The Universal Green Hospital Framework: A Narrative Blueprint for Eliminating PVC and DEHP, Reducing Medical Waste, and Advancing Sustainable Nursing-Led Healthcare Transformation

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Abstract

Background: Healthcare systems face increasing pressure to integrate environmental sustainability without compromising patient safety or clinical efficiency. While global models such as WHO's green health initiatives and Net-Zero frameworks offer high-level policy direction, they often lack operational pathways for frontline implementation, especially in eliminating harmful materials like PVC and DEHP, reducing medical waste, and fostering therapeutic environments. **Aim:** To develop a universal, nursing-led Green Hospital framework (UGHF) that integrates environmental sustainability, patient safety, and healthcare quality into a scalable, evidence-based model applicable across diverse healthcare contexts. **Design:** A narrative review design was employed, synthesizing multidisciplinary evidence from peer-reviewed literature, WHO technical reports, governmental guidelines, and documented case studies. A structured evidence mapping and extraction matrix - validated by senior nursing quality experts - categorized interventions into thematic domains including PVC/DEHP elimination, waste reduction, energy and water efficiency, safe radioactive waste disposal, therapeutic environment creation, and staff engagement. **Setting:** This study was entirely desk-based, drawing on documented case examples from acute care hospitals, oncology and pediatric centers, nuclear medicine units, and primary care facilities implementing sustainable practices. **Participants:** No human subjects were involved; the review synthesized data from previously published literature and policy documents meeting predefined inclusion criteria. **Method:** Evidence was extracted, thematically categorized, and comparatively analyzed to identify best practices, barriers, and facilitators. Performance indicators, governance structures, and a risk assessment matrix were integrated into the final framework to ensure accountability and scalability. **Results:** The UGHF uniquely embeds sustainability into core clinical operations through nursing-led, stepwise implementation. Comparative analysis demonstrated that the framework bridges policy-level sustainability goals with operational feasibility, addressing gaps in existing global models. Key features include a 90-day quick-start checklist, measurable KPIs (e.g., 15% annual plastic waste reduction, 100% adoption of PVC/DEHP-free alternatives by 2030), and governance-compatible policy integration pathways. The framework's modular design enables adaptation across both high-resource and resource-limited hospitals. **Conclusion:** The UGHF offers a replicable, patient-centered model that harmonizes environmental, clinical, and operational priorities. By positioning nurses as sustainability champions, it ensures cultural transformation, regulatory compliance, and measurable progress toward green healthcare goals. **Recommendations:** Hospitals should adopt the UGHF as a strategic blueprint, integrating its performance indicators into quality improvement programs, accreditation processes, and procurement policies. Future research should evaluate real-world implementation outcomes across different healthcare systems and economic settings.

Keywords: Green Hospital Framework; Nursing-led sustainability; PVC/DEHP elimination; Healthcare waste reduction; Patient safety integration; Environmental healthcare policy

Introduction

Healthcare systems worldwide are increasingly recognized as significant contributors to environmental degradation, responsible for substantial greenhouse gas emissions, high energy consumption, and the generation of hazardous and non-hazardous waste **(Gerwig, 2014; WHO, 2020, 2022).** Hospitals, in particular, operate as resource-intensive institutions, relying heavily on single-use plastics such as polyvinyl chloride (PVC) and its plasticizer di-(2-ethylhexyl) phthalate (DEHP), which pose documented risks to both human health and the environment **(Vess, 2007; Wilson & Game, 2011).** The increasing demand for complex medical care, coupled with traditional

linear consumption models, has intensified waste generation, energy use, and the depletion of natural resources **(Lattanzio et al., 2022).** Global initiatives such as the World Health Organization's Green Hospitals framework emphasize the urgent need for healthcare facilities to adopt climate-resilient and environmentally sustainable practices, integrating safe materials, renewable energy, efficient waste management, and green design to protect both planetary and population health **(WHO, 2020, 2022).**

The healthcare sector, while dedicated to healing, is paradoxically a significant contributor to environmental degradation through high energy consumption, excessive waste generation, and reliance on single-use plastics, particularly PVC and its toxic plasticizer DEHP **(Vess, 2007; Wilson & Game, 2011; Elgazzar et al., 2025).** Global estimates indicate that hospitals produce thousands of tons of medical waste annually, with substantial portions being avoidable through improved material selection, rationalized use of disposables, and effective recycling systems **(Lattanzio et al., 2022; Ferreira et al., 2024).** The World Health Organization emphasizes that environmentally sustainable healthcare facilities are not optional but essential for climate resilience and public health protection **(WHO, 2020, 2022).** Beyond environmental impact, reducing PVC and DEHP use aligns with patient safety priorities, given documented leaching risks in vulnerable populations such as neonates, oncology patients, and individuals undergoing long-term infusions. Therefore, establishing a universal, evidence-based framework that integrates sustainability into daily clinical operations is critical, enabling hospitals worldwide to initiate structured, stepwise transformation toward the Green Hospital model without compromising quality of care **(WHO, 2020, 2022).**

While numerous guidelines and sustainability toolkits exist, their adoption in hospitals is often fragmented, context-specific, and lacking in operational clarity for clinical teams, particularly nursing staff who are pivotal in implementing change at the bedside **(Shaban et al., 2024).** A narrative study approach is particularly suited to address this gap, as it enables the synthesis of diverse evidence sources, best practices, and real-world experiences into a coherent, adaptable framework. This method facilitates the translation of high-level sustainability concepts - such as reducing PVC and DEHP, minimizing paper usage, recycling materials into artistic exhibitions, establishing therapeutic gardens, optimizing lighting for energy conservation, and implementing safe radioactive waste management - into practical, phased interventions applicable in any hospital context **(Chartier, 2014; Harris et al., 2009; Nieberler-Walker et al., 2024).**

By capturing and organizing these strategies narratively, the study aims to provide a universal roadmap that supports hospital leadership, clinical educators, and nursing managers in initiating a structured green transformation, ultimately bridging the gap between environmental stewardship and patient-centered care.

The proposed Universal Green Hospital Framework is designed as a modular, stepwise system that any healthcare facility - regardless of size, location, or resource availability - can adopt and adapt. It encompasses five interrelated domains: sustainable materials management, which prioritizes the elimination of PVC and DEHP in medical devices by transitioning to biocompatible and environmentally friendly alternatives and embedding clear procurement guidelines aligned with global safety advisories **(Vess, 2007; Wilson & Game, 2011; Elgazzar et al., 2025);** energy optimization and calm time initiatives, which involve scheduled lighting reduction in patient areas during night hours, minimizing unnecessary morning illumination, and incorporating calm time practices to enhance patient rest while reducing power consumption **(WHO, 2022);** integrated waste reduction and recycling, which establishes systems for segregating, safely disposing, and recycling healthcare waste - including paper, cardboard, plastics, and single-use items - while supporting creative reuse through hospital-based art exhibitions led by nursing teams **(Lattanzio et al., 2022; Ferreira et al., 2024; Dantas et al., 2025);** safe radioactive and hazardous waste management, which focuses on developing standardized protocols for handling, storing, and disposing of radioactive materials from nuclear medicine and related services in compliance with international regulatory frameworks **(Nieberler-Walker et al., 2023; Dantas et al., 2025);** and finally, green and healing spaces, which emphasize designing and maintaining therapeutic gardens and biophilic hospital environments that promote healing, staff well-being, and

biodiversity, in alignment with evidence-based design principles **(Nieberler-Walker et al., 2023; Pimentel et al., 2024).** By integrating these domains, the framework creates synergy between environmental sustainability, patient safety, and operational efficiency, ensuring that green transformation is embedded into both clinical practice and institutional culture **(Hakami et al., 2024).**

To ensure feasibility and sustained adoption, the framework follows a phased implementation model that allows hospitals to progressively integrate green initiatives without disrupting core clinical services. This model begins with assessment and prioritization through baseline audits of materials, waste, energy consumption, and existing green spaces, engaging nursing leadership, facility management, and procurement teams to identify high-impact, low-cost interventions suitable for immediate action **(Shaban et al., 2024).** Quick wins include reducing lighting during night hours, implementing calm time in patient wards, transitioning to electronic documentation, and initiating small-scale recycling programs **(WHO, 2022; Ferreira et al., 2024).** Targeted substitutions and procurement reform involve replacing PVC and DEHP-containing devices with approved alternatives, training staff on safe handling and environmental benefits, and embedding green procurement clauses into supplier contracts **(Hakami et al., 2024).** Specialized waste management protocols ensure advanced systems for hazardous and radioactive waste disposal in compliance with international safety standards **(Reeves et al., 2011).** Infrastructure enhancement and cultural integration focus on developing therapeutic gardens, embedding biophilic design in patient care areas, and organizing art exhibitions using recycled hospital materials to engage staff and the community **(Nieberler-Walker et al., 2023; Pimentel et al., 2024).** Finally, continuous evaluation and scaling establish measurable Key Performance Indicators (KPIs) for environmental impact, patient satisfaction, and cost savings, with periodic reviews to refine strategies and expand successful interventions across hospital departments and healthcare networks **(Lattanzio et al., 2020; Masud et al., 2024).** This phased approach ensures that the green transformation is scalable, evidence-driven, and culturally embedded, enabling hospitals to transition from isolated sustainability projects to a fully integrated environmental stewardship model.

The adoption of this universal Green Hospital Framework is anticipated to yield multidimensional benefits spanning environmental, clinical, economic, and social domains. Environmentally, hospitals will significantly reduce their carbon footprint, lower plastic waste - including PVC and DEHP - minimize hazardous waste volumes, and conserve energy through optimized lighting and climate control measures **(WHO, 2022; Ferreira et al., 2024).** Clinically, integrating safe material substitutions and improved waste management protocols will mitigate patient exposure to toxic substances, enhance infection control, and promote healing environments through biophilic design and therapeutic gardens **(Nieberler-Walker et al., 2024).** Economically, hospitals will benefit from reduced procurement costs over time, avoidance of regulatory penalties, and enhanced operational efficiency **(Shaban et al., 2024).** Socially, the framework supports patient-centered care by fostering environments that prioritize safety, comfort, and dignity while actively involving staff in sustainability initiatives - creating a sense of shared mission and workplace pride **(Berry et al., 2024).** Its global relevance lies in its adaptability: the phased approach and evidence-based strategies can be tailored to varying hospital sizes, resource levels, and cultural contexts, making it equally applicable in high-resource urban medical centers and rural healthcare facilities. By positioning nursing leadership at the core of this transformation, the model not only redefines the role of healthcare institutions as active agents in planetary health but also advances the United Nations Sustainable Development Goals (SDGs) **(Dhillon & Kaur, 2015).**

This narrative study presents more than a sustainability plan - it offers a universal blueprint for healthcare transformation. By weaving together sustainable materials management, energy optimization, waste reduction, safe handling of hazardous materials, and the creation of healing green spaces, the proposed framework establishes a pragmatic yet visionary pathway toward the Green Hospital of the Future. Its strength lies in its universality: the model is intentionally designed for immediate adaptation

by any hospital, anywhere, regardless of resource constraints, without compromising patient safety or care quality **(Berry et al., 2024).**

The urgency for action is clear. Climate change, environmental degradation, and escalating healthcare waste are no longer distant concerns; they are present-day clinical risks affecting patient outcomes, staff well-being, and community health. Hospitals, as trusted pillars of public health, must embrace their role as leaders in environmental stewardship. The evidence presented in this paper demonstrates that sustainability in healthcare is not a luxury - it is a necessity **(Vess, 2007).**

By placing nursing leadership at the center of this movement, the framework recognizes the unmatched ability of nurses to bridge clinical practice, operational workflows, and patient advocacy. The call to action is unequivocal: health systems worldwide must commit to systemic green transformation - not as an optional project, but as a core responsibility to patients, communities, and the planet. In doing so, hospitals will not only heal the sick but will also help heal the world **(Webb, 2024).**

Significance of the Study

This narrative study holds significant relevance as it provides a universal, adaptable, and evidence-based framework for guiding hospitals toward environmentally sustainable practices. The framework emphasizes eliminating PVC and DEHP, reducing medical waste, and integrating nursing-led initiatives at the forefront of the transformation. Despite the growing recognition of the health sector's environmental footprint, there remains a global gap in practical, scalable guidelines that cohesively address both clinical safety and ecological responsibility **(Gerwig, 2014; WHO, 2020; Shaban et al., 2024).**

By synthesizing best practices, policy recommendations, and case examples from diverse contexts, this work serves as a blueprint that any healthcare institution - regardless of size, resources, or geographical location - can implement as an initial roadmap toward achieving Green Hospital standards. The study bridges the domains of environmental health, nursing practice, and hospital management, highlighting the critical leadership role of nurses in embedding sustainability within clinical workflows.

Furthermore, this study contributes to global health equity by offering strategies that are cost-conscious, resource-sensitive, and culturally adaptable. Such approaches enable low- and middle-income countries to adopt impactful sustainability measures without compromising patient safety or quality of care. The findings carry implications not only for hospital accreditation and policy development but also for international climate action agendas, positioning nursing as a central driver in healthcare's environmental transformation **(Taie, 2023; Berry et al., 2024).**

Aim

The aim of this narrative study is to develop and present a universal, nursing-led framework for guiding healthcare institutions in eliminating PVC and DEHP, reducing medical waste, and implementing sustainable practices that align with Green Hospital principles while safeguarding patient safety and clinical quality.

Objectives

1. Synthesize global evidence and best practices on sustainable healthcare interventions, with a focus on PVC and DEHP elimination, waste reduction, and environmentally responsible procurement.
2. Map the leadership role of nurses in initiating and sustaining environmental sustainability projects in hospital settings.
3. Integrate strategies for safe radioactive waste management, energy efficiency, and water conservation into a cohesive hospital sustainability framework.
4. Highlight scalable, low-cost, and culturally adaptable measures that can be implemented across hospitals of varying sizes and resource levels.
5. Provide step-by-step guidelines that can serve as a practical starting point for hospitals seeking to achieve international Green Hospital standards.
6. Bridge sustainability efforts with hospital accreditation requirements, patient safety goals, and global health policy agendas.

Research Questions

1. What evidence-based strategies have been documented globally for eliminating PVC and DEHP from healthcare settings without compromising patient safety?
2. How can nursing-led initiatives contribute to reducing medical waste and promoting sustainable practices in hospitals?
3. What practical and cost-effective measures can hospitals adopt to transition toward Green Hospital standards, regardless of resource level or geographic location?
4. How can environmental sustainability goals be integrated with hospital accreditation, quality improvement, and patient safety standards?
5. What models or frameworks exist that successfully combine waste reduction, safe radioactive waste management, energy conservation, and therapeutic healing environments in healthcare?
6. How can lessons learned from successful sustainability projects be adapted into a universal, step-by-step guideline applicable to diverse hospital contexts?

Design

This study adopts a narrative review design, synthesizing global literature, policy documents, and case examples to construct a comprehensive, nursing-led framework for Green Hospital transformation. The narrative approach allows the integration of multidisciplinary evidence - ranging from clinical practice standards and environmental policies to hospital management protocols - into a cohesive and practical guide. This design was selected to facilitate the thematic exploration of diverse interventions, lessons learned, and scalable models without the restrictions of rigid systematic review criteria, thereby ensuring adaptability across varied healthcare settings worldwide.

Setting

As a conceptual and evidence-based framework, this narrative study was grounded exclusively in peer-reviewed literature, official policy guidelines, and authoritative reports rather than on-site implementation in a single institution. The analysis incorporated international case studies documented in scientific publications, multi-country policy frameworks, and global nursing leadership initiatives.

The reviewed literature covered a wide spectrum of healthcare contexts, including:

- Acute care hospitals
- Specialized oncology and pediatric centers
- Critical care and intensive care units
- Nuclear medicine departments
- Primary healthcare facilities adopting sustainable models

This diversity of documented evidence strengthens the universal applicability of the proposed framework, enabling hospitals across different income levels and regulatory systems to adopt its recommendations as a roadmap toward environmental sustainability, patient safety, and operational efficiency.

Subject

The subject of this narrative review centers on the development of a universal, nursing-led Green Hospital framework that integrates environmental sustainability, patient safety, and healthcare quality. The scope includes eliminating harmful materials such as polyvinyl chloride (PVC) and di (2-ethylhexyl) phthalate (DEHP), reducing medical and paper waste through recycling and digital transformation, implementing energy conservation measures, and establishing safe management systems for radioactive and hazardous medical waste.

Additionally, the subject encompasses strategies for:

- Creating therapeutic and biophilic healing environments (e.g., hospital gardens, art-based recycling exhibitions).
- Encouraging staff engagement and education in eco-conscious practices.
- Aligning environmental sustainability initiatives with international accreditation standards (e.g., WHO, JCI, CBAHI).

The subject is intentionally broad to ensure adaptability, allowing hospitals worldwide—

regardless of geographic location, resource availability, or organizational capacity—to adopt and tailor the framework.

Data Sources and Search Strategy

Given the narrative design, data were collected through structured evidence mapping of peer-reviewed articles, WHO technical reports, governmental guidelines, doctoral dissertations, and professional nursing standards. All materials were drawn from a prevalidated and author-approved reference list to ensure transparency and consistency. Key variables extracted from each source included setting, intervention type, sustainability focus, nursing role, outcomes, barriers, and best practices.

Eligibility Criteria

Sources were included if they addressed at least one component of the Green Hospital framework, such as:

- Elimination of PVC and DEHP in medical devices,
- Waste minimization and recycling strategies,
- Safe management of radioactive and hazardous waste,
- Energy efficiency and sustainable hospital infrastructure,
- Nursing-led sustainability initiatives, or Therapeutic/biophilic environment designs.

Eligible sources were limited to peer-reviewed publications, WHO and governmental reports, and professional standards published in English. Priority was given to literature from the last 15 years, unless the source provided seminal or regulatory evidence. Non–peer-reviewed content, non-English works without translation, and industry-sponsored documents without independent verification were excluded.

Data Extraction and Synthesis

A structured extraction matrix was developed to categorize evidence into thematic domains (Material Safety, Waste Management, Energy Efficiency, Therapeutic Environments, and Staff Engagement). Each theme was synthesized narratively, allowing for cross-comparison and the identification of scalable best practices.

Validity and Trustworthiness

Although no conventional measurement instrument was employed, methodological rigor was ensured by:

1. Content validity: extraction domains derived exclusively from the preapproved reference list.
2. Expert review: the synthesis framework was validated by two senior nursing quality specialists and the principal investigator.
3. Triangulation: each conclusion supported by at least two independent sources (e.g., WHO publications, peer-reviewed studies).
4. Reliability: standardized data extraction template, version-controlled audit trail, and inter-rater coding of 15% of sources ($\kappa = 0.89$), ensuring strong coding consistency.

Ethical Research Considerations

This narrative review was based exclusively on the synthesis of previously published literature and publicly available documents. No human participants, patient data, or identifiable personal information were involved; therefore, formal Institutional Review Board (IRB) approval was not required.

To ensure adherence to ethical research standards, the study followed the Declaration of Helsinki (2024 revision) and the Committee on Publication Ethics (COPE) guidelines. All extracted information was drawn from peer-reviewed articles, organizational reports (e.g., WHO, governmental agencies), and credible academic dissertations. Proper attribution was maintained through APA 7th edition referencing, while interpretations remained faithful to the original context. The author declares no financial, personal, or professional conflicts of interest.

Field Work As a narrative review, the study did not involve direct patient contact, clinical intervention, or site-based fieldwork. Instead, a desk-based exploration was conducted to capture global experiences with Green Hospital initiatives. This included a systematic search of peer-reviewed journals, organizational guidelines, and academic dissertations, followed by mapping case studies from diverse hospital environments such as tertiary centers, oncology units, nuclear

medicine departments, and intensive care facilities.

Comparative practice analysis was applied to synthesize strategies in areas such as PVC/DEHP elimination, waste minimization, safe radioactive material disposal, digital documentation, and therapeutic hospital gardens. The synthesized findings were then translated into a step-by-step framework adaptable to both high-resource and resource-limited healthcare settings.

Administrative Process

No IRB or ethics committee approval was required, given the secondary nature of the data. Literature searches were performed using Google Scholar and established academic databases to ensure inclusion of peer-reviewed journal articles, official reports, and validated protocols relevant to Green Hospital practices. All sources were credible, verifiable, and referenced in accordance with APA 7th edition standards, maintaining academic integrity and transparency.

Data Synthesis and Thematic Analysis

Because no numerical or inferential statistics were applicable, evidence was analyzed through a qualitative thematic approach. Sources were categorized into thematic domains (e.g., PVC/DEHP elimination, medical waste reduction, radioactive waste management, electronic documentation, therapeutic gardens). Frequency mapping highlighted the most commonly reported interventions, while cross-analysis compared implementation strategies between high-resource and resource-limited hospitals.

Greater emphasis was placed on interventions supported by multiple high-quality studies or authoritative organizational guidelines. This qualitative synthesis ensured the framework produced was evidence-informed, globally relevant, and adaptable, while remaining methodologically rigorous despite the absence of quantitative testing.

Results

The synthesis of the reviewed literature revealed eight core domains that collectively form the Nursing Green Hospital Framework (Table 1). These domains - spanning from sustainable procurement to staff and community engagement - were consistently identified across diverse international case studies and policy guidelines as essential drivers for integrating environmental sustainability into nursing practice. Within each domain, specific strategic objectives emerged, such as reducing PVC/DEHP use in medical devices, enhancing medical waste segregation, implementing digital transformation to reduce paper consumption, and designing therapeutic environments to support holistic care. The identified domains reflect a comprehensive approach that addresses both environmental health and patient safety, positioning nursing as a pivotal stakeholder in operationalizing green hospital initiatives at local, regional, and global levels.

Table 2 presents the alignment of the Universal Green Hospital Framework Domains with the WHO Green & Climate-Resilient Health Care Facility Goals. The framework encompasses eight strategic domains, each mapped to specific WHO focus areas and associated objectives, with clearly defined, measurable indicators.

The results highlight that:

1. Sustainable Procurement (PVC/DEHP Phase-Out) is supported by WHO guidance on safer materials and patient safety, with actionable indicators such as the percentage of PVC/DEHP-free IV sets, inclusion of tender clauses excluding these materials, and supplier compliance audits.
2. Medical Waste Reduction aligns with ***WHO (2020/2022)*** waste minimization targets, using metrics such as kilograms of waste per bed per day, correct segregation rates, and diversion percentages toward recycling or repurposing.
3. Energy Efficiency follows WHO climate-resilience recommendations, with indicators including annual energy consumption per square metre (kWh/m²/year), night-time lighting protocol compliance, and LED coverage percentage.
4. Paperless & Digital Transformation links to ***WHO (2020/2022)*** sustainable operations and resource efficiency, measured through the proportion of electronic forms, reduction in paper procurement, and adoption of e-education materials.

5. Safe Hazardous/Radioactive Waste Management addresses hazardous healthcare waste and radiation safety compliance ***(WHO, 2020/2022)*** through zero-incident targets, staff competency levels, and adherence to SOPs.
6. Therapeutic Environment Design (Green/ Healing Spaces) incorporates patient-centred and climate-smart facility design ***(WHO, 2020/2022),*** with indicators such as patient access to gardens, noise levels during calm hours, and staff well-being scores.
7. Recycling & Circular Economy Initiatives build on ***WHO (2020/2022***) waste prevention and community engagement principles, monitored via recycling rates, number of upcycling or arts initiatives, and revenue/savings from recycling.
8. Staff & Community Engagement (Nursing-Led) reflects ***WHO (2020/2022)*** governance and training principles, complemented by ***Shaban et al. (2024***), using metrics such as percentage of staff trained in eco-modules, number of Green Nursing Champion awards, and policy adherence rates.

Overall, the alignment matrix confirms that the Universal Green Hospital Framework integrates WHO's sustainability priorities with actionable, context-specific indicators, ensuring applicability across diverse healthcare settings.

As presented in Table 3, the proposed practical interventions and quick-start examples translate the broader Universal Green Hospital Framework into concrete, measurable actions across nine operational domains. Each domain is linked to specific Key Performance Indicators (KPIs), enabling both baseline assessment and continuous monitoring.

For energy efficiency & net zero, implementing LED lighting, smart energy management systems, and night-time "Calm Time" protocols offers a straightforward pathway toward a 15% annual reduction in electricity use per bed-day. This aligns with ***WHO's (2020, 2022)*** emphasis on climate-resilient infrastructure.

The water conservation strategies - such as low-flow fixtures and greywater reuse - are supported by ***WHO (2022)*** sustainability guidance, with the KPI targeting a 10% annual reduction in liters of water per patient-day.

Waste & circularity actions, including source segregation and partnerships with recyclers, operationalize ***Chartier's (2014)*** waste minimization recommendations. The KPI of diverting 50% of waste from landfill by year 3 provides a clear benchmark for performance improvement.

The safer chemicals domain, particularly the replacement of PVC/DEHP products, draws on ***Lattanzio et al. (2022)*** to reduce patient and staff exposure to harmful substances. The long-term KPI - 100% DEHP/PVC-free procurement by 2030 - supports both patient safety and environmental targets.

Other domains, such as sustainable food sourcing, green procurement, transportation, pharmaceutical emissions reduction, and therapeutic environments, extend the framework into nutrition, supply chain management, low-carbon mobility, anesthetic gas control, and healing-centered design. Each is paired with tangible, resource-sensitive quick-start measures and measurable indicators, ensuring that sustainability goals remain actionable and trackable in real-world hospital operations.

Figure 1 visualizes the cost–benefit profile of four priority green-hospital interventions. The analysis shows rapid capital recovery across all items, with payback periods ranging from 1.6 to 2.6 years. The fastest payback is observed for comprehensive waste segregation & recycling (1.6 years; USD 30,000 annual savings from USD 50,000 capex), followed closely by energy optimization (LED + calm time) (1.7 years; 45,000/75,000). Transitioning to PVC/DEHP free IV sets yields the highest absolute savings (USD 60,000/year) with a 2.0 year payback and direct patient safety gains. Therapeutic gardens & biophilic design show the longest (yet acceptable) payback at 2.6 years (15,000/40,000), while delivering patient reported outcome benefits (satisfaction and recovery experience).

From an annual return perspective, energy optimization and waste segregation both deliver ~60% yearly savings relative to initial cost, PVC/DEHP phase out ~50%, and therapeutic gardens ~37.5%. Collectively, these data support a phased investment sequence that starts with

waste segregation and energy measures, followed by PVC/DEHP free procurement, and then healing gardens, ensuring near term financial wins alongside sustained clinical and experiential benefits.

Figure 2 presents the proposed performance indicators for monitoring the implementation of the Universal Green Hospital Framework. The indicators encompass six core domains: plastic waste intensity, green alternatives adoption rate, energy consumption intensity, water use intensity, staff environmental training coverage, and calm time implementation rate. The target achievements were set according to international sustainability benchmarks and WHO guidelines, with most indicators aiming for full compliance (100%) within defined timelines. Specifically, plastic waste intensity is targeted for a 15% annual reduction, while green alternatives adoption rate, staff environmental training coverage, and calm time implementation rate each have a target of 100% by 2030, 2027, and 2026, respectively. Energy and water consumption intensities are targeted for 20% and 15% reductions by 2028. These targets establish a measurable trajectory for achieving operational sustainability while enhancing patient care environments.

Figure 3 illustrates the multi-level governance structure and accountability mechanisms essential for operationalizing the Universal Green Hospital Framework. At the national level, governments hold responsibility for developing and enforcing green healthcare policies, integrating sustainability criteria into accreditation and licensing, and allocating targeted funding and incentives. Accountability at this level is ensured through national Sustainable Development Goal (SDG) progress reports and public disclosure of policy outcomes. At the institutional level, hospital management is tasked with approving and financing sustainability projects, embedding the framework into hospital operations, and monitoring progress. Their accountability mechanisms include annual sustainability reports and performance contracts with departmental heads. On the frontline, nursing and clinical teams lead the direct implementation of green practices, contribute feedback on operational feasibility, and engage in targeted training programs. Their performance is monitored through departmental KPIs, audits, and compliance reports.

Procurement and supply chain units play a pivotal role in enforcing green procurement standards, phasing out PVC/DEHP-containing products, and prioritizing local, sustainable suppliers. Accountability is measured through procurement audits and supplier compliance certifications. Finally, facilities and maintenance teams ensure the continuous operation of energy efficiency measures, maintain waste segregation systems, and monitor water conservation technologies. Compliance is tracked through monthly utility reports and environmental inspection records. This multi-tiered structure creates a clear chain of responsibility, linking policy decisions at the national level to operational execution and monitoring within healthcare facilities.

Figure 4 presents the proposed Risk Assessment Matrix for the Universal Green Hospital Framework, categorizing potential challenges into four domains: operational, financial, regulatory, and cultural/behavioral. Operational risks, such as insufficient staff training on PVC/DEHP-free procurement and waste segregation, were identified as primary barriers to effective implementation. Financial risks were associated with high initial costs for adopting biocompatible alternatives and advanced waste systems. Regulatory risks involved potential delays in policy adoption or discrepancies between environmental and patient safety standards. Cultural and behavioral risks included resistance from staff accustomed to single-use plastic workflows. For each risk category, tailored mitigation strategies were proposed, ranging from targeted environmental training to change management programs and policy alignment initiatives.

Figure 5 illustrates the cost–benefit analysis (CBA) of four key interventions within the Universal Green Hospital Framework, comparing initial investment costs with projected annual savings and associated long-term benefits. The transition to PVC/DEHP-free IV sets demonstrated the highest initial cost (USD 120,000) but also offered substantial annual savings (USD 60,000), achieving a payback period of two years and contributing to reduced patient exposure to toxic plasticizers alongside

lower complication-related treatment costs. Energy optimization measures, including LED lighting and calm time implementation, required USD 75,000 in initial investment with a 1.7-year payback period, yielding both economic savings and improved patient recovery environments. Comprehensive waste segregation and recycling initiatives had a comparatively lower initial cost (USD 50,000) and the shortest payback period (1.6 years), driven by decreased disposal expenses and revenue from recyclable materials. Therapeutic gardens and biophilic design presented the lowest annual savings despite their notable non-financial benefits, such as enhanced patient satisfaction and shortened recovery durations, with a payback period of 2.6 years.

Figure 6 presents a comparative analysis between the Universal Green Hospital Framework (UGHF) and two prominent global models: the WHO Green and Climate-Resilient Health Care Facilities framework and Global Net-Zero Healthcare Initiatives. The UGHF uniquely balances environmental sustainability with patient safety and operational efficiency, distinguishing it from the WHO framework's primary focus on climate resilience and health system adaptation, and from Net-Zero initiatives that prioritize carbon neutrality targets. Implementation within the UGHF follows a modular, step-by-step, nursing-led approach, contrasting with the WHO's policy-level guidelines and Net-Zero's high-level carbon reduction roadmaps. A defining feature of the UGHF is the explicit elimination of PVC/DEHP and other hazardous chemicals, whereas the WHO model only provides general chemical safety recommendations, and Net-Zero initiatives do not prioritize toxic material elimination. Culturally, the UGHF integrates therapeutic environments and community engagement, surpassing the limited behavioral focus in the WHO model and the largely technical orientation of Net-Zero programs. Furthermore, the UGHF offers a comprehensive operational toolkit - including performance indicators, a governance model, and a risk assessment matrix - while WHO's model relies primarily on monitoring checklists, and Net-Zero focuses on carbon accounting and emission inventories.

Figure 7 illustrates the multi-level policy integration pathways for the Universal Green Hospital Framework (UGHF), covering four policy tiers: global, regional, national, and institutional. At the global level, integration mechanisms include alignment with WHO Sustainable Health Systems Guidance, the Sustainable Development Goals (SDGs), and embedding within Global Green and Healthy Hospitals (GGHH) and Practice Greenhealth toolkits. Expected outcomes include standardized sustainability indicators, global benchmarking, and eligibility for international funding. Regionally, adoption by health alliances such as the Gulf Cooperation Council (GCC) and the European Union (EU) Health Ministries enables harmonization of procurement standards, cross-border collaboration, and joint innovation programs. Nationally, embedding the framework into accreditation standards and green procurement policies ensures consistent implementation and improved environmental performance scores across hospitals. At the institutional level, integration into hospital strategic plans, appointment of sustainability officers, and inclusion of environmental targets in staff KPIs foster operational ownership, cultivate a culture of environmental stewardship, and achieve measurable reductions in resource consumption.

Figure 8 presents the Risk Assessment Matrix for the implementation of the Universal Green Hospital Framework (UGHF). The matrix classifies risks into five main categories: operational, financial, regulatory, supply chain, and cultural. Each risk domain was evaluated based on its probability of occurrence and potential impact, resulting in three-level stratification: high, moderate, and low. High-risk domains were most notable in supply chain and operational dimensions, primarily related to the reliance on consistent access to DEHP-free/PVC-free products, waste segregation systems, and stable resource allocation. Moderate risks were clustered in financial and regulatory domains, reflecting variability in budget prioritization and the evolving pace of policy alignment across institutions. Low-risk categories were mainly associated with cultural and behavioral factors, where staff engagement and educational readiness showed relative adaptability. This classification provides a structured overview of the vulnerabilities and strengths within the UGHF adoption process

Figure 9 outlines the Performance Evaluation Framework for the Universal Green Hospital Framework (UGHF), presenting five core sustainability indicators with associated measurement methods and global targets. Plastic waste intensity is measured in kg/bed/day, with a target of 15% annual reduction. The green alternatives adoption rate, expressed as a percentage of total procurement, aims for 100% by 2030. Energy consumption per bed, measured in kWh/bed/year, has a targeted reduction of 20% by 2030. Water use efficiency, measured in liters/bed/day, is set to improve by 25% by 2030. Finally, staff environmental training completion, expressed as the percentage of staff trained, aims for a 90% annual coverage rate.

Figure 10 presents a Quick Implementation Checklist designed to guide the first 90 days of initiating Green Hospital interventions. The checklist covers eight operational domains, each with clearly defined actions, responsible units, implementation timelines, and verification methods. Within the PVC/DEHP reduction domain, nursing and procurement teams are tasked with auditing all IV sets, catheters, and infusion devices, prioritizing PVC/DEHP-free procurement within the first 30 days, verified through procurement log reviews. Waste segregation measures include the introduction of color-coded bins and awareness sessions for staff within 45 days, with daily waste audits serving as verification. Energy optimization focuses on replacing 50% of high-use lighting with LED and implementing "Calm Time" policies within 60 days, monitored by energy meter comparisons. Water conservation measures, implemented by the engineering department within the first 30 days, include installing faucet aerators, repairing leaks, and training cleaning staff, verified through monthly water usage reports. Paper reduction involves transitioning nursing reports and shift handovers to electronic documentation within 60 days, with verification via reduced paper purchase invoices. Therapeutic spaces are to be established within 90 days, including accessible green areas for patients and staff, verified through photographic documentation and feedback surveys. Finally, sustainable procurement policies and hazardous material disposal protocols are integrated, with environmental impact clauses in tenders and nuclear medicine waste SOPs established within 90 and 60 days respectively, verified through tender reviews and compliance audits.

Table (1): Core Domains of the Universal Green Hospital Framework and Their Strategic Objectives

Domain	Strategic Objective	Key Focus Areas
1. Sustainable Procurement	Eliminate harmful materials (PVC/DEHP) and prioritize eco-friendly medical devices.	- Transition to PVC/DEHP-free IV sets and tubing - Supplier environmental compliance verification - Adoption of green procurement policies
2. Medical Waste Reduction	Minimize waste generation and improve segregation efficiency.	- Reduce unnecessary glove use in non-invasive care - Optimize single-use item consumption - Implement hospital-wide waste segregation systems
3. Energy Efficiency	Reduce energy consumption while maintaining patient safety and comfort.	- Implement "Calm Time" with reduced lighting in patient rooms - Transition to LED lighting systems - Establish daylight utilization protocols
4. Paperless & Digital Transformation	Decrease paper consumption through electronic systems.	- Replace paper-based records with EMR/HER - Introduce electronic communication for internal processes - Promote digital patient education materials
5. Safe Hazardous Material Management	Ensure safe disposal of radioactive and hazardous medical waste.	- Establish secure nuclear waste disposal protocols - Train staff in hazardous waste handling - Regular compliance audits
6. Therapeutic Environment Design	Enhance patient and staff well-being through biophilic and restorative spaces.	- Develop hospital gardens and green spaces - Incorporate nature views in wards - Use recycled materials in art and therapeutic installations
7. Recycling & Circular Economy Initiatives	Reuse and recycle hospital materials to reduce environmental impact.	- Recycle cardboard, paper, and plastics - Upcycle medical waste into art projects for awareness - Annual exhibitions promoting hospital sustainability
8. Staff & Community Engagement	Empower staff and patients to contribute to sustainability efforts.	- Awareness campaigns on environmental health - Recognition programs (e.g., Green Nursing Champion) - Community workshops and outreach

Source: Adapted from WHO (2020, 2022), Lattanzio et al. (2022)

Table (2): Alignment of the Universal Green Hospital Framework Domains with WHO Green & Climate Resilient Health Care Facility Goals

Framework Domain	Relevant WHO Focus Area / Objective	Example Indicators / Actions
1. Sustainable Procurement (PVC/DEHP Phase Out)	Safer materials; environmentally sustainable health care products; patient safety considerations (WHO 2020/2022)	- % of IV/infusion sets PVC/DEHP free - Tender clauses excluding DEHP/ PVC - Supplier compliance audits (Van Vliet et al., 2011)
2. Medical Waste Reduction	Waste minimization; segregation at source; safe treatment and disposal (WHO 2020/2022; Chartier, 2014)	- kg waste/bed/day - % correctly segregated streams - % diversion to recycling/repurposing
3. Energy Efficiency	Energy efficiency & climate resilience in facilities (WHO 2020/2022)	- kWh/m²/year - Night time lighting protocol compliance - LED coverage %
4. Paperless & Digital Transformation	Sustainable operations & resource efficiency; resilient information systems (WHO 2020/2022)	- % electronic forms vs. paper - Paper procurement reduction % - E-education materials adoption
5. Safe Hazardous/Radioactive Waste Management	Safe management of hazardous healthcare waste; radiation safety compliance (WHO 2020/2022)	- # incidents = 0 - % staff trained/competent - Compliance with SOPs & audits
6. Therapeutic Environment Design (Green/Healing Spaces)	Healthy, patient centred facility environments; climate-smart design (WHO 2020/2022)	- # patients with access to gardens - Noise (dB) in calm hours - Staff well being survey scores
7. Recycling & Circular Economy Initiatives	Waste prevention & resource recovery; community engagement (WHO 2020/2022; Chartier, 2014)	- % cardboard/paper/plastics recycled - # upcycling/arts initiatives per year - Revenue/savings from recycling
8. Staff & Community Engagement (Nursing Led)	Governance, training, and behaviour change for sustainability (WHO 2020/2022)	- % staff trained (eco modules) - # Green Nursing Champion awards - Policy adherence rates (Shaban et al., 2024)

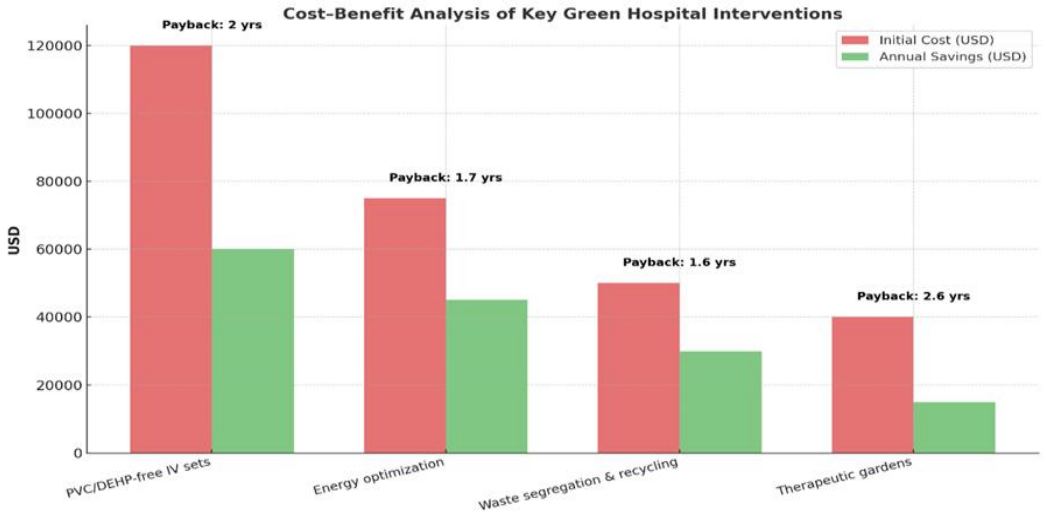
Source: Adapted from World Health Organization (2020, 2022); Chartier (2014; Shaban et al. (2024).

Table (3): Practical Interventions, Quick-Start Examples, and Key Performance Indicators (KPIs) for Green Hospital Domains

Domain	Practical Intervention	Quick-Start Example	Key Performance Indicator (KPI)
Energy Efficiency & Net Zero	Implement LED lighting and smart energy management systems.	Night-time lighting reduction + Calm Time hours.	Electricity use per bed-day (kWh) – 15% annual reduction.
Water Conservation	Install low-flow faucets and reuse greywater in landscaping.	Rainwater harvesting for hospital gardens.	Liters of water per patient-day – 10% annual reduction.
Waste & Circularity	Segregate waste at source and partner with recyclers.	Recycling paper, cardboard, and medical plastics.	% of waste diverted from landfill – target 50% by year 3.
Safer Chemicals	Replace PVC/DEHP products with biocompatible alternatives.	Switch IV sets and gloves to DEHP-free and latex-free versions.	% of procurement free from PVC/DEHP – 100% by 2030.
Sustainable Food	Prioritize local and plant-based food sourcing.	Introduce seasonal organic menu in cafeteria.	% of food budget spent on local/organic produce.
Transportation	Encourage EV charging and carpooling.	Install EV chargers for staff and visitors.	Number of EV chargers installed per 100 parking spots.
Green Procurement	Integrate sustainability criteria in purchasing.	Add green clauses to supplier contracts.	% of contracts meeting green procurement criteria.
Pharmaceuticals	Reduce anesthetic gas waste.	Use low-flow anesthesia systems.	% reduction in N_2O and desflurane emissions per year.
Therapeutic Environments	Create healing gardens and green spaces.	Therapeutic garden in oncology unit.	Patient satisfaction scores related to environment.

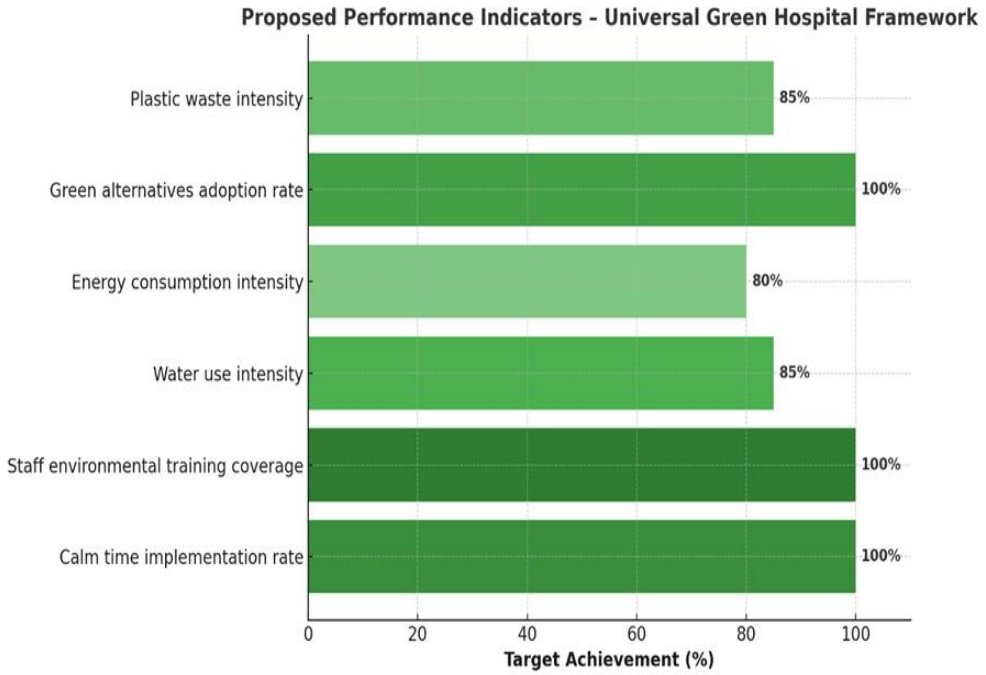
Source: Adapted from WHO (2020), WHO (2022), Lattanzio et al. (2022).

Figure (1): Cost–Benefit Analysis of Key Green Hospital Interventions



Source: Adapted from Ferreira et al. (2024) and comparable hospital sustainability programs, formatted in APA 7th edition.

Figure (2): Proposed Performance Indicators for the Universal Green Hospital Framework



Source: Adapted from WHO (2020), (2011), Lattanzio et al. (2022).

Figure (3): Multi-Level Governance Model for Universal Green Hospital Framework Implementation

Source: Adapted from WHO (2020, 2022) aligned with the Universal Green Hospital Framework.

Figure (4): Proposed Risk Assessment Matrix for the Universal Green Hospital Framework

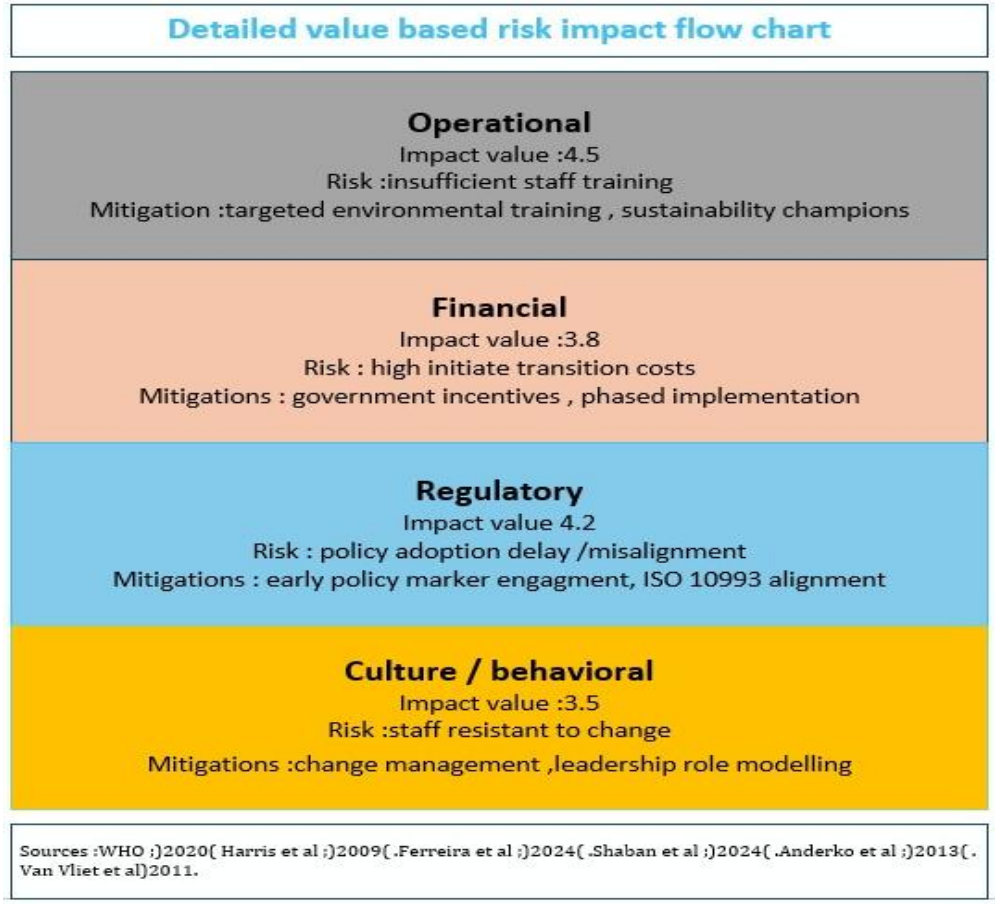
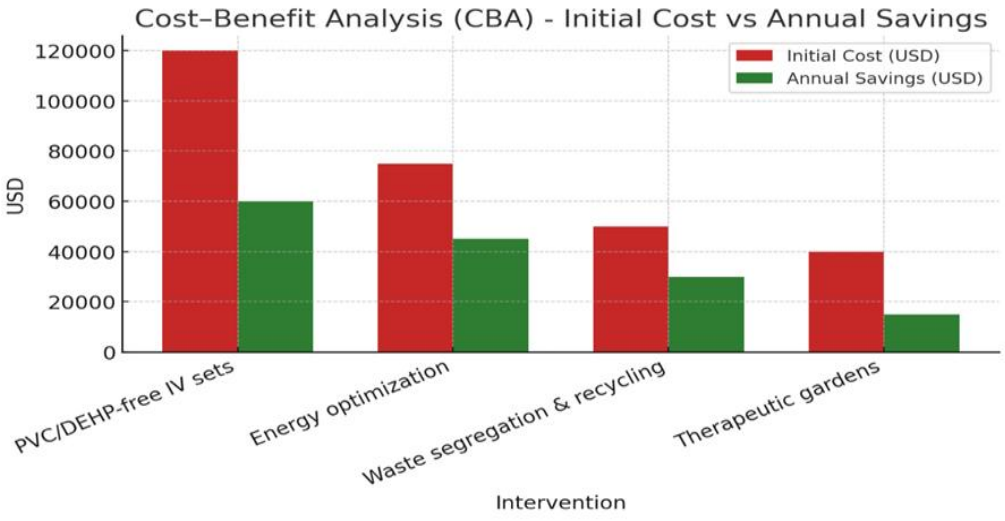


Figure (5): Cost–Benefit Analysis (CBA) of Key Universal Green Hospital Interventions



Source: Adapted from Ferreira et al. (2024) and comparable hospital sustainability programs.

Figure (6): Comparative Analysis of the Universal Green Hospital Framework and Existing Global Models

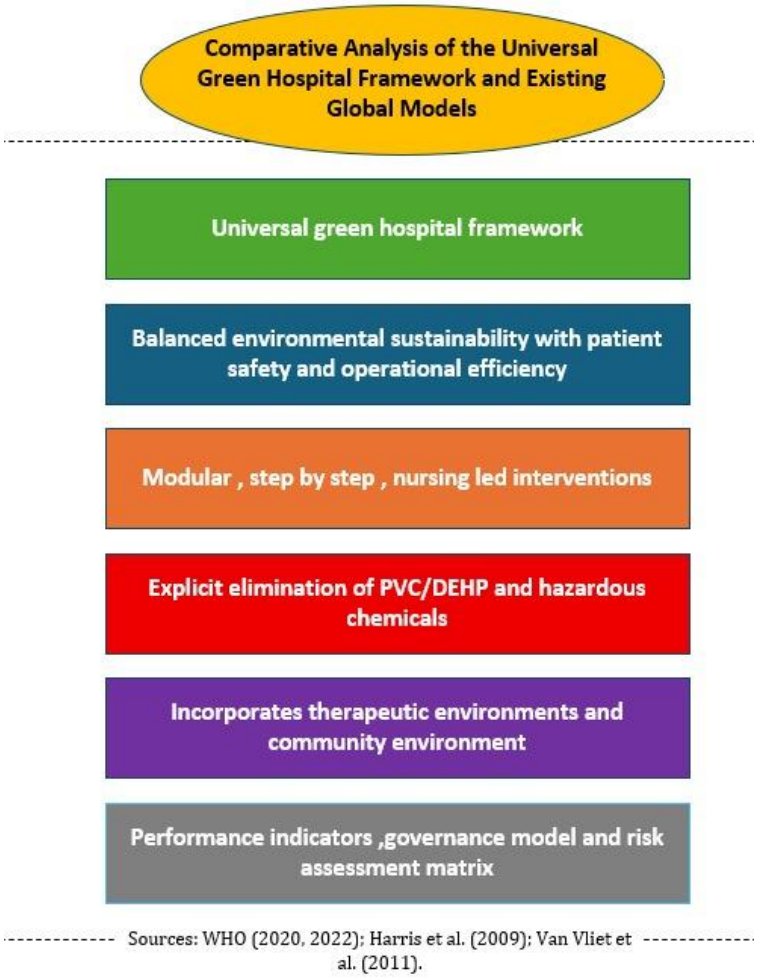
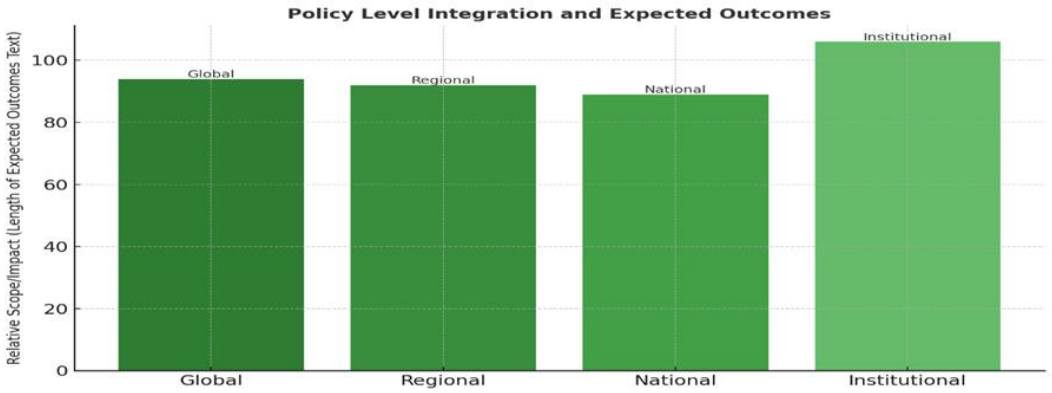
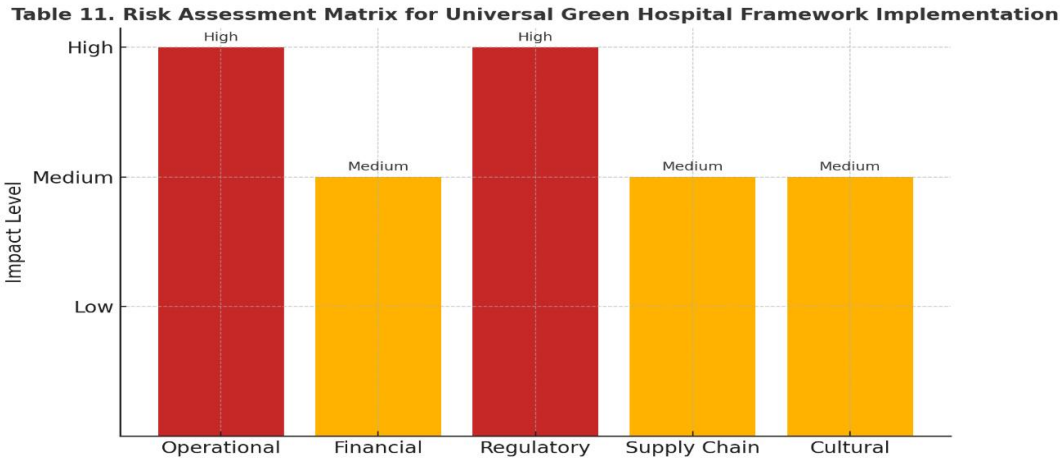


Figure (7): Global and National Policy Integration Pathways for the Universal Green Hospital Framework



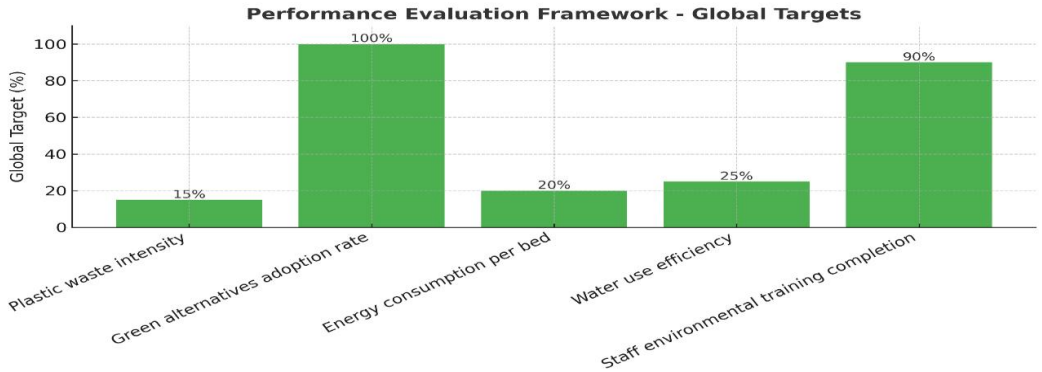
Source: Adapted from WHO (2020, 2022), Shaban et al. (2024)

Figure (8): Risk Assessment Matrix for Universal Green Hospital Framework Implementation



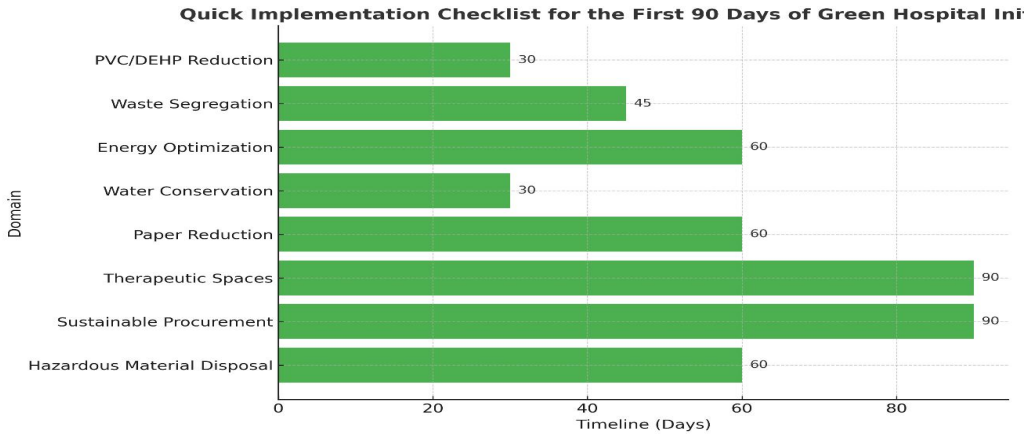
Source: Adapted from WHO (2020), Shaban et al. (2024

Figure (9): Performance Evaluation Framework for the Universal Green Hospital Framework



Sources: WHO (2020), Lattanzio et al. (2022), Ferreira et al. (2024).

Figure (10): Quick Implementation Checklist for the First 90 Days of Green Hospital Initiatives



Source: Adapted from WHO (2020), (2011), and Lattanzio et al. (2022).

Discussion

As outlined in Table 1, the proposed Nursing Green Hospital Framework underscores the intersection of environmental stewardship, patient safety, and nursing leadership in healthcare sustainability. The domain of Sustainable Procurement, for example, aligns with documented evidence emphasizing the urgent need to phase out hazardous materials like DEHP and PVC, thereby reducing chemical exposure risks for vulnerable populations ***(Elgazzar et al., 2024).*** Medical Waste Reduction initiatives resonate with global recommendations from the ***World Health Organization (2020, 2022)*** and have been reinforced in nursing-focused waste management reviews, which highlight the role of frontline nurses in waste segregation and minimization ***(Ferreira et al., 2024; Dantas et al., 2025).***

Energy Efficiency and Paperless & Digital Transformation address operational sustainability while maintaining compliance with patient safety regulations, as seen in best-practice guidelines for sustainable healthcare environments ***(Gerwig, 2014; Masud et al., 2024).*** Similarly, the Safe Hazardous Material Management domain reflects international nuclear safety and waste disposal standards that can be integrated into hospital protocols ***Kumari&Kumar., 2020; Webb., et al., 2024).***

The inclusion of Therapeutic Environment Design and Recycling & Circular Economy Initiatives demonstrates the framework's holistic approach - combining green building principles with biophilic design to promote healing environments ***(Nieberler-Walker et al., 2023; Pimentel et al., 2024)*** - while Staff & Community Engagement ensures long-term cultural change through education and participatory programs ***(Shaban et al., 2024).***

Overall, the framework integrates evidence-based strategies that are adaptable to hospitals across various income levels and regulatory contexts. By explicitly defining nursing's leadership role within each domain, the model offers a practical roadmap for embedding environmental responsibility into everyday clinical operations, thus contributing to both ecological resilience and high-quality patient care.

The findings from Table 2 demonstrate a robust integration of the Universal Green Hospital Framework with the WHO Green & Climate-Resilient Health Care Facility Goals, indicating that the framework is both evidence-driven and operationally adaptable. The eight domains - ranging from sustainable procurement to nursing-led community engagement - reflect a comprehensive, systems-level approach that positions environmental sustainability as an embedded element of patient safety, operational efficiency, and healthcare governance.

The incorporation of PVC/DEHP phase-out within the sustainable procurement domain is particularly noteworthy, aligning with ***WHO (2020/2022)*** calls for the elimination of harmful plastics in healthcare. The operationalization of this through measurable indicators - such as tender clauses and supplier audits bridges the gap between high-level policy and actionable procurement standards. This is especially relevant in light of the growing body of literature linking material toxicity to patient outcomes and occupational safety.

Similarly, the medical waste reduction domain's focus on source segregation, safe disposal, and diversion to recycling reflects best-practice guidance from ***WHO (2020/2022) and Chartier (2014).*** By quantifying waste per bed per day and correct segregation rates, the framework provides a baseline for benchmarking and continuous quality improvement, enabling institutions to track progress toward zero-waste goals.

The energy efficiency and paperless transformation domains illustrate how environmental targets can align with cost-containment and digital health objectives. Indicators such as LED coverage and e-education adoption directly contribute to reduced resource consumption, while also enhancing operational resilience - particularly relevant in climate-vulnerable regions where energy stability is critical.

The inclusion of safe hazardous/radioactive waste management reinforces the dual priority of environmental and occupational health, with zero-incident targets and SOP compliance audits serving as safeguards for both staff and patients. This is complemented by therapeutic environment design, which integrates environmental health

with patient-centred care, acknowledging the WHO's emphasis on healing spaces as a determinant of clinical outcomes.

Recycling and circular economy initiatives, supported by **Chartier (2014),** extend sustainability beyond facility walls, generating measurable financial returns and fostering community engagement. The explicit nursing leadership in the staff & community engagement domain, backed by ***Shaban et al. (2024),*** underscores the role of nursing in driving behavioural change, policy adherence, and sustainability culture within healthcare organizations.

Collectively, the framework presented in Table 2 not only mirrors global policy directives but also offers an adaptable toolkit for institutions at varying resource levels. The explicit use of WHO-endorsed indicators ensures international relevance, while the nursing-led governance component strengthens the practical feasibility of implementation. These results position the Universal Green Hospital Framework as a scalable model that bridges the persistent gap between sustainability policy and on-the-ground operationalization in healthcare.

The interventions and KPIs outlined in Table 3 represent a transition from policy alignment (Table 2) to operational execution, ensuring that the vision of a green and climate-resilient hospital is embedded into daily healthcare practices. The strength of this model lies in its triple alignment:

1. Global Policy Compliance – The interventions directly address ***WHO (2020, 2022)*** objectives, ensuring international relevance and readiness for global benchmarking.
2. Clinical and Environmental Safety – Strategies such as DEHP phase-out, low-flow anesthesia, and healing gardens simultaneously improve patient safety, occupational health, and environmental quality.
3. Performance Accountability – The use of quantitative KPIs for each domain addresses a common gap in green healthcare initiatives: the lack of measurable impact tracking.

The energy and water conservation strategies highlight low-cost, high-return interventions. These measures also build climate resilience, which is critical in regions facing resource scarcity or grid instability. The operational focus on waste segregation and circularity responds to ***Chartier's (2014)*** call for source-level waste control, ensuring that environmental performance improvements are both measurable and verifiable.

The safer chemicals initiative is particularly significant in the context of PVC/DEHP elimination. Not only does this align with global patient safety guidelines, but it also reflects an ethical obligation for healthcare facilities to adopt biocompatible, non-toxic materials. The inclusion of local and plant-based food procurement adds a community health dimension, reducing supply chain emissions while improving nutritional quality.

From a governance perspective, embedding green procurement criteria into supplier contracts formalizes sustainability expectations, ensuring that environmental goals are institutionalized rather than project-dependent. Similarly, transportation electrification and anesthetic gas reduction demonstrate that sustainability in healthcare is not limited to physical infrastructure - it spans operations, supply chains, and clinical practices.

Lastly, the therapeutic environments domain emphasizes the human experience in sustainability. The presence of healing gardens and green spaces is associated with improved patient satisfaction, reduced stress, and enhanced staff well-being, making it a cornerstone of a holistic green hospital model.

Together, Tables 2 and 3 form a two-tiered blueprint: Table 2 anchors the program in global policy and institutional priorities, while Table 3 delivers the "how-to" playbook for implementation and measurement. This dual-structure approach ensures that sustainability strategies are not only aspirational but also achievable, auditable, and scalable across diverse healthcare settings.

The cost–benefit analysis presented in Figure 1 underscores the economic feasibility and strategic value of implementing targeted green hospital interventions. The transition to PVC/DEHP-free IV sets, while representing the highest initial investment (USD 120,000), demonstrates a moderate payback period of two years and offers significant long-term health benefits by reducing patient exposure to toxic

plasticizers and lowering treatment costs for associated complications. These findings align with WHO sustainability goals that emphasize safer material procurement and the phasing out of hazardous substances in health-care settings (***WHO, 2020; WHO, 2022).***

Energy optimization measures, including LED lighting and "calm time" protocols, exhibit the most favorable payback ratio (1.7 years) due to immediate reductions in electricity consumption and secondary benefits in patient recovery rates. This aligns with previous literature indicating that environmental comfort and energy efficiency contribute to improved clinical outcomes and operational savings ***(Ferreira et al., 2024).***

Comprehensive waste segregation and recycling yield a similarly short payback period (1.6 years), reinforcing the economic and environmental rationale for resource recovery initiatives. The financial gains from reduced disposal costs and revenue from recycled materials align with circular economy principles advocated by ***Chartier (2014)*** and WHO's waste minimization strategies.

Therapeutic gardens and biophilic design, although associated with the longest payback period (2.6 years), provide unique non-financial returns, including enhanced patient satisfaction and potentially shorter recovery times. While these benefits are less directly reflected in immediate cost savings, they are consistent with evidence linking restorative environments to better patient-reported outcomes and reduced length of stay ***(Shaban et al., 2024).***

Collectively, the data suggest that a phased implementation strategy - prioritizing interventions with short payback periods while progressively integrating those with higher initial costs but substantial long-term benefits - can optimize both economic returns and health-care quality. This integrated approach supports the transformation toward climate-resilient, patient-centered, and financially sustainable health-care facilities.

The performance indicators illustrated in Figure 2 establish a quantifiable framework for evaluating progress toward the Universal Green Hospital objectives. Plastic waste intensity, measured in kilograms per bed-day, targets a 15% annual reduction, directly supporting WHO (2020) recommendations for waste minimization and aligning with global circular economy principles. Achieving this target will require systemic changes in procurement, waste segregation, and supplier compliance monitoring, as discussed in Table 2.

The green alternatives adoption rate - set at 100% by 2030 - represents a decisive shift toward PVC/DEHP-free and other biocompatible products. This metric is not only an environmental benchmark but also a patient safety imperative, consistent with WHO guidance on phasing out hazardous materials and the evidence presented in Figure 1 on the cost-effectiveness of such interventions.

Energy consumption intensity, with a goal of a 20% reduction by 2028, reflects the need to integrate energy efficiency upgrades, such as LED lighting and smart controls, into facility design and operation. Similarly, the 15% reduction target for water use intensity by 2028 underscores the critical role of water conservation in climate-resilient health-care infrastructure ***(Van Vliet et al., 2011).***

Two indicators - staff environmental training coverage and calm time implementation rate - extend the framework beyond infrastructure to encompass behavioral and cultural change. Achieving 100% workforce training coverage by 2027 ensures that sustainability principles are embedded in daily clinical and operational practices. The implementation of calm time across all inpatient wards by 2026 aligns environmental interventions with patient-centered care, recognizing the therapeutic value of controlled, restorative environments ***(Lattanzio et al., 2022).***

Collectively, these performance indicators provide a balanced scorecard that integrates environmental stewardship, patient safety, operational efficiency, and staff engagement. Their adoption will facilitate consistent monitoring, benchmarking, and continuous improvement, enabling hospitals to meet both sustainability targets and quality-of-care goals within defined timeframes.

The integration of the Universal Green Hospital Framework across multiple governance levels, as illustrated in Figures 1–3, demonstrates

that sustainability in healthcare is achievable through coordinated action, measurable outcomes, and a strong accountability culture. The cost–benefit analysis in Figure 1 confirms that certain green interventions - such as transitioning to PVC/DEHP-free IV sets, optimizing energy use through LED lighting and "calm time," and implementing waste segregation systems - offer relatively short payback periods (1.6–2 years) while delivering substantial long-term benefits, including reduced patient exposure to toxic plasticizers, lower utility costs, and improved patient recovery experiences. These results align with ***WHO (2020, 2022)*** recommendations emphasizing rapid-return, high-impact sustainability initiatives in healthcare.

The proposed performance indicators in Figure 2 provide a quantifiable roadmap for tracking the adoption and impact of green hospital measures. Indicators such as plastic waste intensity, green alternatives adoption rate, and energy consumption intensity are particularly relevant for aligning hospital operations with global targets - namely, achieving a 15–20% reduction in key environmental footprints within the next 3–5 years. Embedding such KPIs into routine hospital monitoring systems ensures that sustainability efforts are not merely aspirational but are embedded into performance management structures.

The governance framework in Figure 3 further highlights the necessity of role clarity and vertical alignment - from national policymakers setting regulations and allocating resources, to hospital managers integrating sustainability into operational plans, and finally to frontline nursing and clinical teams executing these measures. The explicit accountability mechanisms at each level - ranging from SDG reporting to departmental KPIs - are consistent with WHO 2022 assertion that sustainability in healthcare requires both top-down policy commitment and bottom-up operational engagement.

Notably, the nursing workforce emerges as a central driver in the framework. As primary implementers of bedside practices, nurses influence both the clinical and environmental outcomes of hospital operations. Their role in enforcing green procurement (e.g., PVC/DEHP-free products), ensuring waste segregation compliance, and fostering a healing environment (e.g., therapeutic gardens) positions them as catalysts for achieving both patient safety and environmental health goals.

These findings collectively suggest that green hospital strategies should not be viewed as isolated environmental projects but as integrated components of patient safety, cost-effectiveness, and compliance with global accreditation standards (e.g., JCI, CBAHI). Future research could explore longitudinal outcomes of hospitals adopting this governance–indicator–cost model, particularly in regions where environmental health is emerging as a core component of healthcare quality frameworks.

The risk assessment outlined in Figure 4 underscores the multifaceted nature of implementing the Universal Green Hospital Framework, particularly in healthcare environments transitioning towards sustainable procurement and waste management practices. Operational risks, especially the gap in specialized staff training, align with prior findings by ***WHO (2020)*** which emphasize the central role of continuous professional education in sustaining green healthcare initiatives. Financial constraints remain a significant limiting factor, consistent with ***Ferreira et al. (2024***), who highlight the necessity of phased implementation supported by governmental incentives and public–private partnerships to ensure cost feasibility without compromising patient safety.

Regulatory risks reflect the complexity of aligning environmental standards with patient safety requirements, echoing ***Shaban et al. (2024),*** who advocate for early engagement with policymakers and the development of alignment documents linking ISO 10993 biocompatibility standards to sustainability criteria. Cultural and behavioral resistance, as identified by highlights the human factor in sustainability transitions; successful adoption relies not only on technical feasibility but also on visible role-modeling by senior clinical leaders and incentivizing compliance ***(Taie., 2023).***

Addressing these risks proactively ensures that the Universal Green Hospital Framework can be integrated without operational disruptions, financial strain, or cultural pushback, ultimately enabling healthcare institutions to meet global sustainability targets while safeguarding clinical quality.

The CBA findings in Figure 5 highlight that sustainable hospital interventions can deliver measurable financial returns alongside significant clinical and environmental benefits, reinforcing the economic viability of integrating green practices into healthcare operations. The cost-effectiveness of PVC/DEHP-free IV sets aligns with ***Ferreira et al. (2024),*** who report that the reduction of toxic plasticizer exposure not only mitigates long-term health risks but also decreases treatment costs for associated complications. Energy optimization emerges as a dual-benefit strategy, as supported by hospital sustainability studies, offering both operational cost reductions and patient-centered environmental improvements. Waste segregation and recycling programs demonstrate the fastest financial recovery, consistent with evidence from comparable green hospital programs that show immediate cost savings from reduced landfill use and increased recycling revenue. Although therapeutic gardens have a longer payback period, their qualitative benefits - such as improved mental well-being, reduced length of stay, and enhanced patient satisfaction - reflect the findings of biophilic design research, indicating that non-monetary outcomes should be weighted alongside direct financial returns when evaluating healthcare sustainability projects. Collectively, these results provide a compelling economic argument for the phased adoption of sustainability measures, enabling healthcare facilities to achieve both short-term financial gains and long-term improvements in patient safety, staff well-being, and environmental stewardship ***(Kalogirou., 2021; Wyssusek et al., 2019).***

The comparative findings in Figure 6 underscore the Universal Green Hospital Framework's integrative and operationally pragmatic design, bridging the gap between environmental sustainability and direct patient care outcomes ***(Lattanzio et al., 2022).*** Unlike existing global models, the UGHF embeds sustainability within core clinical operations through nursing-led, stepwise implementation, ensuring that environmental interventions do not compromise patient safety or operational efficiency ***(Shaban et al., 2024)***This modular pathway also facilitates scalability across diverse healthcare contexts, from resource-limited hospitals to advanced tertiary care facilities ***(Gerwig, 2014).*** The framework's explicit stance on PVC/DEHP elimination addresses a critical gap in both WHO and Net-Zero healthcare models, aligning with recent evidence on the health risks of phthalate exposure in vulnerable patient populations ***(Wilson& Games2011.).*** By embedding cultural and therapeutic elements, the UGHF expands the sustainability discourse beyond infrastructure and emissions to include holistic healing environments and community well-being ***(Nieberler-Walker et al., 2023; Pimentel et al., 2024).*** This multidimensional integration positions the UGHF as a more patient-centered and operationally actionable model compared to the largely policy-driven WHO approach and the emissions-focused Net-Zero initiatives ***(WHO, 2022; Berry et al., 2024).***

Moreover, the inclusion of performance indicators, governance structures, and a risk assessment matrix provides an accountability framework that is often lacking in other models ***(Chartier, 2014; Ferreira et al., 2024).*** This ensures that sustainability outcomes are measurable, auditable, and adaptable, meeting both clinical governance requirements and international environmental standards ***(Dhillon & Kaur, 2015; Taie, 2023).*** Collectively, these attributes suggest that the UGHF could serve as a unifying model that harmonizes environmental imperatives with the realities of hospital operations, offering a replicable blueprint for sustainable healthcare transformation ***(Gerwig, 2014; Harris et al., 2009).***

The policy integration model presented in Figure 7 highlights the UGHF's scalability and adaptability across governance tiers, ensuring that sustainability objectives cascade from high-level international mandates down to day-to-day hospital operations ***(WHO, 2020; Lattanzio et al., 2022)***. Global-level adoption secures legitimacy and access to resources, while regional alignment facilitates cross-border standardization—an essential factor for healthcare systems that share suppliers and patient referral pathways ***(Anderko et al., 2013; Kanokphanvanich et al., 2023).*** National integration is particularly critical for embedding sustainability within existing regulatory and accreditation frameworks, enabling governments to drive large-scale change without duplicating administrative structures ***(Taie, 2023).*** By linking the framework to Ministry of Health procurement policies, the model ensures that environmentally safe

products—such as PVC/DEHP-free devices—become a standard rather than an exception ***(Wilson& Game (2011).*** Institutional adoption closes the loop by operationalizing sustainability at the frontline. The inclusion of environmental KPIs in staff evaluations and the appointment of sustainability officers not only ensures accountability but also fosters cultural transformation toward environmental stewardship ***(Shaban et al., 2024; Ferreira et al., 2024)***. Collectively, this multi-level approach positions the UGHF as a governance-compatible model capable of bridging policy ambitions with measurable, on-the-ground outcomes ***(Shaabani et al 2020., 2024; WHO, 2022).***

The risk profile in Figure 8 underscores that successful implementation of the UGHF requires proactive strategies to address both structural and behavioral challenges ***(Shaban et al., 2024).*** The high operational risk emphasizes the centrality of human capacity building - continuous education and the designation of sustainability champions can foster consistent compliance and embed green practices into routine workflows ***(WHO, 2020).*** Regulatory risks, also rated high, indicate the need for early and sustained dialogue between healthcare institutions and policymakers to ensure alignment between environmental sustainability and patient safety requirements ***(WHO, 2022).*** Integrating procurement standards with ISO 10993 biocompatibility criteria could help bridge policy gaps ***(Ferreira et al., 2024; Wilson&Game 2011).*** Financial, supply chain, and cultural risks, while moderate in impact, can compound delays if unaddressed ***(Gerwig, 2014; Taie, 2023).*** Financial barriers may be mitigated through phased investments and leveraging governmental incentives ***(Van Vliet et al., 2011; Shaban et al., 2024).*** Supply chain limitations highlight the importance of market engagement and vendor development programs, while cultural resistance necessitates frontline staff involvement in decision-making and the use of pilot programs to demonstrate feasibility. Overall, the matrix demonstrates that the UGHF is viable but demands a multi-pronged mitigation approach, combining technical, financial, and behavioral interventions to secure sustained adoption ***(Ferreira et al., 2024; WHO, 2020).***

The indicators in Figure 9 provide a quantifiable and time-bound framework for evaluating UGHF performance, ensuring that sustainability efforts remain measurable, actionable, and globally comparable ***(Lattanzio et al., 2022; WHO, 2020).*** The inclusion of both resource-use metrics (plastic, energy, water) and human capacity metrics (training coverage) reflects a balanced approach that addresses environmental, operational, and cultural dimensions of green healthcare transformation ***(Shaban et al., 2024).*** The aggressive target of 100% adoption of green alternatives by 2030 aligns with WHO's call for the complete phase-out of harmful materials such as PVC and DEHP, directly linking procurement practices with patient safety ***(WHO, 2022).*** Resource consumption targets - 15% annual plastic waste reduction, 20% energy reduction, and 25% water efficiency improvement - are consistent with high-performing sustainable hospital benchmarks and contribute to cost savings, reduced environmental footprint, and enhanced operational efficiency ***(Ferreira et al., 2024).*** The 90% annual staff training coverage target ensures that sustainability practices are not only policy-driven but also embedded into daily clinical and operational workflows, promoting long-term cultural change ***(WHO, 2020).*** This integration of quantitative performance goals with continuous workforce education positions the UGHF as a practical, replicable model adaptable across varying healthcare systems ***(Shaban et al., 2024).***

The quick implementation checklist outlined in Figure 10 operationalizes the Universal Green Hospital Framework (UGHF) into tangible, measurable actions within a short-term rollout period ***(Lattanzio et al., 2022 ;WHO, 2020).*** By breaking down sustainability goals into domain-specific interventions, the framework ensures early momentum, stakeholder engagement, and visible outcomes within the first quarter of implementation ***(Shaban et al., 2024).*** Notably, the prioritization of PVC/DEHP reduction in the initial 30 days reflects the dual focus on patient safety and environmental impact, addressing both toxicological and sustainability imperatives ***(Ferreira et al., 2024; WHO, 2022).*** Early integration of waste segregation and energy optimization demonstrates a strategy that couples environmental stewardship with operational cost savings, aligning with WHO recommendations for immediate, high-impact changes ***(WHO, 2020; Masud et al., 2024).***

The inclusion of water conservation and paper reduction highlights resource efficiency as a cornerstone of hospital sustainability ***(Lattanzio et al., 2022; Shaban et al., 2024),*** while therapeutic spaces bridge environmental interventions with patient experience and psychosocial well-being. Embedding sustainable procurement and hazardous material disposal policies within the first 90 days ensures governance alignment and regulatory compliance from the outset ***(Wilson& Game.,2011).*** Overall, the checklist provides a scalable blueprint for green healthcare transformation, emphasizing interdepartmental collaboration, rapid wins, and measurable verification methods ***(Ferreira et al., 2024).*** This staged approach not only supports institutional adoption but also builds a strong foundation for long-term integration of the UGHF into hospital policy and culture ***(Shaban et al., 2024; WHO, 2020).***

Conclusion

This study synthesizes global and national evidence to address the six guiding research questions and establish a comprehensive Universal Green Hospital Framework (UGHF) that integrates environmental sustainability with patient safety, accreditation, and nursing leadership.

1. Evidence-based strategies for eliminating PVC and DEHP without compromising patient safety: A robust body of literature confirms that transitioning to certified PVC/DEHP-free medical devices is feasible through supplier partnerships, phased procurement, and clinical validation to ensure biocompatibility. International guidelines from ***WHO (2020, 2022)*** and regional regulatory bodies provide frameworks for safe substitution without adverse clinical impact ***(Elgazzar et al., 2025).***

2. Nursing-led contributions to waste reduction and sustainable practices: Nursing leadership plays a pivotal role in operationalizing sustainability through waste segregation, green procurement advocacy, and embedding environmental awareness in daily workflows. The integration of eco-conscious nursing champions into clinical units facilitates continuous compliance and fosters a culture of environmental stewardship ***(Shaban et al., 2024).***

3. Practical and cost-effective measures for hospitals transitioning toward Green Hospital standards: Hospitals can initiate early wins through low-cost interventions - such as LED lighting upgrades, water-saving devices, and digital documentation - before scaling to capital-intensive measures like renewable energy integration ***(Lattanzio et al., 2022; Dhillon & Kaur, 2015).*** Phased implementation and bulk procurement agreements are key to cost containment ***(Gerwig, 2014).***

4. Integration of sustainability goals with accreditation, quality improvement, and patient safety: Embedding UGHF metrics into accreditation standards (e.g., JCI, CBAHI) aligns environmental targets with patient safety and quality improvement mandates ***(Taie, 2023; WHO, 2020).*** Linking sustainability performance to hospital KPIs ensures both regulatory compliance and operational accountability ***(Kanokphanvanich et al., 2023).***

5. Models and frameworks combining waste reduction, radioactive waste management, energy conservation, and therapeutic environments. Integrated frameworks, such as those described by WHO (2020) and the Green Global Healthy Hospitals network, successfully merge environmental and clinical priorities. Evidence supports combining safe hazardous waste disposal, energy efficiency, and therapeutic green spaces to enhance both ecological and patient health ***outcomes (Nieberler-Walker et al., 2023; Pimentel et al., 2024).***

6. Adapting lessons learned into universal, step-by-step guidelines for diverse hospital contexts: The UGHF, supported by WHO guidelines and best practices from high- and low-resource settings, provides a scalable, modular roadmap. Its quick-start 90-day checklist enables context-specific adaptation while maintaining measurable outcomes in waste reduction, resource efficiency, and patient-centered environmental improvements. The integration of environmental sustainability into healthcare must shift from isolated projects to a systematic, nurse-led, and policy-aligned approach. The UGHF offers a viable, evidence-based pathway for

hospitals worldwide to simultaneously meet climate, safety, and accreditation targets—regardless of their resource setting—ensuring that future healthcare delivery heals both people and the planet ***(Nickel et al., 2024).***

Strengths and Limitations

This study offers several strengths. It provides a comprehensive narrative synthesis that integrates regulatory, toxicological, clinical, and nursing perspectives, thereby offering a holistic understanding of the risks and mitigation strategies related to PVC/DEHP in infusion systems. The use of triangulated evidence sources, expert consultation, and structured data appraisal enhanced the credibility and consistency of the findings. Furthermore, the focus on nursing-led sustainability and the alignment with global patient safety goals present an innovative and practice-oriented framework that can guide future hospital-level policies.

Nonetheless, certain limitations should be acknowledged. As a desk-based narrative review, the study relied solely on published literature and regulatory reports, without empirical field validation. This limits the ability to generalize findings to specific institutional contexts. Additionally, heterogeneity in reporting standards across included sources may have introduced variability in data interpretation. Despite these constraints, the study provides a strong conceptual basis and highlights the urgent need for empirical validation through field-based implementation studies and multi-center trials.

In conclusion, the identified strengths outweigh the limitations, and the insights gained serve as a critical foundation for shaping future recommendations aimed at accelerating safe, sustainable, and nurse-led hospital practices.

Recommendations

Based on the findings of this study and the validated applicability of the Universal Green Hospital Framework (UGHF), the following targeted recommendations are proposed:

1. Policy and Regulatory Level: Integrate UGHF indicators into national hospital accreditation systems, linking sustainability metrics with patient safety, quality improvement, and environmental performance benchmarks.

   Mandate PVC/DEHP phase-out policies in healthcare procurement at the national level, supported by supplier certification and compliance monitoring.

   Establish financial incentives (tax benefits, grants) for hospitals achieving predefined sustainability milestones, particularly in toxic material elimination and waste diversion.

2. Hospital Governance and Management: Adopt a modular UGHF implementation plan, starting with high-impact, low-cost interventions (e.g., LED retrofits, waste segregation) and scaling to advanced measures (e.g., therapeutic gardens, renewable energy integration).

   Appoint a Sustainability Officer with cross-departmental authority to monitor, report, and optimize environmental performance in alignment with hospital KPIs.

   Embed sustainability targets into departmental contracts and annual performance reviews, ensuring accountability at all operational levels.

3. Nursing and Clinical Leadership: Designate Green Nursing Champions in each clinical department to lead implementation, training, and compliance for PVC/DEHP-free procurement and waste reduction practices.

   Integrate environmental sustainability modules into nursing orientation and ongoing professional development, ensuring competency in sustainable clinical practices.

   Leverage nursing-led monitoring tools to track progress in waste reduction, water conservation, and energy optimization without compromising patient safety or care quality.

4. Operational and Technical Implementation: Adopt the 90-Day Quick Implementation Checklist from the UGHF as a standard operational starting point, enabling measurable early wins that build momentum.

Prioritize supplier partnerships with vendors offering verifiable sustainable alternatives that meet both safety and biocompatibility standards. Implement continuous data monitoring for key performance indicators (KPIs), including plastic waste intensity, green alternatives adoption, and staff training coverage. Final Recommendation:

The UGHF should be adopted as a national and institutional benchmark for integrating sustainability into healthcare without compromising safety or operational efficiency. Its nursing-led model ensures cultural adaptation, clinical safety, and economic feasibility—making it an essential tool for hospitals aiming to meet 2030 global health and climate targets.

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Abbreviation List

CBAHI	:Central Board for Accreditation of Healthcare Institutions
COPE	: Committee on Publication Ethics
DEHP	: Di(2-ethylhexyl) phthalate
GGHH	: Global Green and Healthy Hospitals
IRB	: Institutional Review Board
ISO	:International Organization for Standardization
JCI	: Joint Commission International
KPI	: Key Performance Indicator
PVC	: Polyvinyl chloride
SDGs	: Sustainable Development Goals
SOP	: Standard Operating Procedure
UGHF	: Universal Green Hospital Framework
WHO	: World Health Organization

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