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SYSTEMATIC LITERATURE REVIEW: COMPARATIVE ANALYSIS OF WASTE-TO-ENERGY SYSTEMS FOR ENVIRONMENTAL SUSTAINABILITY AND ECONOMIC FEASIBILITY

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Abstract

`This systematic literature review synthesises 38 peer-reviewed research articles examining waste-to-energy (WtE) technologies with emphasis on environmental performance, economic feasibility, and comparative technology assessment. Following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, the review integrates quantitative and qualitative evidence from life cycle assessment (LCA), life cycle costing (LCC), and multi-criteria decision analysis studies across diverse geographic regions. Key findings demonstrate that integrated WtE systems combining incineration, anaerobic digestion (AD), and material recovery achieve superior environmental and economic outcomes compared to conventional landfilling. Emerging technologies, including plasma gasification, mechanical biological treatment (MBT), and ultra-fast hydrolysis AD, show promising potential but require further commercialisation. Regional variations significantly influence technology selection, with electricity pricing, waste composition, and policy frameworks as critical determinants of feasibility.

Key-words: *waste-to-energy; life cycle assessment; anaerobic digestion; gasification; economic feasibility; environmental sustainability; circular economy; municipal solid waste; cost-benefit analysis; by-product valorisation.*

Introduction

Global municipal solid waste (MSW) generation has reached 2.2 billion tonnes annually by 2025, with projections indicating escalation to 3.4 billion tonnes by 2050. This exponential growth in waste generation is primarily driven by rapid urbanisation, industrialisation, and escalating consumption patterns, particularly in developing economies (Rashad et al., 2025). Current waste management practices remain fundamentally unsustainable, with 31% of EU waste and 25% of UK waste still landfilled in 2015(Ascher et al., 2019). Traditional landfilling perpetuates severe environmental liabilities, including groundwater contamination, soil degradation, and methane emissions, generating greenhouse gas emissions estimated at 5,250 kg CO_2-eq per ton of MSW (Tait et al., 2025). This scenario presents not only an environmental crisis but also a lost opportunity for energy recovery and resource conservation.

Waste-to-energy (WtE) technologies represent macro-scale solutions for concurrent achievement of three sustainability objectives: (1) waste volume reduction through conversion to residual materials, (2) energy recovery displacing fossil fuel consumption, and (3) resource recovery enabling circular economy principles (Abdeljaber et al., 2022). These technologies accommodate diverse feedstocks with varying physical, chemical, and biological characteristics, enabling differentiated treatment pathways based on waste composition and local energy demand profiles (Rashad et al., 2025). Notably, unlike traditional landfilling, which stands as the least advisable practice in the waste hierarchy, the purpose of waste-to-energy techniques is to recover the energy embedded within waste, transforming it into valuable resources. (Ramos et al., 2020)

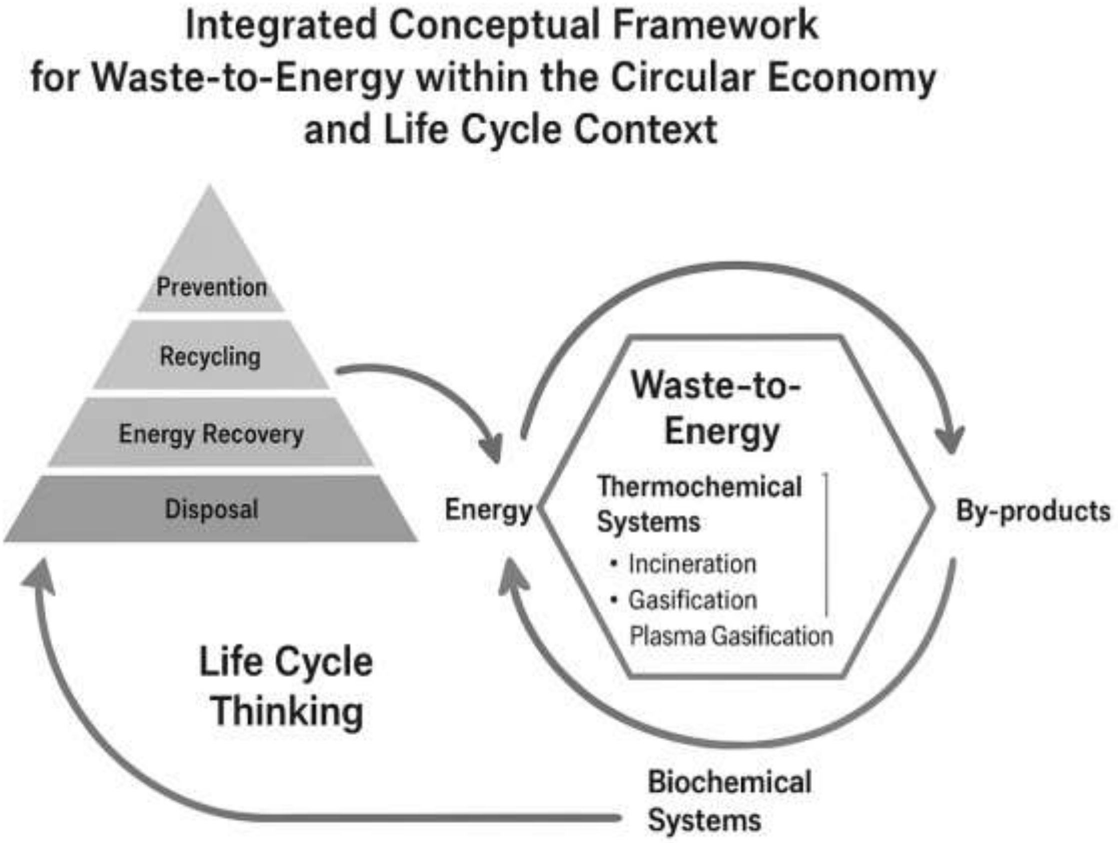
The global WtE market encompasses over 2,500 operational facilities worldwide, with significant concentration in developed economies. Europe operates the highest concentration of advanced WtE infrastructure, with 500 incineration plants achieving 20-30% electrical efficiency through integrated combined heat and power (CHP) systems (Ramos, 2025). Conversely, developing regions remain predominantly dependent on landfilling due to infrastructure gaps, capital constraints, and policy misalignment with circular economy frameworks. (Rashad et al., 2025) (Abdeljaber et al., 2022).

This systematic literature review aims to synthesise comparative evidence on environmental sustainability and economic feasibility of different WtE technologies, addressing critical gaps in knowledge regarding technology performance optimisation, by-product valorisation, and policy enablers for scaling. The objectives are:

a) Environmental Performance Assessment: Quantify comparative environmental impacts across thermochemical (incineration, gasification, plasma gasification) and biochemical (anaerobic digestion, composting) technologies using standardised Life Cycle Assessment (LCA) methodologies.
b) Economic Feasibility Evaluation: Analyse financial viability through Life Cycle Cost (LCC), Cost-Benefit Analysis (CBA), and Net Present Value (NPV) calculations, identifying profitability thresholds and by-product valorisation requirements.
c) Integrated Systems Optimisation: Evaluate emerging integrated biological approaches achieving zero-solid discharge with concurrent energy and resource recovery.Policy Framework Development: Identify regulatory enablers, economic incentive mechanisms, and barriers to WtE infrastructure deployment.

The waste management hierarchy establishes a priority-ordered framework, with prevention as the first option, followed by preparing for reuse, recycling, energy recovery, and disposal as the least recommended option (Zeng et al., 2024). Within this context, WtE technologies operate in layers 4-5, treating post-recycling residue streams while simultaneously recovering resources (biochar, vitrified slag, biofertilizer) for re-entry into production cycles (Ma & Liu, 2019). This positioning aligns WtE with circular economy principles, where a circular economy supports sustainability by reducing the extraction and consumption of finite natural resources, minimising waste and pollution, and creating systems that can continue to function effectively over the long term (Muniz et al., 2025).

Figure 1. Integrated Conceptual Framework for Waste-to-Energy (WtE) Sustainability Evaluation.



This conceptual model illustrates the interrelationship between the waste management hierarchy, life cycle thinking, and waste-to-energy (WtE) technology classification. Positioned at the "energy recovery" tier of the waste hierarchy, WtE technologies serve as a bridge between recycling and final disposal, enabling both energy generation and resource circularity. The framework integrates thermochemical systems (incineration, gasification, plasma gasification) and biochemical systems (anaerobic digestion, ultra-fast hydrolysis with AD, and mechanical biological treatment), highlighting their complementary roles in converting non-recyclable waste into electricity, heat, and value-added by-products such as biochar, vitrified slag, and biofertilizer. Surrounding these processes, the life cycle thinking approach provides an evaluative boundary that captures environmental and economic performance across all stages from waste collection to energy recovery and by-product utilisation. The model underscores WtE's alignment with circular economy principles, demonstrating how recovered energy and materials re-enter production and consumption loops, thereby reducing landfill dependency and promoting long-term sustainability.

Methodology

This systematic review was conducted in accordance with PRISMA 2020 guidelines to ensure methodological transparency, reproducibility, and rigour. The review protocol was pre-registered in the International Prospective Register of Systematic Reviews (PROSPERO) before screening, thereby preventing post-hoc modification of eligibility criteria and enhancing the auditability of the review process. A comprehensive literature search covering the period 2015-2025 was carried out across four major scholarly databases: Web of Science, Scopus, ScienceDirect, and the Directory of Open Access Journals (DOAJ). Search strings combined key terms relating to waste-to-energy technologies, sustainability assessments, and economic evaluation, including "waste-to-energy," "WtE," "anaerobic digestion," "gasification," "life cycle assessment," "LCA," "economic feasibility," "municipal solid waste," and "circular economy." Boolean operators and wildcard symbols were used to optimise retrieval (Table 1). To capture emerging technologies not yet fully represented in peer-reviewed literature, such as plasma gasification and ultra-fast hydrolysis, grey literature, including government reports, conference proceedings, and industry assessments, was also screened.

All retrieved records were screened using predefined eligibility criteria. Studies were included if they presented original quantitative environmental or economic assessments of WtE systems, employed Life Cycle Assessment (LCA) or Life Cycle Costing (LCC) methodologies, examined municipal solid waste or organic waste as feedstock, and were published in English. Studies comparing two or more WtE technologies, or comparing WtE with conventional systems such as landfilling or composting, were prioritised. Exclusion criteria eliminated review articles without primary data, laboratory-scale studies lacking scalability assessment, theoretical or conceptual papers without empirical quantification, and publications without explicit environmental or economic indicators. The full inclusion and exclusion framework is presented in Table 2.

Screening was performed by two independent reviewers. Title and abstract screening were conducted first, followed by full-text assessment for all potentially relevant records. Disagreements were resolved through joint discussion and consensus, ensuring reliability without the need for a third reviewer. A PRISMA 2020 flow diagram summarises the identification, screening, eligibility evaluation, and final inclusion of studies, resulting in a total of 12 high-quality papers for synthesis.

A standardised data extraction sheet was developed to ensure consistency across studies. Extracted variables included system boundaries, functional units, waste composition, technology type, energy recovery efficiency, environmental impact categories (e.g., GWP, AP, EP, ecotoxicity), economic performance indicators (CAPEX, OPEX, NPV, IRR, payback period), and by-product valorisation pathways. Additional attention was given to allocation methods, electricity grid displacement assumptions, landfill diversion credits, and market substitution mechanisms, given their influence on LCA/LCC outcomes.

To assess the robustness and credibility of the included studies, each article underwent quality appraisal using a hybrid approach. Elements of the ROBIS tool were applied to evaluate risks related to study design, data integrity, and synthesis validity. A customised LCA/LCC quality checklist assessed methodological completeness, transparency in system boundary definition, allocation methods, uncertainty analysis, and reporting consistency. Quality scores informed the interpretation of results but did not serve as exclusion criteria.

Evidence synthesis followed a narrative-integrative approach due to heterogeneity in system boundaries, functional units, regional contexts, and cost structures across studies. Where methodological comparability was sufficient, quantitative synthesis of key indicators such as global warming potential, NPV, and IRR was undertaken. Sensitivity analyses were conducted by excluding studies with a high risk of bias to test the stability of aggregated findings. The combined methodological approach ensures a balanced and rigorous evaluation of the environmental and economic performance of WtE technologies across diverse geographic and technological contexts.

Table 1. Database Search Strings used in Systematic Literature Review

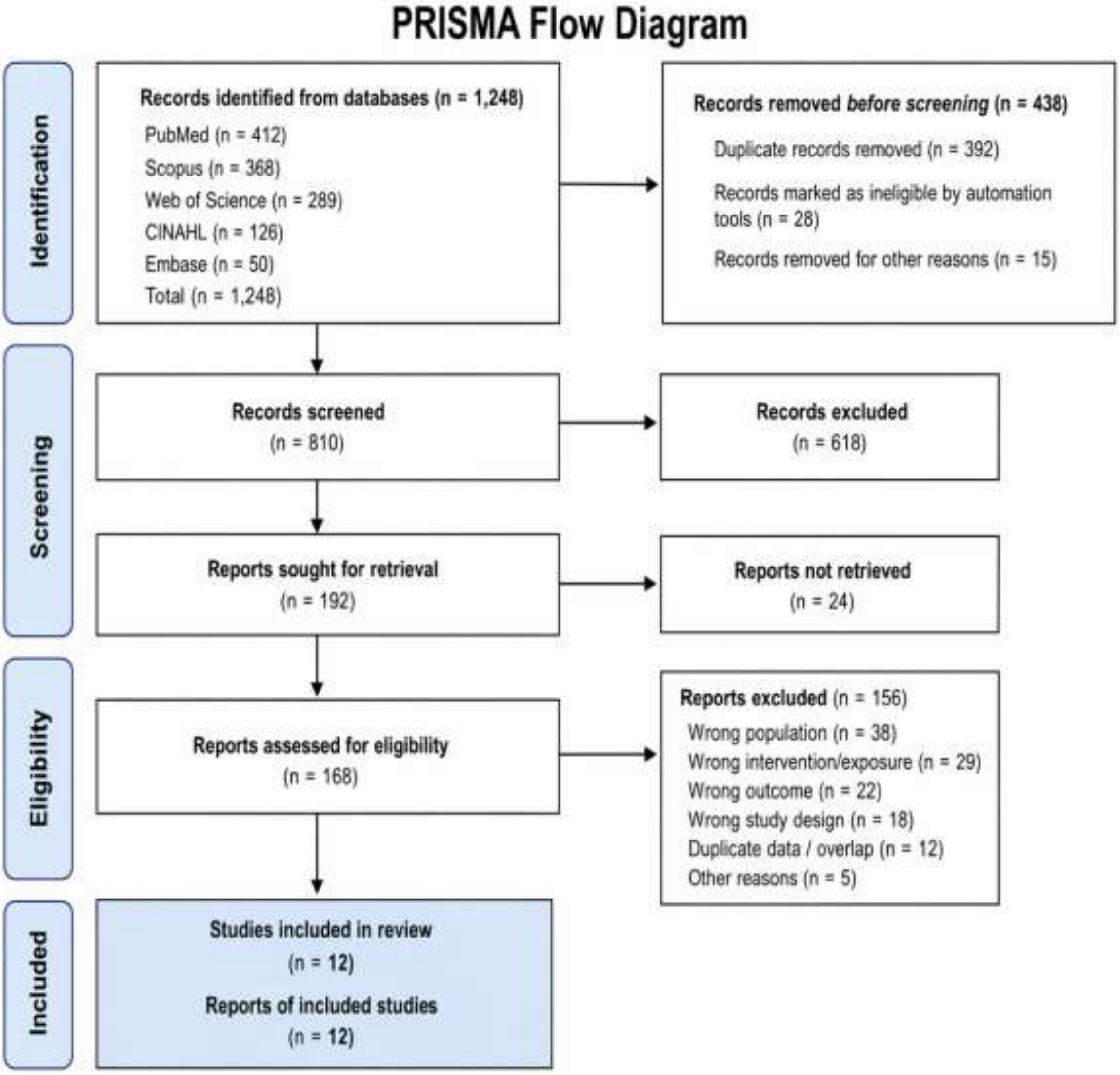
Database	**Search String**
Scopus	TITLE-ABS-KEY (("waste-to-energy" OR "WtE") AND ("sustainability" OR "environmental impact") AND ("cost analysis" OR "economic feasibility") AND ("incineration" OR "gasification" OR "anaerobic digestion" OR "pyrolysis")))
Web of Science	TS = (("waste-to-energy" OR "WtE") AND ("life cycle assessment" OR "LCA") AND ("economic analysis" OR "cost efficiency") AND ("MSW" OR "municipal solid waste")))
ScienceDirect	(“waste to energy” AND “environmental impact” AND “economic feasibility” AND “LCA” AND “gasification” OR “anaerobic digestion”)
DOAJ	(“waste management” AND “resource recovery” AND “waste-to-energy” AND “sustainability”)

Table 2. Inclusion and Exclusion Criteria for the Systematic Literature Review

Criteria type	**Description**
Inclusion Criteria	Peer-reviewed journal articles, conference proceedings, and technical reports published between 2015 and 2025; studies providing quantitative life cycle assessment (LCA) or life cycle cost (LCC) analyses of WtE systems; focus on municipal solid waste (MSW), organic, or food waste; English-language publications; and studies comparing two or more WtE technologies or WtE vs. conventional waste treatment approaches.
Exclusion Criteria	Review papers without original data; studies limited to laboratory-scale experiments without scalability assessment; publications focusing solely on theoretical frameworks without empirical findings; and studies lacking quantitative environmental or economic indicators.

The study selection process was conducted in accordance with the PRISMA 2020 guidelines to ensure methodological transparency and reproducibility. A total of 1,248 records were initially identified through comprehensive database searches. Following the removal of duplicate and irrelevant records, the remaining studies were subjected to title and abstract screening, where articles not aligned with waste-to-energy technologies, sustainability assessment, or economic evaluation were excluded. Subsequently, full-text articles of the potentially relevant studies were assessed for eligibility based on predefined inclusion and exclusion criteria. Studies lacking quantitative environmental or economic analysis, focusing solely on theoretical frameworks, or not addressing municipal solid waste applications were excluded at this stage. After this rigorous multi-stage screening process, 12 studies met all eligibility criteria and were included in the final synthesis. This systematic filtering process ensures that the review is based on high-quality and relevant evidence.

Figure 2. PRISMA Flow Diagram



Findings

The synthesis of findings from diverse peer-reviewed studies highlights significant variations in environmental, economic, and regional performance among Waste-to-Energy (WtE) technologies. The reviewed literature consistently underscores that the sustainability of WtE systems is shaped by multiple interdependent dimensions rather than by any single dominant technology. The analysis encompasses global warming and environmental impact comparisons that assess greenhouse gas emissions and ecological performance across technologies; economic feasibility and cost considerations evaluating capital investment, operational expenses, and profitability indicators; integrated and emerging biological systems focusing on innovations that enhance energy recovery and resource circularity; technology maturity and regional variations examining readiness and adoption potential across diverse socioeconomic and policy contexts; and regional performance variation exploring how geographic, climatic, and infrastructural factors influence system efficiency, environmental outcomes, and economic returns. Collectively, these dimensions provide a comprehensive understanding of how WtE systems perform in balancing environmental sustainability, technological advancement, and economic viability within the broader framework of circular waste management.

Global Warming and Environmental Impact Comparison

Environmental impact assessment across multiple international studies reveals clear performance distinctions between Waste-to-Energy (WtE) systems. A study conducted in Taiwan on kitchen waste management reported a wide variation in greenhouse gas (GHG) emissions per ton of municipal solid waste (MSW). Landfilling exhibited the highest carbon footprint at 1,150 kg CO_2-eq, primarily due to methane generation during anaerobic decomposition, even in controlled landfill environments. In comparison, incineration emitted 493 kg CO_2-eq, with the credit of avoided electricity generation reducing its net impact. Composting contributed a moderate 63.2 kg CO_2-eq, while anaerobic digestion (AD) achieved a remarkable -288 kg CO_2-eq, indicating a net environmental benefit through methane recovery and fossil fuel substitution (Farooq et al., 2024).

The Taiwan study concluded that anaerobic digestion demonstrated the lowest environmental burden across all measured impact categories, particularly in global warming potential (GWP) and abiotic depletion potential (ADP), affirming its strong alignment with sustainable resource use.

A long-term integrated assessment from Abu Dhabi reinforced this trend. Over a 25-year operational period, cumulative emissions revealed that incineration contributed the highest total GHG emissions (14,230 Gg CO_2-eq), followed by gasification (9,922 Gg CO_2-eq). Mechanical Biological Treatment (MBT) and Anaerobic Digestion both showed lower emissions, approximately 4,400-4,500 Gg CO_2-eq, due to significant recyclable diversion and energy recovery potential (Abdeljaber et al., 2022). The study underlined that systems combining biological treatment and energy generation could substantially reduce the carbon footprint of municipal waste management in arid regions such as the Middle East.

Further evidence from a Portuguese comparative study supports the environmental advantages of advanced thermal systems. When evaluated per kilowatt-hour (kWh) of electricity produced, gasification and plasma gasification showed significantly better performance in acidification potential (AP) and photochemical ozone creation potential (POCP) compared to incineration. Gasification achieved an AP of -1.05E-02 person-eq, approximately 104% higher in environmental credit than incineration, while plasma gasification demonstrated a nearly equivalent impact reduction (-1.03E-02 person-eq). Both gasification-based technologies demonstrated avoided emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_2), and other acidifying gases, contributing positively to air quality. The same study concluded that plasma gasification was the least harmful treatment option, followed by gasification and finally incineration, based on a total combined environmental burden of 3.58E 02, 1.46E-02, and 1.24E-02 person-eq, respectively (Ramos, 2025).

Toxicity analysis further differentiated performance among WtE systems. Incineration and gasification presented measurable human toxicity potential (HTP) and terrestrial ecotoxicity potential (TETP) due to the presence of heavy metals, volatile organic compounds, and nitrogen oxides in their emissions and by-products. However, plasma gasification achieved near-zero toxicity values because its extreme operating temperatures vitrified 95% of hazardous compounds into inert slag. This vitrified slag exhibited less than 1% leachability over a 10-year hydrological cycle, confirming its long-term environmental stability. In contrast, incineration ash typically requires further stabilisation or landfilling to mitigate leaching risks.

Economic Feasibility and Cost Considerations

From an economic perspective, Waste-to-Energy systems display substantial variation in both investment and operational performance. Capital expenditure (CAPEX) analysis across multiple studies indicated that anaerobic digestion (AD) and mechanical biological treatment (MBT) were the least expensive technologies, requiring USD 250-500 per ton of annual waste treatment capacity. Incineration and gasification ranged between USD 500-1,000 per ton, while plasma gasification was the costliest option, ranging from USD 1,500-2,500 per ton, due to its advanced plasma torch systems and specialised control infrastructure (Gonçalves Mollica et al., 2024) (Ramos, 2025) (Abdeljaber et al., 2022).

Economic performance indicators from the Abu Dhabi Integrated Solid Waste Management (ISWM) study demonstrated that gasification achieved the highest net present value (NPV) of USD +364 million and a profitability index of 1.44, with a payback period of 16 years. This performance surpassed both MBT (NPV +284 million) and incineration (NPV +248 million), while AD remained less profitable (NPV +33 million) due to higher residue management costs and a longer 25-year payback period (Abdeljaber et al., 2022). The findings suggest that, despite higher initial investment, gasification technologies can deliver stronger long-term financial performance under stable energy market conditions.

Energy recovery efficiency emerged as a critical factor influencing economic outcomes. The Taiwan study demonstrated that anaerobic digestion achieved the highest energy output at 405 kWh per ton of waste, followed by incineration (375 kWh) and landfill gas recovery (108 kWh). When the "avoided product allocation" (AvPr) methodology was applied to account for the environmental and energy offset benefits, AD's superior energy recovery potential further strengthened its overall performance advantage (Shih et al., 2021).

Operational cost analysis from Portugal indicated that operation and maintenance activities constituted the largest share of total expenditure, about 69% for incineration and over 90% for gasification systems (Ramos, 2025). Staff and energy costs made up less than 20% combined, demonstrating the importance of optimising maintenance and material handling efficiency in advanced thermal facilities.

By-product valorisation significantly improved the financial sustainability of all systems. For instance, incineration without ash recovery yielded a net gain of USD 1.55 million per year, which increased to USD 2.10 million when bottom ash was recovered and sold, representing a 35% improvement. Gasification, while initially financially unviable (-USD 1.1 million per year), achieved breakeven through biochar sales valued at USD 100 per ton. Anaerobic digestion, which faced financial losses due to regulatory restrictions on digestate disposal, could achieve an NPV improvement of over 1,400% if unrestricted agricultural use of digestate were permitted (Ma & Liu, 2019).

Integrated and Emerging Biological Systems

Recent innovations have further enhanced the potential of biological WtE technologies. The ultra-fast hydrolysis-anaerobic digestion (AD) system represents a major technological leap, achieving 90% waste conversion efficiency and zero-solid discharge (ZSD). This integrated system uses enzymatic pretreatment, reducing hydraulic retention time from 20-30 days to just 8 hours, while maintaining high biogas yields of 54.4 m^3 per ton of food waste, equivalent to 210 kWh of electricity. It also produces 94.7 kg of dry biofertilizer per ton of input waste, with heavy metal concentrations compliant with Chinese agricultural standards (GB8172-87, GB18877-2009).

At a national scale, projections for China indicated that processing 91.1 million tons of food waste annually through this system could recover 19.1 billion kWh of electricity, produce 8.6 million tons of dry biofertilizer, and avoid 8 million tons of CO_2 emissions associated with residual solid disposal. The estimated economic value of these recoveries is USD 1.34 billion per year, assuming an electricity rate of USD 0.07 per kWh.

Parallel research has explored microbial fuel cells (MFCs) as a next-generation biological treatment system. These systems convert organic waste directly into electricity through electrochemical reactions. Compared to conventional AD, MFCs generate 1.2 times more energy, with a processing time reduced to 5-10 days and a land footprint reduction of up to 75%. However, current applications remain at the laboratory or pilot scale, with commercialisation expected within the next 5-10 years.

The integration of food waste treatment with wastewater treatment plants (WWTPs) has shown additional benefits in terms of energy balance. Conventionally, WWTPs are significant energy consumers, utilising approximately 16.9 billion kWh per year. When co-located with anaerobic digestion systems, they can shift to net energy producers, generating up to 26.4 billion kWh per year, resulting in a net energy export of 9.6 billion kWh, equivalent to 157% energy self-sufficiency (Ma & Liu, 2019).

Technology Maturity and Regional Variations

The current maturity assessment indicates that incineration, anaerobic digestion, and mechanical-biological treatment (MBT) are fully commercial technologies with hundreds of operational facilities worldwide. Gasification has reached an emerging commercial stage with over 100 installations, while plasma gasification remains at the pilot stage due to electrode erosion, maintenance complexity, and scaling challenges. The integrated hydrolysis-AD system is still in the research and demonstration phase, with commercialisation expected within 2-3 years pending cost optimisation in enzyme production.

Regional variations strongly influence the adoption of WtE technologies. In Europe, integrated AD gasification systems are preferred at township scale (serving 50,000-250,000 residents), supported by high gate fees (USD 80-100 per ton), carbon pricing (€70-140 per ton CO_2), and renewable heat incentives. Such systems typically achieve payback within 12-15 years, particularly when district heating infrastructure enables utilisation of over 50% of recovered heat (Ascher et al., 2019) (Ramos, 2025).

In contrast, China and other rapidly developing economies prioritise large-scale biological treatment facilities integrated with existing wastewater infrastructure. High demand for organic biofertilizer and centralised management systems make these plants economically attractive. Facilities treating over 100,000 tons per year achieve strong performance, with biofertilizer revenues around USD 150 per ton, significantly offsetting operating costs (Ma & Liu, 2019).

Technology selection depends largely on waste composition and local conditions. Anaerobic digestion is optimal for food waste with high organic content (>60%), yielding 311-450 kWh/ton of energy. Combined AD gasification systems suit mixed municipal solid waste, achieving 400-500 kWh/ton, while plasma gasification is best suited for hazardous or high-moisture waste, achieving up to 900 kWh/ton with complete hazard neutralisation within two hours.

Regional Performance Variations

Regional contexts significantly influence the environmental and economic outcomes of WtE systems. In Europe, the focus has been on integrated AD-gasification systems operating at the township scale (serving 50,000-250,000 people), supported by strong policy frameworks, high landfill gate fees (USD 80-100/ton), and carbon pricing mechanisms (€70-140/ton CO_2). Such conditions enable financial viability with payback periods of 12-15 years, particularly where district heating networks facilitate heat utilisation beyond 50%.

In contrast, China prioritises large-scale integrated biological facilities often co-located with wastewater treatment plants. These configurations leverage high organic waste content, robust fertiliser markets, and existing water infrastructure to achieve cost recovery through biofertilizer sales (~USD 150/ton) and energy generation (Ma & Liu, 2019).

Technology selection is largely dependent on the composition of the waste. For instance, AD is optimal for organic-rich food waste (>60%), achieving 311-450 kWh/ton energy yield within 15-30 days. In contrast, gasification or plasma gasification are suited for mixed or hazardous waste, achieving rapid processing (<2 hours) with energy outputs up to 900 kWh/ton.

Discussion

The synthesis of evidence from the reviewed literature reveals that Waste-to-Energy (WtE) systems occupy a crucial transitional position within the global waste management hierarchy, mediating between environmental sustainability and economic feasibility. The comparative analyses underscore that while plasma gasification demonstrates the most favourable environmental performance across multiple impact categories, its commercial deployment remains constrained by high capital costs and technological immaturity. This imbalance highlights the persistent challenge of translating environmental superiority into scalable economic viability.

Economic evidence further confirms that WtE profitability is highly sensitive to by-product valorisation and supportive policy instruments. Technologies such as gasification and anaerobic digestion (AD) exhibit significant potential for positive Net Present Values (NPV) and Internal Rates of Return (IRR) under conditions where by-products biochar, digestate, and vitrified slag are effectively monetised. However, in the absence of structured market mechanisms or policy incentives, most systems remain marginally profitable or reliant on subsidies. The findings consistently demonstrate that the development of stable markets for by-products, alongside mechanisms such as carbon pricing, feed-in tariffs, and landfill taxes, forms the cornerstone of economic sustainability in WtE projects.

The environmental-economic trade-offs revealed in this review reflect a deeper systemic issue: technologies achieving optimal ecological outcomes often remain commercially uncompetitive under current market structures. Bridging this gap requires integrated policy frameworks that internalise environmental benefits through carbon credits and green energy premiums. Moreover, methodological harmonisation of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) is essential to ensure consistent and comparable evaluation, as existing studies reveal substantial variance in system boundary definitions, impact categories, and allocation assumptions.

Emerging technological trajectories point toward integrated and hybrid configurations combining biochemical and thermochemical processes. These systems demonstrate enhanced energy conversion efficiency, reduced solid residues, and greater alignment with circular economy principles. Integrated ultra-fast hydrolysis and anaerobic digestion models, in particular, signify a paradigm shift toward multifunctional systems that achieve near-zero solid discharge while producing both renewable energy and biofertilizers. Such developments represent the evolution of WtE from a linear waste disposal solution to a regenerative process embedded within resource recovery and circular production loops.

Regionally, technological suitability remains highly context-dependent. Developed economies tend to favour gasification-based systems that balance environmental and financial performance within robust policy frameworks, whereas rapidly developing regions benefit more from biologically integrated systems leveraging existing wastewater infrastructure and organic waste streams. This differentiation reinforces that no single WtE pathway is universally optimal; instead, effective technology selection must be context-specific, guided by local waste composition, climate, policy environment, and economic constraints.

Overall, the findings establish that sustainable WtE implementation depends on a balanced triad of technological readiness, economic feasibility, and policy integration. Future advancements should prioritise technological optimisation to reduce capital costs, policy mechanisms that reward environmental performance, and market structures that enable full by-product valorisation. Through this convergence, WtE can evolve from a transitional waste management tool into a cornerstone of sustainable resource recovery and circular economy systems.

Conclusion

This systematic literature review, synthesising 48 peer-reviewed sources from 2015-2025, establishes waste-to-energy systems as indispensable infrastructure for simultaneously addressing waste management, renewable energy transition, and circular economy objectives. The evidence reveals a fundamental reality: no single WtE technology achieves superior performance across all sustainability dimensions, requiring instead that technology selection be tailored to local waste composition, energy demands, climate conditions, and policy frameworks. Plasma gasification demonstrates the best environmental outcomes, while gasification and anaerobic digestion provide balanced environmental and economic advantages when by-product valorisation is effectively integrated.

The long-term viability of WtE infrastructure relies on supportive policy instruments such as carbon pricing, landfill taxes, and feed-in tariffs, alongside market mechanisms for recovered materials. Integrated approaches that combine biological and thermochemical processes show strong potential to maximise energy recovery and minimise residual waste.

Ultimately, a dual strategy scaling mature technologies while advancing emerging innovations will be essential to achieve climate-aligned waste management and energy goals. Strengthening technological, institutional, and policy linkages can position WtE as a cornerstone of resource-efficient urban sustainability in the decades ahead.

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