Adopting Circular Economy Models for Healthcare Waste Management: Issues and Prospects in Saudi Arabia

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Received: April 12, 2025 Accepted: May 11, 2025 Online Published: May 14, 2025

doi:10.5430/ijfr.v16n2p44 URL: https://doi.org/10.5430/ijfr.v16n2p44

Abstract

The current research explores key determinants of the uptake of circular economy (CE) principles in healthcare waste management in Saudi Arabian healthcare facilities. Data were collected using a mixed-method exploratory research strategy from 165 respondents including healthcare practitioners, waste management professionals, and regulatory officials. Findings show that the key challenges to CE adoption are infrastructural constraints, poor regulatory enforcement, financial constraints, and technological integration limitations. Though awareness of CE principles is present, actual application is low, particularly in rural or small facilities. Smart waste monitoring, automated segregation, and policy-based incentives were identified as main enablers by the participants. Saudi Arabia's Vision 2030 was considered to be promising for sustainable waste management strategies, although gaps exist in local implementation and institutional preparedness. This study contributes new findings to the intersection of healthcare sustainability, national policy, and environmental conservation in Saudi Arabia.

Keywords: CE, healthcare, recycling, healthcare waste management

1. Introduction

1.1 Background

The Circular Economy (CE) idea has been a sustainable alternative to the traditional linear economy "take-make-waste" model. CE is focused on minimizing waste through reuse, recycling, and efficiency in use of resources, keeping materials within the economic loop for as long as possible (Velenturf & Purnell, 2021). Saudi Arabia, through its Vision 2030 initiative, is seeking innovative solutions for environmental sustainability across sectors, including healthcare, where increasing service demands generate significant medical waste requiring sustainable management approaches.

Medical waste consists of hazardous wastes (pharmaceutical residues, chemicals, sharps), infectious wastes (used gauze bandages, gloves, laboratory cultures), and non-hazardous wastes (administrative documents, packaging materials). Even though Saudi Arabia's waste management sector is being transformed into more sustainable alternatives under Vision 2030, areas of deficiency continue to exist such as inadequate infrastructure, poor regulatory enforcement, and small-scale recycling facilities in healthcare.

The National Center for Waste Management and the Saudi Investment Recycling Company (SIRC) are at the forefront of policy and infrastructure development that supports sustainable waste disposal. Implementation of circular economy in healthcare waste management is in its infancy, yet there is a need for more investment, policy-making, and stakeholder participation.

1.2 Problem Statement

Although Saudi Arabia's health sector has more focus on environmental conservation, its healthcare sector cannot utilize circular economy approaches in managing its wastes. It lacks waste segregation, recycling, and reduction facilities in its current systems. Effective implementation is also hindered by the absence of programmatic recycling, weak regulatory enforcement, and low levels of financial and technological investment. These unsustainable approaches are responsible for pollution and natural resource depletion through incineration and landfilling.

Healthcare facilities incur increased overhead costs due to mismanagement of waste, while inefficient collection, transportation, and disposal entail considerable environmental risks. Almubarak et al. (2024) add that improper segregation of waste and inadequate government-healthcare sector coordination also exacerbate these challenges. These challenges call for critical review of existing waste management systems and exploration of potential circular economy approaches for Saudi Arabian healthcare facilities.

The paper analyzes determinants discouraging the adoption of circular economy in healthcare waste management practice. Based on an assessment of policy gaps and current recycling efforts, the work aims at building the foundations upon which sustainable waste management programs could be established for Saudi Arabia's healthcare environment.

1.3 Research Questions

This study addresses three primary research questions:

1. How is waste managed in Saudi Arabian healthcare facilities?
2. What are the primary obstacles to implementing a circular economy in healthcare waste management?
3. What is the impact of policies and regulations on achieving sustainable waste management?

1.4 Research Objectives

The research objectives include:

- Exploring current healthcare waste management practices in Saudi Arabia and identifying challenges associated with traditional linear systems
- Evaluating the applicability of circular economy principles in healthcare waste management, focusing on waste minimization, recycling, and material recovery
- Analyzing regulatory frameworks influencing healthcare waste management and their alignment with Vision 2030 sustainability goals
- Examining technological innovations for improving healthcare waste segregation and traceability
- Identifying barriers and opportunities in adopting circular economy approaches within Saudi healthcare facilities

1.5 Significance of the Study

This research offers critical contributions both in theory and in application. This research brings forth new information to the academic world about sustainable healthcare and circular economy models, namely among the little-studied Gulf and MENA regions. Evidence-based data about sustainable practices of waste management can be learned by policymakers, healthcare managers, and environmental officers. This research is in response to Saudi Arabia's Vision 2030 goal of environmental preservation as it prepares the country towards economic reform. Through the identification of emerging technologies, effective policy regimes, and institutional reform needed, this study contributes to greater public health gains, environmental sustainability, and resource efficiency for Saudi Arabia's evolving healthcare sector.

2. Literature Review

2.1 Circular Economy and Healthcare Waste Management

The circular economy maximizes resource use by minimizing waste and maximizing material lifecycles. While CE application in healthcare has the potential to maximize economic productivity while reducing environmental impacts (Alturif et al., 2024), previous studies have mostly focused on developed economies with mature waste management infrastructure. Previous studies have not fully investigated the unique challenges of developing economies, particularly in healthcare systems characterized by varying levels of technological maturity and regulatory adherence.

Abdulaziz and Al-Saidi (2023) contend that Saudi Arabia is able to optimize circular economy approaches by implementing more effective waste management practices. However, none of their research, along with most published literature, has operational application frameworks adapted for use in healthcare settings. Perhaps one of the biggest areas of research shortfalls is understanding how closed-loop systems - where medical goods and equipment are redirected back into supply chains for recycling - can be practically implemented on existing Saudi healthcare facilities. This study bridges this gap by speaking to both conceptual ideas and challenge issues in practice simultaneously.

2.2 Waste Management in Healthcare

Previous research on segregation of waste, recycling, and purchasing behavior has revealed improved performance in hospital waste management in circular economy settings (Almulhim & Al-Saidi, 2023). Such research frequently, however, does not cover operational aspects unique to healthcare settings, such as infection control practices that might be incompatible with recycling objectives. Though there are uneven healthcare experiences offered by European and North American systems to learn from Saudi Arabia, adoption of their models directly without local adaptation has proved challenging in numerous implementation attempts.

Literature has established that training in segregation of waste within the hospital setting is critical to effective circular economy strategies, where compliant and trained facilities have greater material recovery and reuse and less landfilling loads (Aldhafeeri & Alhazmi, 2022). Existing literature fails to take into account how training programs are sustained in high-turnover healthcare environments or recognized in existing professional development systems. Similarly, while other studies by Almadhi et al. (2023) highlight the application of recyclable and biodegradable medical packages in demonstrating sustainability benefits, they do not reflect on the costing elements and supply chain adjustments for their mass-scale application in low-resource settings. This study adds to the shortcomings by involving operational, costing, and system perspectives.

2.3 Healthcare Waste Management in GCC and MENA Regions

The countries of the GCC generate over 150 tons of medical waste daily, with Saudi Arabia contributing as much as 80 tons alone. This large amount needs robust healthcare waste management facilities (Hadhrami, n.d.). While previous studies have also documented these volumes, they typically have not addressed implications for facility-level management processes or resource planning. Waste management problems in the MENA region are complex because of population growth, modernization in healthcare, and political instability, yet regional analyses have remained more descriptive than prescriptive.

A number of threats have been documented in the literature, such as a lack of facilities for the safe disposal of waste, environmental contamination, political instability promoting improper disposal of waste, and a lack of sufficient laws and monitoring capacity (Wassie et al., 2022). Most studies, though, have considered these issues individually instead of being treated as interrelated systemic challenges. Such fragmentation has constrained the formulation of holistic solutions that can tackle several challenges concurrently.

Though there have been reports of improvement initiatives - such as the implementation of clinical audits within Iran, which improved adherence to waste management policy by 30% (Wassie et al., 2022), and backing from the WHO Regional Centre for Environmental Health Action - these case studies rarely address transferability conditions or implementation requirements. This research addresses these shortcomings by exploring effective interventions in the specific Saudi Arabian institutional, cultural, and infrastructural environment, leading to a more complete image than has been available previously.

2.4 Policy Framework and Implementation Barriers

Regulatory frameworks play a pivotal role in adopting circular economy concepts in healthcare waste management. The positive influence of Saudi Vision 2030 sustainability objectives on green waste management practice has been affirmed in earlier research, yet regulatory control and incentives are at issue (Aldhafeeri & Alhazmi, 2022). The primary gap in existing research is that policy development and implementation mechanisms have no connection. Non-standardized waste categorization standards across facilities have been quoted by research as undermining segregation and recycling but have largely stopped short of proposing viable standardization models that address various facility types and sizes.

Although implementation obstacles like insufficient awareness among health professionals, resistance to change, no budget allocation, infrastructural shortcomings, and few recycling facilities have been well reported (Jie et al., 2023), research has primarily focused on identifying but not on overcoming these obstacles. Few studies have examined effective solutions for overcoming obstacles or development of implementation models in light of constrained resources. The study extends beyond the identification of barriers in exploring strategic solutions for overcoming implementation hurdles through participatory investments that synergize resources towards the development of effective waste management systems (Youssef & Mostafa, 2022). Contrary to current literature, the study fills theoretical frameworks and pragmatic implementation plans that are applicable in Saudi Arabia's distinct healthcare context.

3. Methodology

3.1 Research Design

This study employed a mixed-method exploratory method of investigation in examining circular economy uptake in healthcare waste management across Saudi Arabian facilities. A 165-sample participant population of healthcare professionals, waste management specialists, and regulatory authorities across public and private facilities was sent a guided questionnaire.

3.2 Sampling Technique and Data Collection

Stratified random sampling offered representation by regions and types of healthcare. Both qualitative and quantitative data were collected using the survey of waste management practices, awareness of circular economy, implementation barriers, perceived benefits, and recommendations for improvement. Online data collection was carried out using hard copies where appropriate following a pilot study to validate the tool.

3.3 Data Analysis

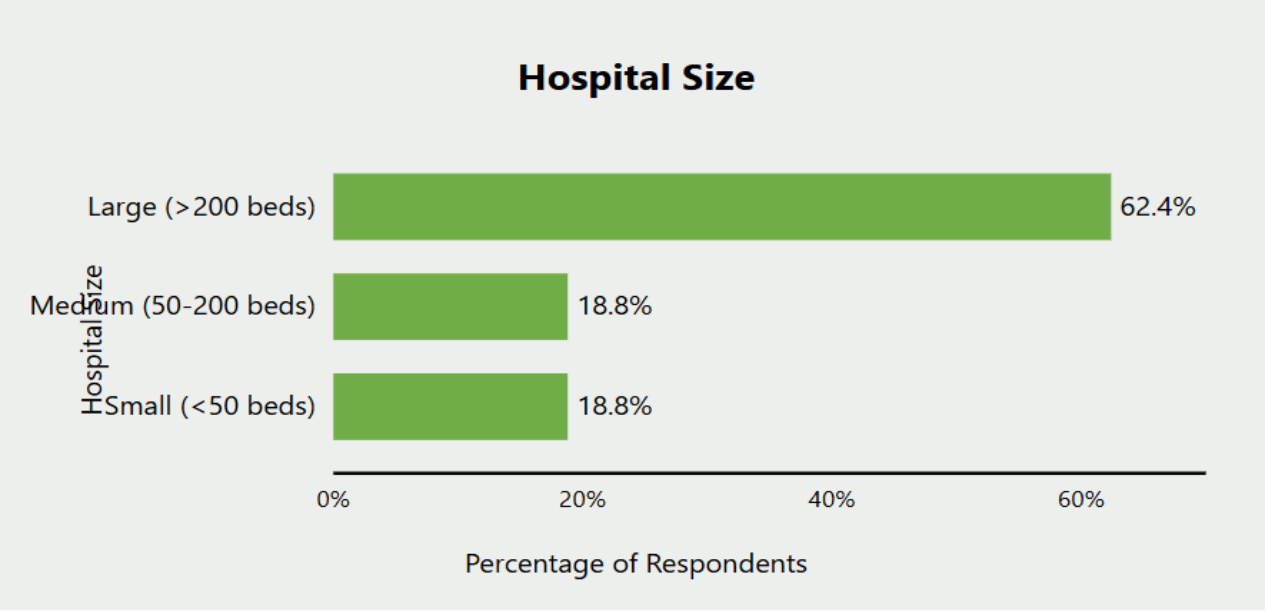
Quantitative data were analyzed using descriptive statistics (means, standard deviations, frequencies) and inferential statistics. Qualitative responses were analyzed using thematic analysis to identify patterns, attitudes, and challenges towards adoption of CE. This mixed approach provided in-depth insights into what currently exists and what potentially could be in the future of circular economy application in Saudi Arabian healthcare waste management.

4. Results and Findings

4.1 Demographics and Facility Characteristics

A total of 165 respondents took part in the study, with healthcare professionals making up 68.5% of those responding. Hospital administrators were the next largest group, supplying vital management input regarding waste management procedures and policies. Waste management workers, regulatory personnel, and other healthcare professionals made up the other participants.

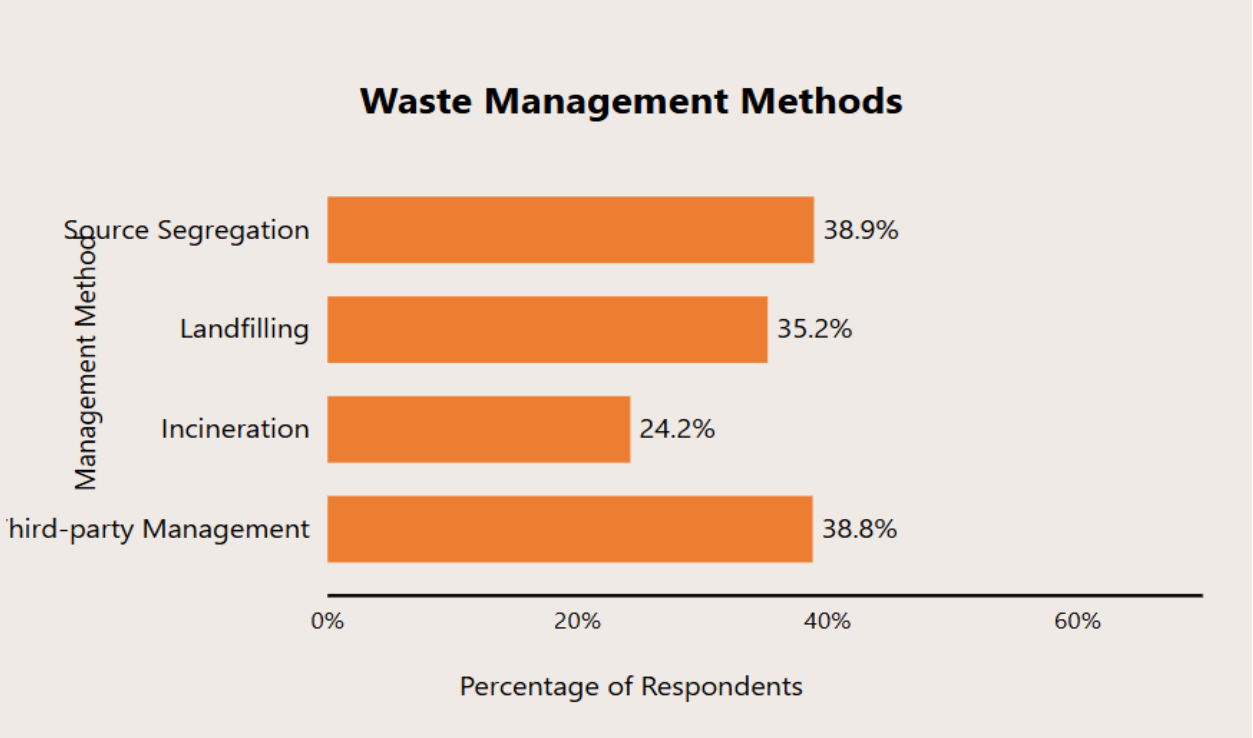
Most of the participants (60.6%) were from public hospitals, followed by specialized medical centers (14.5%), private hospitals (12.7%), and primary healthcare centers (8.5%). Hospitals with a capacity of more than 200 beds accounted for 62.4% of responses, and medium-sized hospitals (50-200 beds) accounted for 18.8%, with smaller hospitals accounting for the remaining portion. A majority (91.5%) of the hospitals were located in urban areas.



4.2 Current Waste Management Practices

The study revealed dissimilar healthcare facility waste management practices. Source segregation was practiced by 38.9% of facilities, while incineration (24.2%) and landfilling (35.2%) were also practiced despite their

environmental impacts. Recycling activities were observed by 28.5% of respondents, while 38.8% of facilities subcontracted waste management to third-party operators.



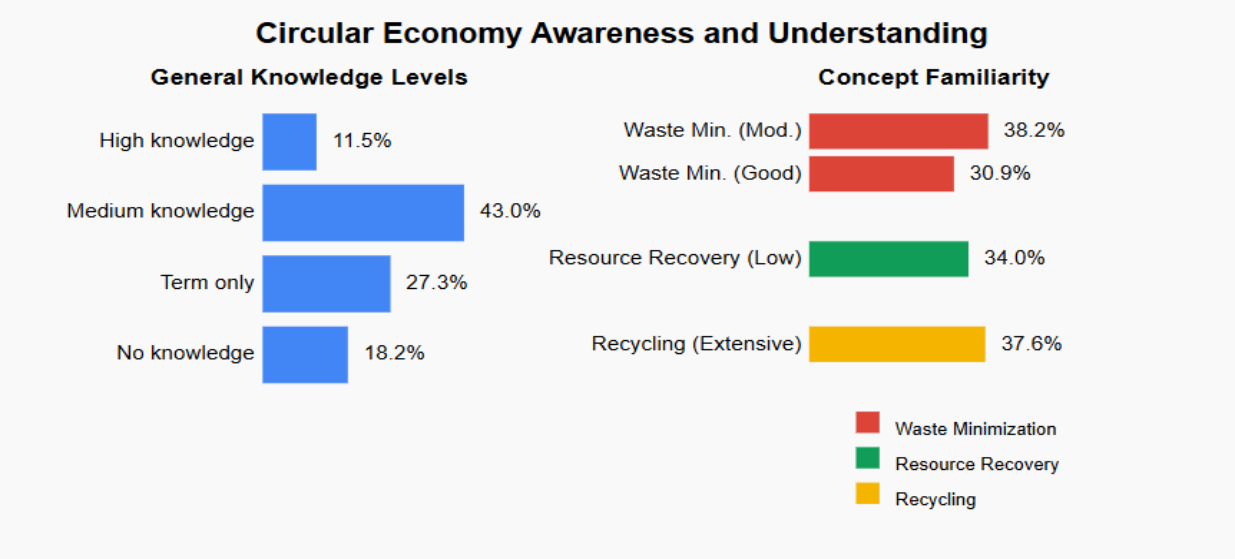
The health facilities generated a number of different wastes, the most common being general non-hazardous waste (73.9%), followed by sharps (66.7%) and infectious waste (61.8%). Pharmaceutical waste (49.1%), chemical waste (47.9%), and radioactive waste (34.5%) were also significant components of the waste stream.

For waste segregation, color-coded bins (62.4%) and labeled containers (60%) were most commonly used. However, 13.3% of the respondents reported no waste segregation activities in their establishments, which is a concern for the potential of improper hazardous waste treatment.

4.3 Circular Economy Principles Awareness and Understanding

Circular economy concept knowledge among the participants varied greatly. Only 11.5% had high-level knowledge, while 43% reported medium-level knowledge. The remaining participants either knew the term but did not have any specific knowledge (27.3%) or had no knowledge at all (18.2%).

Familiarity with specific circular economy notions differed. For waste minimization, 38.2% responded with moderate knowledge (level 3) and 30.9% with good knowledge (level 4). Notions of resource recovery were poorly known, with 34% evaluating their knowledge at the lower levels (1-2). Recycling notions were better known, with 37.6% describing extensive knowledge (level 5).

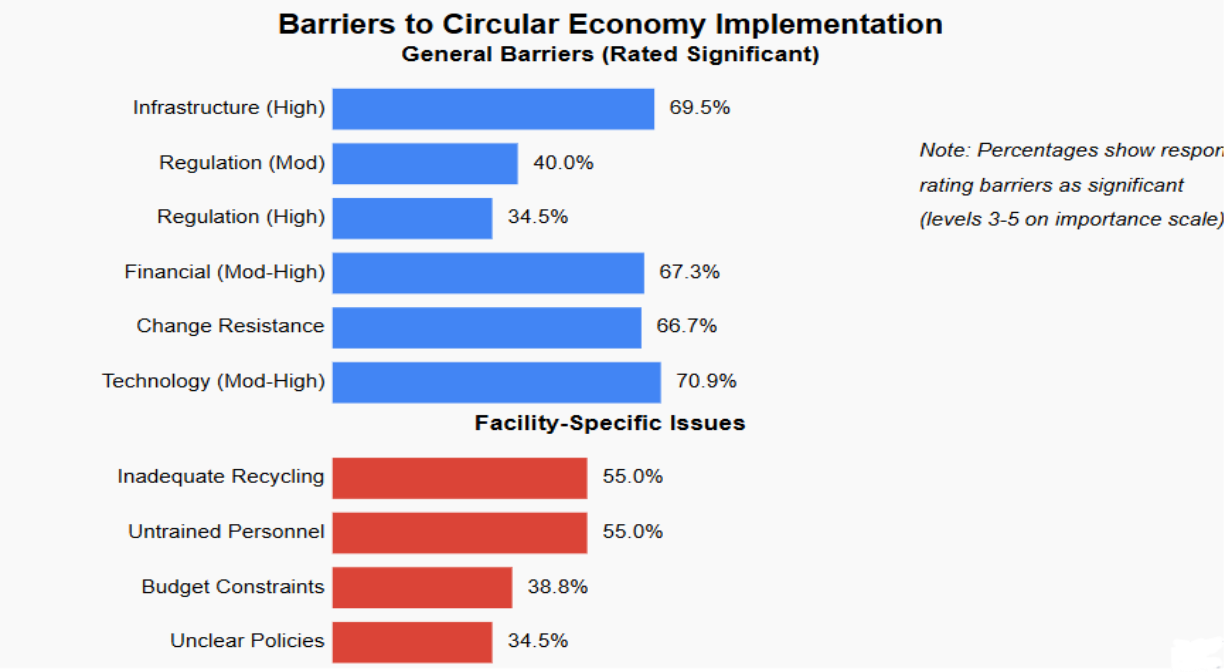


4.4 Barriers to Circular Economy Implementation

Participants identified several significant barriers to implementing circular economy principles in healthcare waste management:

1. Infrastructure limitations: Rated as important by 69.5% of respondents (levels 4-5)
2. Regulatory enforcement: Considered significant by 40% (level 3) and 34.5% (level 4)
3. Financial constraints: Identified as a major obstacle by 67.3% (levels 3-4)
4. Resistance to change: Rated as moderate to significant by 66.7% (levels 3-4)
5. Technological limitations: Considered significant by 70.9% (levels 3-4)

Upon being questioned regarding facility-specific issues, respondents pointed to inadequate recycling facilities (55%), untrained personnel (55%), budget constraints (38.8%), and unclear policies (34.5%) as major hurdles.

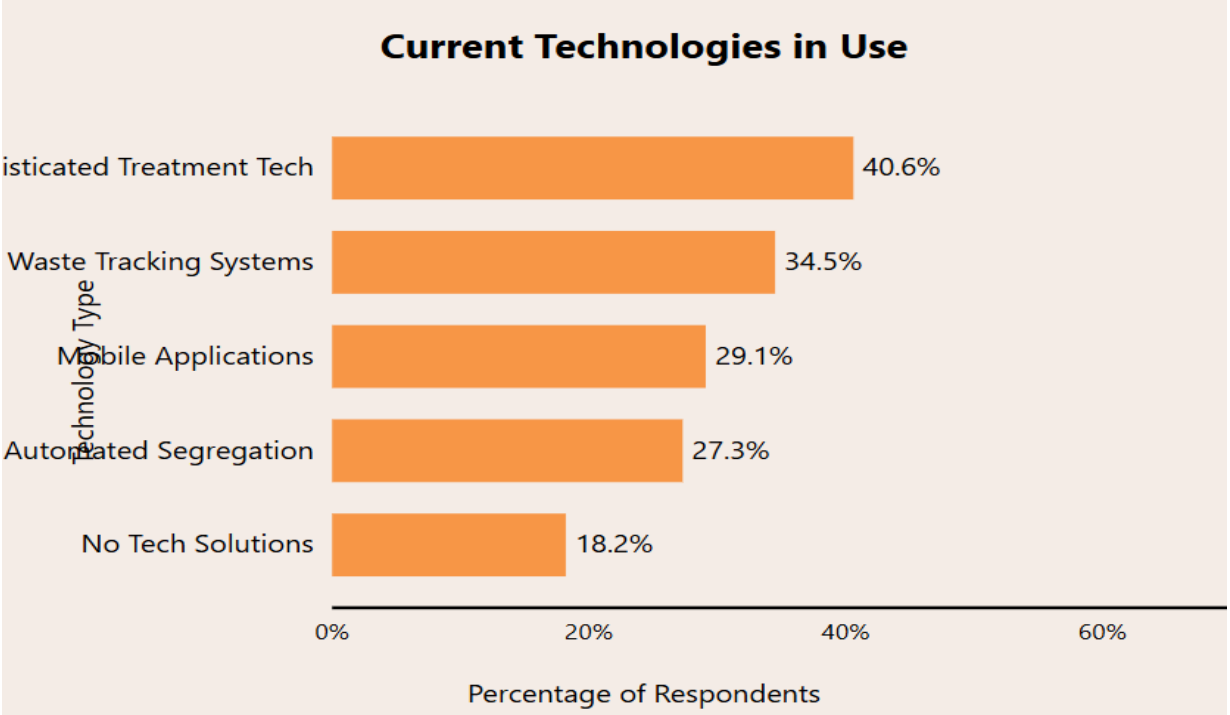


4.5 Policy and Regulatory Environment

The majority of the respondents (55.2%) indicated average familiarity with waste management regulations in Saudi Arabia, whereas 32.7% admitted limited familiarity. A mere 12.1% indicated complete familiarity with applicable regulations.

In terms of facility-specific policies, 33.3% reported extensive coverage and 29.1% reported limited scope. But 12.1% reported that no specific policies existed in their facilities and 25.5% were not sure if any policies existed, indicating a disconcerting lack of guidance and standardization.

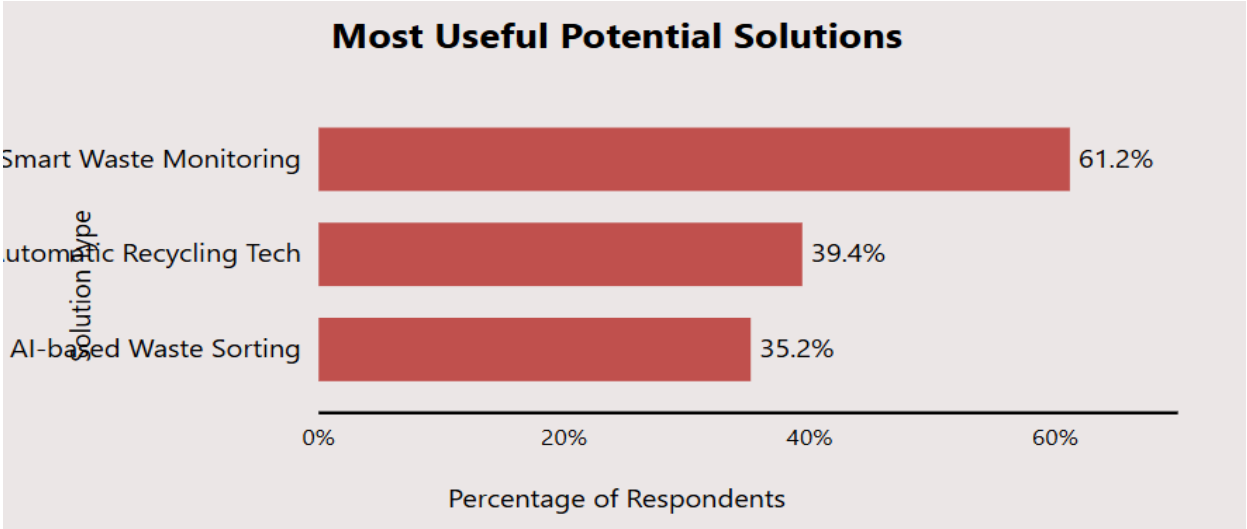
Current legislation was rated as moderately effective in promoting sustainable waste management, and 77.6% of them employed middle ratings (3-4). On the front of policy reform that is most desirable, mandatory segregation of waste with auditing (58.2%), extended producer responsibility (40.6%), and economic incentives (40%) emerged as most critical.



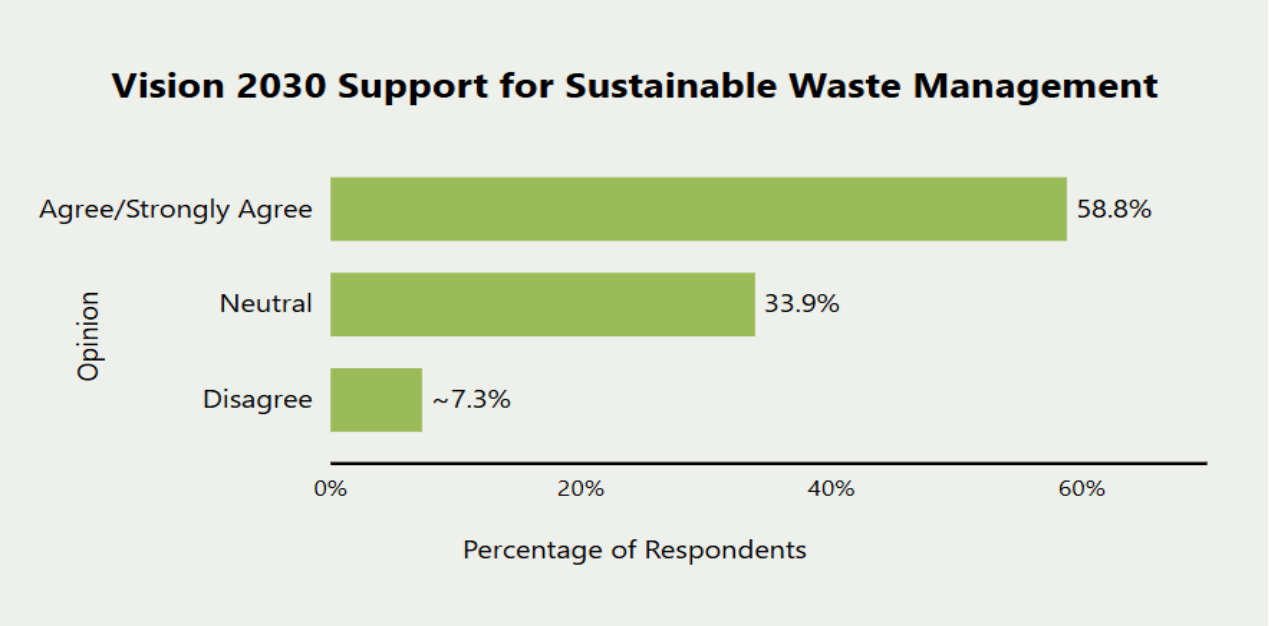
4.6 Technological Solutions and Vision 2030

Most commonly used technological solutions in healthcare facilities were sophisticated treatment technologies (40.6%) and waste tracking systems (34.5%). Mobile applications (29.1%) and automated segregation (27.3%) were used less, and 18.2% of the facilities had not adopted any technological solutions.

Respondents named smart waste monitoring (61.2%), automatic recycling technologies (39.4%), and AI-based waste sorting technologies (35.2%) as the most useful potential solutions to implement circular economy principles. Most of the respondents (64.8%) believed that technological advancements could play a significant or moderate role in enhancing healthcare waste management.



As for Vision 2030, 58.8% of respondents said that they agree or strongly agree it supports good sustainable waste management practice adequately, with 33.9% feeling neutral and potentially indicating a lack of local application or information.



5. Discussion and Recommendations

5.1 Discussion

The results indicate a transitioning healthcare industry in the adoption of circular economy principles. There is awareness, but operational adoption is constrained by various issues. The commonality of conventional methods of waste disposal (landfilling and incineration) and nascent recycling operations clearly indicates this transitional phase, which stands in stark contrast to cutting-edge applications in European health systems outlined by Almulhim & Al-Saidi (2023).

Unlike existing studies that were either concentrating on policy frameworks by themselves or operational challenges by themselves, this research reveals the key merging of the two. Although infrastructure issues, financial deficits, and

loopholes in regulations were the stark challenges, the work of Jie et al. (2023) on implementation barriers was corroborated since our research gives a measurable indication of how much each of the barriers within the Saudi context counted comparatively. While Almubarak et al. (2024) had identified inappropriate waste segregation and poor coordination between the government and healthcare sector as major challenges, our study specifically illustrates how these elements particularly hinder circular economy adoption as opposed to waste management in general.

The intense urban bias in medical facilities suggests radical disparities in health care waste management capacities between the urban and rural environments. Such rural-urban divide has persisted as under-researched within Saudi Arabian research on health care waste management but emerges as an essential problem calling for set rural development policies – a pioneering discovery providing insight into implementation issues at a spatial level.

The supportive attitude towards Vision 2030 indicates a promise of policy-level change, but widespread knowledge gaps about individual regulations recognize a key communication divide between national policy formulation and facility-level practice. This finding draws on Aldhafeeri and Alhazmi's (2022) recommendation on regulatory control challenges by introducing specific information flows that must be improved to translate national frameworks into local practice.

Our discovery that technological solutions – especially smart monitoring and autonomous systems – are considered promising facilitators for circular economy uptake is an improvement over previous research that concentrated mainly on regulatory strategies. The low existing use of these technologies revealed in our research indicates a particular investment and development opportunity that has not been previously measured in the Saudi healthcare environment.

5.2 Recommendations

Based on our findings and their relationship to existing research gaps, this study recommends:

1. Policy Making and Implementation: Strengthen the national waste management policy through clear-cut frameworks embracing circular economy practices for both private and public healthcare systems. Standardize waste classification and render segregation compulsory with regular audits.
2. Capacity Development: Develop comprehensive training modules and workshops to ensure better understanding and application of circular economy principles by health practitioners and waste management staff.
3. Investment in Infrastructure: Construct the recycling infrastructure, waste sterilization technology, and waste-to-energy systems specific to healthcare institutional requirements, with emphasis on rural facilities.
4. Public Initiatives: Form initiatives alongside government departments, employing private sector firms to adopt best practices, innovations, and scale-up successful pilot projects.
5. Analyses: Develop people and industry-wide tracking circular economy monitoring frameworks to hold the entire health sector accountable.
6. Integration of Technologies: Integrate advanced monitoring and automated segregation tracking systems, provide AI-driven healthcare waste management solutions, and improve efficiency along with identifiability.

6. Conclusion

This study has placed important scrutiny on the current situation of healthcare waste management in Saudi Arabia and the way forward to embracing the circular economy. With a clear understanding of practice, enablers, and barriers from this research, we have identified the most significant areas of change to deliver the Vision 2030 sustainability targets in Saudi Arabia. Contrary to previous studies that have either concentrated on theoretical models or isolated operational concerns, our study bridges the gap between practice and theory by outlining specific implementation paths tailored to Saudi Arabia's unique healthcare context.

Our findings show that while there is recognition of circular economy principles among practitioners, their implementation is hampered by infrastructure limitations, knowledge gaps, cost constraints, and regulatory problems. The contrast between urban and rural facilities is a very important finding that has not been adequately addressed in the literature. Similarly, our identification of specific technological solutions that are seen as useful by practitioners provides concrete advice for future investments.

The transition from conventional waste management processes to circular economy approaches in Saudi Arabian healthcare requires coordinated efforts across policy, infrastructure, technology, and human resource development.

With the implementation of the recommendations presented in this study, Saudi Arabia can propel its sustainability agenda while improving healthcare waste management effectiveness and reducing environmental impacts.

Future research must aim to develop and pilot specific implementation models for the implementation of circular economy in healthcare settings, quantify the economic and environmental worth of different circular approaches, and test transferability to the Saudi environment of successful international models. Longitudinal research with follow-up intervals assessing the impact of Vision 2030 interventions on healthcare waste management practices would also provide valuable information regarding policy performance in the long run**.**

Acknowledgments

We greatly appreciate the valuable contributions of Saudi Electronic university advisory committee members. We would also like to thank the all the respundants and every member who took the time to participate in this study.

Authors' contributions

Sample: Dr. Saad Mohammed Alnefaee was responsible for study design and revising. Mr. Omar Alshamri was responsible for data collection and drafting the manuscript and Dr. Saad Mohammed Alnefaee revised it. All authors read and approved the final manuscript.

Competing interests

I herby declare that I don't have known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Sciedu Press.

The journal and publisher adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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