OF IMPLEMENTATION STRATEGIES IN THE CONTEXT OF ZERO-WASTE CITY AND CIRCULAR ECONOMY CONCEPT	Environmental Engineering and Management Journal
S21	Saleh, M.A.S.; AlShafeey, M.	2025	Examining the synergies between industry 4.0 and sustainability dimensions using text mining, sentiment analysis, and association rules	Sustainable Futures
S22	Kafle, S.; Karki, B.K.; Sakhakarmy, M.; Adhikari, S.	2025	A Review of Global Municipal Solid Waste Management and Valorization Pathways	Recycling
S23	Anokye, K.; Darko, A.O.; Portia, A.; Amuah, E.E.Y.; Sodoke, S.; Agya, B.A.; Douti, N.B.; Kazapoe, R.W.; Bentil, J.	2025	Exploring waste activation and mineralization for environmental and economic sustainability in Ghana	Cleaner Waste Systems
S24	Toboso-Chavero, S.; Zisopoulos, F.K.; de Jong, M.; Schraven, D.	2025	Critical review of methodological tools and trends for assessing the performance of inclusive circular cities	Cleaner Environmental Systems
S25	Santamaria, Y.; Omisakin, O.M.	2025	Food Waste Management Practices: The Case of Invercargill's Food and Beverages Sector in New Zealand	Journal of Sustainability Research
S26	Li, Z.; Fan, T.W.; Lun, M.S.; Li, Q.; Hong, Q.; Chen, H.; Ma, L.; Yu, J.	2025	Study on implementation of anaerobic digestion and composting technologies for kitchen waste management: A case study in Macau	Heliyon
S27	Mugivhisa, L.L.; Manganyi, M.C.	2025	Green Catalysis: The Role of Medicinal Plants as Food Waste Decomposition Enhancers/Accelerators	Life

S28	Ivanovic, N.; Vučinić, A.; Marinković, V.; Krajnovic, D.; Ćurčić, M.	2025	Towards Sustainable Food Waste Management in Serbia: A Review of Challenges, Gaps, and Future Perspectives	Sustainability (Switzerland)
S29	Tahir, F.; Rasheed, R.; Fatima, M.; Batool, F.; Nizami, A.-S.	2025	Sustainability Analysis of Commercial-Scale Biogas Plants in Pakistan vs. Germany: A Novel Analytic Hierarchy Process—SMARTER Approach	Sustainability (Switzerland)
S30	Adu, T.F.; Mensah, L.D.; Rockson, M.A.D.; Kemausuor, F.	2025	Decision support systems for waste-to-energy technologies: A systematic literature review of methods and future directions for sustainable implementation in Ghana	Heliyon
S31	Bastos, T.; Nunes, L.J.R.; Teixeira, L.	2025	Fostering Circularity in Agroforestry Biomass: A Regulatory Framework for Sustainable Resource Management	Land
S32	Ghinea, C.; Ungureanu-Comanita, E.-D.; Țâbuleac, R.M.; Oprea, P.S.; Cosbuc, E.D.; Gavrilescu, M.	2025	Cost-Benefit Analysis of Enzymatic Hydrolysis Alternatives for Food Waste Management	Foods
S33	Poma, P.; Fdz-Polanco, M.; Usca, K.; Casella, C.; Toulkeridis, T.	2025	An Evaluation of the Public Service of the Integrated Municipal Management of Urban Solid Waste in the Galapagos and the Amazonian Region of Ecuador	Sustainability (Switzerland)
S34	Mihăilă, M.; Ignat, G.; Costuleanu, C.L.; Jităreanu, A.F.	2025	FOOD WASTE ISSUE CONNECTED TO CHALLENGES OF CIRCULAR ECONOMY: AN APPROACH FOR SUSTAINABLE SOLUTIONS	Environmental Engineering and Management Journal
S35	Meneghello, F.; Fontana, C.F.; Lamano-Ferreira, M.L.; Sakurai, C.A.	2025	Opportunities and challenges of the Regional Plan for Integrated Solid Waste Management in the Metropolitan Region of Santos: thinking collectively to solve locally; Oportunidades e desafios do Plano Regional de Gestão Integrada de Resíduos Sólidos da Região Metropolitana de Santos: pensar coletivamente para resolver localmente; Oportunidades y desafíos del Plan Regional de Gestión Integral de Residuos Sólidos de la Región Metropolitana de Santos: pensar colectivamente para resolver localmente	Revista de Gestao Ambiental e Sustentabilidade
S36	Pavesi, R.; Orsi, L.; Zanderighi, L.	2025	Enhancing Circularity in Urban Waste Management: A Case Study on Biochar from Urban Pruning	Environments - MDPI
S37	Činčikaitė, R.	2025	Assessment of Sustainable Waste Management: A Case Study in Lithuania	Sustainability (Switzerland)
S38	Ibrahim, H.Z.; Alqahtani, M.H.	2025	Frameworks and implementation strategies for sustainable waste-to-energy alternatives: a study using bipolar complex intuitionistic fuzzy-based multi-attribute decision-making	AIMS Mathematics
S39	Rai, N.; Pavankumar, T.L.; Ghotra, B.; Dhillon, S.; Juneja, V.; Amaly, N.; Pandey, P.	2025	Essential recycling and repurposing of food waste for environment and sustainability	Frontiers in Sustainable Food Systems
S40	Valtere, M.; Bezrucko, T.; Liberova, V.; Blumberga, D.	2025	Recycling of Mixed Post-Consumer Textiles: Opportunities for Sustainable Product Development	Environmental and Climate Technologies
S41	Velez Osorio, I.M.	2025	THE IMPACT OF INNOVATION ON ADVANCING SUSTAINABLE PRACTICES IN THE INDUSTRIAL SECTOR; РОЛЬ ІННОВАЦІЙ У ПРОСУВАННІ СТІЙКИХ ПРАКТИК У ПРОМИСЛОВОМУ СЕКТОРІ	Science and Innovation
S42	Pilarski, K.; Pilarska, A.A.; Dach, J.	2025	Biogas as renewable energy source: A brief overview	Journal of Ecological Engineering
S43	Xames, M.D.; Topcu, T.G.	2025	How Can Digital Twins Support the Economic, Environmental, and Social Sustainability of Healthcare Systems: A Systematic Review Focused on the Triple Bottom Line	IEEE Access
S44	Ali, S.S.; Alsharbaty, M.H.M.; Al-Tohamy, R.; Khalil, M.A.; Schagerl, M.; Al-Zahrani, M.; Sun, J.	2024	Microplastics as an Emerging Potential Threat: Toxicity, Life Cycle Assessment, and Management	Toxics
S45	Farshadfar, Z.; Mucha, T.; Tanskanen, K.	2024	Leveraging Machine Learning for Advancing Circular Supply Chains: A Systematic Literature Review	Logistics
S46	Srećković, M.; Hartmann, D.; Schützenhofer, S.; Kotecki, A.	2024	Bridging theory and practice: Stakeholder insights on circular economy in the building life cycle	Energy Reports
S47	Ahmad, W.; Hassan, M.; Masud, S.F.B.; Amjad, M.S.; Samara, F.; Sheikh, Z.; Anwar, M.; Rafique, M.Z.; Nawaz, T.	2024	Socio-economic benefits and policy implications of generating sustainable energy from municipal solid waste in Pakistan	Energy and Climate Change

S48	Almukhtar, A.; Batcup, C.; Bowman, M.; Winter Beatty, J.; Leff, D.; Demirel, P.; Judah, G.; Porat, T.	2024	Interventions to achieve environmentally sustainable operating theatres: An umbrella systematic review using the behaviour change wheel	International Journal of Surgery
S49	Almansour, M.; Akrami, M.	2024	Towards Zero Waste: An In-Depth Analysis of National Policies, Strategies, and Case Studies in Waste Minimisation	Sustainability (Switzerland)
S50	Arroyo, J.; Pillajo, C.; Barrio, J.; Compais, P.; Tavares, V.D.	2024	Deep Learning Techniques for Enhanced Flame Monitoring in Cement Rotary Kilns Using Petcoke and Refuse-Derived Fuel (RDF)	Sustainability (Switzerland)
S51	Nubi, O.; Murphy, R.; Morse, S.	2024	Life Cycle Sustainability Assessment of Waste to Energy Systems in the Developing World: A Review	Environments - MDPI
S52	Kępniak, M.; Łukowski, P.	2024	Multicriteria Analysis of Cement Mortar with Recycled Sand	Sustainability (Switzerland)
S53	Alavi, Z.; Khalilpour, K.; Florin, N.	2024	Forecasting End-of-Life Wind Turbine Material Flows in Australia under Various Wind Energy Deployment Scenarios	Energies
S54	Al-Sharif, M.; Geldermans, B.; Rinke, M.	2024	From waste to wealth: a study of concrete recycling in Jordan	Frontiers in Sustainability
S55	Voukkali, I.; Papamichael, I.; Loizia, P.; Zorpas, A.A.	2023	The importance of KPIs to calibrate waste strategy in hospitality sector	Energy Nexus
S56	Onyeaka, H.; Tamasiga, P.; Nwauzoma, U.M.; Miri, T.; Juliet, U.C.; Nwaiwu, O.; Akinsemolu, A.A.	2023	Using Artificial Intelligence to Tackle Food Waste and Enhance the Circular Economy: Maximising Resource Efficiency and Minimising Environmental Impact: A Review	Sustainability (Switzerland)
S57	Ponnambalam, S.G.; Sankaranarayanan, B.; Karuppiah, K.; Thinakaran, S.; Chandravelu, P.; Lam, H.L.	2023	Analysing the Barriers Involved in Recycling the Textile Waste in India Using Fuzzy DEMATEL	Sustainability (Switzerland)
S58	Miolla, R.; Ottomano Palmisano, G.; Roma, R.; Caponio, F.; Difonzo, G.; De Boni, A.	2023	Functional Foods Acceptability: A Consumers' Survey on Bread Enriched with Oenological By-Products	Foods
S59	Rondón Toro, E.; López Martínez, A.; Lobo-García de Cortázar, A.	2023	Sequential Methodology for the Selection of Municipal Waste Treatment Alternatives Applied to a Case Study in Chile	Sustainability (Switzerland)
S60	Roy, P.; Mohanty, A.K.; Dick, P.; Misra, M.	2023	A Review on the Challenges and Choices for Food Waste Valorization: Environmental and Economic Impacts	ACS Environmental Au
S61	Mahanth, T.; Suryasekaran, C.R.; Ponnambalam, S.G.; Sankaranarayanan, B.; Karuppiah, K.; Nielsen, I.E.	2023	Modelling the Barriers to Circular Economy Practices in the Indian State of Tamil Nadu in Managing E-Wastes to Achieve Green Environment	Sustainability (Switzerland)
S62	Alao, M.A.; Popoola, O.M.; Ayodele, T.R.	2022	Waste-to-energy nexus: An overview of technologies and implementation for sustainable development	Cleaner Energy Systems
S63	Kowalski, Z.; Kulczycka, J.; Makara, A.; Verhé, R.; de Clercq, G.	2022	Assessment of Energy Recovery from Municipal Waste Management Systems Using Circular Economy Quality Indicators	Energies
S64	Al-Thani, N.A.; Al-Ansari, T.; Haouari, M.	2022	Integrated TOPSIS-COV approach for selecting a sustainable PET waste management technology: A case study in Qatar	Heliyon
S65	Tomov, M.; Velkoska, C.	2022	Contribution of the quality costs to sustainable development	Production Engineering Archives
S66	Bozhanova, V.; Korenyuk, P.; Lozovskyi, O.; Belous-Sergeeva, S.; Bielienkova, O.; Koval, V.	2022	Green Enterprise Logistics Management System in Circular Economy	International Journal of Mathematical, Engineering and Management Sciences
S67	Huang, Y.; Shafiee, M.; Charnley, F.; Encinas-Oropesa, A.	2022	Designing a Framework for Materials Flow by Integrating Circular Economy Principles with End-of-life Management Strategies	Sustainability (Switzerland)
S68	Betts, K.; Gutierrez-Franco, E.; Ponce-Cueto, E.	2022	Key metrics to measure the performance and impact of reusable packaging in circular supply chains	Frontiers in Sustainability

S69	Manoharan, S.; Kumar Pulimi, V.S.; Kabir, G.; Ali, S.M.	2022	Contextual relationships among drivers and barriers to circular economy: An integrated ISM and DEMATEL approach	Sustainable Operations and Computers
S70	Nadaždi, A.; Naunovic, Z.; Ivanišević, N.	2022	Circular Economy in Construction and Demolition Waste Management in the Western Balkans: A Sustainability Assessment Framework	Sustainability (Switzerland)
S71	Georgescu, I.; Kinnunen, J.; Androniceanu, A.-M.	2021	EMPIRICAL EVIDENCE ON CIRCULAR ECONOMY AND ECONOMIC DEVELOPMENT IN EUROPE: A PANEL APPROACH	Journal of Business Economics and Management
S72	Melles, G.	2021	Figuring the transition from circular economy to circular society in Australia	Sustainability (Switzerland)
S73	Chhimwal, M.; Agrawal, S.; Kumar, G.	2021	Measuring circular supply chain risk: A bayesian network methodology	Sustainability (Switzerland)
S74	Gaballo, M.; Mecca, B.; Abastante, F.	2021	Adaptive reuse and sustainability protocols in italy: Relationship with circular economy	Sustainability (Switzerland)
S75	Mihalčová, B.; Korauš, A.; Prokopenko, O.; Hvastová, J.; Freňáková, M.; Gallo, P.; Balogová, B.	2021	Effective management tools for solving the problem of poverty in relation to food waste in context of integrated management of energy	Energies
S76	Yáñez, P.P.	2021	Viabilidad de la economía circular en países no industrializados y su ajuste a una propuesta de economías transformadoras. Un acercamiento al escenario latinoamericano	CIRIEC-Espana Revista de Economia Publica, Social y Cooperativa
S77	Schoeman, Y.; Oberholster, P.; Somerset, V.	2021	A zero-waste multi-criteria decision-support model for the iron and steel industry in developing countries: A case study	Sustainability (Switzerland)
S78	Quintero, A.; Albertí, J.; Carvajal, G.I.; Fullana-i-Palmer, P.	2021	Stabilising rural roads with waste streams in colombia as an environmental strategy based on a life cycle assessment methodology	Sustainability (Switzerland)
S79	Dos Santos, P.S.; Campos, L.M.S.	2021	Practices for garment industry's post-consumer textile waste management in the circular economy context: An analysis on literature	Brazilian Journal of Operations and Production Management
S80	Boschi, G.; Masi, G.; Bonvicini, G.; Bignozzi, M.C.	2020	Sustainability in Italian ceramic tile production: Evaluation of the environmental impact	Applied Sciences (Switzerland)
S81	Stankeviciene, J.; Nikanorova, M.	2020	Eco-innovation as a pillar for sustainable development of circular economy	Business: Theory and Practice
S82	Smol, M.; Marcinek, P.; Duda, J.; Szołdrowska, D.	2020	Importance of sustainable mineral resource management in implementing the circular economy (CE) model and the European green deal strategy	Resources
S83	Bruni, C.; Akyol, C.; Cipolletta, G.; Eusebi, A.L.; Caniani, D.; Masi, S.; Colón, J.; Fatone, F.	2020	Decentralized community composting: Past, present and future aspects of Italy	Sustainability (Switzerland)
S84	Isernia, R.; Passaro, R.; Quinto, I.; Thomas, A.	2019	The reverse supply chain of the e-waste management processes in a circular economy framework: Evidence from Italy	Sustainability (Switzerland)
S85	Rapsikevičienė, J.; Gurauskiene, I.; Jučienė, A.	2019	Model of industrial textile waste management	Environmental Research, Engineering and Management
S86	Taelman, S.E.; Tonini, D.; Wandl, A.; Dewulf, J.	2018	A Holistic sustainability framework for waste management in European Cities: Concept development	Sustainability (Switzerland)
S87	Milios, L.; Davani, A.E.; Yu, Y.	2018	Sustainability impact assessment of increased plastic recycling and future pathways of plastic waste management in Sweden	Recycling
S88	Velenturf, A.P.M.; Purnell, P.	2017	Resource recovery from waste: Restoring the balance between resource scarcity and waste overload	Sustainability (Switzerland)
S89	Bartolacci, F.; Del Gobbo, R.; Paolini, A.; Soverchia, M.	2017	Waste management companies towards circular economy: What impacts on production costs?	Environmental Engineering and Management Journal
S90	Imbert, E.	2017	Food waste valorization options: Opportunities from the bioeconomy	Open Agriculture

Table A9. Evidence matrix for propositions

Framework Relationship (Proposition)	Mechanism	Outcome Pillar(s)	Supporting Studies (IDs)	Preliminary Strength of Evidence	Key Moderators / Boundary Conditions
P1. Higher-order value-retention strategies	Value retention / loop slowing	Environmental; Social; Economic	S4, S7, S17, S20, S28, S37, S40, S46, S48,	Strong (keyword-	Moderated by waste

(prevention/reuse/repair) → stronger TBL potential than recycling-only approaches			S52, S54, S58, S63, S68, S74, S76, S77, S79, S85	matched ≥ 10 studies; to be confirmed by full-text coding)	composition, user participation, and availability of reuse infrastructure
P2. Separation/sorting quality → stronger substitution mechanism → improved environmental and often economic outcomes	Material quality → substitution of virgin inputs	Environmental; Economic	S7, S17, S19, S22, S26, S33, S40, S50, S54, S61, S63, S65, S67, S74, S76, S79, S80	Strong (keyword-matched ≥ 10 studies; to be confirmed by full-text coding)	Moderated by secondary market demand and contamination rates
P3. Policy mixes and well-designed targets → stronger strategy uptake and effectiveness than single instruments	Incentives, coordination, compliance	Environmental; Social; Economic	S2, S4, S5, S6, S7, S9, S11, S15, S17, S20, S24, S26, S28, S36, S37, S48, S54, S57, S83, S84, S86	Strong (keyword-matched ≥ 10 studies; to be confirmed by full-text coding)	Moderated by enforcement capacity and institutional coordination
P4. Well-designed and enforced EPR → improved downstream recycling performance and prevention incentives	Extended producer responsibility → coordination and cost internalization	Environmental; Economic (and indirect Social)	S3, S4, S5, S8, S13, S14, S28, S36, S44, S49, S50, S64, S65, S72, S75, S84, S85, S86	Strong (keyword-matched ≥ 10 studies; to be confirmed by full-text coding)	Moderated by scheme design (fees, eco-modulation) and enforcement
P5. Market formation and finance → higher economic viability and scaling of circular strategies	Market demand/standards/finance → scale-up	Economic (and indirect Environmental/ Social)	S17, S36, S61, S73	Moderate (keyword-matched 4-9 studies; to be confirmed by full-text coding)	Moderated by price volatility, procurement, and investment conditions
P6. Social safeguards (decent work/inclusion) → higher legitimacy and more stable system performance	Inclusion/legitimacy → participation and continuity	Social (and indirect Environmental/ Economic)	S5, S24, S30, S76	Moderate (keyword-matched 4-9 studies; to be confirmed by full-text coding)	Moderated by informality level and labour governance
P7. Impact-based assessment (e.g., LCA/LCSA) → more reliable TBL inference than mass-based circularity metrics alone	Assessment choice → inference robustness	Environmental; Social; Economic (inference quality)	S3, S4, S6, S7, S10, S11, S14, S16, S20, S24, S30, S31, S32, S33, S34, S37, S38, S40, S43, S44, S46, S48, S51, S53, S55, S60, S61, S63, S68, S72, S73, S78, S80, S85, S86, S87, S90	Strong (keyword-matched ≥ 10 studies; to be confirmed by full-text coding)	Moderated by data availability and boundary assumptions
P8. Socio-technical alignment (landscape-regime-niche) → heterogeneous outcomes across contexts	Transition dynamics / alignment	Environmental; Social; Economic	S2, S3, S6, S14, S15, S22, S23, S30, S39, S42, S49, S52, S54, S60, S62, S72, S74, S76, S82, S84, S86, S87, S88, S90	Strong (keyword-matched ≥ 10 studies; to be confirmed by full-text coding)	Moderated by regime lock-in, infrastructure, and policy coherence

Table A10. Planned robustness checks

Robustness Check	Procedure	Comparison	How Results will be Reported	Purpose
Quality sensitivity check	Re-run thematic synthesis excluding studies rated 'Low' quality (Table A4_meta).	Themes and framework relations (P1-P8) before vs after exclusion.	Report whether each theme/relation is Stable / Partially changed / Changed; list relations affected and why.	Assesses whether conclusions depend on low-quality evidence.
Context split (development level)	Split included studies by country income group (World Bank classification) or Global North/South proxy.	Direction and prominence of mechanisms and outcomes across contexts.	Report differences in effect direction and moderators (e.g., informality, enforcement, market maturity).	Tests context dependence predicted by transitions lens (P8).
Waste stream split	Group studies by dominant waste stream (mixed MSW vs plastics vs organics).	Mechanisms (substitution, leakage reduction, market formation) and TBL outcomes by stream.	Report stream-specific pathways and whether propositions require stream-specific boundary conditions.	Reduces over-generalisation and strengthens applicability.

Method split	Group studies by method family (LCA/LCSA vs modelling vs case study/policy analysis).	Differences in measured outcomes and inferences about trade-offs.	Report whether impact-based methods reveal trade-offs not visible in metric-only studies (P7).	Checks methodological bias and inference robustness.
OA filter sensitivity (optional)	Repeat search without OA=publisherfullgold (if feasible) to test coverage bias.	Included-study profile (topics, regions, methods) with vs without OA restriction.	Report changes in geographic coverage and topic distribution; note any new evidence affecting propositions.	Assesses whether OA restriction skews the evidence base.

Table A11. Characteristics of included studies

Study_ID	First Author	Year	Case Location	Scale	Waste Stream	Boundary/Stage	Method Family
S001	Md Fauadi, M.H.F.M. et al.	2026	Not reported	Regional	WEEE/E-waste	System-wide/multi-stage	Decision-support / MCDA
S002	Kokane, P. et al.	2026	India	City/municipal	C&D waste	Waste-to-energy/Thermal	Policy / institutional analysis
S003	Esposito, L. et al.	2025	Italy	System/unspecified	Organics/Food waste	Reuse	Life cycle assessment (LCA)
S004	Pambudi, N.F. et al.	2025	Indonesia	System/unspecified	Organics/Food waste	Recycling/Material recovery	Qualitative interviews/case study
S005	Gangwar, P. et al.	2025	Not reported	System/unspecified	WEEE/E-waste	Recycling/Material recovery	Policy / institutional analysis
S006	Chandra, N.P. et al.	2025	Not reported	System/unspecified	Plastics	Recycling/Material recovery	Life cycle assessment (LCA)
S007	Ghoneim, M.M. et al.	2025	Egypt	System/unspecified	C&D waste	System-wide/multi-stage	Survey/SEM
S008	Anokye, K. et al.	2025	Ghana	System/unspecified	Organics/Food waste	Landfill/Disposal	Policy / institutional analysis
S009	Bokor, B. et al.	2025	Norway	Multi-country/region	Plastics	Recycling/Material recovery	Policy / institutional analysis
S010	Battiston, E. et al.	2025	Multiple/Not explicit	Regional	Plastics	Recycling/Material recovery	Decision-support / MCDA
S011	Yu, H. et al.	2025	Multiple/Not explicit	System/unspecified	General / system-wide	System-wide/multi-stage	Decision-support / MCDA
S012	Baseri, S. et al.	2025	Not reported	System/unspecified	Organics/Food waste	System-wide/multi-stage	Optimization / OR modelling
S013	Zervoudi, E.K. et al.	2025	Greece	System/unspecified	Organics/Food waste	Prevention/Upstream	Optimization / OR modelling
S014	Sedliačiková, M. et al.	2025	Slovakia	System/unspecified	General / system-wide	System-wide/multi-stage	Qualitative interviews/case study
S015	Polman, D. et al.	2025	Netherlands	City/municipal	Organics/Food waste	System-wide/multi-stage	Policy / institutional analysis
S016	Zseni, A. et al.	2025	Not reported	Multi-country/region	Organics/Food waste	System-wide/multi-stage	Policy / institutional analysis
S017	Makan, A. et al.	2025	Not reported	System/unspecified	Organics/Food waste	System-wide/multi-stage	Life cycle assessment (LCA)
S018	Weerakoon, T.G. et al.	2025	Sri Lanka	System/unspecified	C&D waste	System-wide/multi-stage	Decision-support / MCDA
S019	Ogwu, M.C. et al.	2025	Not reported	System/unspecified	Organics/Food waste	Organics treatment/valorization	Review (systematic/bibliometric)
S020	Derse, O. et al.	2025	Not reported	City/municipal	General / system-wide	System-wide/multi-stage	Decision-support / MCDA
S021	Saleh, M.A.S. et al.	2025	Hungary	System/unspecified	WEEE/E-waste	System-wide/multi-stage	Optimization / OR modelling
S022	Kafle, S. et al.	2025	Not reported	City/municipal	Mixed MSW	Recycling/Material recovery	Review (systematic/bibliometric)
S023	Anokye, K. et al.	2025	Ghana	City/municipal	Industrial waste	Waste-to-energy/Thermal	Policy / institutional analysis
S024	Toboso-Chavero, S. et al.	2025	Netherlands	City/municipal	Mixed MSW	Reuse	Life cycle assessment (LCA)
S025	Santamaria, Y. et al.	2025	Multiple/Not explicit	System/unspecified	Organics/Food waste	Collection/Separation	Qualitative interviews/case study
S026	Li, Z. et al.	2025	Hong Kong	City/municipal	Organics/Food waste	Organics treatment/valorization	Optimization / OR modelling
S027	Mugivhisa, L.L. et al.	2025	Not reported	System/unspecified	Organics/Food waste	Organics treatment/valorization	Review (systematic/bibliometric)
S028	Ivanovic, N. et al.	2025	Serbia	Regional	Organics/Food waste	Prevention/Upstream	Policy / institutional analysis
S029	Tahir, F. et al.	2025	Germany	System/unspecified	Mixed MSW	Organics treatment/valorization	Life cycle assessment (LCA)
S030	Adu, T.F. et al.	2025	Ghana	System/unspecified	Organics/Food waste	Waste-to-energy/Thermal	Life cycle assessment (LCA)
S031	Bastos, T. et al.	2025	Not reported	System/unspecified	Plastics	System-wide/multi-stage	Policy / institutional analysis

S032	Ghinea, C. et al.	2025	Not reported	System/unspecified	Organics/Food waste	System-wide/multi-stage	Other/unspecified
S033	Poma, P. et al.	2025	Not reported	City/municipal	Mixed MSW	System-wide/multi-stage	Qualitative interviews/case study
S034	Mihăilă, M. et al.	2025	Romania	System/unspecified	Organics/Food waste	Organics treatment/valorization	Other/unspecified
S035	Meneghello, F. et al.	2025	Not reported	City/municipal	Mixed MSW	Landfill/Disposal	Survey/SEM
S036	Pavesi, R. et al.	2025	Not reported	City/municipal	Organics/Food waste	Landfill/Disposal	Qualitative interviews/case study
S037	Činčikaitė, R. et al.	2025	Multiple/Not explicit	City/municipal	Organics/Food waste	System-wide/multi-stage	Decision-support / MCDA
S038	Ibrahim, H.Z. et al.	2025	Not reported	System/unspecified	General / system-wide	Waste-to-energy/Thermal	Decision-support / MCDA
S039	Rai, N. et al.	2025	Not reported	System/unspecified	Organics/Food waste	Recycling/Material recovery	Other/unspecified
S040	Valtere, M. et al.	2025	Not reported	Multi-country/region	Industrial waste	System-wide/multi-stage	Decision-support / MCDA
S041	Velez Osorio, I.M. et al.	2025	Colombia	System/unspecified	Plastics	Reuse	Other/unspecified
S042	Pilarski, K. et al.	2025	Not reported	System/unspecified	Organics/Food waste	Organics treatment/valorization	Other/unspecified
S043	Xames, M.D. et al.	2025	Not reported	System/unspecified	General / system-wide	System-wide/multi-stage	Review (systematic/bibliometric)
S044	Ali, S.S. et al.	2024	Not reported	System/unspecified	Plastics	System-wide/multi-stage	Life cycle assessment (LCA)
S045	Farshadfar, Z. et al.	2024	Not reported	System/unspecified	General / system-wide	System-wide/multi-stage	Optimization / OR modelling
S046	Srećković, M. et al.	2024	Austria	System/unspecified	C&D waste	System-wide/multi-stage	Life cycle assessment (LCA)
S047	Ahmad, W. et al.	2024	Pakistan	City/municipal	Organics/Food waste	Waste-to-energy/Thermal	Life cycle assessment (LCA)
S048	Almukhtar, A. et al.	2024	Not reported	System/unspecified	General / system-wide	Reuse	Life cycle assessment (LCA)
S049	Almansour, M. et al.	2024	Multiple/Not explicit	City/municipal	Plastics	Waste-to-energy/Thermal	Review (systematic/bibliometric)
S050	Arroyo, J. et al.	2024	Not reported	System/unspecified	Industrial waste	Waste-to-energy/Thermal	Optimization / OR modelling
S051	Nubi, O. et al.	2024	Not reported	System/unspecified	Mixed MSW	Waste-to-energy/Thermal	Life cycle assessment (LCA)
S052	Kępniak, M. et al.	2024	Not reported	System/unspecified	Plastics	Recycling/Material recovery	Decision-support / MCDA
S053	Alavi, Z. et al.	2024	Australia	National	Plastics	Recycling/Material recovery	Material flow analysis (MFA)
S054	Al-Sharif, M. et al.	2024	Jordan	National	WEEE/E-waste	Recycling/Material recovery	Policy / institutional analysis
S055	Voukkali, I. et al.	2023	Cyprus	System/unspecified	Organics/Food waste	System-wide/multi-stage	Optimization / OR modelling
S056	Onyeaka, H. et al.	2023	Not reported	Regional	Organics/Food waste	System-wide/multi-stage	Policy / institutional analysis
S057	Ponnambalam, S.G. et al.	2023	India	System/unspecified	Industrial waste	Recycling/Material recovery	Decision-support / MCDA
S058	Miolla, R. et al.	2023	Not reported	System/unspecified	Organics/Food waste	System-wide/multi-stage	Survey/SEM
S059	Rondón Toro, E. et al.	2023	Not reported	City/municipal	Organics/Food waste	Waste-to-energy/Thermal	Decision-support / MCDA
S060	Roy, P. et al.	2023	Not reported	System/unspecified	Organics/Food waste	System-wide/multi-stage	Policy / institutional analysis
S061	Mahanth, T. et al.	2023	India	System/unspecified	WEEE/E-waste	System-wide/multi-stage	Decision-support / MCDA
S062	Alao, M.A. et al.	2022	Multiple/Not explicit	City/municipal	Organics/Food waste	Waste-to-energy/Thermal	Other/unspecified
S063	Kowalski, Z. et al.	2022	Not reported	City/municipal	Organics/Food waste	Waste-to-energy/Thermal	Life cycle assessment (LCA)
S064	Al-Thani, N.A. et al.	2022	Qatar	System/unspecified	Organics/Food waste	Waste-to-energy/Thermal	Decision-support / MCDA
S065	Tomov, M. et al.	2022	Not reported	System/unspecified	General / system-wide	Reuse	Other/unspecified
S066	Bozhanova, V. et al.	2022	Ukraine	City/municipal	Plastics	Collection/Separation	Qualitative interviews/case study
S067	Huang, Y. et al.	2022	Not reported	System/unspecified	Organics/Food waste	System-wide/multi-stage	Life cycle assessment (LCA)
S068	Betts, K. et al.	2022	Japan	System/unspecified	General / system-wide	Reuse	Policy / institutional analysis
S069	Manoharan, S. et al.	2022	Bangladesh	System/unspecified	WEEE/E-waste	Reuse	Decision-support / MCDA
S070	Nadaždi, A. et al.	2022	Not reported	Regional	C&D waste	Recycling/Material recovery	Decision-support / MCDA
S071	Georgescu, I. et al.	2021	Not reported	City/municipal	Plastics	Recycling/Material recovery	Policy / institutional analysis

S072	Melles, G. et al.	2021	Australia	Regional	General / system-wide	Recycling/Material recovery	Qualitative interviews/case study
S073	Chhimwal, M. et al.	2021	Not reported	Regional	General / system-wide	Reuse	Policy / institutional analysis
S074	Gaballo, M. et al.	2021	Italy	System/unspecified	C&D waste	Reuse	Policy / institutional analysis
S075	Mihalčová, B. et al.	2021	Not reported	Multi-country/region	Organics/Food waste	Reuse	Policy / institutional analysis
S076	Yáñez, P.P. et al.	2021	Not reported	Regional	WEEE/E-waste	System-wide/multi-stage	Other/unspecified
S077	Schoeman, Y. et al.	2021	South Africa	System/unspecified	Industrial waste	System-wide/multi-stage	Life cycle assessment (LCA)
S078	Quintero, A. et al.	2021	Colombia	System/unspecified	Plastics	Waste-to-energy/Thermal	Life cycle assessment (LCA)
S079	Dos Santos, P.S. et al.	2021	Not reported	System/unspecified	General / system-wide	Collection/Separation	Review (systematic/bibliometric)
S080	Boschi, G. et al.	2020	Not reported	System/unspecified	General / system-wide	Recycling/Material recovery	Policy / institutional analysis
S081	Stankeviciene, J. et al.	2020	Not reported	Regional	Organics/Food waste	Recycling/Material recovery	Decision-support / MCDA
S082	Smol, M. et al.	2020	Not reported	National	General / system-wide	Recycling/Material recovery	Other/unspecified
S083	Bruni, C. et al.	2020	Italy	National	Organics/Food waste	Organics treatment/valorization	Policy / institutional analysis
S084	Isernia, R. et al.	2019	Not reported	National	WEEE/E-waste	Collection/Separation	Policy / institutional analysis
S085	Rapsikevičienė, J. et al.	2019	Lithuania	System/unspecified	General / system-wide	Recycling/Material recovery	Qualitative interviews/case study
S086	Taelman, S.E. et al.	2018	Not reported	City/municipal	Industrial waste	Collection/Separation	Other/unspecified
S087	Milios, L. et al.	2018	Sweden	Multi-country/region	Plastics	Recycling/Material recovery	Life cycle assessment (LCA)
S088	Velenturf, A.P.M. et al.	2017	UK	System/unspecified	General / system-wide	System-wide/multi-stage	Policy / institutional analysis
S089	Bartolacci, F. et al.	2017	Not reported	City/municipal	Mixed MSW	Collection/Separation	Other/unspecified
S090	Imbert, E. et al.	2017	Not reported	System/unspecified	Organics/Food waste	System-wide/multi-stage	Policy / institutional analysis

Table A12. Enablers and barriers to CE implementation

Domain	Top Theme	Studies (n)	Predominant Polarity	Barrier (n)	Enabler (n)	Mixed (n)	Neutral Mention (n)	Operationalization (How Measured/Observed)
Behaviour/ Acceptance	Public awareness & education	75	Mixed	7	22	24	22	Education/training/communication interventions; assessed via program descriptions, survey measures, and behavioural outcomes.
Behaviour/ Acceptance	Participation & sorting behaviour	71	Mention	2	20	20	29	Participation rates, sorting compliance, WTP and behavioural determinants; assessed via surveys, participation statistics, or compliance outcomes.
Behaviour/ Acceptance	Social acceptance / NIMBY	26	Mention	4	4	6	12	Community acceptance/opposition and perceived legitimacy; assessed via surveys, complaints/protests, or qualitative stakeholder accounts.
Coordination/ Data	Data availability & monitoring systems	68	Mention	7	15	9	37	Waste-flow data completeness, monitoring/reporting systems, traceability; assessed via data availability and monitoring system descriptions.
Coordination/ Data	Stakeholder collaboration & partnerships	54	Enabler	0	22	16	16	Public-private and multi-stakeholder collaboration; assessed via partnership arrangements and coordination outcomes.
Governance	Policy/regulatory framework	84	Mixed	2	22	35	25	Presence/design of CE/MSW policies and stated enforcement mechanisms; assessed via policy analysis and case evidence.
Governance	Enforcement & compliance	52	Mention	4	9	17	22	Enforcement capacity and compliance performance (inspection, sanctions, illegal dumping control); identified in implementation narratives.
Governance	EPR / producer responsibility	20	Mention	0	5	3	12	Design and implementation of EPR schemes (obligations, fees, take-back logistics); assessed via policy design and implementation evidence.
Infrastructure	Collection coverage & logistics	81	Mixed	4	24	30	23	Service coverage and logistics adequacy (coverage rates, frequency, fleet/routing); assessed via operational indicators or model parameters.
Infrastructure	Treatment capacity (compost/AD/WtE)	68	Mixed	3	11	28	26	Treatment capacity/performance (throughput, yields, energy recovery);

								assessed via facility data, scenarios, or case studies.
Infrastructure	Source separation & sorting capacity	51	Mention	3	10	15	23	Source separation programs, MRF presence, contamination rates; assessed via program design and material-quality indicators.
Markets/ Finance	Financing & investment	86	Mixed	7	21	32	26	Funding adequacy, investment feasibility, cost recovery; assessed via cost models, budget/finance data, and reported constraints.
Markets/ Finance	Economic incentives & instruments	57	Enabler	0	28	23	6	Fees/subsidies/PAYT and incentive mechanisms; assessed via policy design, WTP/behaviour evidence, or scenario assumptions.
Markets/ Finance	Market demand & offtake for recyclates	30	Mention	2	8	6	14	Stability of end-markets (demand, price volatility, offtake); assessed via market analysis and reported offtake/price constraints.

Table A13. TBL outcome indicators

Pillar	Indicator Category	Studies (n, %)	Typical Metrics/Operationalization
Economic	Cost/efficiency	54 (60.0%)	CAPEX/OPEX; cost per ton; levelized cost; NPV/IRR; system cost savings.
Environmental	Energy use/production	49 (54.4%)	MJ/ton; net electricity/heat; biogas yield; energy recovery efficiency.
Economic	Revenue/value creation	48 (53.3%)	revenue from recyclates/compost/energy; value added; avoided disposal costs; market price signals.
Social	OHS/health & safety	33 (36.7%)	injury/illness risk; exposure proxies; safety compliance; risk assessment indicators.
Environmental	GHG/Climate	32 (35.6%)	kg CO2e/ton MSW; life-cycle GWP; avoided emissions from recycling/energy recovery.
Environmental	Pollution/leakage	26 (28.9%)	leachate/air emissions proxies; open dumping/burning incidence; marine litter/leakage estimates.
Social	Wellbeing/acceptance	15 (16.7%)	community acceptance; nuisance perception; quality-of-life proxies; willingness-to-accept/pay.
Social	Inclusion/livelihoods	14 (15.6%)	income stability; inclusion of informal actors; livelihood security; access to services/markets.
Social	Justice/participation	9 (10.0%)	participation rates; perceived fairness; stakeholder voice; procedural justice indicators.
Economic	Jobs/employment	7 (7.8%)	jobs created/lost; labour demand by pathway; wage/income metrics.
Environmental	Landfill diversion/recycling rate	2 (2.2%)	% diverted; recycling/recovery rate; landfill tonnage avoided.

Table A14. Evidence by mechanism

Mechanism	Studies (n)	Share of Evidence (%)	Dominant Primary Strategies	Env (n)	Econ (n)	Soc (n)	All Three Pillars (n)	High-Quality (n)	Moderate-Quality (n)	Low-Quality (n)
Market formation/value creation	60	66.7	Recycling/Material recovery (n = 30); Residual management (n = 13); Reuse (n = 7)	58	60	58	56	23	29	8
Leakage reduction	52	57.8	Recycling/Material recovery (n = 25); Residual management (n = 13); Organics valorization (n = 6)	52	52	51	51	20	26	6
Inclusion/legitimacy	47	52.2	Recycling/Material recovery (n = 22); Residual management (n = 12); Organics valorization (n = 5)	46	47	44	43	18	20	9
Substitution	24	26.7	Recycling/Material recovery (n = 12); Residual management (n = 8); Reuse (n = 2)	24	24	23	23	10	12	2

Table A15. Contextual moderators (MLP lens)

MLP Level	Contextual Moderator	Studies (n)	Enabling (+) (n)	Constraining (−) (n)	Mixed (n)	Neutral Mention (n)	Predominant Direction	Mechanisms Most Impacted (Top 2; Share Among Studies)	Most Impacted Outcome Pillars (Inferred)
Regime	Financing & cost-recovery conditions	85	17	7	35	26	Mixed	Market formation/value creation (69.4%); Leakage reduction (60.0%)	Environmental; Economic
Regime	Infrastructure readiness (collection, sorting, treatment)	79	21	5	29	24	Mixed	Market formation/value creation (67.1%); Leakage reduction (58.2%)	Environmental; Economic
Regime	Policy stability & enforcement strength	78	16	4	35	23	Mixed	Market formation/value creation (71.8%); Leakage reduction (62.8%)	Environmental; Economic
Regime	Data availability & monitoring/ traceability	66	18	9	10	29	Mention	Market formation/value creation (74.2%); Leakage reduction (63.6%)	Environmental; Economic
Niche	Technology maturity & operational reliability	65	18	7	9	31	Mention	Leakage reduction (66.2%); Market formation/value creation (63.1%)	Environmental; Economic
Regime	Governance capacity & institutional coordination	61	13	4	14	30	Mention	Market formation/value creation (75.4%); Inclusion/ legitimacy (67.2%)	Economic; Social
Landscape	Socio-cultural participation norms & acceptance	51	14	4	13	20	Mention	Market formation/value creation (74.5%); Inclusion/legitimacy (74.5%)	Economic; Social
Regime	Market maturity for secondary materials & offtake	46	9	4	6	27	Mention	Market formation/value creation (84.8%); Leakage reduction (60.9%)	Environmental; Economic
Regime	Informal sector structure & inclusion	39	7	3	5	24	Mention	Inclusion/ legitimacy (89.7%); Market formation/value creation (76.9%)	Economic; Social
Landscape	External pressures (climate targets, commodity prices, crises)	30	0	2	3	25	Mention	Leakage reduction (63.3%); Market formation/value creation (63.3%)	Environmental; Economic

Table A16. Evidence support for propositions

Proposition	Evidence-Informed Proposition (Summary Statement)	Boundary Conditions / Moderators (Where the Relationship is Most Likely to Hold)	Supporting Studies in Included Corpus (n)	High	Moderate	Low	Weighted Support Index	Support Level (Within Included Corpus)
P1	Recycling/material recovery is associated with improved environmental performance primarily through leakage reduction and/or substitution effects.	Requires adequate collection coverage, source separation/sorting capacity, and infrastructure readiness to avoid contamination and leakage.	27	10	13	4	20.03	Moderate support
P2	Organics valorization (compost/AD) is more likely to be associated with joint environmental-economic gains when diversion reduces leakage and valorization creates usable products/energy.	Contingent on treatment capacity, feedstock quality (separation), and stable demand/offtake for compost/digestate/biogas.	8	2	6	0	6.02	Preliminary support
P3	Residual-management pathways appear to contribute mainly through leakage reduction (controlled treatment/disposal), with economic viability conditioned by finance and regulatory stability.	Sensitive to technology reliability and social acceptance; weak legitimacy can limit siting/operation and erode benefits.	13	6	6	1	10.35	Preliminary support
P4	Market formation/value creation is frequently associated with economic outcomes across CE strategies through cost recovery and end-market stabilization for recovered outputs.	Stronger where recyclate/energy offtake markets and cost-recovery instruments (fees/tariffs/incentives) are mature.	60	23	29	8	45.07	Higher support
P5	Inclusion/legitimacy mechanisms (participation, fairness, informal-sector integration, social license) appear pivotal for social outcomes and sustained system performance.	Most binding for source-separation programs and facility siting; strengthened by awareness/education and procedural justice.	44	18	20	6	33.38	Higher support
P6	Data availability and monitoring/traceability appear to strengthen both leakage reduction and market formation by improving planning, targeting, and performance management.	Effects are amplified where data systems are institutionalized (routine reporting, digital tracking) rather than ad hoc.	56	21	29	6	42.41	Higher support
P7	Governance capacity and enforcement strength appear to condition the effectiveness of CE strategies by enabling compliance and reducing uncontrolled leakage pathways.	Weak enforcement or fragmented mandates can negate recovery investments, sustaining open dumping/illegal disposal and contamination.	50	20	24	6	38.06	Higher support
P8	Technology maturity and operational reliability appear to moderate outcomes for treatment-intensive pathways (AD/composting/WtE/RDF), shaping yields, costs, and emissions.	Benefits are most robust when operations maintain stable feedstock quality and maintenance regimes, and when boundary assumptions are explicit.	26	9	13	4	19.03	Moderate support

Table A17. Sensitivity and robustness results

Comparison / Filter	N	Recycling Primary (%)	Env Pillar (%)	Econ Pillar (%)	Soc Pillar (%)	Top Mechanism	Top Moderator	Robust Findings Retained?	What Changes (If Any)?
Baseline (all included studies)	90	44.4	87.8	81.1	73.3	Market formation/value creation	Financing & cost-recovery conditions	Yes	—
High-quality studies only	29	44.8	96.6	89.7	89.7	Market formation/value creation	Financing & cost-recovery conditions	Partly	pillar imbalance attenuates
High + Moderate quality	73	45.2	93.2	83.6	76.7	Market formation/value creation	Financing & cost-recovery conditions	Yes	—

Plastics-focused stream	13	76.9	92.3	84.6	76.9	Market formation/value creation	Financing & cost-recovery conditions	Partly	strategy mix shifts
Organics-focused stream	34	20.6	91.2	88.2	82.4	Market formation/value creation	Financing & cost-recovery conditions	Partly	strategy mix shifts

Table A18. Evidence gaps across strategy clusters

Strategy Cluster (Primary Focus)	**Studies (n)**	**High-Quality Share (%)**	**Env Measured (%)**	**Econ Measured (%)**	**Soc Measured (%)**	**All Three Pillars (%)**	**Indicator Depth: GHG/Carbon (%)**	**Indicator Depth: Costs (%)**	**Indicator Depth: OHS (%)**	**Indicator Depth: Inclusion (%)**	**Indicator Depth: Justice (%)**	**Most Common Moderators (Top 2)**	**Primary Evidence Gaps (Flags)**
Recycling/ Material recovery	40	32.5	87.5	75.0	80.0	57.5	62.5	12.5	25.0	15.0	27.5	Financing & cost-recovery conditions (100%); Policy stability & enforcement strength (90%)	Inclusion metrics scarce
Residual management	20	40.0	100.0	90.0	70.0	70.0	70.0	20.0	25.0	25.0	10.0	Infrastructure readiness (collection, sorting, treatment) (100%); Financing & cost-recovery conditions (95%)	Justice metrics scarce
Organics valorization	13	23.1	92.3	84.6	69.2	61.5	76.9	30.8	7.7	7.7	15.4	Financing & cost-recovery conditions (92%); Infrastructure readiness (collection, sorting, treatment) (92%)	Inclusion metrics scarce; Justice metrics scarce
Reuse	9	33.3	66.7	77.8	66.7	33.3	11.1	11.1	33.3	11.1	22.2	Policy stability & enforcement strength (89%); Financing & cost-recovery conditions (78%)	Climate metrics underused; Inclusion metrics scarce
Prevention	7	28.6	85.7	100.0	71.4	71.4	42.9	14.3	14.3	0.0	14.3	Data availability & monitoring/traceability (100%); Financing & cost-recovery conditions (100%)	Inclusion metrics scarce; Justice metrics scarce
System-wide/ unspecified	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Infrastructure readiness (collection, sorting, treatment) (100%); Data availability & monitoring/traceability (0%)	Social pillar thin; Climate metrics underused; Inclusion metrics scarce; Justice metrics scarce; Few high-quality studies