

Municipal Solid Waste Management: Governance, Digitalization, and Technological Innovation for Sustainable Transitions

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1. Introduction and Context

Municipal solid waste management (MSWM) is increasingly recognized as a critical socio-technical subsystem within broader sustainability transitions, linking urban metabolism, institutional governance, environmental risk, and climate mitigation. Although technological innovation in waste treatment has expanded rapidly, empirical evidence continues to reveal uneven system performance across contexts, indicating that technical capability alone is insufficient to explain sustainability outcomes.

Building on the first edition of this Special Issue, which framed MSWM through integrated management and environmental performance perspectives, the present second edition advances the discussion by foregrounding institutional capacity, digitalization as a governance instrument, and the conditional nature of technological effectiveness within circular economy strategies. Rather than revisiting established hierarchies or best-practice narratives, this edition examines how MSWM systems operate under conditions of institutional asymmetry, infrastructural constraint, and environmental and health risk.

2. Conceptual Orientation and Objectives

This Special Issue brings together thirteen contributions structured around three interrelated analytical strands: (i) governance, behavior, and institutional capacity; (ii) digitalization and intelligent decision-support systems; and (iii) waste treatment technologies, risk, and circular valorization.

Across these strands, the objective is not to catalogue technical solutions, but to interrogate the conditions under which MSWM interventions deliver effective, scalable, and socially robust outcomes, as well as the circumstances under which they stagnate or generate unintended effects, particularly across heterogeneous institutional and geographical settings.

3. Governance, Behavior, and Institutional Capacity

The governance- and behavior-focused contributions reframe MSWM sustainability as a problem of institutional sequencing rather than technological choice. Empirical analyses demonstrate that internal municipal capacity—encompassing staffing adequacy, financial coordination, service regularity, and planning coherence—accounts for a substantial share of performance variation, exceeding 40% in low-capacity contexts [contribution 1]. This finding challenges technology-first narratives that implicitly assume institutional adaptation will follow technical deployment.

Behavioral analyses further undermine individualistic interpretations of household non-compliance. Evidence showing that more than half of households in underserved



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municipalities engage in informal disposal practices despite pro-environmental attitudes [contribution 2] indicates that such behaviors are rational responses to infrastructural deficits and service unreliability rather than attitudinal failure. When considered alongside disaster waste management case studies [contribution 3] and multi-level indicator frameworks for zero-waste strategies [contribution 4], a consistent pattern becomes evident: governance fragmentation and misaligned service provision systematically transfer responsibility to households while simultaneously constraining feasible compliance pathways.

MSWM failures thus emerge less from behavioral resistance or technological inadequacy than from misordered institutional development, in which policy ambition persistently outpaces administrative, financial, and operational capacity. This insight has direct implications for policy design, sequencing, and capacity-building strategies.

4. Digitalization, Data, and Intelligent Systems

The digitalization-focused contributions assign a conditional and context-dependent role to intelligent systems in MSWM. Digital tools function primarily as capability amplifiers, with their effectiveness contingent on the presence of robust governance arrangements, data infrastructures, and decision-making routines.

Advanced predictive models applied to incineration processes reduce temperature forecasting errors by approximately 40% under variable waste composition [contribution 5], while automated waste identification systems achieve classification accuracies exceeding 90% in controlled environments [contribution 6]. Data-driven optimization models further demonstrate efficiency gains in construction and demolition waste systems when analytical tools are aligned with operational constraints [contribution 7]. These gains, however, depend critically on data quality, process formalization, and institutional absorptive capacity.

Digitalization does not compensate for weak governance; instead, it magnifies existing institutional strengths and weaknesses. In low-capacity contexts, intelligent systems risk producing technically sophisticated yet operationally marginal or symbolic interventions, offering limited contribution to substantive system transformation.

5. Treatment Technologies, Risk, and Circular Valorization

The technological contributions challenge efficiency-centered interpretations of sustainability in MSWM by exposing the disconnect between treatment performance and broader environmental and health outcomes. Integrated industrial park models demonstrate that coordinated systems can achieve material recovery rates approaching 90% [contribution 8], yet such efficiency gains do not inherently correspond to reduced environmental burden or risk.

Evidence from organic waste treatment illustrates this tension clearly. Despite process optimization, anaerobic digestion reduces antibiotic resistance gene concentrations by less than one logarithmic unit, leaving residual loads between 10^4 and 10^9 gene copies per kilogram of digestate [contribution 11]. These findings raise substantive concerns regarding land application practices and question assumptions that biological treatment aligns automatically with circular economy objectives.

Efficiency gains in treatment and material recovery do not translate into sustainability outcomes when environmental and health risks remain weakly governed, particularly within circular economy strategies that prioritize valorization over risk containment. Analyses of thermochemical treatment [contribution 9], landfill leachate management [contribution 10], and hospital bio-waste valorization [contribution 12] further reinforce the need for assessment frameworks that integrate risk governance alongside efficiency and recovery metrics.

This systemic perspective is reinforced by a comprehensive review included in this Special Issue, synthesizing evidence from more than 170 studies and estimating that circular economy integration in the waste sector could reduce projected greenhouse gas emissions growth by 30–39% by 2050 [contribution 13]. Crucially, this mitigation potential depends on coordinated governance, controlled material flows, and explicit management of environmental and health risks, rather than on isolated technological adoption.

6. Geographical Diversity and Transferability

Across all three analytical strands, geographical diversity functions as an explanatory lens rather than a descriptive variable. The contributions demonstrate that MSWM interventions are deeply contingent on institutional maturity, regulatory enforcement, and infrastructural baselines. Strategies that yield efficiency gains in high-capacity settings frequently generate limited or counterproductive outcomes when transferred without adaptation to contexts characterized by governance fragmentation or service deficits.

These findings underscore the importance of context-sensitive policy transfer and caution against the uncritical replication of MSWM models across institutional environments.

7. Concluding Remarks

This second edition of the Special Issue reframes sustainability transitions in municipal solid waste management as fundamentally institutional and conditional processes. Across governance, digitalization, and treatment technologies, the contributions converge on a central insight: technological potential translates into sustainability outcomes only when aligned with institutional sequencing, governance coherence, and explicit risk management.

Progress in MSWM therefore depends less on the continuous introduction of new technologies than on the capacity to govern existing ones under conditions of institutional asymmetry, uncertainty, and environmental and health risk. MSWM should thus be understood not as a technical problem awaiting optimization, but as a socio-technical system requiring deliberate, context-sensitive coordination across policy, infrastructure, and knowledge domains.

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