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From Waste to Health: Integrating Zero Waste and Circular Economy Principles in Healthcare Sustainability

Od ograniczania odpadów do zdrowia. Integracja zasad zero waste i gospodarki obiegu zamkniętego w zrównoważonym systemie opieki zdrowotnej

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Abstract: Contemporary environmental and healthcare sustainability challenges have driven the evolution of zero waste systems from simple waste reduction strategies into comprehensive frameworks that prioritise public health alongside ecological protection and social equity. This transformation is critical within healthcare sustainability contexts, where environmental policy frameworks, public health imperatives, circular economy principles, and sustainable healthcare delivery must be systematically integrated. This article investigates the transformation of zero waste frameworks toward health-centred approaches and develops an integrated theoretical model through evolutionary analysis. Based on the conceptual systematic review (CSR) framework, the study employs dual analytical and prescriptive methodologies, examining theoretical developments through the systematic analysis of conceptual frameworks from economy, sustainable environments, and public health domains. Analysis reveals that zero waste frameworks have evolved through multiple pathways that incorporate health-centred approaches: reducing toxic exposures, improving infectious disease control, enhancing community wellbeing, creating economic opportunities, and promoting environmental justice. Effective implementation requires multisectoral collaboration, adaptive governance mechanisms, and inclusive community engagement for systemic transformation. The proposed integrated theoretical framework leverages evolutionary insights to guide the development of zero-waste systems that simultaneously prioritise health protection while advancing sustainability dimensions.

Keywords: zero waste, public health, waste management, circular economy, environmental sustainability, social equity, SDG 3: Good Health and Well-being, SDG 12: Responsible Consumption and Production

Streszczenie: Współczesne wyzwania związane ze zrównoważonym rozwojem w obszarze środowiska i ochrony zdrowia doprowadziły do ewolucji systemów *zero waste* – od prostych strategii ograniczania ilości odpadów po kompleksowe rozwiązania, które obok ochrony środowiska i zasad sprawiedliwości społecznej stawiają na pierwszym miejscu troskę o zdrowie publiczne. Zmiany te mają kluczowe znaczenie w kontekście zrównoważonej opieki zdrowotnej, wymagającej systematycznej integracji polityki środowiskowej, potrzeb zdrowotnych, zasad gospodarki o obiegu zamkniętym oraz zrównoważonego świadczenia usług medycznych. Artykuł przedstawia proces ewolucji koncepcji *zero waste* w kierunku podejścia zorientowanego na zdrowie oraz propozycję zintegrowanego modelu teoretycznego opracowanego w oparciu o analizę ewolucyjną. Na podstawie systematycznego przeglądu literatury (CSR), badanie wykorzystuje podwójną metodologię analityczno-normatywną, analizując rozwój teorii poprzez systematyczne badanie ram koncepcyjnych w obszarze

ekonomii, zrównoważonego środowiska i zdrowia publicznego. Analiza wykazuje, że koncepcja *zero waste* ewoluowała wieloma ścieżkami, obejmując podejścia ukierunkowane na zdrowie: ograniczanie wpływu substancji toksycznych, poprawę kontroli chorób zakaźnych, wzmacnianie dobrostanu społeczności, stwarzanie możliwości gospodarczych oraz promowanie sprawiedliwości środowiskowej. Skuteczne wdrożenie tych zasad wymaga współpracy międzysektorowej, wdrożenia adaptacyjnych mechanizmów zarządzania oraz inkluzywnego zaangażowania społeczności w proces systemowej transformacji. Proponowany zintegrowany model teoretyczny wykorzystuje wnioski z analizy ewolucyjnej, aby wspierać rozwój systemów *zero waste*, które jednocześnie nadają priorytet ochronie zdrowia i zachowują zasady zrównoważonego rozwoju.

Słowa kluczowe: zero waste, zdrowie publiczne, gospodarka odpadami, gospodarka o obiegu zamkniętym, zrównoważony rozwój środowiskowy, sprawiedliwość społeczna, SDG 3: Dobre zdrowie i jakość życia, SDG 12: Odpowiedzialna konsumpcja i produkcja

Introduction

The global waste crisis has reached unprecedented proportions, with over 2 billion tonnes of municipal solid waste generated annually worldwide and projected to increase to 3.4 billion tonnes by 2050 (Valavanidis 2023). The consequences of this waste extend far beyond filled landfills and polluted landscapes, creating cascading negative effects on public health, climate systems, biodiversity, and social equity (Siddiqua et al. 2022). The theoretical foundations of zero waste management have evolved from early industrial ecology frameworks to contemporary integrated approaches that recognize waste systems as interconnected networks. Early integrated solid waste management established hierarchical frameworks prioritizing waste prevention (Marshall & Farahbakhsh 2013), while subsequent circular economy developments demonstrated systemic approaches to material flow optimization. These foundational works established critical precedents for understanding waste systems as requiring multi-stakeholder coordination and adaptive governance mechanisms. Traditional approaches to waste management that prioritise disposal are increasingly recognised as inadequate for addressing these interconnected challenges. The relationship between environment, healthcare systems, and waste management has become particularly evident during recent global health crises. Sarkodie & Owusu (2021) noted that the COVID-19 pandemic revealed critical vulnerabilities in waste management systems worldwide, with medical waste generation increasing dramatically and informal waste workers facing heightened health risks. These challenges have underscored the necessity for waste systems that protect human and environmental health while ensuring resilience against future shocks. The European context provides particularly relevant policy frameworks for health-centred zero waste implementation. The European Green Deal (2019) and Circular Economy Action Plan (2020) explicitly integrate health considerations within sustainability objectives, while the EU Strategy for Sustainability in the Health Sector emphasizes circular economy principles in healthcare delivery. Many European cities participating in the C40 Cities Climate Leadership Group have implemented comprehensive zero waste programs that incorporate health and safety considerations, as documented in the C40 "Towards Zero Waste Accelerator" program, which demonstrates how cities are creating cleaner, healthier communities through circular economy approaches (C40 Cities 2023). Similarly, cities across North America, including San Francisco's zero waste program, have demonstrated successful integration of public health objectives within waste reduction strategies.

Zero waste management has emerged as a transformative approach to addressing the escalating global waste crisis and

its environmental consequences. Recent updates to the Zero Waste International Alliance hierarchy (Zero Waste International Alliance 2025) provide enhanced frameworks for health integration that build upon previous versions while strengthening public health considerations across all intervention levels. Khurshid, Zubair & Humaira (2024) pointed out that Zero Waste Management represents a revolutionary and proactive strategy to address the escalating global waste predicament and its negative environmental effects, emphasising waste reduction, reuse, and recycling within circular economy frameworks. Mahanta et al. (2022) consider that zero waste has emerged as an alternative paradigm that aims to redesign resource lifecycles so that all products are reused, with no waste sent to landfills, incinerators, or the environment. This paradigm offers significant social, economic, and environmental benefits while fostering sustainable development.

Contemporary zero-waste frameworks have evolved beyond their initial focus on waste prevention and recycling to acknowledge that true sustainability requires integrated systems addressing public health protection, environmental preservation, and social well-being simultaneously. This theoretical evolution reflects growing recognition of the fundamental interconnections between waste management practices and population health outcomes, particularly highlighted by recent global health crises and the escalating waste generation worldwide. This article investigates the transformation of zero waste frameworks toward health-centred approaches and develops an integrated theoretical model based on a prescriptive analysis. The main research question guiding this investigation is: "How can theoretical frameworks for zero waste systems be systematically integrated to prioritize public health protection while incorporating environmental sustainability and social equity considerations?"

1. Materials and Methods

1.1. Study Design

This study employs a conceptual analysis methodology based on the Conceptual Systematic Review (CSR) framework proposed by Schreiber and Cramer (2024). Rather than conducting an exhaustive systematic literature review, this research focuses on theoretical synthesis and conceptual integration across interdisciplinary domains. The CSR methodology is particularly suited to this investigation as it addresses the "tangled" nature of zero waste terminology, where the concept encompasses diverse meanings across disciplines and lacks systematic conceptual mapping.

The conceptual analysis approach prioritizes theoretical coherence and framework development over comprehensive literature coverage, making it appropriate for addressing complex, multi-disciplinary concepts that require conceptual clarification rather than empirical synthesis.

1.2. Data Collection through Literature Review

This study is underpinned by a conceptual literature analysis rather than an exhaustive systematic review, which examines key areas of zero waste theory, public health frameworks, environmental governance, and waste management practices through purposive selection of high-impact theoretical contributions. The analysis draws on seminal works to identify prevailing trends, theoretical gaps, and practical challenges in integrating health considerations within zero waste systems. The approach adheres to Stage 4 of the CSR framework (see Figure 1 below), employing targeted database searches with strategic selection criteria rather than comprehensive coverage, using Boolean combinations of "zero waste" and related terms alongside health-specific terminology across peer-reviewed articles, policy documents, and grey literature. This focused corpus of approximately 45 sources facilitates theoretical synthesis of how health considerations are conceptualised across different disciplinary contexts and publication

types, prioritizing conceptual depth over exhaustive coverage.

The purposive literature selection employed Boolean search strategies across multiple databases (PubMed, Scopus, Web of Science, and Google Scholar) using the following search terms: ("zero waste" OR "circular economy") AND ("healthcare" OR "medical waste" OR "hospital waste") AND ("public health" OR "health outcomes" OR "occupational health"). Additional searches incorporated terms specific to waste management frameworks: ("waste hierarchy" OR "integrated waste management") AND ("health" OR "safety" OR "risk assessment"). Grey literature searches included policy documents from WHO, UNEP, Ellen MacArthur Foundation, and national health ministries. Inclusion criteria prioritized theoretical relevance over comprehensive coverage: English-language publications addressing conceptual frameworks, theoretical models, or high-impact empirical studies connecting waste management practices with health outcomes. Exclusion criteria eliminated purely technical studies focused solely on treatment technologies without health considerations, and studies limited to single-facility case reports without broader theoretical implications. The final corpus comprised approximately 45 strategically selected sources, with intentional emphasis on foundational works (15%), contemporary frameworks from 2020-2025 (60%), policy documents (15%), and grey literature (10%), reflecting conceptual synthesis objectives rather than exhaustive review methodology.

This approach acknowledges several inherent limitations: (1) Geographic bias toward European and North American frameworks with limited representation from Global South perspectives, (2) Temporal emphasis on post-2020 developments reflecting paradigm shifts following the COVID-19 pandemic, (3) Language limitations to English-language sources, and (4) Selective scope prioritizing theoretical coherence and integration potential over comprehensive disciplinary coverage. These limitations are intentional and reflect the study's focus on theoretical integration and framework development rather than systematic empirical synthesis.

1.3. Data Analysis

Prescriptive analytics, as described by Lepenioti et al. (2020), operates at two levels of human involvement: decision support, which offers recommendations to guide choices, and decision automation, which directly implements the recommended actions without human intervention. The analytical component involves a structured review and synthesis of conceptual frameworks drawn from key domains: public health, economy, industrial engineering, including environmental science and governance. These frameworks were selected based on their theoretical relevance to zero waste principles and their explicit or implicit engagement with health-related outcomes, rather than exhaustive disciplinary coverage.

This methodology enables the theoretical mapping of health considerations across existing zero waste frameworks, revealing how public health dimensions are currently conceptualised and integrated within waste management approaches. The CSR framework facilitates the development of an integrated theoretical model for health-centred waste systems by identifying conceptual gaps and synthesising insights from multiple disciplinary perspectives through comparative theoretical analysis rather than quantitative synthesis.

Stage 1: Identifying Zero Waste as a Tangled Term – "Zero waste" qualifies as a "tangled term" because it encompasses fundamentally different meanings across policy contexts (regulatory compliance vs. aspirational targets), activist frameworks (community-based social justice vs. individual behaviour change), and academic disciplines (industrial ecology's technical optimization vs. public health's risk-based approaches). This semantic diversity creates conceptual confusion that impedes systematic analysis, as researchers may unknowingly compare

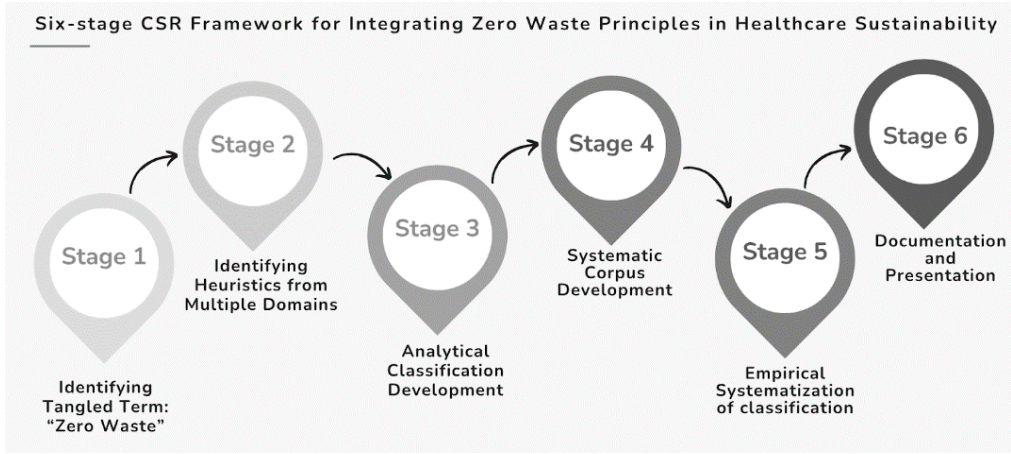

Figure 1. Six-stage CSR Framework for Integrating Zero Waste Principles in Healthcare Sustainability. Source: Authors' elaboration, 2025.

incompatible definitions or overlook relevant literature from adjacent fields. The CSR methodology specifically addresses such terminological complexity by providing structured approaches for mapping conceptual variations and identifying underlying theoretical coherence.

Stage 2: Identifying Heuristics – Existing frameworks from environmental science, public health, and circular economy literature serve as theoretical starting points for systematic classification. These foundational approaches are further strengthened by circular economy frameworks from business and industrial ecology literature, which provide additional theoretical foundations for understanding economic value creation within zero waste systems and offer comprehensive models for integrating environmental sustainability with economic viability.

Stage 3: Analytical Classification – Heuristics are subjected to quality criteria of definiteness, selectivity, and independence to develop a coding framework distinguishing environmental, economic, social, and health perspectives.

Stage 4: Corpus Development – Systematic literature searches using "zero waste" and health-related terminology (e.g. "circular economy healthcare"; "medical waste recovery", "healthcare resource efficiency") create a corpus including peer-reviewed articles, policy documents, and grey literature.

Stage 5: Empirical Systematisation – Classifications are tested through inductive coding, applying criteria of generality, operationalizability, and reliability (Krippendorff's alpha > 0.667) (Krippendorff 2022).

Stage 6: Documentation and Presentation – Produces qualitative systematisation of term usage patterns of health integration across frameworks.

The prescriptive component builds upon this analysis to develop an integrated theoretical model for health-centred waste systems through systematic theoretical comparison of existing frameworks. This investigation employs comparative theoretical analysis to examine the evolution of waste management paradigms, from traditional disposal-focused approaches to contemporary holistic zero waste systems. The methodology incorporates multiple theoretical lenses, including systems theory, complexity science, and adaptive governance frameworks, to understand the dynamic relationships between health, environmental, and social dimensions of waste systems.

The theoretical comparison reveals three dominant models for zero waste-public health integration: the Hierarchical Model (2020-2022), the Intersectional

Model (2022-2024), and the Systems Model (2024-present). Each model represents different conceptualisations of the relationship between public health and sustainability dimensions, with approaches ranging from health-prioritised hierarchies to integrated systems thinking. The comparative analysis demonstrates how theoretical frameworks have evolved from linear, sector-specific models to complex, adaptive approaches that acknowledge interdependencies across multiple domains.

1.4. Methodological Rigour through Interdisciplinary Collaboration

The interdisciplinary collaboration between researchers from Slovakia economy and management (AS) and Norway – industrial engineering, including environmental science (OK) and public health (MT) strengthened the methodological foundation through complementary analytical approaches. This synergy enhanced validity through methodological triangulation and cross-field verification of findings, while reliability was improved through jointly developed standardised coding protocols and inter-rater agreement measures (Donkoh and Mensah 2023).

1.5. Ethical Considerations

Ethical approval was not required for this study as it employed a purely theoretical approach utilising existing literature available through public access or institutional scientific databases. All reviewed materials were publicly accessible scholarly works, policy documents, and grey literature, with no primary data collection involving human participants or sensitive information.

2. Discussion

The discussion employs a structured analytical framework addressing the theoretical evolution of zero waste systems toward health-centred approaches, comparative paradigm analysis, theoretical integration models, and implementation frameworks. This approach ensures comprehensive examination of theoretical developments while maintaining focus on practical implementation considerations within the conceptual analysis methodology employed in this study.

2.1. Evolution of Waste Management Paradigms

The theoretical foundations for health-centred zero waste systems emerge from a systematic evolution of waste management paradigms over the past three decades. This evolution demonstrates the increasing centrality of public health considerations in waste system design and implementation. Table 1 describes the fundamental transformation from waste management models where public health was a peripheral concern to integrated approaches where health considerations become increasingly central. The most significant theoretical shift occurred post-2020, catalysed by the COVID-19 pandemic, which highlighted waste management as essential public health infrastructure. The holistic zero waste systems paradigm (2023-present) represents the most comprehensive integration of public health frameworks with environmental and social considerations, treating health not as a co-benefit but as a central organizing principle (Appendix 1).

The conceptual synthesis of selected high-impact theoretical frameworks from the literature corpus revealed three distinct evolutionary phases in health integration. The Traditional Waste Management period (pre-1990s) showed minimal health integration within foundational frameworks examined, primarily limited to reactive responses to immediate exposure risks. The transitional period (1990s-2020) demonstrated increasing but inconsistent health considerations across analysed theoretical models, with significant variation across geographic regions and institutional contexts. The contemporary period (2020-present) shows systematic health integration within the majority of examined frameworks, with explicit health outcomes measurement and health-protective system design becoming standard

components. These patterns emerged from theoretical comparison rather than quantitative analysis, reflecting the study's focus on conceptual integration over empirical synthesis.

While this paradigmatic evolution demonstrates the increasing centrality of health considerations in waste management thinking, the practical challenge remains of how to operationalize these integrated approaches. Theoretical literature has responded to this challenge by developing specific theoretical models that provide concrete frameworks for implementing health-centred zero waste systems.

2.2. Synthesis of Contemporary Integration Models: From Fragmentation to Integration

Within the current paradigm of health-centred zero waste systems, three distinct but complementary theoretical approaches have emerged to address the specific mechanisms for integrating public health considerations into zero waste frameworks. Rather than representing competing paradigms, the Hierarchical Model (2020-2022), Intersectional Model (2022-2024), and Systems Model (2024-present) constitute evolutionary stages in the development of increasingly sophisticated integration frameworks. Each model addresses specific limitations of its predecessors while contributing essential insights for holistic implementation.

The Hierarchical Model's strength lies in establishing public health as a non-negotiable foundation, ensuring that health protection receives priority consideration in all zero waste interventions (Ellen MacArthur Foundation 2021). However, its linear conceptualization of relationships between health, environmental, and social dimensions fails to capture the complex interdependencies that characterize real-world waste systems.

The Intersectional Model addresses, as described by Kirchherr et al. (2022), this limitation by recognizing the overlapping nature of sustainability domains, facilitating multi-criteria decision-making and stakeholder collaboration. Yet its static representation of relationships cannot adequately account for the dynamic feedback loops and adaptive requirements essential for effective system governance.

The Systems Model represents the most sophisticated understanding of these relationships, incorporating complexity science insights to address dynamic interdependencies through adaptive governance mechanisms (Purvis et al. 2023). However, practical implementation of systems approaches remains challenging due to their conceptual complexity and resource requirements. This evolutionary progression suggests the need for an integrated framework that synthesizes the foundational prioritization of the Hierarchical Model, the multi-domain recognition of the Intersectional Model, and the dynamic adaptability of the Systems Model.

2.3. Integrated Theoretical Framework: Core Components and Relationships

Building upon this evolutionary synthesis, we propose an Integrated Theoretical Framework for Health-Centred Zero Waste Systems that addresses the limitations of individual models while preserving their essential contributions. This framework positions public health protection as the central organizing principle while incorporating environmental sustainability and social equity as co-equal domains within a dynamic, adaptive system architecture.

At the framework's core lies a Zero Waste Integration Hub (see Figure 2) that serves as the primary coordination mechanism for health-centred implementation. This hub operates on the principle that effective zero waste systems require active integration rather than passive coordination, employing systematic protocols for identifying synergies, managing trade-offs, and optimizing outcomes across all sustainability domains. The hub incorporates health impact assessment methodologies, environmental life-cycle analysis, and social equity evaluation

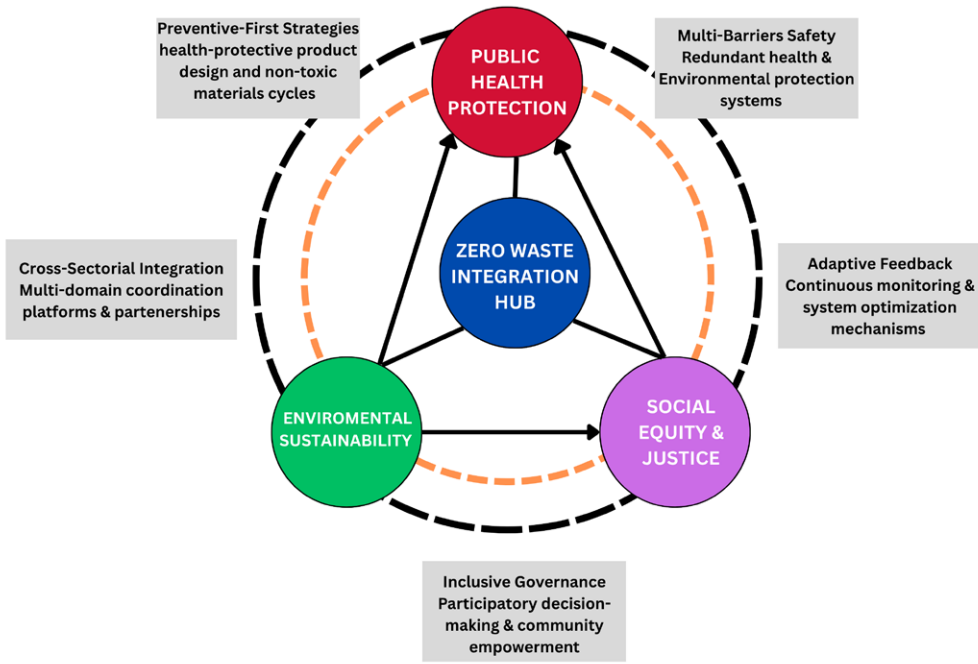

Figure 2. An Integrated Theoretical Framework for Health-Centred Zero Waste Systems. Source: Authors' elaboration, 2025

protocols within unified decision-making frameworks.

The framework conceptualizes domain relationships between public health protection, environmental sustainability, and social equity as interconnected domains with bidirectional feedback relationships rather than separate spheres (Maalouf et al. 2025). Public health considerations inform environmental interventions through exposure pathway analysis and risk assessment, while environmental protection strategies influence health outcomes through ecosystem service provision and pollution reduction. Social equity dimensions shape both health and environmental outcomes through their effects on exposure patterns, access to resources, and participation in decision-making processes.

Drawing from complexity science insights, the framework incorporates dynamic feedback loops that enable continuous learning and adaptation (Awino et al. 2024). These mechanisms operate at different temporal scales, from real-time operational adjustments to long-term strategic reorientation, ensuring that systems remain responsive to changing conditions, emerging challenges, and new opportunities for optimization.

The framework operationalizes integration through *five essential components* that provide concrete mechanisms for health-centred zero waste implementation:

Prevention-First Strategies establish health-protective approaches at the source of waste generation through systematic product redesign, business model innovation, and consumption pattern transformation. These strategies prioritize non-toxic material cycles, durability optimization, and repairability enhancement while incorporating comprehensive health impact assessment throughout product lifecycles (Kirchherr et al. 2022; World Economic Forum 2022). Implementation requires collaboration between manufacturers, healthcare

providers, and regulatory agencies to establish standards that simultaneously optimize health protection and environmental performance (Ellen MacArthur Foundation 2021).

Multi-Barrier Safety Approaches incorporate redundant protections against health and environmental hazards at each stage of the material lifecycle. Drawing from public health risk management frameworks, these approaches establish multiple independent safeguards that prevent system failures from creating unacceptable exposures (Prüss-Ustün et al. 2022). For example, in hospital operating room waste management, a multi-barrier approach would include: (1) source segregation protocols separating infectious from non-infectious materials, (2) redundant containment systems with primary and secondary packaging, (3) automated tracking systems preventing mishandling, (4) multiple treatment stages with backup processing capabilities, and (5) post-treatment monitoring ensuring complete pathogen inactivation before final disposal or recovery processes. In healthcare contexts, this involves integrating infection control protocols with waste management procedures, establishing backup treatment systems, and implementing comprehensive monitoring programs that detect and respond to potential hazard releases (WHO 2022).

Adaptive Feedback systems enable continuous monitoring, evaluation, and adaptation through integration of technical metrics (material flows, contamination rates, treatment efficiency) with social indicators (community satisfaction, health outcomes, economic benefits, worker safety). These systems employ both quantitative measurement protocols and qualitative assessment methods, ensuring that system performance evaluation captures the full range of health, environmental, and social outcomes that characterize effective zero waste implementation (Awino et al. 2024; Maalouf et al. 2025).

Inclusive Governance mechanisms ensure meaningful participation from all stakeholders, particularly those historically marginalized in waste decision-making processes. These mechanisms include formal recognition and integration of informal waste workers, establishment of community oversight boards, implementation of participatory planning processes, and creation of transparent accountability systems (Amugsi et al. 2022; Purvis et al. 2023). Effective governance requires addressing power imbalances, providing capacity-building resources, and establishing decision-making processes that prioritize health equity alongside technical efficiency (Geng & Wu 2020).

Cross-Sectoral Integration platforms connect waste systems with related domains including public health, economic development, education, urban planning, and healthcare delivery. These platforms facilitate coordination across traditionally siloed sectors, enabling identification of synergies, management of trade-offs, and optimization of system-wide outcomes (Ferronato & Torretta 2019). In healthcare settings, integration platforms coordinate waste management with infection control, supply chain management, facility operations, and community health programs (FAO 2024).

2.4. Healthcare and Circular Economy Applications of the Integrated Framework

The integrated theoretical framework demonstrates particular relevance for healthcare environments, where the complexity of infection control requirements, patient safety imperatives, and environmental sustainability goals creates unique implementation challenges. Healthcare waste management operates at the critical intersection of these competing demands, requiring specialized application of the framework's five essential components.

As demonstrated in Table 1, existing healthcare waste management frameworks address specific aspects of the integration challenge, but each exhibits notable limitations when applied independently. The Integrated Infection Control approach eliminates operational silos but requires complex

Table 1. Comparative Analysis of Healthcare Waste Management Theoretical Frameworks
The table offers an overview of major public health and sustainability paradigms over time, indicating for each paradigm its time period, main focus, links to health and equity, typical governance model and key theoretical references.

Theoretical Framework	Core Focus	Risk Approach	Key Implementation Features	Primary Advantages	Notable Limitations
Integrated Infection Control & Waste Management	Unified infection prevention and waste handling systems	Systematic integration across all facility operations	• Systematic integration across all facility operations • Joint staff training protocols • Integrated monitoring systems • Coordinated policy frameworks	• Eliminates operational silos • Enhances facility-wide safety • Streamlines compliance	• Requires organizational restructuring • Complex coordination demands • Potential over-treatment of low-risk streams
Precautionary Principle Application	Maximum safety through presumptive infectious treatment	Universal high-level precautions regardless of confirmed risk	• Standardised protective protocols • Enhanced PPE requirements • Uniform high-level treatment	• Maximises safety margins • Addresses pathogen uncertainty • Simple decision framework	• Potentially inefficient resource use • May inhibit sustainable innovations • Can create an unnecessary operational burden
Tiered Risk Management	Proportionate response based on scientific risk assessment	Evidence-based stratification and targeted interventions	• Multi-level classification systems • Risk-appropriate technologies • Cost-benefit optimization	• Efficient resource allocation • Science-based decision making • Adaptable to emerging challenges	• Requires sophisticated assessment capabilities • Risk of mis-classification errors •Implementation complexity
Circular Healthcare Theory	Resource recovery within strict safety parameters	Balanced sustainability and safety through advanced processing	• Technology-enabled material recovery • Closed-loop system design • Sustainability metrics integration	• Environmental benefits • Economic value creation • Innovation catalyst	• Dependent on emerging technologies • Higher capital investment • Regulatory framework gaps

Source: Authors' elaboration, 2025.

organizational restructuring, while Precautionary Principle Application maximizes safety but may inhibit sustainable innovations. Tiered Risk Management enables efficient resource allocation but faces implementation complexity, and Circular Healthcare Theory offers environmental benefits but depends on emerging technologies with regulatory gaps.

Asian healthcare systems have increasingly adopted integrated approaches combining all five framework components, with several pilot programs reporting significant improvements in waste diversion and cost reduction while maintaining safety standards (Asian Development Bank 2024).

The integrated theoretical framework addresses these limitations by synthesizing the strengths of these approaches while mitigating their individual weaknesses. The Prevention-First Strategies component addresses healthcare-specific needs through implementation of non-toxic procurement policies, reusable medical device programs, and pharmaceutical waste reduction initiatives that maintain strict safety standards. Multi-Barrier Safety Approaches become particularly crucial in healthcare settings, where the framework's redundant protection systems integrate seamlessly with existing infection control protocols while enhancing environmental protection measures.

The framework's Cross-Sectoral Integration Platforms prove especially valuable in healthcare contexts, facilitating coordination between traditionally siloed departments including infection control, environmental services, supply chain management, and clinical operations. This integration enables healthcare facilities to optimize resource flows while maintaining patient safety as the paramount concern, demonstrating how the theoretical framework adapts to sector-specific requirements without compromising its core health-centred principles (WHO 2022; FAO 2024).

Contemporary frameworks now prioritize health-protective material cycle design that establishes non-toxic material cycles as the foundation for circular economy implementation. This approach requires systematic health impact assessment at each stage of material flow, ensuring that circularity does not inadvertently create or perpetuate health risks. The traditional 9Rs framework has been systematically expanded to incorporate health-specific considerations at each intervention level, creating more integrated theoretical approaches that simultaneously optimize health, environmental, and economic outcomes (Kirchherr et al. 2022; World Economic Forum 2022). This reconceptualization represents a fundamental shift from viewing circular economy and public health as separate domains to understanding them as mutually reinforcing components of sustainable systems.

2.5. Implementation Framework and Future Challenges

The framework's practical application is exemplified by European healthcare sustainability initiatives documented in recent EU circular economy reports, where multiple facilities across member states have implemented integrated approaches showing measurable improvements in waste reduction, cost efficiency, and operational safety while maintaining regulatory compliance standards (European Commission 2024).

Based on theoretical analysis, this research proposes a systematic framework for integrating zero waste and circular economy principles into healthcare systems. The framework consists of five interconnected components: organizational readiness assessment, stakeholder engagement protocols, pilot program design, scaling strategies, and continuous improvement mechanisms.

The research identifies several emerging challenges and opportunities for systematic integration. Regulatory harmonization represents a critical challenge, as current healthcare regulations were developed for linear economic models and may not accommodate circular economy innovations. Technology integration opportunities offer significant potential through digital health technologies, artificial intelligence, and Internet of Things applications that can optimize resource flows while maintaining patient safety and data security. Future success will require sustained commitment from healthcare leaders, ongoing stakeholder collaboration, and continued research to refine integration approaches.

3. Limitations and Future Research Directions

Several limitations must be acknowledged. Analysis predominantly examined frameworks from European and North American healthcare systems, with limited

representation from emerging economy healthcare contexts where resource constraints and informal sector participation create different implementation challenge potentially limiting transferability to healthcare systems with different resource constraints and regulatory environments. The CSR methodology prioritized theoretical framework synthesis over exhaustive literature coverage, focusing on conceptual integration rather than comprehensive empirical review. Additionally, the rapid evolution of theoretical frameworks, particularly since 2020, means some emerging approaches may not yet have sufficient empirical validation to assess practical effectiveness.

Future research should prioritize empirical validation of integrated theoretical models across diverse healthcare settings and cultural contexts. Longitudinal studies examining health, environmental, and social outcomes associated with different implementation approaches would strengthen the evidence base supporting policy development and organizational decision-making processes. Integration of digital technologies including AI-enabled monitoring systems and IoT-based tracking represents an emerging area for framework application. Critical gaps remain in adaptive governance theories for rapidly evolving waste contexts, theoretical integration of emerging digital technologies, and incorporation of diverse cross-cultural perspectives beyond Western conceptualizations.

Conclusion

This comprehensive examination reveals the fundamental transformation of zero waste frameworks from disposal-focused approaches to health-centred systems that integrate environmental sustainability and social equity. The proposed Integrated Theoretical Framework addresses critical gaps in existing models by providing concrete mechanisms for implementing health-protective zero waste systems through Prevention-First Strategies, Multi-Barrier Safety Approaches, Adaptive Feedback systems, Inclusive Governance, and Cross-Sectoral Integration. The framework's particular relevance to healthcare contexts demonstrates how theoretical integration can guide practical implementation while maintaining safety as the paramount concern. This work establishes robust foundations for developing resilient zero waste systems that prioritize public health protection while advancing broader sustainability objectives, offering both theoretical coherence and practical guidance for policy makers, healthcare administrators, and waste management practitioners.

The integrated theoretical understanding moves beyond siloed approaches to waste management, offering a comprehensive framework that recognizes complex interdependencies within waste systems and their broader societal implications. Future theoretical development should prioritize integrated assessment methodologies that evaluate synergies and trade-offs across multiple dimensions simultaneously, while establishing more robust causal frameworks linking specific zero waste interventions to measurable health outcomes. Addressing these theoretical gaps will strengthen the foundation for developing more effective, equitable, and resilient zero waste systems that prioritize public health while advancing environmental sustainability and social wellbeing.

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Appendix 1

Supporting Data for From Waste to Health: Integrating Zero Waste and Circular Economy Principles in Healthcare Sustainability.

Table A1. Theoretical Comparison of Waste Management Paradigms.
The table compares several theoretical frameworks used in environmental and public health policy, showing their main focus, how they approach risk and implementation, and the most important advantages and limitations of each framework.

Paradigm	Period	Primary Focus	Public Health Integration	Environmental Considerations	Social Equity Components	Governance Model	Key Theoretical References
Traditional Waste Management	Pre-1990s	End-of-pipe disposal; Pollution control	Reactive; Focus on immediate exposure risks	Limited to pollution control;	Minimal; Often reinforces inequitable distribution of waste burdens	Centralized; Technical; Expert-driven	Hoornweg & Bhada-Tata 2012; Chen et al. 2020
Integrated Solid Waste Management	1990s-2000s	Hierarchy of preferred options (reduce, reuse, recycle, recover, dispose)	Partial; Considered in facility siting and operations	Resource conservation; Emissions reduction	Limited; Some consideration of facility siting equity	Coordinated public-private systems; Limited public participation	Marshall & Farahbakhsh 2013; Sidique et al. 2021
Zero Waste 1.0	2000s-2010s	Diversion from disposal; High recycling rates	Secondary consideration: Focus on toxic reduction	Central focus: Material conservation; Emissions reduction	Informal sector recognition	Mixed models; Increased stakeholder involvement	Zaman 2022; Halfman 2020
Circular Economy	2010s-2020	Material value retention; System redesign	Variable; Often secondary to resource efficiency	Emphasised; Decoupling growth from resource use	Limited; Primarily focused on business models	Market-driven with policy supports; Private sector leadership	Kirchherr et al. 2022; Morseletto 2020
Public Health-Centred Zero Waste	2020-2023	Disease prevention, Toxic reduction, Health promotion	Central organising principle; Primary consideration	Integrated, recognised as a prerequisite for health	Strong, Health equity as a central component	Collaborative; Multi-sectoral; Community engaged	Ellen MacArthur Foundation 2021; UNEP 2023
Holistic Zero Waste Systems	2023-Present	Integration of health, environmental, and social objectives	Fully integrated; Occupational and community health frameworks applied	Systems perspective: Climate, biodiversity, and resource considerations	Integral, Just transitions, Equitable distribution of benefits	Participatory; Adaptive; Multi-level integration	Purvis et al. 2023; Maalouf et al. 2025; Awino et al. 2024

Source: Authors' elaboration, 2025.Source: Authors' elaboration, 2025.