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STAFF AWARENESS OF MEDICAL WASTE MANAGEMENT AND ITS IMPACT ON ENVIRONMENTAL PERFORMANCE IN HOSPITALS IN SAUDI ARABIA

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Abstract. The research investigates the impact of staff awareness of medical waste management on environmental performance in hospitals in the Kingdom of Saudi Arabia. The study conceptualises staff awareness through four dimensions: concept and risk awareness, procedural awareness, safety and responsibility awareness, and organisational awareness. Hospital environmental performance is examined across four dimensions: internal environmental cleanliness, pollution and risk reduction, waste-handling efficiency, and environmental compliance and improvement. A quantitative cross-sectional survey design was adopted. Data were collected from 384 employees working in selected Saudi hospitals, including physicians, nurses, laboratory staff, pharmacists, technicians, housekeeping staff, environmental services workers, and administrative employees. The data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM) through SmartPLS. The measurement model confirmed adequate reliability, convergent validity, and discriminant validity. The structural model results showed that all four dimensions of staff awareness had positive and statistically significant effects on the dimensions of hospital environmental performance. Concept and risk awareness had their strongest effect on internal environmental cleanliness. Procedural awareness was the strongest predictor of pollution and risk reduction, as well as waste handling efficiency. Safety and responsibility awareness showed consistent positive effects across all environmental performance dimensions. Organisational awareness had the strongest effect on environmental compliance and improvement. The findings confirm that staff awareness is not merely an informational factor but an important organisational capability that supports cleaner, safer, more efficient, and more compliant hospital waste-management practices. The study contributes theoretically by integrating staff awareness and hospital environmental performance into one explanatory model. Practically, it highlights the need for continuous role-based training, clear procedures, visible supervision, organisational communication, and shared responsibility among all hospital staff.

Keywords: staff awareness; medical waste management; environmental performance; hospitals; Saudi Arabia; waste handling efficiency; environmental compliance

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1. Introduction

Background

Hospitals provide critical services for safeguarding human health while creating significant environmental impacts due to their high consumption of resources to deliver services continuously, use of chemicals, release of wastewater, consumption of energy, the creation of medical waste (both hazardous and non-hazardous), and the generation of numerous categories of other types of waste. Medical waste is particularly significant because it may include infectious waste, sharps, pathological waste, pharmaceutical waste, chemical waste, and

contaminated items that cannot be safely reused or recycled. Although most medical waste has been determined to be similar in nature to household (domestic) waste according to the World Health Organisation (WHO), the hazardous portions of the waste must be carefully separated from regular (non-hazardous) waste, and stored, transported, and treated safely to prevent harm to human health or the environment (WHO, 2014). Thus, identifying, separating, handling, and managing waste from the moment it is generated are all part of ensuring these two responsibilities can be satisfied.

Recent literature confirms that the environmental burden of healthcare waste is increasing globally across countries and health systems. In Taiwan, the amount of medical waste continued to rise steadily between 2016 and 2019, with infectious waste accounting for the largest fraction (Tsai, 2021; Kaposi et al., 2024). Consistent with our results, Khoshnevis et al. (2024) also reported a time-dependent increase in total hospital waste and hazardous healthcare waste generation in a university hospital, along with their association with intensive clinical activities, including surgical specialties, anaesthesiology, emergency care, and healthcare-associated infections. These results indicate that hospital ambient performance is not separate from clinical administration, infection-control methods, and staff behaviour.

Hospital waste systems are also susceptible to operational shocks, as accentuated during the COVID-19 pandemic. Wearables such as masks, gloves, face shields, and plastic-made testing materials are another growing sector of single-use protective items that increase pressure on waste management systems. Although most of the waste generated in hospitals is non-hazardous with proper segregation, Lee and Lee (2022) reported that healthcare institutions were not immune to environmental challenges, as healthcare workers widely use disposable products to minimise infection risk. That is important because poor segregation can turn recyclable materials and general waste into hazardous waste: treatment costs rise, and emissions and environmental risks increase. Thus, proper medical waste management is a strategic environmental issue and not just a technical housekeeping activity.

In this context, staff awareness is a key building block of hospital environmental performance. Awareness does not mean being aware of what medical waste is alone; it means understanding the levels of risk, correctly segregating procedures and colour-coding systems, knowing your responsibilities and those of your institution, and complying with institutional rules on waste management. According to a study conducted in Saudi Arabia (Thirunavukkarasu et al., 2022), there were significant differences in the knowledge, attitude and practice of biomedical waste management among the healthcare workers studied, with only 50% achieving high practice scores. This indicates that while there are both regulations and facilities in place for the management of biomedical waste, the ultimate environmental outcome will be directly related to the level of awareness among all staff regarding proper disposal methods and whether this awareness translates into their day-to-day behaviour.

The dimensions outlined in this document have been addressed to a large degree by various forms of empirical research. For example, Miamiliotis and Talias (2024) found that healthcare workers at Nicosia General Hospital had moderate familiarity with the disposal of infectious medical waste and good familiarity with the practice of segregating infectious waste. Thus, it was not surprising to find that a significant amount of infectious waste had been reported as mixed with non-hazardous waste. Their research also provided a major indication of the disconnect between knowledge and action, specifically regarding colour coding and the physical act of separating the two types of waste. Bizuneh et al. (2024) A study conducted by Bizuneh et al. (2024) found that only 20.8 per cent of respondents reported having good behaviour. Still, they had an average of 66.2 per cent of respondents reporting good knowledge and 86.9 per cent demonstrating a positive attitude toward their work. Both studies highlight the need for continuous staff education, the establishment of consistent guidelines, the implementation of staff monitoring systems, and management's follow-up with staff members to improve hospital environmental performance beyond just a positive attitude towards their work.

Staff awareness of waste management is particularly relevant for non-clinical and support staff. Millanzi et al. (2023) found that sanitary workers had not received adequate education on the proper handling of Healthcare Waste and that many believed they had no responsibility for handling the waste. These results raise an important issue because sanitary workers, cleaners, and waste handlers typically have the most direct contact with waste

after it has been removed from a patient by the clinical staff. The absence of these groups from environmental communication and/or training may prevent hospitals from properly maintaining internal cleanliness, facilitating efficient waste transport and preventing pollution. This study will categorise staff awareness as a hospital-wide capability that encompasses clinical, non-clinical, technical, administrative, and support staff members.

Environmental performance in hospitals refers to the extent to which a hospital's operations harm the environment while still providing safe and effective medical services. When we think of environmental performance in terms of medical waste, it encompasses factors such as the cleanliness of the hospital's internal environment, efforts to reduce pollution and risk, the efficiency of waste handling, compliance with environmental regulations, and continual improvement. These measures are part of the growing trend towards "green" and sustainable healthcare, where hospitals strive to reduce their overall emissions through improved waste separation, reducing the inappropriate burning of waste, responsible management of water and energy, and compliance with environmental regulations without compromising patient safety.

Waste management has been highlighted as an element of environmental performance in several studies. The study by Thakur and Sharma (2021) evaluating existing health care solid waste management practices in hospitals in Himachal Pradesh, India, regarding environmental performance revealed weaknesses in segregation, marking of infectious waste bags, and transportation facilities; handling practices are deficient, and recycling is done without chemical disinfection or sanitisation. Their study elaborates on the direct relationship between operational practices such as collection, segregation, storage, and transportation, and stakeholder awareness, and environmental performance. Mushtaq et al. (2022) utilised a life cycle impact assessment (LCA) to demonstrate that properly segregated and recycled waste can reduce greenhouse gas emissions, thereby establishing an integrated hospital waste management scenario that is more effective than current practices. This strongly supports the notion that environmental performance is a measurable outcome variable, such as waste handling efficiency and pollution reduction.

The environmental performance perspective is not limited to waste collection alone. Yang et al. (2023) presented a dynamic framework for circularity performance in medical waste management. They proposed that traditional recycling-rate indicators may fall short of capturing the quality and circularity of recovered resources. The results indicate that hospitals and policymakers require more sophisticated performance measures to account for recycling efficiency, waste types and temporal changes. Dolcini et al. (2025) also claimed that hospitals should have environmental key performance indicators in energy, waste management, water consumption, greenhouse gas emissions (GHG), transport and traffic, and site sustainability. These contributions suggest that environmental performance is part of hospital performance management systems rather than a discrete compliance issue.

So, this study focuses on the staff awareness of medical waste management and environmental performance in hospitals. It is an answer to the call for a model that connected one side of human awareness regarding hospital waste management with the environmental performance side of operations. Employees will most likely improve environmental performance by strengthening proper segregation, reducing waste-related risks, supporting a cleaner internal environment, and doing everything possible to comply with environmental rules and regulations through continuous improvement in waste-handling practices. This position is well aligned with recent evidence that knowledge, education, and awareness play a significant role in safer practices for biomedical waste management. (Krishnamurthy et al., 2024; Thapa & Laskar, 2024), while effective waste strategies contribute to sustainability and environmental performance (Lee & Lee, 2022; Mushtaq et al., 2022; Dolcini et al., 2025).

Research Problem and Questions

The research problem arises from the extent of the existence of policies and procedures related to medical waste in health institutions, on the one hand, and the actual level of awareness among workers about these requirements, as well as their compliance with them, on the other hand. The staff vary in their professional disciplines, education pathways and histories, departments of care, exposure to waste and training experiences. The physicians, nurses, laboratory staff, pharmacists, technicians, housekeeping staff and administrative staff of the healthcare facilities cannot have awareness regarding medical waste type, colour coding segregation, etc.,

storage and internal transport; their knowledge is poor as compared to their respective departments about personal protective equipment (PPE), emergency and responsibilities placed by the institution on employees themselves. The difference might make the hospital cleaner, reducing pollution and the risk of illness, improving waste management efficiency, and fulfilling other environmental regulations.

Earlier empirical studies found that training and knowledge are strongly correlated with safe biomedical waste management. Observational studies have suggested that not only knowledge but also attitude, training, and professional experience are associated with appropriate waste management behaviour among healthcare workers (Letho et al., 2021; Thirunavukkarasu et al., 2022; Udayanga et al., 2023). Other investigations have highlighted that environmental performance associated with hospitals requires systematic separation, storage, and transportation, monitoring, environmental assessment, and administrative commitment (Alighardashi et al., 2024; Dolcini et al., 2025; Mushtaq et al., 2022). But various studies have treated staff awareness and hospital environmental performance as two disjointed aspects. However, a relevant study is required to investigate the relationship between staff knowledge of medical waste management and hospitals' environmental performance.

Study Objectives

The main purpose of this study is to explore the effect of hospital employee awareness regarding medical waste management on environmental performance. This is significant because medical waste management is not a one-time technical process; rather, it involves a continuous organisational procedure that requires awareness, motivation, monitoring, and environmental control. Through this relationship, it will be helpful for hospital management to set up a better training programme and environmental practices, as well as improve waste-handling procedures.

Study Hypotheses

The research findings assert that awareness of medical waste management has a significant effect on environmental performance in hospitals, as indicated by the literature review, problem, and objectives. This leads to the main hypothesis and sub-hypotheses, which are worded as follows (Table 1).

Table 1. Study Hypotheses

Hypothesis Code	Hypothesis Statement
H1	Staff awareness of medical waste management has a statistically significant positive impact on hospitals' environmental performance.
H1a	Concept and risk awareness have a statistically significant positive impact on environmental performance in hospitals.
H1b	Procedural awareness has a statistically significant positive impact on environmental performance in hospitals.
H1c	Safety and responsibility awareness has a statistically significant positive impact on environmental performance in hospitals.
H1d	Organisational awareness has a statistically significant positive impact on environmental performance in hospitals.
H2	There are statistically significant differences in staff awareness of medical waste management across selected demographic and professional variables, such as job title, department, experience, and training.
H3	There are statistically significant differences in perceived hospital environmental performance across selected demographic and professional variables, such as job title, department, experience, and training.

2. The Theoretical Framework

2.1. The Independent Variable: Staff Awareness of Medical Waste Management

Conceptual and risk awareness relate to a particular worker's comprehension of what constitutes medical waste, how they differ from ordinary waste, which waste streams are considered hazardous, and how improper handling may place patients at risk; staff members must also consider the transmission of infectious diseases, potential needle-stick injuries, exposure to hazardous chemicals, the risks associated with pharmaceutical waste, the potential for contamination of soil and groundwater through mismanaged medical waste, and the potential for generating emissions through improperly treating or transporting medical waste by uncontrolled burning. WHO (2024) provides additional information about the potential release of chemical and/or biological hazards due to the unsafe management of healthcare waste; therefore, conceptual and risk awareness are viewed as the baseline

for enabling workers to view the management of medical waste as an important safety and sustainability issue, and not just an everyday routine housekeeping issue.

Procedural awareness involves understanding the appropriate operational steps for handling medical waste. It includes knowledge of the colour-coding system, containers and bags for different waste streams, segregation at source, labelling, temporary storage, internal transportation of biomedical waste within the institution's premises, and guidelines for reporting and classification of infectious waste, including sharps waste, pharmaceutical waste, chemical hazardous waste, and non-hazardous medical waste. And procedural awareness is important because generic knowledge of risk is not very helpful if the employee does not know precisely what to do at the time of waste generation. Practical procedures are emphasised in the WHO handbook (WHO, 2014) and in the Saudi technical guidelines for safe identification, separation, containment, transport and management of healthcare waste (MWAN, 2023; WHO, 2014). Hospitals are real-Life systems where processes are performed under time pressure. This makes procedural awareness less ambiguous and more standardised behaviour in those settings. Here are a few examples: sharps must be placed immediately in puncture-resistant containers, infectious waste must be placed in the correct bags and labelled properly, pharmaceutical waste may need to be separated and treated separately when discarded, and non-hazardous recyclable materials should not be mixed with hazardous waste unnecessarily. Staff who understand these procedures are better equipped to avoid cross-contamination, minimise the volume of hazardous waste produced, and facilitate efficient waste handling.

The concept of responsibility and safety awareness is a staff member's understanding of their personal and collective responsibility for the safe management of waste. This covers understanding the use of Personal Protective Equipment, prevention of exposure incidents, and how to report them; appropriate immunisation of employees before treatment; how to handle spills; the segregation of waste at the point of generation; and responsibility for co-workers, patients, waste handlers, and the community. This dimension is significant because the management of medical waste has both environmental and occupational health impacts. Poor management can endanger employees in the hospital, as well as contractors and municipal systems, which are at risk of transferring the danger beyond the hospital vicinity to the community.

Service providers are required to continually train and orient staff on how to handle appropriate waste streams in accordance with Saudi technical guidelines (MWAN, 2023) by conducting fitness and health checks on staff. This means that responsibility awareness encompasses both personal liability and corporate duty of care. Waste safety does not start with disposal after clinical work; it starts at the generation of waste, and staff must understand this. Specifically, safe segregation of chemistries mitigates later risk posed to the workforce (in particular cleaners and waste transporters); correct labelling minimises potential danger to individuals working in treatment plants; immediate reporting of spills/injuries reduces both occupational and environmental impacts.

Organisational literacy is a staff member's understanding of the hospital policies, waste-management plan, infection-control requirements, environmental regulations, reporting lines (who must report to whom), the documentation system for these processes, the training schedule, audit principles and mechanisms, as well as accountability frameworks. This dimension assumes that staff understanding goes beyond technical knowledge to include awareness of the institutional system that facilitates or controls waste-management behaviour (Alharbi et al., 2021). The authors also argue that a holistic understanding of sustainable environmental management of healthcare waste, encompassing policy, organisational, and individual levels, is presented in Alharbi et al. (2021). This strengthens the messages regarding medical waste management as a governance process that spans not only clinical and housekeeping functions but also all areas of a hospital.

Organisational awareness is vital for the hospital to function effectively with external sources of waste, such as licensed waste transporters and treatment providers, regulatory inspectors, and environmental authorities. A staff member must know who is responsible for every step in the waste chain; how to fill out waste-related documentation; where temporary waste storage occurs; when waste pick-up occurs; how to report instances of non-compliance; and how to follow through with incident management. The technical guidelines provided by the Kingdom of Saudi Arabia mandate that every facility write a waste management plan that includes all waste generated by the facility and outlines all aspects of the waste management process, including classification,

segregation, separation, storage, transportation, treatment, as well as health and safety (MWAN, 2023). Overall, organisational awareness ties individual actions to institutional compliance.

2.2. The Dependent Variable: Hospital Environmental Performance

The study's dependent variable is hospital environmental performance. Environmental performance is defined as the hotel or hospital's efficiency, safety, compliance and sustainability in its environmental practices. As applied to hospital environmental performance, these included internal environmental cleanliness, pollution and risk reduction, waste handling efficiency, and compliance with and improvement on environmental regulations. This conceptualisation is in line with the general literature that treats environmental performance as a multidimensional construct comprising operational outcomes (pollution prevention, resource efficiency), compliance, and continuous improvement (Seifert & Guenther, 2019; Trumpp et al., 2015).

Internal environmental cleanliness consists of ensuring that the hospital units, corridors, treatment rooms, laboratories, storage areas, and waste rooms are free from visible accumulation or cross-contamination between facilities. Due to the direct implications of cleanliness for infection prevention, staff protection, and the assurance of patient and environmental quality, it is a core marker of hospital ecological performance. Environmental cleanliness is sometimes seen as a housekeeping by-product and underpinned by behaviour factors at the point of waste creation. If this waste is improperly disposed of, not made safe, or stored in inappropriate areas, it can compromise the cleanliness of the ward's clinical spaces.

Segregation behaviour is integral to the purity of an internal environment. The correct segregation reduces leakage and odour — it is also an attractive site for pests and can lead to accidental exposure. It further facilitates the smooth transportation of waste from clinical sectors to storage and treatment facilities. WHO (2014) states that safe waste-management practices must ensure protection for healthcare workers, patients, visitors, and the public from risks posed by waste due to inadequate management. Thus, having a clean is not only an aesthetic consideration; it is in fact a safety and performance requirement. In the present study, internal cleanliness is considered one of the immediate responses expected to improve when staff cognise waste types, risks, and practices.

Pollution and risk reduction: The hospital should have a plan for managing medical waste to minimise environmental pollution and health risks. This encompasses soil and water pollution, reducing unsafe emissions, cross-contamination between dangerous and non-dangerous waste, physical exposure to the natural world, improper fire disposal, and addressing bad practices. As stated by the WHO (2024), safe and environmentally sound management of healthcare waste can prevent negative impacts on human health and the environment. Thus, pollution prevention and risk reduction are key outcomes of proper medical waste management.

Mismanagement of medical waste poses multiple environmental risks. Infectious waste can carry pathogens; sharps can injure and/or infect people; and chemical and pharmaceutical waste can contaminate ecosystems. In addition, improper incineration can lead to air pollution. Mushtaq et al. (2022) compared hospital waste-management scenarios using a life cycle assessment method and determined that a combined waste-management approach utilising segregation and recycling could provide a pathway to sustainability. Thus, your environmental risk will be determined not just by what happens at the end of the waste-management chain but also by the decisions made throughout the entire chain.

Efficiency: Waste handling refers to the hospital's ability to manage waste in a timely, organised, low-cost, and eco-friendly manner. It encompasses the segregation of hazardous waste material, reduced volume of unwanted hazardous waste disposal, internal collection with appropriate containers and a quickly filled, high-efficiency storage medical depot, efficient coordination with external contractors for their utilisation, appropriate equipment identification, and proper documentation. Therefore, it is fundamental to take effective measures in waste management; hospitals that misclassify or mix waste increase treatment costs, put pressure on storage capacity, and require greater transportation capacity while increasing environmental risk. Lee and Lee (2022) also recognised operational management issues—medical waste management, training, awareness, and environmental assessment—for effective green healthcare, with potential implications for sustainable efficiency, further illustrating the interconnectedness of operational and human factors.

Staff awareness has a significant impact on the efficiency of waste management. Without procedures, employees may contaminate infectious-waste containers with a lot of waste, may ignore instructional streams for recyclables, may not use the correct bag, or may, by all odds, put their own trash in the incorrect items. These practices slacken operational efficiency and may need to be redone by housekeeping or waste-management teams. On the other hand, proper staff training can prevent mistakes and make assistance easier by directing how to execute correct procedures. Efficient waste handling improves environmental performance by minimising unnecessary waste treatment, lowering emissions, and creating more opportunities for resource recovery.

To create more environmentally sound and economically viable outcomes, the Saudi Arabian waste management system promotes waste reduction, separation, reuse, recycling, and proper disposal (MWAN, 2023). Efficiency should therefore be defined not only in terms of time and money but also of the environment. For instance, if a hospital disposes of its waste quickly but fails to separate hazardous from non-hazardous waste, this practice does not demonstrate environmental efficiency. As a result, an efficient waste management system should enable proper classification and the safe movement of waste while minimising environmental impact. By helping staff understand waste-handling processes, it is anticipated that they will adopt daily practices consistent with both technical and regulatory requirements.

Environmental compliance and improvement are the hospital's commitment to following national regulations and institutional policies, meeting technical audit requirements, and continuously improving medical waste management. Compliance means following the rules for classifying, segregating, storing, transporting, treating, documenting, protecting workers, and coordinating contractors. Improvements include training, monitoring, correcting identified issues, assessing performance, and gradually developing more sustainable practices. According to Alharbi et al. (2021), the performance of hospital waste management is the result of the interaction among policy, organisation, and individuals, thus making compliance a regulatory and behavioural outcome.

The compliance regime is well established through Saudi regulations and guidelines. The Uniform Law for the Management of Hazardous Substances and Medical Waste requires strict segregation between hazardous and non-hazardous medical waste, as well as specialised personnel trained to collect and transport the waste (Ministry of Health, 2019). These technical guidelines will supplement the Waste Management Law and its implementing regulations, outlining waste producers' obligations regarding the segregation, packaging, labelling, handling, storage, and treatment of waste, as well as training (MWAN, 2023). Thus, having qualified personnel who know not only what to do but also the best practices and the complete reasoning behind regulations will contribute to superior environmental performance and compliance with all applicable laws at any given moment.

Environmental performance is made up of continual improvement, too. They should be assessed through audits, incident reports, training updates, environmental indicators, and staff feedback to improve local-level medical waste management systems. Environmental management literature has highlighted that performance measurement is multi-faceted, with both outcomes and management processes needing to be incorporated (Trumpf et al., 2015). In hospitals, compliance without improvement results in doing only what is within the routine minimum performance level and improvement without compliance lacks legal discipline. Thus, compliance with and improvement in environmental issues constitute the governance aspect of hospital facility performance.

2.3 The Relationship Between the Variables Considering Different Theories

Several complementary theories may help explain the relationship between staff awareness of medical waste management and hospital environmental performance. Medical waste management is a behavioural, organisational, regulatory, ethical, and resource issue all at once, so no single theory will suffice. This framework incorporates the Knowledge–Attitude–Practice (KAP) perspective, the Theory of Planned Behaviour, Social Cognitive Theory, Institutional Theory, Stakeholder Theory, and the Natural-Resource-Based View. All these mechanisms together shed light on how awareness influences environmental performance through $\text{infotainment} = \text{awareness} + \text{capacity (knowledge, motivation \& perceived control)} + \text{rituals: social}$

learning by copying better workplaces to fill gaps; regulatory pressure for change in corporate behaviour; ethical responsibility; and organisational capability (Table 2).

Table 2. Critical Synthesis of Previous Studies, Research Gaps, and Implications for the Current Study

Theoretical perspective	Core idea	Implication for the study
KAP perspective	Knowledge and awareness influence attitudes and practices.	Staff awareness is expected to guide proper waste management behaviour.
Theory of Planned Behaviour	Attitude, subjective norms, and perceived control shape behavior.	Awareness strengthens the willingness and capability to follow waste procedures.
Social Cognitive Theory	People learn through observation, reinforcement, and self-efficacy.	Training, role modelling, and feedback help convert awareness into practice.
Institutional Theory	Organisations respond to regulatory and normative pressures.	Awareness helps staff internalise legal and organisational waste-management requirements.
Stakeholder Theory	Organisations should protect the interests of affected stakeholders.	Waste management is a responsibility toward patients, workers, communities, and the environment.
Natural-Resource-Based View	Pollution prevention and environmental capabilities support performance.	Staff awareness is an intangible capability that supports hospital environmental performance.

3. Previous Studies

3.1. Independent Variable: Staff Awareness of Medical Waste Management

Millanzi et al. (2023) examined the knowledge, attitudes, and perceived practices of sanitary workers concerning health care waste management in the Dodoma region of Tanzania. The researchers targeted sanitary workers as they can be directly engaged in the collection, transportation, storage and disposal (when necessary) of health care waste, but have historically received little to no training in infection control or waste management compared to those in clinical jobs; therefore, focusing on this group is relevant as they comprise a significant percentage of hospital waste management staff. Sanitation employees are not very familiar with, and do not concern themselves with, the collection, transportation, and storage of health care waste. It would benefit them to receive training in waste management tailored to the sociodemographic characteristics of sanitation employees. This research supports the current work, which holds that awareness should not be given only to physicians and nurses but also to all staff members who handle the waste, such as housekeepers and environmental services employees, who should have proper awareness and training.

Venugopal et al. (2024) identified predictive variables for nursing personnel's use of biomedical waste disposal practices at a tertiary care teaching facility in India. This study was specifically directed towards nursing staff because they are actively engaged in patient care and have a unique impact on the creation, separation, storage, and disposal of biomedical waste at the healthcare facility. The researchers stated that potential adverse effects on patients and other individuals from the unsafe disposal of biomedical waste materials could be significant, while safe disposal supports environmental protection. Researchers concluded that staff nurses should participate in periodic training programs to enhance their knowledge and strengthen their existing knowledge of biomedical waste management. Recommendations for future studies include developing creative ways to train nurses and investigating the effects of training on nurses' behaviours towards biomedical waste management across multiple centres. The original research applies to my current research because it shows a direct relationship between knowledge, training and practice and demonstrates that awareness (of environmentally responsible waste management practices) is a predictor of environmentally responsible waste management behaviour in hospitals.

Thapa and Laskar (2024) surveyed health care providers in a Primary Health Centre in Sikkim, India, to assess their understanding, attitudes, and behaviours regarding biomedical waste disposal. The research included a test to examine the relationships among knowledge, attitudes, behaviours, and demographic/professional variables. The researchers believe that biomedical waste poses a substantial risk of serious illness and that sufficient training and education are necessary for waste handlers to ensure the safe and secure handling of biological waste. The study findings revealed that 66% of participants achieved an adequate score in knowledge, 66%

achieved a favourable score in attitude, and 60% achieved a good score in practice regarding biowaste management. However, substantial gaps exist in the knowledge of supportive health care employees due to the minimal availability of formal training. The maximum time allotted for biowaste storage was known to only 12% of respondents. Comprehension of personal protective equipment, the use of colour codes, and potential infectious risks was well understood by most respondents; however, refresher training was not conducted frequently.

Webb et al. (2024) conducted a pilot study within the United Kingdom National Health Service (NHS) to explore barriers to sustainable medical waste segregation and to understand why some medical waste is incorrectly classified as hazardous. The study is relevant to staff awareness because it focused on the practical decisions made by healthcare workers at the point of waste disposal, particularly in distinguishing between hazardous, non-hazardous, infectious, and potentially recyclable waste streams. The findings showed that staff were generally attentive to identifying hazardous waste. Still, they often classified materials that had contact with bodily fluids as hazardous even when the waste might not be infectious. The main practical barriers were limited availability of different bins, lack of space, busy schedules, and insufficient clarity about recyclable materials. The authors recommended clearer visual information, posters, bin labels, and more practical training to help staff correctly identify both hazardous and non-hazardous waste. This study supports the current thesis by emphasising that staff awareness must encompass procedural clarity, confidence in classification, and organisational support, rather than mere general knowledge of risk.

Sturm et al. (2026) examined staff attitudes toward healthcare waste separation in Germany from a triple-bottom-line perspective. The study was conducted in a developed healthcare context where hospitals and comparable facilities are expected to separate glass, paper/cardboard, residual waste and other non-hazardous materials. The study is important because it links staff interest, perceived proficiency, opinions, and awareness of waste separation to environmental, economic, and practical sustainability considerations. The results indicated that healthcare staff generally recognised the importance of sustainable waste separation; however, effective implementation depended on practical enablers such as simple instructions, accessible containers, and organisational encouragement. The study therefore reinforces the point that awareness alone is insufficient unless it translates into routine behaviour through visible procedures and supportive workplace systems. This study is highly relevant to the present thesis because it supports the procedural and organisational awareness dimensions of staff awareness of medical waste management.

3.2. Dependent Variable: Hospital Environmental Performance

Thakur and Sharma (2021) were motivated to evaluate solid waste management practices in hospitals in relation to environmental performance: Evidence from Himachal Pradesh, India. This study presents itself as necessary because of excess healthcare waste and the growing challenge of maintaining environmental quality in developing health systems. It targeted four performance areas: collection and segregation of health care solid waste; storage and transport; special precautions for handling infectious waste; and knowledge of health care solid waste management among stakeholders involved in its generation. Findings showed that most hospitals utilised separate containers and/or colour-coded bins to collect infectious healthcare solid waste, and many had on-site segregation. A few key weaknesses identified were poor demarcation of infectious waste areas and bags, inadequate storage and transport facilities, poor handling practices, and recycling without proper chemical disinfection. The study further noted that knowledge levels among stakeholder groups also differed, underscoring the need for ongoing awareness-raising and training for all workers handling waste. Lee and Lee (2022) sought to investigate the significance of medical waste management activities in promoting sustainable green healthcare. The paper contended that medical waste management is not simply a technical issue but an operational imperative for hospitals to reduce their environmental footprint, enhance resource utilisation, and support sustainable healthcare. The research context is the increased volume of medical waste produced in hospitals due to the COVID-19 pandemic and the growing urgency for sectors like health to move towards more sustainable practices. The analysis would yield five core consequences for managing medical waste toward sustainable, green healthcare. The most significant areas were medical waste management per se, operational management issues, training for the delivery of medical waste management, awareness-raising, and environmental assessment.

To conclude, the study showed that safe storage of infectious waste, ensuring adequate policies and manuals, periodic monitoring of compliance, training staff on handling measures, and integrating waste management into day-to-day activities are key to effective waste management. It also stressed that keeping waste to a minimum is not the responsibility of one department — all members of the hospital need to be involved. Shakoor et al. (2024) conducted a quantitative/qualitative evaluation of hospital solid waste management at the Pakistan Institute of Medical Sciences Hospital in Islamabad. The present analysis described health care-related solid waste as an environmental and occupational health dilemma, particularly in developing countries, where improper disposal can increase exposure to pollutants and diseases, and expose workers involved in solid waste management. This research is significant because it examines the amount of waste and operational practices at a large-capital healthcare facility. According to this study, the hospital produces 61,030 kg of hazardous waste and 254,866.9 kg of non-hazardous waste each year. The hospital has an effective solid waste management program that segregates hazardous from non-hazardous waste at the point of generation using a colour-coded system. Non-hazardous waste is transported securely to a covered storage area in carts, whereas hazardous waste is incinerated in on-site dual-chamber incinerators. The research found that personnel responsible for managing solid waste also face significant health risks on the job, including injuries from sharp objects, exposure to diseases, stress, and anxiety.

Kaposi et al. (2024) sought to quantify the waste generated by health systems to identify the drivers of hazardous waste at a University Hospital. This research was motivated by the rapidly increasing global volume of healthcare waste and aimed to identify the clinical and operational drivers most responsible for generating hazardous waste in healthcare. The authors conceptually position health system waste as both an environmental and a patient safety issue, as detailed studies of the amount of health system waste generated, its tracking, and accountability for the origins of that waste are essential for minimising the amount of waste produced. According to the study, total healthcare waste increased by 2.11% each year, and the healthcare waste generation rate per bed ranged from 2.53 to 2.68 kg/day. Over the five years studied, hazardous healthcare waste increased by 20.19%, with an estimated hazardous healthcare waste generation rate per bed of 1.13-1.31 kg/day. Surgical specialties, anaesthesia, the Intensive Care Unit (ICU), and emergency departments produced greater-than-average amounts of hazardous waste. A positive relationship existed between hazardous waste and healthcare-associated infections, and the quantity of adult and child diapers used. Also, these predictors were validated by multiple regression analysis.

Dolcini et al. (2025) found that environmental performance dimensions and key performance indicators (KPIs) are common and important in the current scientific literature on hospitals' sustainable environmental practices. The rationale for this study was that hospitals are among the most resource-intensive healthcare institutions and have a major negative impact on the environment. Therefore, environmental sustainability must be included in hospital performance measurement systems to provide for structured assessments, comparisons between facilities or organisations, tracking over time, and the ability to continually make improvements. Six primary sustainability areas have been identified for assessing the environmental efficiency of hospitals: the management of energy resources; the management of waste products; the use of water; the production of greenhouse gases; the movement of people and goods; and the long-term sustainability of hospital sites. In addition, the review suggested a combined framework comprising 18 indicators (KPIs) to assess hospitals' environmental performance. There was significant variation in the level and detail of the information available to measure hospitals' environmental sustainability performance. This significant degree of variance demonstrates that there is currently no uniform method of measuring environmental sustainability performance in hospitals. Because there is no standard method for measuring environmental sustainability performance in hospitals, it is also impossible to effectively compare hospitals, measure progress toward sustainable practices, or incorporate environmental sustainability measures into broader hospital performance systems. Vielsack et al. (2026) conducted a nationwide benchmark study on healthcare waste in German hospitals. The study was motivated by the lack of detailed, scientifically reliable hospital-level data on waste generation in Germany, which limits hospitals' and policymakers' ability to develop evidence-based circular economy and waste-reduction initiatives. The study, therefore, directly addresses hospital environmental performance using measurable waste indicators. The results showed strong associations between waste generation and hospital structural characteristics, especially staffing levels, and revealed differences between general and university hospitals across key performance indicators. The authors proposed a differentiated extrapolation model that uses

the number of beds as a reference to estimate waste generation. This study is relevant to the current thesis because it demonstrates how hospital environmental performance can be measured using objective indicators such as total waste mass, hazardous-waste share, infectious-waste share, benchmarking indicators, and waste-generation models, thereby supporting environmental compliance and continuous improvement.

3.3. Research Gap, and Added Value of the Current Study

Table 3 provides an overview of the most important strengths and weaknesses, as well as implications for this research based on the literature review.

Table 3. Overview of the Literature

Literature Stream	Main Strengths	Main Limitations	Implication for the Current Study
Awareness / KAP studies	Recent evidence on knowledge, attitudes, training, and practices across different hospital staff categories.	Often focus on staff scores without directly testing hospital environmental performance.	Supports measuring staff awareness as an independent variable.
Training and procedural studies	Show that training is associated with better knowledge and safer waste-management behaviour.	Training effects are often examined descriptively or cross-sectionally.	Supports testing the role of procedural awareness and safety awareness.
Support-staff studies	Highlight the importance of sanitary workers, cleaners, and waste handlers.	Often limited to a single occupational group or region.	Supports using a broader hospital-staff sample.
Environmental performance studies	Provide indicators related to waste, emissions, recycling, circularity, and compliance.	Often, they under-emphasise the human awareness factor behind performance.	Supports measuring environmental performance as a dependent variable.
Integrated waste-management studies	Show that segregation, recycling, and treatment strategies can reduce emissions and improve sustainability.	Some studies are technical and do not test staff awareness as a predictor.	Supports linking awareness to waste-handling efficiency and pollution reduction.
Green hospital/sustainability studies	Provide broad frameworks for environmental performance and continuous improvement.	Sometimes too broad for direct connection with staff waste-management awareness.	Supports focusing the current study on waste-related dimensions of environmental performance.
Saudi studies	Provide valuable local evidence on knowledge and training gaps among healthcare professionals.	Do not sufficiently connect the dimensions of awareness to hospital environmental performance outcomes.	Justifies the contextual relevance and contribution of the current study.

Accordingly, the central research gap can be articulated as follows: how the disparate impacts of different tranches of staff awareness on medical waste management and environmental performance in hospitals are explained has not been sufficiently explicated in previous studies. There is a demand for the study of concept and risk awareness, procedural awareness, safety and responsibility awareness, and organisational awareness in relation to internal environmental cleanliness, pollution and risk reduction (i.e., cleanup), waste-handling efficiency, and enhancement of environmental compliance. The present study fills the gap by proposing and testing an integrated model in which staff awareness of medical waste management positively influences hospital environmental performance. The anticipated contribution of this model is to create a bridge connecting the human, procedural, organisational, and environmental dimensions that separate medical waste management pathology. Thus, this research does not replicate earlier KAP or environmental performance studies; rather, it seeks to explain how staff awareness can be a concrete step toward cleaner, safer, more compliant hospital practice grounded in environmental responsibility.

4. Research Methodology

Population and Sample

The study population included employees working in selected hospitals within the Kingdom of Saudi Arabia whose tasks and duties were directly or indirectly related to medical waste management and environmentally responsible practices. This group comprised physicians, nurses, laboratory technicians, pharmacists, infection-control personnel, housekeeping staff, environmental services workers, and administrative employees involved

in handling, segregating, collecting, storing, transporting, supervising, or monitoring medical waste. Since the study required participants with relevant practical experience in hospital medical waste management, a non-probability purposive sampling technique was applied. Using this criterion, 384 participants were selected from Saudi hospitals. This approach was appropriate because the research focused on staff members who had direct or indirect exposure to medical waste management practices and were therefore able to provide meaningful responses regarding awareness and environmental performance.

Data Collection Procedure

Data were collected from individuals working in selected hospitals within the Kingdom of Saudi Arabia who had direct or indirect involvement in medical waste management and related environmental practices. The field data collection process was conducted from 1 March 2026 to 15 April 2026. Before data collection, participants were informed about the study's aims, the voluntary nature of participation, and the confidentiality of their responses. They were also informed that the collected data would be used for academic research purposes only. A purposive sampling technique was adopted to target participants with relevant experience and practical involvement in medical waste handling and related environmental practices. The questionnaire was distributed to eligible hospital staff during the specified data collection period, and adequate time was provided for self-administered completion. Returned questionnaires were reviewed for completeness and suitability for analysis, and only properly completed responses were retained in the final dataset.

Respondent Profile and Sample Characteristics

The demographic profile of the respondents was reasonably diverse (Table 1), which reinforces the conclusion that the sample was representative of the heterogeneity across hospitals (and hospital functions). Regarding gender, the sample was balanced (49.7% males and 50.3% females). Age-wise, most respondents were in the 25–34 age range (37.5%), suggesting that most participants were in the early to mid-evolution stage. In terms of job titles, nurses (37.0%) were highest in proportion, followed by physicians (18.5%), and housekeeping/cleaning staff (12.8%); this demonstrates the main role that both clinical and support personnel have in respect to medical waste management practices. The highest proportions in regard to departmental affiliation were in internal medicine (18.8%) and outpatient departments (16.7%), which were followed up by ICU (13.3%) and emergency units (12.2%), showing that the sample covered a wide range of hospital units with different exposure towards medical waste handling; Approximately half of the respondents were educated to degree level (53.6%), followed by diploma holders (18.5%) and postgraduate qualifications constituted a smaller but still salient cohort. Regarding work experience, the two largest groups were those with less than 5 years (27.1%) or 5–10 years of experience (29.7%), indicating that the sample was mostly composed of relatively experienced yet still active mid-level personnel. Noteworthy was the disparity between 71.4% who had received any medical waste management training and 28.6% who had not; still, within a generally acceptable level of institutional attention to the issue, with perceptions measured using socio-demographic variables. This is reinforced by the training frequency distribution: 28.6% reported having attended no training courses, while the others reported having completed one or more. On the whole, Table 4 shows that a heterogeneous and practically relevant sample was used in the study, which was enriched to examine staff awareness of medical waste management and its impacts on hospitals' environmental performance.

Table 4. Demographic Profile of Respondents

Characteristic	Categories	Frequencies	Percentages
Geographical scope	Selected hospitals within Saudi Arabia	384	100.0%
Gender	Male	191	49.7%
	Female	193	50.3%
Age	Less than 25 years	27	7.0%
	25–34 years	144	37.5%
	35–44 years	110	28.6%
	45–54 years	72	18.8%
	55 years or above	31	8.1%
Job title	Physician	71	18.5%
	Nurse	142	37.0%
	Pharmacist	20	5.2%
	Laboratory Staff	32	8.3%
	Technician	39	10.2%

Department / Unit	Housekeeping / Cleaning Staff	49	12.8%
	Administrative Staff	19	4.9%
	Other	12	3.1%
Department / Unit	Emergency	47	12.2%
	Surgery	38	9.9%
	Internal Medicine	72	18.8%
	ICU	51	13.3%
	Laboratory	31	8.1%
	Pharmacy	17	4.4%
	Outpatient Department	64	16.7%
Educational level	Housekeeping	40	10.4%
	Other	24	6.2%
	Secondary school or below	49	12.8%
	Diploma	94	24.5%
	Bachelor's degree	171	44.5%
Years of experience	Master's degree	47	12.2%
	Doctorate	23	6.0%
	Less than 5 years	104	27.1%
	5–10 years	114	29.7%
	11–15 years	73	19.0%
	16–20 years	58	15.1%
Received training in medical waste	More than 20 years	35	9.1%
	Yes	274	71.4%
Number of training courses attended	No	110	28.6%
	None	110	28.6%
	1	94	24.5%
	2	70	18.2%
	3	70	18.2%
	More than 3	40	10.4%

Statistical Analysis

The data from the questionnaire were analysed using SmartPLS, employing partial least squares structural equation modelling (PLS-SEM). This approach was used because it is suitable for investigating causal relationships between latent constructs and for evaluating research models that aim to predict and explain. Statistical analyses were performed in two sequential steps. Stage 1: Measurement of the measurement model to confirm that the study measures are sufficient. Namely, this was done by exploring indicator loadings, Cronbach's alpha, composite reliability, and average variance extracted (AVE) to assess convergent validity and internal consistency. Subsequently, discriminant validity was evaluated with the Fornell–Larcker criterion and the heterotrait–monotrait ratio (HTMT). The structural model was assessed during the second stage by analysing collinearity, path coefficients, coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2). The significance of pathways was checked through the bootstrapping procedure (5,000 subsamples). It is important to note that only the questionnaire data were included in the SmartPLS analysis, and 45 personal interviews were conducted, independently of the quantitative model analysis, to strengthen the contextual understanding of the results.

Bootstrapping was added to assess the significance and stability of the structural model estimates. In SmartPLS, the bootstrapping procedure was conducted using 5,000 resamples to generate empirical t-values, p-values, standard errors, and confidence intervals for the path coefficients. This non-parametric procedure was appropriate because it does not require the assumption of multivariate normality and allows the researcher to determine whether each hypothesised relationship is statistically significant (Hair et al., 2021).

Semi-Structured Interview Guide

The semi-structured interview guide was designed to align with the study variables and explain how the interviews supported the interpretation of the quantitative results (Table 5).

Table 5. The Semi-Structured Interview Guide

Theme	Interview Question	Purpose
Opening	Can you briefly describe your current role in the hospital and your connection with medical waste management?	To identify participant role and level of exposure to waste-related activities.
Concept and risk awareness	How do you define medical waste, and how do you distinguish it from general hospital waste?	To assess conceptual understanding of medical waste categories.
Concept and risk awareness	What risks may result from improper handling or disposal of medical waste?	To explore perceived risks to staff, patients, visitors, community, and environment.
Procedural awareness	What are the main steps followed in your hospital for segregating, collecting, storing, and moving medical waste?	To understand procedural knowledge and workflow clarity.
Procedural awareness	How clear are the colour-coded containers, labels, and disposal instructions used in your workplace?	To assess the clarity of segregation tools and visual guidance.
Safety and responsibility awareness	What safety precautions do staff usually follow when dealing with medical waste?	To explore PPE use, exposure prevention, and incident response.
Safety and responsibility awareness	Who do you think is responsible for safe medical waste management inside the hospital?	To identify whether waste management is viewed as a shared responsibility or delegated only to support staff.
Organisational awareness	Are hospital policies and procedures related to medical waste clearly communicated to staff?	To assess awareness of institutional rules, instructions, and communication.
Organisational awareness	What type of training or supervision is provided regarding medical waste management?	To explore role-based training, monitoring, and supervision mechanisms.
Environmental performance	In your view, how does proper waste management affect internal cleanliness and hygiene in the hospital?	To connect awareness and procedures with internal environmental cleanliness.
Environmental performance	How can proper medical waste management reduce pollution, risks, and unnecessary hazardous waste?	To connect awareness and procedures with pollution and risk reduction.
Environmental performance	What improvements would you suggest to strengthen medical waste management and environmental performance?	To identify practical recommendations from participants.

Thematic Analysis Procedure

- Step 1: Familiarisation. The researcher reviewed all interview notes several times to identify recurring themes related to awareness, procedures, responsibility, organisational practices, and environmental outcomes.
- Step 2: Initial Coding. Statements were coded according to the study's main dimensions: concept and risk awareness, procedural awareness, safety and responsibility awareness, organisational awareness, internal cleanliness, pollution and risk reduction, waste-handling efficiency, and environmental compliance.
- Step 3: Theme Development. Related codes were grouped into broader qualitative themes. For example, comments about colour-coded containers, storage, and transport were grouped under procedural clarity; comments about policy, reporting, and supervision were grouped under organisational awareness.
- Step 4: Theme Review. Themes were reviewed against the quantitative findings to determine whether they helped explain the pattern of significant relationships found in the structural model.
- Step 5: Interpretation. The final themes were used as contextual support in Chapter Five. They were not used to calculate statistical relationships and were not entered into SmartPLS.

Qualitative Interview Findings as Contextual Support

The qualitative interviews provided additional contextual support for the quantitative findings. Although the interview data were not included in the SmartPLS analysis, they helped explain how different types of staff awareness were reflected in daily hospital waste-management practices. The interview findings were organised into six main themes.

First, participants generally perceived medical waste management as a shared responsibility across clinical, technical, support, and administrative groups. This supports the quantitative finding that safety and responsibility awareness had consistent positive effects across all environmental performance dimensions. Participants indicated that errors in waste handling may occur when some staff assume that medical waste management is the responsibility of housekeeping or environmental services only. Therefore, the interviews reinforced the importance of fostering a culture of collective responsibility rather than assigning waste management to a single occupational group.

Second, the interviews showed that conceptual and risk awareness helped staff understand why medical waste should be separated from general waste and why incorrect disposal may increase infection risk, environmental contamination, and treatment burden. This contextualises the positive effect of concept and risk awareness on internal environmental cleanliness. When staff understood the risks of improper segregation, they were more likely to describe cleanliness as a direct outcome of careful disposal behaviour at the point of waste generation.

Third, procedural awareness emerged as the most practical theme in the interviews. Participants repeatedly emphasised the importance of knowing the correct container, colour code, label, temporary storage point, and internal movement procedure. This supports the quantitative result showing that procedural awareness was the strongest predictor of pollution and risk reduction, and a strong predictor of waste handling efficiency. The qualitative evidence suggests that pollution prevention begins within the hospital, when staff follow proper procedures before waste reaches final treatment or disposal.

Fourth, organisational awareness was strongly linked to compliance and improvement. Participants referred to the importance of clear policies, visible supervision, reporting channels, responsible units, training programs, and audit procedures. This explains why organisational awareness had the strongest effect on environmental compliance and improvement in the structural model. The interviews indicate that compliance is not achieved solely through individual knowledge; it also depends on whether staff understand the hospital waste-management system and know how to operate within it.

Fifth, training was repeatedly identified as a major factor in improving awareness and reducing errors. Participants emphasised that general lectures are less effective than practical, role-based training that shows staff how to segregate waste, use PPE, respond to exposure incidents, and report non-compliance. This finding is consistent with the study recommendations calling for continuous training, visual reminders, supervision, and feedback mechanisms.

Sixth, the interviews helped explain perceived barriers to stronger environmental performance. These barriers included inconsistent training, uncertainty about responsibilities in some departments, weak follow-up after training, limited visibility of reporting channels, and variation in procedural knowledge across occupational groups. These barriers suggest that hospitals should not rely only on written policies but should combine policies with practical training, continuous monitoring, and departmental accountability.

Overall, the interview findings support the conclusion that staff awareness is not merely theoretical knowledge. Rather, it operates as a practical organisational capability that helps hospitals improve internal cleanliness, reduce pollution and risk, increase waste-handling efficiency, and strengthen environmental compliance and improvement efforts. The qualitative findings, therefore, enrich the quantitative results by showing how awareness translates into daily waste-management behaviour within hospitals.

5. Results

Common Method Bias (CMB) and Data Normality

We conducted Harman's single-factor test as a preliminary diagnostic method for testing common method bias (CMB). An unrotated exploratory factor analysis was conducted on all 29 measurement items, and the initial overall variance explained by the first factor relative to the total variance was calculated to be 40.19%. The result indicates that common method bias is not a serious problem in the current study, as this value falls below the conventional cut-off point of 50%. This interpretation is consistent with the methodological literature,

suggesting that if a single factor drives most of the variance, then common method variance poses a major threat (Podsakoff et al., 2003). But Harman's single-factor test is generally seen as a preliminary criterion rather than as determinative. Thus, researchers in PLS-SEM also suggest complementary statistical tests, particularly a full collinearity test, since variance inflation factor (VIF) values above 3.3 can indicate common method bias (Kock, 2015). So, it may be concluded that common method variance does not seem to jeopardise the external validity of a study, and as shown in current research, based on Harman's single factor result, which was discovered was 40.19%, though assessments of reports' full collinearity VIF values would be extra methodological incremental evidence.

Evaluating the Reflective Measurement Model

Before testing the reflective indicator reliability and validity, the overall fit of the conceptual measurement model was evaluated by assessing how well the proposed model structure represented the data. In SmartPLS, model fit indices provide further evidence of whether the measurement specification at both the saturated and estimated levels is acceptable. Thus, several frequently reported fit indicators were considered: standardised root mean square residual (SRMR), geodesic discrepancy (d_G), unweighted least squares discrepancy (d_{ULS}), chi-square, and the normed fit index (NFI). Table 6 shows the results of these indices for both saturated and estimated models.

Table 6. Model fit indices for the saturated and estimated models

Fit index	Saturated model	Estimated model
SRMR	0.040	0.042
d _{ULS}	0.690	0.754
d _G	0.397	0.402
Chi-square	934.243	943.077
NFI	0.875	0.874

The model-fit results presented in Table 4.1 indicate that both the saturated and estimated models had low SRMR values, reflecting a relatively small discrepancy between the observed correlations and those implied by the model. The close values of d_{ULS} and d_G across the two model specifications provide further evidence of model stability. In addition, the NFI values (0.875 and 0.874 for the saturated and estimated models, respectively) are sufficiently high and nearly identical, supporting the adequacy of the hypothesised model. Overall, the close-fit statistics indicate that the measurement model is stable and well-specified, providing a reliable foundation for examining reliability, convergent validity, and discriminant validity.

As shown in Table 5, the assessment of the measurement model revealed adequate levels of indicator reliability, internal consistency reliability, and convergent validity, in addition to collinearity diagnostics, for both first-order constructs. First, standardised outer loadings for all items were above the desired cut-off value of 0.70 (ranging from 0.813 to 0.924), indicating that each indicator makes a proper contribution to its representative construct. In particular, Concept and Risk Awareness items loaded strongly on their respective constructs, with Procedural Awareness, Safety and Responsibility Awareness, and Organisational Awareness indicators exceeding the minimum acceptable threshold, thereby confirming sufficient staff awareness dimensions. Similarly, the items corresponding to each of the four SD dimensions of environmental performance (e.g., Internal Environmental Cleanliness, Pollution and Risk Reduction, Waste Handling Efficiency, and Environmental Compliance and Improvement) had high loadings, providing further evidence for the appropriateness of the indicators retained. High outer loadings (greater than 0.70 in PLS-SEM) are conventionally interpreted as indicating that a significant portion of the variance in its measured variables is accounted for by the latent construct being reflected (Hair et al., 2021). Cronbach's alpha values at the construct level ranged from 0.861 to 0.907. At the same time, composite reliability ranged between 0.907 and 0.942 — neatly above the necessary cut-off of 0.70, offering evidence that all constructs demonstrate decent internal consistency reliability (Hair et al., 2021).

Furthermore, the AVE values ranged from 0.687 to 0.843, all above the minimum threshold of 0.50 (Fornell & Larcker, 1981), thereby indicating an adequate level of convergent validity, as each construct captured more than half of the variance of its indicators (Hair et al., 2021). Overall, these results indicate that the first-order dimensions used to investigate staff awareness of medical waste management in hospitals, as well as those of

environmental performance, were both psychometrically robust and appropriate for modelling at the structural level. The measurement results indicate that Waste Handling Efficiency ($\alpha = 0.907$; CR = 0.942; AVE = 0.843) performed best on reliability, whilst Procedural Awareness recorded the least strong yet acceptable AVE value (0.687), indicating that even the most conservative construct still resides well within acceptable statistical parameters (see Table 7).

Table 7. Reliability and Convergent Validity of First-Order Constructs

Construct and Items	λ	VIF	Alpha	CR	AVE
Concept and Risk Awareness			0.863	0.907	0.709
SMA1	0.864	2.262			
SMA2	0.825	1.913			
SMA3	0.833	1.955			
SMA4	0.846	2.103			
Procedural Awareness			0.886	0.917	0.688
SMA5	0.813	2.008			
SMA6	0.852	2.342			
SMA7	0.822	2.070			
SMA8	0.839	2.207			
SMA9	0.819	2.050			
Safety and Responsibility Awareness			0.882	0.919	0.738
SMA10	0.850	2.165			
SMA11	0.861	2.262			
SMA12	0.877	2.464			
SMA13	0.849	2.163			
Organisational Awareness			0.878	0.917	0.733
SMA14	0.856	2.272			
SMA15	0.870	2.354			
SMA16	0.871	2.384			
SMA17	0.828	1.983			
Internal Environmental Cleanliness			0.861	0.915	0.782
EPH1	0.884	2.181			
EPH2	0.881	2.137			
EPH3	0.888	2.231			
Pollution and Risk Reduction			0.891	0.932	0.821
EPH4	0.902	2.548			
EPH5	0.902	2.554			
EPH6	0.913	2.769			
Waste Handling Efficiency			0.907	0.942	0.843
EPH7	0.924	3.150			
EPH8	0.917	2.947			
EPH9	0.913	2.849			
Environmental Compliance and Improvement			0.870	0.920	0.794
EPH10	0.880	2.154			
EPH11	0.892	2.334			
EPH12	0.901	2.451			

Note: All standardised loadings exceeded 0.70, Cronbach's alpha and composite reliability values exceeded 0.70, and all AVE values were above 0.50, supporting internal consistency reliability and convergent validity. In addition, all VIF values were below 3.30, indicating the absence of critical multicollinearity concerns.

In addition, all variance inflation factor (VIF) values for the indicators fell within a reasonable range from 1.913 to 3.150. This indicates that collinearity among indicators was not serious and did not threaten the stability of

the estimation results. Although VIF values below 5.00 are commonly considered acceptable in PLS-SEM (Hair et al., 2021), the more conservative threshold of 3.30 provides stronger evidence that common collinearity and potential common method bias are not problematic (Kock, 2015). Overall, the evidence confirms that the first-order constructs show strong psychometric properties and are suitable for testing the relationships between staff awareness of medical waste management and hospital environmental performance. The reflective measurement model is presented in Figure 1 below.

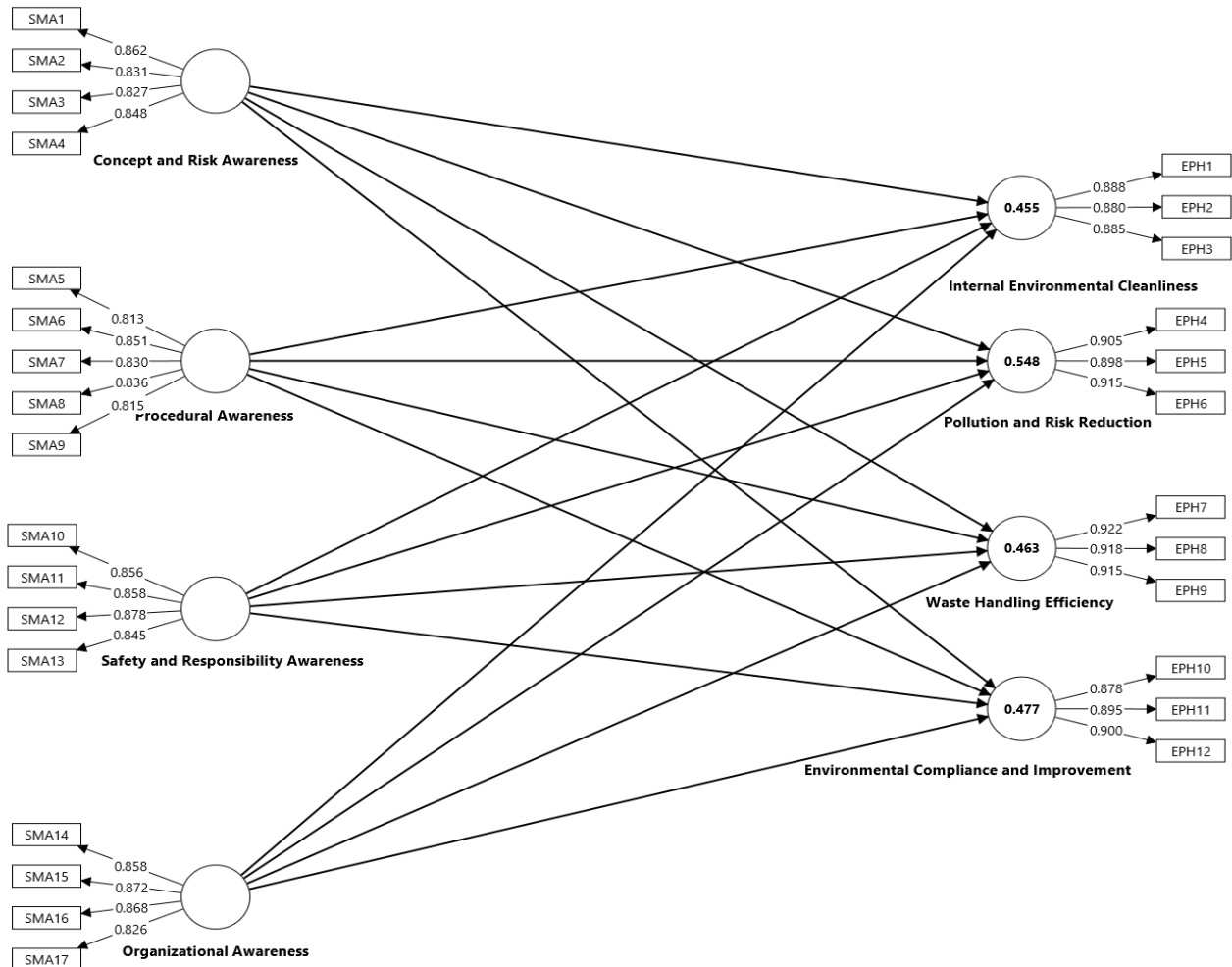


Figure 1. The reflective measurement model

Table 8. Descriptive statistics and correlations between constructs (Fornell-Larcker method)

Construct	1	2	3	4	5	6	7	8	Mean	SD
Concept and Risk Awareness	0.842								3.393	1.000
Procedural Awareness	0.339	0.829							3.419	0.979
Safety and Responsibility Awareness	0.335	0.328	0.859						3.395	1.006
Organisational Awareness	0.480	0.355	0.351	0.856					3.406	1.002
Internal Environmental Cleanliness	0.516	0.475	0.473	0.482	0.884				3.417	1.057
Pollution and Risk Reduction	0.471	0.603	0.521	0.495	0.520	0.906			3.394	1.051
Waste Handling Efficiency	0.436	0.514	0.507	0.483	0.471	0.545	0.918		3.435	1.108
Environmental Compliance and Improvement	0.483	0.378	0.514	0.572	0.491	0.534	0.492	0.891	3.402	1.070

Table 8 presents the descriptive properties of the study constructs and the discriminant validity results using the Fornell-Larcker criterion. The model measures eight first-order constructs: four dimensions of staff awareness of medical waste management, namely Concept and Risk Awareness, Procedural Awareness, Safety and Responsibility Awareness, and Organizational Awareness; and four dimensions of hospital environmental

performance, namely Internal Environmental Cleanliness, Pollution and Risk Reduction, Waste Handling Efficiency, and Environmental Compliance and Improvement. The construct means ranged from 3.393 to 3.435, indicating generally moderate-to-positive perceptions across all dimensions. Standard deviations ranged from 0.979 to 1.108, suggesting sufficient variation in respondents' views for further structural analysis.

The correlation matrix also showed that all inter-construct correlations were positive and moderate, ranging from 0.328 to 0.603. The strongest correlation was between Procedural Awareness and Pollution and Risk Reduction ($r = 0.603$), which is theoretically reasonable because staff who understand segregation, storage, transport, and disposal procedures are more likely to perceive stronger pollution-control and risk-reduction outcomes. Organisational awareness was also moderately correlated with Environmental Compliance and Improvement ($r = 0.572$), while Safety and Responsibility Awareness was moderately correlated with Environmental Compliance and Improvement ($r = 0.514$). These correlations confirm that the constructs are related but still conceptually distinct.

For discriminant validity, Table 6 shows that the square root of AVE for each construct on the diagonal exceeded all corresponding inter-construct correlations. The diagonal values ranged from 0.829 to 0.918, while the largest off-diagonal correlation was 0.603. This fulfils the Fornell-Larcker criterion, indicating that each construct explains more variance in its own indicators than it shares with other constructs (Fornell & Larcker, 1981). Although recent PLS-SEM literature recommends using HTMT as an additional and more sensitive test (Hair et al., 2021; Henseler et al., 2015), the Fornell-Larcker results are clearly within acceptable limits.

The findings are summarised in Table 9 are broadly consistent with two key conclusions: First, the overview of descriptive statistics shows that respondents assessed the dimensions of staff awareness and environmental performance at moderate-to-high levels in general. Second, the discriminant validity evidence shows that the eight constructs are empirically distinguishable dimensions, supporting their retention as separate variables in subsequent structural model analysis. This is relevant, as the conceptual model of the present study hypothesises that different facets of staff awareness may have differential effects on various dimensions of environmental performance in hospitals and do not represent a simple, undifferentiated factor.

Table 9. Heterotrait-monotrait (HTMT) Criterion Values

Construct	1	2	3	4	5	6	7
Concept and Risk Awareness	—						
Procedural Awareness	0.388	—					
Safety and Responsibility Awareness	0.384	0.372	—				
Internal Environmental Cleanliness	0.598	0.545	0.543	—			
Organisational Awareness	0.551	0.403	0.398	0.555	—		
Pollution and Risk Reduction	0.537	0.679	0.588	0.594	0.560	—	
Waste Handling Efficiency	0.492	0.574	0.567	0.533	0.541	0.606	—
Environmental Compliance and Improvement	0.557	0.430	0.587	0.568	0.654	0.606	0.553

As shown in Table 7, the HTMT results provide additional evidence for discriminant validity in the PLS-SEM model. Discriminant validity is important because it confirms that each latent variable captures a distinct conceptual domain and is not merely measuring the same concept as another construct. Since HTMT is more sensitive than conventional methods such as the Fornell-Larcker criterion or cross-loadings, it has become one of the most frequently recommended criteria for assessing discriminant validity (Henseler et al., 2015).

All HTMT values were below the recommended threshold of 0.90, supporting acceptable discriminant validity across the eight first-order constructs. The HTMT values ranged from 0.372 to 0.679. The highest value was observed between Procedural Awareness and Pollution and Risk Reduction (HTMT = 0.679), indicating that these two constructs are related yet empirically distinct. This result is theoretically reasonable because procedural awareness of segregation, storage, transport, and disposal is closely associated with perceived pollution prevention and risk reduction in hospitals.

In summary, the HTMT results provide strong evidence that all constructs included in this study have sufficient discriminant validity and should be retained as separate dimensions in the measurement model. This strengthens the credibility of the subsequent structural model analysis because the relationships among constructs can be interpreted as associations among conceptually distinct variables rather than artefacts of measurement overlap.

Evaluating the Structural Model

Subsequently, after validating the measurement model, the structural model was assessed to test the hypothesised relationships among the study constructs. It was dedicated to testing the predictive associations between staff awareness of medical waste management dimensions and hospital environmental performance components. Similar to the pathwise logic of PLS-SEM, the evaluation of the structural model provides support for whether paths are positive or negative and the strength of those relationships, indicating whether the theoretical assumptions of this research are supported empirically. The model also shed light on the extent to which the different awareness dimensions help explain the variance in environmental performance outcomes in the hospital context. The results of the structural model are shown in Figure 2, which highlights the relationships between the constructs included in this study.

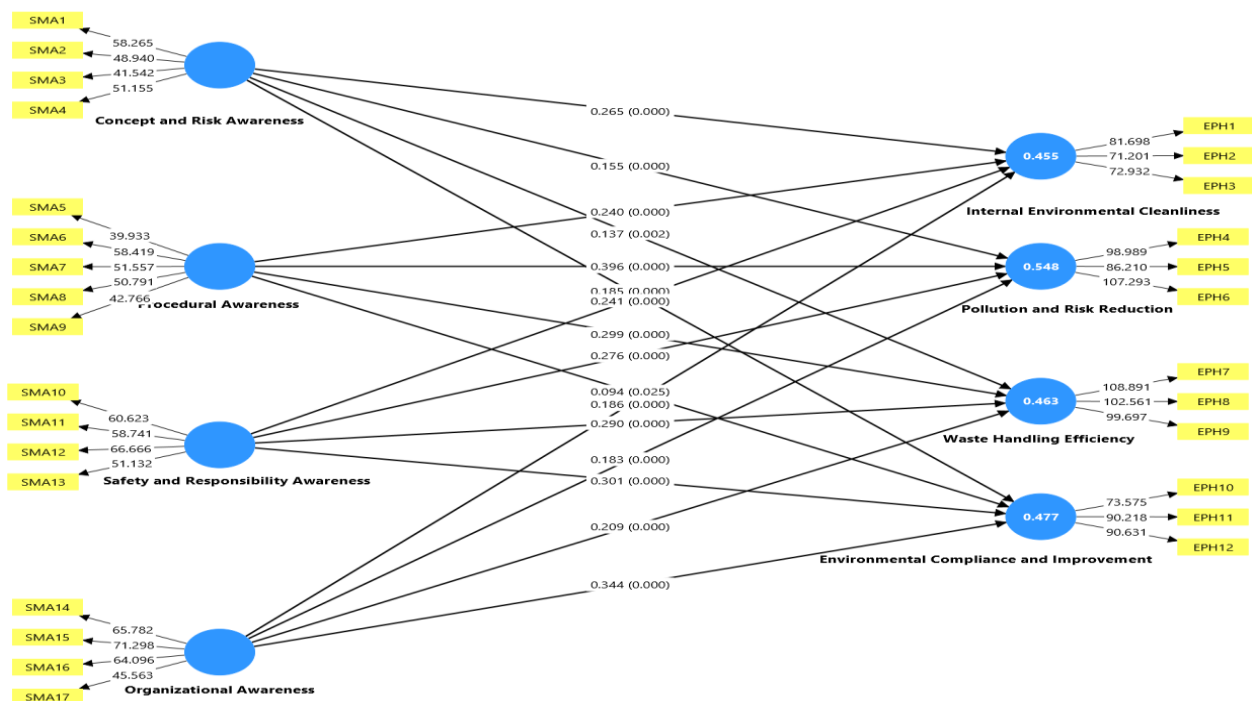


Figure 2. The Structural Model

Table 10. Results of Hypotheses Testing

Hypothesis	Path	Beta (β)	t-value	p-value	Decision
H1a	CRA → IEC	0.265	5.828	< 0.001	Supported
H1b	CRA → PRR	0.155	3.678	< 0.001	Supported
H1c	CRA → WHE	0.137	3.124	0.002	Supported
H1d	CRA → ECI	0.185	3.839	< 0.001	Supported
H2a	PA → IEC	0.240	5.330	< 0.001	Supported
H2b	PA → PRR	0.396	10.879	< 0.001	Supported
H2c	PA → WHE	0.299	7.742	< 0.001	Supported
H2d	PA → ECI	0.094	2.244	0.025	Supported
H3a	SRA → IEC	0.241	5.895	< 0.001	Supported
H3b	SRA → PRR	0.276	7.047	< 0.001	Supported
H3c	SRA → WHE	0.290	7.427	< 0.001	Supported
H3d	SRA → ECI	0.301	7.411	< 0.001	Supported
H4a	OA → IEC	0.186	3.989	< 0.001	Supported

Hypothesis	Path	Beta (β)	t-value	p-value	Decision
H4b	OA $\rightarrow$ PRR	0.183	4.048	< 0.001	Supported
H4c	OA $\rightarrow$ WHE	0.209	4.529	< 0.001	Supported
H4d	OA $\rightarrow$ ECI	0.344	8.029	< 0.001	Supported

Abbreviations: CRA = Concept and Risk Awareness; PA = Procedural Awareness; SRA = Safety and Responsibility Awareness; OA = Organisational Awareness; IEC = Internal Environmental Cleanliness; PRR = Pollution and Risk Reduction; WHE = Waste Handling Efficiency; ECI = Environmental Compliance and Improvement.

Note: All hypothesised paths were positive and statistically significant at the 5% level, indicating support for all proposed relationships in the structural model.

The analysis of results for the hypothesis testing (Table 10) suggests that all the proposed direct relationships in the structural model were positive and significant at the 5% level, thus fully supporting our study hypotheses. In general, the results indicated that various aspects of staff knowledge on medical waste disposal and management significantly contributed toward predicting environmentally sustainable performance outcomes in hospitals. Concept and Risk Awareness, Procedural Awareness, Safety and Responsibility Awareness, and Organisational Awareness were found to have significant positive effects on the four dimensions of environmental performance: Internal Environmental Cleanliness, Pollution and Risk Reduction, Waste Handling Efficiency, and Environmental Compliance and Improvement. The results validate that staff awareness is not a general perception but rather a multidimensional capability that influences environmental performance through many distinct yet complementary pathways. The analytical approach used in the research study was implemented using SmartPLS with bootstrapping to measure the structural relationships among the mediating effects.

A closer look at the path coefficients shows meaningful differences in the relative strength of each predictor. Table 4.5 summarises the results of hypothesis testing. For internal environmental cleanliness, Concept and Risk Awareness was the strongest predictor ($\beta = 0.265$, $t = 5.828$, $p < 0.001$). Safety and Responsibility Awareness ($\beta = 0.241$, $t = 5.895$, $p < 0.001$) and Procedural Awareness ($\beta = 0.240$, $t = 5.330$, $p < 0.001$) also contributed strongly, while Organisational Awareness showed a smaller but still positive effect ($\beta = 0.186$, $t = 3.989$, $p < 0.001$). This pattern suggests that a cleaner internal hospital environment depends not only on formal organisational guidance but also on staff understanding of medical waste risks and their responsibility for safety.

For Pollution and Risk Reduction, Procedural Awareness was the most important predictor by a wide margin ($\beta = 0.396$, $t = 10.879$, $p < 0.001$). Safety and Responsibility Awareness was next ($\beta = 0.276$, $t = 7.047$, $p < 0.001$). Concept and Risk Awareness ($\beta = 0.155$, $t = 3.678$, $p < 0.001$) and Organisational Awareness ($\beta = 0.183$, $t = 4.048$, $p < 0.001$) remained important but to a lesser extent. This finding is theoretically and practically sound, as pollution prevention and risk mitigation in hospitals are significantly contingent upon the proper implementation of daily waste segregation, storage, transportation, and disposal protocols. So, procedural knowledge seems to be the most important kind of awareness when the goal is to reduce pollution and the health risks that come with it.

A similar trend was noted for Waste Handling Efficiency, with Procedural Awareness exhibiting the most significant positive impact ($\beta = 0.299$, $t = 7.742$, $p < 0.001$), closely succeeded by Safety and Responsibility Awareness ($\beta = 0.290$, $t = 7.427$, $p < 0.001$). Organisational awareness ($\beta = 0.209$, $t = 4.529$, $p < 0.001$) and Concept and Risk Awareness ($\beta = 0.137$, $t = 3.124$, $p = 0.002$) were also important factors. These results suggest that effective waste management is primarily determined by employees' practical and safety-related awareness, which is logical considering that efficiency in this context relies on proper operational conduct, consistent adherence, and responsible management throughout the waste management process. To put it another way, knowing how to do things and understanding your safety responsibilities seem to be more important for operational efficiency than just having general knowledge.

For Environmental Compliance and Improvement, the strongest effect was seen in Organizational Awareness ($\beta = 0.344$, $t = 8.029$, $p < 0.001$), followed by Safety and Responsibility Awareness ($\beta = 0.301$, $t = 7.411$, $p < 0.001$), Concept and Risk Awareness ($\beta = 0.185$, $t = 3.839$, $p < 0.001$), and Procedural Awareness ($\beta = 0.094$, $t = 2.244$, $p = 0.025$). This part of the model is very important because institutional rules, supervision,

accountability structures, and clear hospital protocols are often linked to environmental compliance and improvement. This indicates that enhancing environmental practices in hospitals may be more contingent on staff's understanding of the institutional framework, reporting obligations, and managerial expectations regarding medical waste management. Even though procedural awareness was still important, its smaller coefficient indicates that improving the environment at the institutional level goes beyond simply knowing how to do things and depends more on how well the organisation works together and is governed.

The structural model results, when read together, tell a consistent story: all four awareness dimensions matter, but their effects vary by the type of environmental performance outcome (delivery) being addressed. Organisational awareness is the most important facilitator of environmental compliance and improvement, while Procedural Awareness is decisive for operational processes, namely, pollution control and waste-handling efficiency. Meanwhile, Safety and Responsibility Awareness were consistently strong and significant across all dependent constructs, suggesting that it is a stable, multidimensional predictor of environmental performance. Thus, the results imply that a uniform training focus would not apply to hospital managers. A more promising embodiment, however, should involve the construction of integrated awareness programs targeting significant enhancement of conceptual comprehension and procedural proficiency, as well as personal safety responsibility (SSR) and organisational role clarification regarding medical waste management.

6. Discussion

The significance decisions reported in Table 11 were based on bootstrapping results generated in SmartPLS using 5,000 resamples. Paths were considered statistically significant when the bootstrapped t-value exceeded the accepted threshold, and the p-value was below 0.05.

Table 11. Summary of the Supported Structural Hypotheses

Hypothesis	Path	Beta	t-value	p-value	Decision
H1a	CRA -> IEC	0.265	5.828	< 0.001	Supported
H1b	CRA -> PRR	0.155	3.678	< 0.001	Supported
H1c	CRA -> WHE	0.137	3.124	0.002	Supported
H1d	CRA -> ECI	0.185	3.839	< 0.001	Supported
H2a	PA -> IEC	0.240	5.330	< 0.001	Supported
H2b	PA -> PRR	0.396	10.879	< 0.001	Supported
H2c	PA -> WHE	0.299	7.742	< 0.001	Supported
H2d	PA -> ECI	0.094	2.244	0.025	Supported
H3a	SRA -> IEC	0.241	5.895	< 0.001	Supported
H3b	SRA -> PRR	0.276	7.047	< 0.001	Supported
H3c	SRA -> WHE	0.290	7.427	< 0.001	Supported
H3d	SRA -> ECI	0.301	7.411	< 0.001	Supported
H4a	OA -> IEC	0.186	3.989	< 0.001	Supported
H4b	OA -> PRR	0.183	4.048	< 0.001	Supported
H4c	OA -> WHE	0.209	4.529	< 0.001	Supported
H4d	OA -> ECI	0.344	8.029	< 0.001	Supported

Abbreviations: CRA = Concept and Risk Awareness; PA = Procedural Awareness; SRA = Safety and Responsibility Awareness; OA = Organisational Awareness; IEC = Internal Environmental Cleanliness; PRR = Pollution and Risk Reduction; WHE = Waste Handling Efficiency; ECI = Environmental Compliance and Improvement.

The results support H1a, in which concepts and awareness of risk positively impact environmental cleanliness in the internal environment ($\beta = 0.265$, $t = 5.828$, $p < 0.001$). This provides insight into how employees who understood the meaning of medical waste were able to discriminate between hazardous and non-hazardous hospital waste, were aware of the risks involved in improper handling, and supported a clean internal area within the hospital environment. Of the four dimensions of awareness, the effect was the best predictor of internal environmental cleanliness. This implies that cleanliness depends not only on housekeeping activities but also on the extent to which both clinical and non-clinical staff are aware of the environmental and infection-related consequences of their daily disposal decisions. This finding aligns with the Knowledge-Attitude-Practice perspective, which assumes that knowledge is the basis that may stimulate safer and more regular practices.

H1b also received support with concept and risk awareness, positively influencing pollution and reducing the risk ($\beta = 0.155$, $t = 3.678$, $p < 0.001$). While the coefficient was weaker than those for procedural awareness and safety and responsibility awareness, it is still a significant relationship, as a lack of risk awareness is the motivational basis for pollution prevention. Employees who have some understanding of the potential environmental hazards associated with the combination of hazardous and non-hazardous wastes will be less likely to engage in activities that increase the risk of contamination, exposure, and treatment obligations. This effect is only moderate because when you tell people about risks without having very clear and responsible behaviour, the pollution remains quite the same. Thus, the findings emphasise that conceptual knowledge needs to be operationalised into action through training, monitoring, and waste-handling routines.

H1c was supported, as concept and risk awareness had a significant positive effect on waste handling efficiency ($\beta = 0.137$, $t = 3.124$, $p = 0.002$). The result suggests that staff members who recognise medical waste categories and related hazards can contribute to better segregation, lower unnecessary contamination of general waste, and smoother waste movement within the hospital. However, this was the weakest effect among the predictors of waste handling efficiency. This pattern is theoretically reasonable because efficiency depends heavily on knowing exactly how to act, not only on understanding why waste is dangerous. In practical terms, general awareness helps employees respect waste-management rules, but efficient handling requires specific procedural knowledge, adequate containers, clear labelling, and coordination between departments and support staff.

Support for H1d showed that concept and risk awareness significantly influenced environmental compliance and improvement ($\beta = 0.185$, $t = 3.839$, $p < 0.001$). The implication is that real benefits can be gained if those who manage the files understand the risks of medical waste, rather than treating environmental rules and improvement efforts as mere administrative boxes to check. By increasing staff awareness that institutional policies, environmental guidelines and reporting requirements exist to protect both people and the natural environment, risk awareness can reinforce compliance. However, we note that this effect was smaller than that for organisational awareness and for safety and responsibility awareness. This suggests that risk knowledge needs to be combined with observable hospital policies, accountability structures, and ongoing training to deliver better compliance and improvement outcomes.

Hypothesis 2a: Procedural awareness has a positive effect on internal environmental cleanliness. The above analyses supported H2a, as indicated by the significant use of procedural awareness in improving internal environmental cleanliness ($\beta = 0.240$, $t = 5.330$, $p < 0.001$). The authors show that improved staff knowledge of segregation, the use of containers, and proper storage, transportation, and disposal methods contributes directly to cleaner hospital units. Awareness of procedures also helps prevent improper disposal, overfilling waste containers, leakage, and odour escaping from biohazard waste bags, as well as ensuring that clinical and general waste locations do not contain cross-contaminated materials. The outcome mirrors the reality of hospital cleanliness, especially since thousands of small tasks determine hygiene performed countless times in every department and on every shift. The research also shows that training should not be just general information about medical waste risks; it needs to provide actionable, practical advice that employees can apply at the point of waste generation right away.

H2b found support and produced the most substantial path coefficient in the structural model ($\beta = 0.396$, $t = 10.879$, $p < 0.001$). It shows that procedural awareness is the strongest predictor of pollution and risk reduction. It's an obviously reasonable conclusion, since preventing pollution relies on proper segregation, labelling, storage, and transport methods. When employees know which waste streams they have and the proper bags/containers to use, this can help prevent the unnecessary mixing of hazardous waste with non-hazardous waste. This reduces the generation of hazardous materials, the exposure of waste, and thus lessens their release to the environment. This is a strong indication that pollution reduction does not rely solely on treatment technologies or external waste contractors but begins with staff procedures within the hospital, he argues.

H2c was supported, with a strong positive all-size effect of procedural awareness on efficiency in terms of waste handling ($\beta = 0.299$; $t = 7.742$; $p < 0.001$). The acknowledgement of this result is mainly contingent on employees' knowledge of the true steps required to practice safe waste management. When processes are understood, waste will flow through the hospital system in a more orderly and timely manner, resulting in fewer

errors that need to be corrected by housekeeping, environmental services, or infection-control teams. This finding also suggests that knowledge of the procedure can prevent unnecessary costs in treatment and storage, as well as delays in waste pick-up. So efficiency is more than mere logistics: it is the result of staff ability and results from continually following standardised procedures.

H2d was verified, with the effect of procedural awareness on environmental compliance and improvement being significant ($\beta = 0.094$, $t = 2.244$, $p = 0.025$). To be sure, this was the lowest important coefficient in the model. It indicates that knowing the procedures is indeed partially responsible for compliance, but this alone does not drive broader environmental improvement. Even though you know how to segregate and transport waste, it is equally important to understand hospital policies, regulatory expectations, and environmental compliance, i.e., documentation, audit systems, and managerial accountability. Hence, the lower coefficient is significant: it indicates that processes are needed to comply, but there is a need for greater institutional awareness and accountability/ownership around safety and culture at the organisational level. This result stresses the importance of combining procedural training with the communication of governance and policy.

H3a was supported, given that safety and responsibility awareness had a significant impact on internal environmental cleanliness ($\beta = 0.241$, $t = 5.895$, $p < 0.001$). This result shows that cleanliness is better when waste management is perceived as a professional responsibility of staff rather than a task delegated to housekeeping staff. Communicating well about exposure risks, personal protective measures, incident reporting, and responsibility to patients/colleagues is more likely to uphold safe disposal behaviour. This result is particularly important, as multiple occupational groups are involved in a hospital, including physicians (our main focus here), nurses and assistants, technicians (imaging and laboratory), cleaners, and administrative staff; see Box 1. Cleaner even gets diluted when one set of the group decides that the onus of dealing with waste safety is someone else's responsibility. Thus, the finding lends support to shared responsibility as a component of internal environmental purity.

Hypothesis H3b was supported, as awareness of safety and responsibility had a significant positive influence on pollution and risk reduction ($\beta = 0.276$, $t = 7.047$, $p < 0.001$). The outcome indicates that awareness of personal and collective responsibility contributes to reducing environmental and health impacts. Workers trained to recognise the repercussions of poor handling, sharps injuries, chemical exposure and spills, and infectious waste contamination are more likely to take steps to prevent unsafe practices and respond appropriately in the event of an accident. This coefficient was stronger than those for concept and risk awareness, and for organisational awareness, for this outcome; stress pollution prevention requires feeling responsible for controlling risks, not merely knowing what they are. The finding is consistent with stakeholder-oriented thinking as safe waste management safeguards patients, staff, waste handlers, surrounding communities and the environment.

H3c: The existence of safety and responsibility awareness positively influenced the efficiency of waste handling with strong support ($\beta = 0.290$, $t = 7.427$, $p < 0.001$). This product is a validation: Employees with knowledge of their responsibilities and a heavy-handed approach to handling Medical Waste take more precautionary measures and follow correct protocols to minimise or eliminate operational errors. Knowing who is responsible can eliminate delays due to incorrect sorting, incorrect transport containers, inadequate reports in neonates, and careless internal transport. It facilitates coordination between clinical staff and support staff, because everyone acknowledges their place in the waste-management line. The conclusion indicated that efficiency is beyond a technical problem, it is a behavioural and ethical effect driven by staff responsibility.

H3d was also supported by substantial historical incidence development in the contribution of safety and responsibility awareness to environmental compliance and improvement ($\beta = 0.301$, $t = 7.411$, $p < 0.001$). This was the second biggest influence on compliance and improvement behaviour (after their levels of organisational awareness). The study also shows that hospital compliance efforts garner more support from staff when they consider waste management as part of their job responsibilities, and they are more willing to comply with environmental criteria, report issues, and become involved in improvement practices. Obedience is bolstered by the belief among employees that handling waste responsibly directly affects their careers and moral obligations. The effect aligns with the belief that environmental amelioration needs norms of responsibility, in addition to

legal constraints. It also demonstrates that personal accountability in safety training can be harnessed to support environmental governance.

Thus, H4a was supported; organisational awareness significantly promoted internal environmental cleanliness ($\beta = 0.186$, $t = 3.989$, $p < 0.001$). Your knowledge of hospital policies, reporting channels, responsible units, training systems, and supervision mechanisms contributes to cleanliness in hospital interiors. While the impact of awareness of practices was smaller than that of both conceptual and risk awareness, and procedural awareness, safety and responsibility awareness remains a key contributor to alignment within departments regarding waste behaviour. Meetings are shorter when employees know who does the actual collection, where waste should go, and how to complain about non-compliance. Therefore, organisational awareness is the institutional basis that sustains everyday practices for cleaning and disposal.

H4b Supported: Organisational awareness had a strong positive impact on pollution and risk reduction ($\beta = 0.183$, $t = 4.048$, $p < 0.001$). The study concludes that both hospital policy and effective communication across departments can mitigate environmental risk. Staff who understand institutional waste-management plans, supervision systems, and reporting mechanisms will take better precautions against unsafe practices, spills, storage issues, and deviations from environmental standards. The effect was low compared to the very strong effect of procedural awareness, indicating that organisational awareness alone can never replace field operational know-how. Nonetheless, it remains important because procedures are likely to be adhered to only when there is a clear institutional system of responsibility, leadership, and monitoring.

The results thus supported H4c, showing that organisational awareness had a significant positive influence on waste handling efficiency ($\beta = 0.209$, $t = 4.529$, $p < 0.001$). This finding suggests that successful waste management is a function not only of procedural knowledge among individual staff members but also of the staff's understanding of the larger system at play in hospitals. Management of waste involves interaction among clinical departments, housekeeping and infection-control staff, the environmental services team, and outside contractors. When staff are familiar with the institutional hierarchy, delays, duplication, confusion and inconsistent practices can all be avoided. The finding also highlights the critical necessity for clearly defined internal policies, communication channels and responsibility matrices. If a hospital has solid technical procedures but those procedures are unknown to staff regarding the organisational architecture system, then efficiency will always be limited.

H4d is supported and has the most powerful effect on environmental compliance and improvement ($\beta = 0.344$, $t = 8.029$, $p < 0.001$). This finding is one of the study's major discoveries. It lends credence to the idea that institutional compliance and ongoing improvement are closely tied to staff's understanding of hospital regulation, oversight systems, reporting requirements, training programs, and accountability relationships. Organisational clarity is a requirement of governance, and compliance is an outcome of good governance. Although staff may know how to throw away waste, sustainability can be achieved only when they understand the hospital's environmental expectations, audit processes, and accountability plans. According to institutional theory, this finding holds that rules and regulations must be internalised by organisational members so that daily behaviour and performance change as a result.

The general pattern of results supports the conclusion that all four awareness dimensions are relevant, but they impact environmental performance through different processes. For internal environmental cleanliness, concept and risk awareness were particularly relevant, as a base understanding of hazards helps staff consider waste disposal as a matter of safety and cleanliness. The most decisive predictor of pollution/risk reduction and waste-handling efficiency was procedural awareness, thus confirming the operational importance of knowing how to classify, segregate, store, and transport medical waste. The awareness of safety and responsibility was consistently high across the four dependent variables, implying that personal accountability is a stable predictor of environmental performance. For environmental compliance and improvement, domain-specific organisational awareness was key, suggesting the need for formal rules and institutional systems for continued governance.

These discoveries cast a significant shadow over the literature on managing medical waste. These show that staff awareness should not be viewed as a single, overarching variable. Different forms of awareness lead to different environmental outcomes. Hence, hospitals should not implement a single large, generic awareness campaign but rather adopt targeted interventions. If the objective is to improve pollution control, training should emphasise procedural mastery. Persuasion regarding organisational policies, reporting structures, audits, and accountability is needed to strengthen compliance and continuous improvement. To improve internal cleanliness, hospitals should start making dual use of risk awareness, responsibility, and procedural clarity. The study's value comes in part from this differentiated interpretation.

7. Conclusions

Staff awareness of medical waste management is the strongest determinant of hospitals' environmental performance, according to this study's conclusion. The results validate the observation that awareness is not just an informational variable; it is, in fact, a practical organisational capability which aids hospitals to avoid conterminous and hazardous conditions internally, do well with sorting and segregating waste more efficiently as part of pollution prevention, while contributing towards enhanced environmental compliance aligned with improving overall environmental performance. The results across all paths we tested were both good and statistically significant, indicating that hospital environmental performance is determined by staff knowledge, interpretations of roles and responsibilities, and clarity about rules and regulations.

The first major conclusion is that the human side of medical waste management plays a key role in hospital environmental performance. Hospitals may have containers, contracts, protocols and treatment systems, but these systems are based on staff behaviour at the source of waste generation and handling. Formally established systems can be counterproductive if incorrect segregation, insecure storage, poor reporting, or confused roles undermine their impact. Thus, it is not infrastructure alone that drives environmental performance, but the combination of infrastructure with employee awareness and organisational control.

The second conclusion is that awareness is not one-dimensional. Concept and risk awareness have laid down the basic reasons for how medical waste management should be conducted. Procedural awareness details what staff should actually do. The implications of safety and responsible conduct naturally galvanise personnel to own safe waste behaviour. Organisational awareness links individual action to hospital policy, supervision, and compliance obligations. The study reveals that these dimensions must be measured and managed separately, as they exert different magnitudes of influence on specific environmental effects.

The third conclusion is that the effect of procedural awareness is particularly important for pollution and risk reduction, as well as for waste-handling efficiency. Thus, hospitals looking for immediate operational improvements should focus on training related to waste categories, colour coding and container selection, labelling of containers, segregation at source and during temporary storage, and internal transport, in addition to final disposal sites. Well-documented procedural knowledge keeps mistakes from propagating up the waste-management chain.

The fourth is that, this timely study concludes, the key dimension for environmental compliance and improvement is organisational awareness. This finding demonstrates that putting bins and bags to good use is insufficient for compliance. To implement this, staff awareness of hospital policies and responsible departments is needed, along with monitoring systems for reporting channels to be employed, and training and documentation of environmental objectives. Hospital management should thus view medical waste management as a component of institutional environmental governance.

Fifth, awareness of safety and responsibility is a consistently significant predictor of dimensional environmental performance. This implies that Hospitals should not only teach their staff about medical waste and its management but also explain why every individual affiliated with the hospital is responsible for safeguarding patients, co-employees, waste handlers, and the environment. Establishing a culture of shared responsibility for waste management can turn what is usually a bureaucratic task into a professional and ethical practice.

7.1 Theoretical Contributions

Theoretical contributions of the study to medical waste management, sustainable healthcare and hospital environmental performance literature. The first contribution is to integrate staff awareness and environmental performance into a single empirical model. Previous studies have typically investigated attitudes, knowledge, and practices in parts of practice concerning healthcare workers or the environmental performance indicators of hospitals. This study connects those two streams by demonstrating that staff awareness can account for differences in environmental performance among hospitals. In doing so, it addresses the need for a socio-technical perspective on medical waste management: a view where human awareness and organisational factors are considered important determinants of environmental impact.

The second theoretical contribution is its multidimensional conceptualisation of staff awareness. Instead, the study differentiates among concept and risk awareness, procedural awareness, awareness of safety and responsibility, and organisational awareness, rather than relying on general constructs to measure awareness. To clarify these concepts, the distinction between awareness and doctor wisdom is clarified through its practice-relative application in the medical waste (MW) context. It also aids in clarifying the variance of effects amongst measures of awareness across outcomes. The results confirm, as expected, that procedural awareness is most strongly related to operational outcomes, and organisational awareness is most strongly related to compliance and improvement.

Third, this paper examines hospital environmental performance from a multidimensional perspective. This study does not reduce environmental performance to a single unified attitude. Attached to that, it differentiates the construct into internal environment cleanliness, pollution and risk reduction, waste disposal efficiency and environmental management. This method enables researchers to pinpoint the specific factors of environmental performance that are most effectively influenced by each type of staff awareness. It also makes it a more valuable resource for future research that will connect specific human or organisational drivers to specific environmental outcomes in the health care sector.

The fourth contribution concerns the empirical validation of several theoretical positions. So, given the positive influence of knowledge on environmental performance, they are in line with the traditional perspective called the Knowledge-Attitude-Practice because awareness is placed upon Practice. Procedural and organisational awareness also support the Theory of Planned Behaviour, as these dimensions primarily strengthen perceived behavioural control and subjective norms regarding proper waste behaviour. Because training, role modelling and awareness of responsibility can translate knowledge into more habitual practices, Social Cognitive Theory is also an important aspect. Institutional Theory corroborates the strong impact of organisational awareness on compliance and improvement. Stakeholder Theory shows that, through awareness of safety and responsibility, there is a sense of obligation toward staff, patients, waste handlers, communities, and the environment.

The fifth contribution is contextual. The study provides information on the Saudi healthcare context, which is characterised by concerns regarding waste management institutions, environmental performance, and regulatory compliance, by focusing on hospitals in the Al-Qassim Region. These results further extend medical waste management research beyond descriptive and technical approaches by showing how staff awareness can inform a practical organisational capability in hospital environmental management systems.

Last but not least, the paper adds to research on PLS-SEM applications in the healthcare environment. The analysis revealed adequate psychometric properties, with reliable indicators, acceptable convergent validity, discriminant validity using the Fornell-Larcker and HTMT calculators, and relevant structural relationships. This is an advantageous methodological example for approaching a multidimensional awareness-performance model in hospital settings for future researchers.

7.2 Practical Contributions

The study has practical implications, and the findings are relevant for hospital managers, quality departments, infection-control units, environmental services, and training departments, as well as for health policymakers.

The first practical contribution is the identification of staff awareness as an organisation-controllable driver of hospital environmental performance. Awareness can be trained, oriented, supervised, communicated, and reinforced through reminders (e.g., post-it notes or signboards), audits, and feedback systems, and made part of accountability. So, some aspects of environmental performance can be strengthened without waiting for large-scale changes in infrastructure; hospitals can begin by strengthening daily waste-handling behaviour and staff awareness.

The second main contribution is that the study demonstrates which dimensions of awareness need to be targeted for specific environmental objectives. If the second goal is to increase internal cleanliness, concept and risk awareness, procedural awareness, and responsibility awareness should be reinforced in hospitals. Finally, if the aim is to reduce pollution and risk, practical procedural training should be favoured because it has a greater impact on these outcomes. For instance, if the aim is to enhance efficiency in waste management, then hospitals must ensure procedural awareness and assume safety accountability. However, if the goal is to improve environmental compliance and continuous improvement, hospitals need to raise organisational awareness by discussing policies, reporting lines, audit procedures & accountability structures.

The third, it contributes in practical terms by highlighting collective responsibility. The findings revealed that an awareness of safety and responsibility has a large positive impact on all aspects of environmental performance. Hence, medical waste management should not be regarded as just an obligation of housekeeping staff. Waste-management chain: physicians, nurses, pharmacists, laboratory workers, technicians and administrative staff, cleaning team with environmental services. This result allows for hospitals to structure inter-departmental awareness programs that minimise responsibility shifting amongst groups.

The fourth practical contribution is the role-based training support. Various forms of waste are encountered, and each staff group has its own responsibilities. Nurses and doctors are on the front lines of healthcare waste and needles. It is all the more special because laboratory staff handle specimens, chemicals, and contaminated objects. The pharmacist may handle expired or end-of-life drugs. Housekeeping and cleaning personnel also collect, transport, and, in some cases, store waste. Administrative staff will need to be included if they are involved in documentation, supervision or policy implementation. A single general training session, therefore, is unlikely to be enough. Discipline should be customised according to job categories, departments, exposure levels, and responsibilities performed.

The fifth practical contribution is the prominent role of organisational awareness in compliance with environmental regulations and the amelioration of the environment, suggesting that leaders within hospitals should be visible and clear about waste-management policies. Employees need to know who makes decisions about waste, where to report incidents, how non-compliance is handled, and how waste performance is defined. This can help transform environmental compliance from a piece of paper into an operational reality.

The sixth practical contribution is that the study creates a basis for strong performance monitoring by hospital managers. Awareness indicators could be incorporated within internal audits and quality improvement systems. Hospitals can assess their staff's knowledge of: waste categories, procedural steps to follow when encountering a hazardous waste incident, reporting an incident, awareness of the hospital policy, and perceived environmental performance. Comparing across time by department helps hospital managers pinpoint weaknesses and tailor fixes. This is a great contribution because medical waste management is not a one-off activity, and you need to stay up to date with practices until October 2023, as that is the data I am looking at.

7.3 Limitations and Future Directions

This is a cross-sectional study, meaning that while it can show significant associations between staff awareness and environmental performance, it cannot confirm causal relationships over time. Variations in staff awareness, practices within the delivery of care, and environmental performance can change over time as regulations give rise to new practices, training programs, or infection outbreaks, managerial changes occur, or waste-management systems are updated. A second limitation was that questionnaire data were self-reported. Although staff perceptions are meaningful, as employees are directly involved in medical waste practices, self-report data may be vulnerable to social desirability and recall biases, as well as to differences in the interpretation of

questionnaire items across groups. Statistical checks for common method bias were performed, and the study ruled it out. However, such evidence may be further strengthened in future studies that combine surveys with direct observation, audit records, or objective waste data. The third limitation is geographic. The study was conducted within hospitals in Al-Qassim Region. The findings have utility within this area but should be extrapolated with caution to other areas or countries, as these factors (hospital size and resources, regulatory enforcement mode, training systems, waste infrastructure, etc.) can differ across regions.

Future work should utilise longitudinal designs to determine whether changes in staff awareness over time are linked to objectively measured environmental performance. A longitudinal design would be well-suited to assessing the impacts of training programs, new hospital policies, or environmental improvement activities. Future research may focus on integrating both self-reported questionnaire data and objective performance measurements. These include the true weights of waste, proportions of hazardous and non-hazardous waste, tipping-point error rates, incident reports, audit scores, average treatment costs, and emissions to the environment. It would also allow for a broader evaluation of hospitals' environmental performance.

While quantitative frameworks and Key Performance Indicators (KPIs) exist to measure hospital environmental performance—such as energy use intensity, regulated medical waste ratios, and greenhouse gas footprint protocols—this study faces limitations regarding data accessibility, heterogeneity, and reporting fragmentation. First, environmental reporting in healthcare remains largely voluntary in many jurisdictions, resulting in disparate datasets and a reliance on self-reported institutional surveys. Second, significant variations exist in data normalisation methodologies; for instance, differences in how "Adjusted Patient Days" (APD) are calculated or in accounting for outpatient surgical volume complicate direct cross-institutional benchmarking. Finally, while hospitals generally track direct operational metrics such as Scope 1 and Scope 2 energy emissions, comprehensive data on Scope 3 supply chain lifecycle impacts and anaesthetic gas carbon intensities remain highly fragmented or completely opaque in administrative records. Consequently, these data tracking gaps limit the generalizability and seamless comparative analysis of environmental sustainability metrics across diverse healthcare systems.

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