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REVIEW ARTICLE

Minimizing the environmental impact of hospitals by focusing on carbon footprint reduction

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ABSTRACT

The environmental sustainability of hospitals is an increasingly critical issue globally, as healthcare systems are expanding rapidly, together with the growing concerns about climate change and depletion of resources. With healthcare systems expanding, the environmental impact of hospitals, particularly their carbon footprint, has become a critical concern. The study aimed to examine a range of approaches aimed at minimizing the environmental impact of hospitals, with an emphasis on reducing carbon footprints to pinpoint effective strategies and underscore areas where research is lacking. Following the Preferred Reporting Items for systematic reviews and meta-analysis guidelines, a comprehensive search was conducted across PubMed, SCOPUS, and Embase databases from January 1, 2018, to December 31, 2024. The study included 17 studies highlighting effective strategies for reducing hospitals' carbon footprints. Key interventions included integrating renewable energy sources, energy-efficient technologies, and sustainable procurement practices. Hospitals implementing these strategies have noted considerable declines in carbon emissions, with certain facilities realizing reductions of as much as 40 percent by incorporating renewable energy sources. Waste reduction strategies, such as improved segregation, recycling programs, and reducing single-use plastics, contributed to lower indirect emissions. Despite these successes, challenges such as high initial investment costs, limited technical expertise, and resistance to change were noted, particularly in low- and middle-income countries. Key strategies such as renewable energy adoption, energy-efficient technologies, and sustainable procurement have effectively reduced carbon emissions and enhanced operational efficiency. However, high upfront costs, technical gaps, and resistance to change, especially in low-resource settings, hinder widespread implementation.

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INTRODUCTION

The environmental sustainability of hospitals is an increasingly critical issue globally, as healthcare systems are expanding rapidly, together with the growing concerns about climate change and depletion of resources (Soares *et al.,* 2023; Cristiano *et al.,* 2024). Hospitals consume a substantial portion of energy, water and natural resource (Maden and Kerse, 2026; Eckelman and Sherman, 2016; Vallée, 2024; WHO, 2020), and produce large amounts of waste generation, contributing to greenhouse gas (GHG) emissions and resource depletion (Melnyk *et al.,* 2023; Alhamza *et al.,* 2026; Akman *et al.,* 2026). Pichler *et al.* (2019) reported that the healthcare sector generates the environmental emission similar in size to the entire aviation industry. As healthcare institutions strive to enhance patient care, the necessity for sustainable practices that reduce their environmental impact has become essential (Li *et al.,* 2025; MacNeill *et al.,* 2017). Research estimates suggesting that the UK's National Health Service (NHS) is responsible for 4-5 percent of total emissions (Pencheon and Wight, 2020), and the U.S. healthcare system accounts for about 9-10 percent (Eckelman *et al.,* 2018). Global organizations now treat healthcare decarbonization as a top public health priority (Ma *et al.,* 2022). The World Health Organization (WHO) identifies climate action in healthcare as the most significant health opportunity of the 21st century, urging hospitals to reduce emissions and withstand climate impacts (WHO, 2025). Although much of these figures primarily focus on high-income contexts, the environmental impact of hospitals is a global concern, affecting nations at all levels of economic development (Cimprich and Young, 2023). The environmental effects of hospitals encompass various domains, including energy consumption, water use, waste management, and sustainable procurement practices (Seifert and Guenther, 2019). Integrating sustainable practices within daily operations can lead to considerable environmental benefits, improve public health outcomes, and enhance economic efficiency (Han *et al.,* 2024). Sustainable hospital designs lower operational expenses and elevate patient care by enhancing indoor environments through a focus on hospital design, energy management, waste management, and promoting behavioral change (Borges de Oliveira *et al.,* 2021; Borges de Oliveira *et al.,* 2022; Mostepaniuk *et al.,* 2023). To make healthcare green, systems must require the multi-step approaches that reduces the energy (Karliner *et al.,* 2023; Braithwaite *et al.,* 2024), and water consumption (Potgieter *et al.,* 2020). The design of hospital architecture significantly influences their environmental footprint (Stevanovic *et al.,* 2019). Research has shown that sustainable building practices can significantly reduce energy consumption and improve efficiency. The direct consumption of energy significantly impacts the operating expenses of hospitals. By integrating renewable energy solutions such as solar panels and co-generation systems, hospitals can bolster their energy security and simultaneously decrease greenhouse gas emissions (Borges de Oliveira *et al.,* 2022). Waste management is also a crucial component, as hospitals generate vast amounts of waste, much of which is hazardous. Various studies (Hennessy *et al.,* 2021; Kooner *et al.,* 2020; Thiel *et al.,* 2019) showed that disposable plastics and their waste made up a huge part of a hospital's carbon footprint such as recycling and composting. Furthermore, implementing circular economy strategies can assist hospitals in minimizing waste production by enhancing resource management (Nematollahi *et al.,* 2025; Saha *et al.,* 2025; Alighardashi *et al.,* 2024). The engagement of healthcare professionals suggests that staff behavior significantly influences resource use, and training programs promoting sustainable practices among healthcare workers can lead to more responsible consumption patterns (Kalogirou *et al.,* 2021). Hospitals encounter various challenges and opportunities as they move towards becoming green hospital

(Koh *et al.,* 2025; Ibrahim *et al.,* 2025; Aboueid *et al.,* 2023). This transition involves the implementation of innovative designs, efficient energy usage, effective waste management, and fostering a culture among staff that can eliminate (Abubakar *et al.,* 2022; Firoozi *et al.,* 2024). Hence, there is a need to design sustainability strategies tailored to healthcare systems' needs and capacities globally. Data-driven identification of major emission sources, combined with proven, targeted solutions, enables significant carbon footprint reductions across healthcare systems. This approach allows organizations to move from identifying pollution hotspots to implementing effective, high-impact sustainability improvements and stakeholder engagement (Rodríguez-Jiménez *et al.,* 2023; Alicante *et al.,* 2026). This systematic review explores a range of techniques and methodologies for decreasing the environmental footprint of hospitals on a global scale by consolidating existing studies to pinpoint effective approaches and underscore gaps in the literature. This review strengthens efforts to improve hospital sustainability worldwide by synthesizing current knowledge and identifying key areas for further research. This study has been conducted in the ASEAN Institute for Health Development, Mahidol University, Thailand in 2026.

METHODOLOGY

Guidelines

The review protocol was not registered with International Prospective Register of Systematic Reviews (PROSPERO), as the registry only accepts systematic reviews with health-related outcomes (Moher *et al.,* 2015). Preferred reporting items for systematic review and meta-analysis (PRISMA) checklist was conducted and is presented in Table 1 (Page *et al.,* 2021). Although the non-health focus precluded PROSPERO registration, methodological concern was maintained through a structured research question, a comprehensive multi-database search strategy, and standardized study selection procedures. The mixed methods appraisal tool (MMAT) was applied to evaluate the quality of the selected studies (Hong *et al.,* 2018).

Search strategy

Relevant peer-reviewed journal publications were identified via a comprehensive database search of PubMed, SCOPUS, and Embase spanning January 1, 2018, to December 31, 2025 because this review included publication sources under 10 years to gather relevant, up-to-date data without exceeding practical research limits (van der Braak *et al.,* 2020). These databases were extensively employed in academic research, offering thorough, multidisciplinary coverage across both the social and natural sciences (Álvarez Jaramillo *et al.,* 2019; Parmentola *et al.,* 2022). To ensure data credibility, the literature search was confined to peer-reviewed journals, using the specific search terms detailed in Table 1. This methodology ensured data quality by focusing exclusively on rigorous, academic literature. The designated tracking window was deliberately chosen to analyze contemporary advancements in mitigating the environmental impact of healthcare institutions. Descriptors for the search terms "Approaches," "Environmental Impact Reduction," and "Hospital" were created to facilitate a comprehensive review of relevant literature. To ensure a comprehensive retrieval of relevant literature and minimize the risk of omitting vital data, tailored search strategies were deployed across PubMed, SCOPUS, and Embase.

Eligibility criteria of the studies

The review's inclusion criteria were established using the population, intervention, comparison, and outcome (PICO) framework (Eriksen and Frandsen, 2018) and are itemized in Table 2. Studies eligible for inclusion in this systematic review were required to meet the established review criteria: a) Population: The environmental impact of hospitals caused by waste, energy use, and resource consumption; (b) Intervention:

Table 1: Search strategy adopted for systematic review

Search terms	Descriptors
1. Approaches	Approaches OR "strategies" OR "practices" OR "measures" OR "methods" OR "techniques" OR "solutions" OR "initiatives" OR "actions" OR "programs" OR "plans" OR "policies" OR "procedures" OR "frameworks" OR "models" OR "guidelines" OR "systems" OR "mechanisms" OR "processes"
2. Environmental Impact Reduction	"Sustainability" OR "green practice" OR "energy efficiency" OR "waste reduction" OR "carbon footprint reduction" OR "CO2 emissions reduction" OR "resource conservation" OR "eco-friendly practices" OR "low-impact technologies" OR "renewable energy adoption" OR "water conservation" OR "carbon neutrality" OR "waste management" OR "green initiatives" OR "eco-sustainability" OR "climate action" OR "environmental footprint reduction" OR "circular economy" OR "eco-efficiency" OR "green technologies" OR "sustainable procurement" OR "pollution reduction" OR "environmental protection"
3. Hospital	"Healthcare facility" OR "medical institution" OR "clinical setting" OR "health institution" OR "healthcare organization" OR "hospital setting" OR "patient care facility" OR "acute care hospital" OR "hospital environment" OR "healthcare system" OR "public hospital" OR "private hospital" OR "medical center" OR "hospital infrastructure" OR "healthcare building" OR "clinical environment" OR "hospital staff" OR "hospital administrators" OR "hospital managers"
Combination	#1 AND #2 AND #3

Table 2: The inclusion and exclusion criteria of review process for studies selected.

Items	Inclusion criteria
Population	The environmental impact of hospitals caused by waste, energy use, and resource consumption.
Intervention	Strategies or interventions to reduce environmental impact
Comparison	Hospitals without interventions or using traditional practices have a higher environmental impact.
Outcome	Reduction in environmental impact, energy consumption, carbon footprint, waste reduction, improved resource efficiency, sustainability certifications, cost savings, improved health outcomes from green practices
Study design	Cohort studies, longitudinal studies, randomized controlled trials, Quasi-experimental studies, and Cross-sectional studies.

Strategies or interventions to reduce environmental impact; (c) Comparison: Hospitals without interventions or using traditional practices that have a higher environment impact; (d) Outcome: Reduction in environmental impact, energy consumption, carbon footprint, waste reduction, improved resource efficiency, sustainability certifications, cost savings, improved health outcomes from green practices; (e) Study design: Randomized controlled trials (RCTs), Quasi-experimental studies, Cross-sectional studies, longitudinal studies, and Cohort studies; and (f) Language: English. To address complex problems requiring innovative interventions, this socio-environmental systematic review synthesizes literature across diverse fields, including technology, innovation, and the social sciences. Within this framework, literature reviews facilitate theoretical development through the systematic organization and temporal visualization of data, highlighting existing research gaps and charting future trends while emphasizing sustainability awareness initiatives (Eyzaguirre and Fernandes, 2024; Madhyamapurush, 2026).

Study selection and data extraction

Durach *et al.* (2017) minimized potential biases in their study by employing a standardized form to extract data from 17 selected articles. Coded information was categorized using a structured form that separated specific metadata, including author, title, and publication date from broader study characteristics, such as methodology, objectives, context, and journal. The study selection process was managed in Microsoft Excel after exporting the search results from the database. The analyzed data included publication years, geographic locations, sample characteristics, study designs, and targeted environmental reduction measures. The systematic review did not perform a meta-analysis

due to the variability in the outcome analyzed (Deeks *et al.,* 2019) because combining diverse data points through statistical pooling can yield misleading results, a narrative synthesis was deemed more appropriate (Biondi-Zoccai *et al.,* 2011).

Study quality assessment

The quality of the included studies was assessed using MMAT (Hong *et al.,* 2018). The scientific rigor of various research designs—spanning randomized controlled trials to descriptive surveys—was evaluated using the MMAT. This appraisal utilizes a two-step protocol, wherein all studies are initially subjected to screening questions to verify a study's relevance and methodological appropriateness. Subsequently, they are evaluated according to five distinct quality criteria that are customized for their particular study design. A comprehensive database search yielded 3,827 records, which were narrowed down to 17 eligible studies for final synthesis after screening and duplicate removal (Table 3 and Fig. 1).

RESULTS AND DISCUSSION

Search overview

Extensive empirical research demonstrates a systemic commitment to analyzing and minimizing the environmental impact of hospital facilities. Publication frequency peaked in 2024 with eight studies, followed by four in 2022, and three in 2019. In contrast, 2021 and 2023 accounted for a single study each. The systematic review findings are organized based on the key themes and patterns of hospital environmental sustainability initiatives being highlighted across the studies (Cristiano *et al.,* 2024).

Population

Spanning diverse international contexts, this systematic review synthesizes literature on healthcare practices across a wide array of countries and clinical environments. In Switzerland, one study analyzed 33 acute care hospitals, focusing on healthcare services provided by one full-time equivalent annually (Keller *et al.,* 2021), while another assessed 62 anaesthesia providers implementing sustainable guidelines (Gasciauskaite *et al.,* 2023), Similarly, in the United States, the research included surgeons at a tertiary academic center (Palmisano *et al.,* 2021). In contrast, an alternative study surveyed 14 Veterans Affairs (VA) hospital food service directors to examine the intersection of surgical support practices and foodservice management (Williams *et al.,* 2024). In Canada, a study focused on staff and patients at a primary care clinic (Ilona *et al.,* 2024), while in Italy, approximately 6,000 residents participated in health screenings in Tuscany (Benedetto *et al.,* 2024). France contributed studies on anesthesiologists, anaesthesia nurses [Society of Anesthesia, Critical Care, and Perioperative Medicine (SFAR) members] (Tordjman *et al.,* 2022), and hospital energy systems (Toughzaoui *et al.,* 2024). In Sweden, the focus was on 24 postgraduate intensive-care nursing students (Sundberg *et al.,* 2024). Libya examined healthcare delivery across 11 public hospitals in 8 cities (Badi *et al.,* 2019), while a study in Egypt examined hospitals in Alexandria (William *et al.,* 2019). Furthermore, a comprehensive study conducted worldwide, involving 2.5 million patients with respiratory ailments from 40 countries, has brought to light major health challenges (Wilkinson *et al.,* 2022). Additional studies included 48 healthcare workers from 45 facilities in Malawi (Tu *et al.,* 2022), 1,065 public buildings undergoing green remodelling in South Korea (Woo *et al.,* 2024), and evaluations of green lean six sigma (GLSS) in Greece (Vasileiou *et al.,* 2024). The study encompassed imaging techniques utilized in Australian hospitals (McAlister *et al.,* 2022) as well as environmental reports from German hospitals (Seifert and Guenther, 2019), emphasizing worldwide initiatives aimed at sustainable healthcare delivery, environmental responsibility, and operational efficiency through innovative resource management and evidence-based sustainability practices.

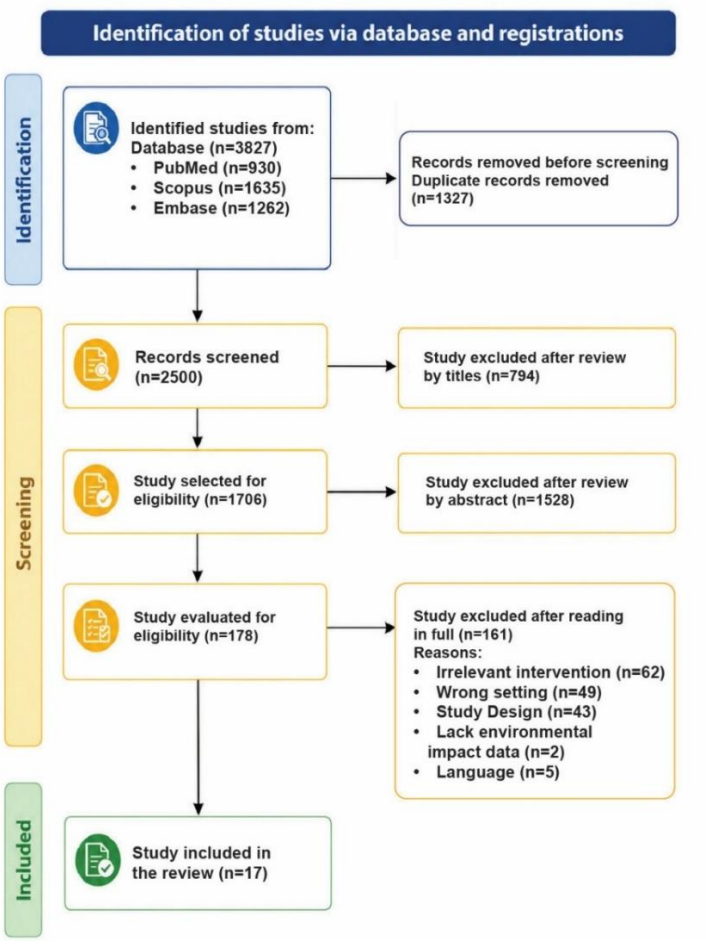


Fig. 1: PRISMA flowchart of the literature review search and selection process

Intervention

A systematic review highlights various initiatives aimed at improving environmental sustainability in healthcare settings across different countries. A study conducted in Switzerland used life cycle assessment (LCA) to evaluate 16 environmental impact categories in hospitals, identifying key areas such as catering, building infrastructure, heating, and electricity as significant contributors to greenhouse gas emissions (Keller *et al.,* 2021). In the United States, researchers investigated surgeon attitudes and practices regarding preference card optimization, highlighting institutional barriers that hinder sustainable healthcare practices (Williams *et al.,* 2024). A study in Canada focused on reducing waste by removing exam table paper in clinics (Ilona and Amanda, 2024), while Italy introduced a mobile screening unit for cancer detection (Benedetto *et al.,* 2024). A survey was conducted to evaluate environmentally sustainable anesthesiology practices, focusing on waste sorting and the reduction of polluting anaesthetic gases in France (Tordjman *et al.,* 2022). Researchers developed a grey-based assessment model in Libya to evaluate healthcare waste treatment technologies (Badi *et al.,* 2019). Another study in the U.S. also used an assessment of environmental sustainability standards in food service operations, emphasizing plant-forward dishes and local sourcing

(Woo *et al.,* 2024). In Switzerland, another study explored perceptions of environmental sustainability in anaesthesia through an online survey (Gasciauskaite *et al.,* 2023). While Greece adopted GLSS methodologies to improve, operational efficiency and quality of care (Vasileiou *et al.,* 2024). A global analysis quantified the carbon footprint of respiratory care across 40+ countries (Wilkinson *et al.,* 2022) and a thematic analysis was conducted in Malawi on barriers to infection prevention and control practices (Tu *et al.,* 2022). Geographic and technological approaches varied across the literature; for instance, Woo *et al*. (2024) assessed post-remodeling energy efficiency improvements in South Korean healthcare facilities. Conversely, research conducted in France shifted focus toward infrastructure development, modeling a solar- and hydrogen-powered fuel cell combined heat and power (FC–CHP) system (Toughzaoui *et al.,* 2024). In Sweden, experiences related to environmental sustainability in intensive care units were explored (Sundberg *et al.,* 2024), and Germany assessed environmental management in hospitals under the eco-management and audit scheme (EMAS) (Seifert and Guenther, 2019). Energy efficiency evaluations in hospitals were performed using retrofit techniques (Toughzaoui *et al.,* 2024). At the same time, the study executed in Australia analyzed CO_2e emissions from various imaging modalities (McAlister *et al.,* 2022).

Comparison

In the comparison section, this review evaluates institutional disparities in sustainability implementation and baseline environmental metrics within healthcare environments. Palmisano *et al.* (2024) compared early-career surgeons with mid-to-late-career surgeons regarding preference card maintenance and environmental stewardship in the United States. In Canada, Han *et al.* (2024) conducted a pre-and post-intervention analysis to measure changes following the removal of exam table paper in clinics. Benedetto *et al.* (2024) evaluated current cancer screening programs for their effectiveness and sustainability in Italy. Tordjman *et al.* (2022) explored differences in sustainable practices and training between early-career and mid-to-late-career providers in France. An assessment of healthcare waste management in Libya by Badi *et al*. (2019) compared traditional practices—specifically open-air burning and municipal dumping—with advanced waste segregation methodologies. In the U.S., Williams *et al.* (2024) analyzed self-rated implementation of sustainability standards in food services, identifying barriers and facilitators. Additionally, William *et al.* (2019) conducted a baseline energy consumption study in Egypt to inform energy efficiency improvements in hospitals, while McAlister *et al.* (2022) assessed baseline energy use and emissions from diagnostic imaging modalities in Australia.

Outcome

The interventions yielded diverse outcomes across environmental, operational, financial, and social dimensions. The reviewed studies demonstrate considerable environmental impacts associated with healthcare practices. Keller *et al.* (2021) found that the average carbon footprint per functional unit in Swiss hospitals is 3.2 tons carbon dioxide equivalent (t CO_2eq), with heating being the primary contributor at 0.82 t CO_2eq. Furthermore, research by Woo *et al*. (2021) documented a 30 percent (%) average increase in building energy efficiency, though the magnitude of these improvements varied regionally. Wilkinson *et al.* (2022) assessed the carbon footprint of various medications using life cycle assessment software to quantify emissions. Furthermore, McAlister *et al.* (2022) provided specific emissions data for imaging modalities, revealing that magnetic resonance imaging (MRI) contribute 17.5 kilograms (kg) CO_2e per scan, underscoring the need for targeted interventions to reduce these impacts. See (2023) reported the

implementing LCA to monitor environmental footprints, specifically focusing on water consumption, chemical toxicity, and resource consumption. By assessing the environmental impact resulting from waste generated in intensive care units (ICUs), supply chain requirements, and chemical contamination, these studies yielded practical information for sustainable hospital management.

Operational efficiency

Several studies emphasized the potential for operational efficiency improvements through sustainable practices. Han *et al.* (2024) indicated that the annual savings amounted to 718 United States dollars (USD), in addition to considerable ecological benefits derived from the removal of exam table paper, equating to the preservation of 10 trees and a reduction of 148 kg CO_2e on an annual basis. Williams *et al.* (2024) identified motivators for sustainability in food service, including reducing waste and serving healthier foods, while noting barriers such as patient preferences and contractual difficulties. The adoption of lean six sigma (LSS) methodologies in Greece was highlighted by Vasileiou *et al.* (2024), who acknowledged potential efficiency gains and waste reduction as key benefits. According to Rajagopalan *et al*. (2023), single hospitals can utilize their operational agility to circumvent bureaucratic delays and rapidly implement localized Scope 3 interventions. However, addressing systemic value-chain emissions requires enduring cooperation and active partnerships with external suppliers.

Financial benefits

Financial savings were evident in multiple studies. Benedetto *et al.* (2024) reported an annual reduction of over 110,238 USD in travel costs and productivity losses, alongside 35 tons of CO_2e travel emissions. Similarly, Tordjman *et al.* (2022) found that 69% of workplaces organized waste sorting, which could lead to long-term cost savings despite initial investment needs. Concurrently, research conducted in Egypt by William *et al*. (2019) demonstrated that mitigating heating, ventilation, and air conditioning (HVAC) energy demands by 55% directly correlates with enhanced long-term financial sustainability for hospitals.

Social and organizational impact

The social implications of sustainability initiatives were underscored by Gasciauskaite *et al.* (2021), where 89% of respondents deemed environmental sustainability essential in their work, and 95% reported implementing measures to "green" their practice. Furthermore, the study by Tordjman *et al*. (2022) revealed that a substantial majority of respondents (73%) advocated for expanded sustainability training, thereby emphasizing the necessity for robust educational frameworks within healthcare institutions.

Challenges and barriers

Despite positive outcomes associated with sustainability initiatives, several challenges persist. Furthermore, research by Tordjman *et al.* (2022) revealed that infrastructure development is hindered by two critical constraints: a lack of staff training (70%) and insufficient funding (66%). Badi *et al.* (2019) highlighted the limitations of current waste management practices in Libya, where open-air burning and inadequate segregation remain prevalent. Vasileiou *et al.* (2024) also noted concerns regarding resource limitations and the need for training as barriers to implementing sustainable practices effectively. Ultimately, these findings emphasize the significance of resolving educational deficits and reconfiguring resource allocation are foundational prerequisites for fostering long-term healthcare sustainability. Green hospital initiatives, such as using reusable materials and optimizing energy, improve clinical care and reduce infection risks while minimizing waste.

Table 3: Characteristics and study design of the selected studies

Study ID	Author(s), year	Study design	Study characteristics				Country	Key findings/ Recommendations
			Population	Intervention	Comparison	Outcome		
1	Keller *et al.*, 2021	Life Cycle Assessment	33 acute care hospitals	Life cycle assessment of 16 environmental impact categories in hospitals	N/A	Average carbon footprint: 3.2 tonnes CO_2eq per FU; main impact from heating (0.82 t CO_2eq per FU)	Switzerland	Hospital emissions are driven primarily by infrastructure and catering, heating and electricity. While waste, chemicals, and paper have a moderate footprint, direct water use, laundry, and heavy machinery show negligible effects.
2	Palmisano *et al.*, 2024	Mixed Methods	Surgeons at a single tertiary academic medical center	Assessment of surgeon perceptions and practices regarding preference card maintenance,	Comparison between early-career and mid-to-late-career surgeons	Frequency of card updates; accuracy of preference cards; perceived environmental impact; barriers to card maintenance	USA	46.1% of respondents rarely or never updated their preference cards; 98.9% observed unused items on their cards; most updates were made via verbal requests; unfamiliar processes (83.7%) and required effort (64.0%)
3	Hale *et al.*, 2024	Quality Improvement	Primary care clinic (staff and patients)	Removal of exam table paper from exam tables in the clinic	Pre-intervention baseline vs. post-intervention	Annual cost savings of USD 515; environmental savings of 8.2 km of exam table paper, preservation of 10 trees, and reduction of 148 kg CO_2e per year (equivalent to driving 1233 km)	Canada	The QI project demonstrated that eliminating exam table paper improves staff efficiency and motivation. (approximately 95,940 km of paper, 121,680 trees, USD 6,029,500, and a reduction of 3054 T carbon dioxide (CO_2) emissions annually)
4	Benedetto *et al.*, 2024	Cost and Environmental Analysis	Residents in an inner area of Tuscany; ~59,000 inhabitants	Introduction of comprehensive full-service mobile screening unit for cancer screening	Current screening programs	Annual reduction of over 110,238 USD in travel costs and productivity losses, and 35 tons of CO_2-equivalent travel emissions saved per year	Italy	The mobile screening unit model enhances sustainability and reduces non-medical costs. This study recommends combining environmental, social, and economic sustainability in rural health.
5	Tordjman *et al.*, 2022	Cross-sectional	Anesthesiologists and anesthesia nurses (SFAR members)	Evaluation of environmentally sustainable anesthesiology practices via a 28-question survey	Comparison between early-career and mid-to late-career providers	- Response rate: 10% (1092/10,877 recipients) - 69% of workplaces organized waste sorting	France	French anesthesia providers are generally aware and actively engaged in sustainable practices. However, barriers such as inadequate training, limited budgets, and insufficient administrative support hinder broader adoption.
6	Badi *et al.*, 2019	Case Study	11 public hospitals across eight cities	Developed a grey-based assessment model using grey systems theory	Compared to burning waste in the open air or disposing of	Microwave technology was identified as the best option for waste treatment, followed by steam sterilization, with	Libya	Poor waste segregation practices were noted to increase environmental and public health risks. It is recommended that decision-

				to evaluate four healthcare waste treatment	it in municipal dumps	landfilling being the least preferred.		makers adopt microwave technology and improve waste segregation to mitigate these risks.
7	Williams *et al.*, 2024	Mixed Methods	VA hospital food service directors (14 survey respondents; 11 interviewees)	Assessment of environmental sustainability implementation in food service	Comparison of self-rated implementation and experiences	Motivators included food waste reduction, healthier foods, and cost efficiency, while barriers involved patient preferences, contracts, and waste reduction costs.	USA	Despite barriers, food service directors identified solutions to improve sustainability initiatives and environmental performance in VA hospital food services.
8	Gasciauskait*et al.*, 2023	Qualitative Study	62 anesthesia providers at a center implementing internal environmentally sustainable anesthesia guidelines	Exploration of perceptions and practices regarding environmental sustainability in anesthesia	N/A	- 89% of respondents stated environmental sustainability is essential in their work - 95% reported implementing measures to "green" their practice - Conscious choice of anesthetics was the most common measure	Switzerland	The study suggests sustainable anesthesia initiatives have significant potential to reduce healthcare's climate impact. Increased education and training are recommended to overcome barriers and enhance adoption of environmentally friendly practices.
9	Vasileiou *et al.*, 2024	Qualitative Study	Healthcare professionals and academics evaluating Green Lean Six Sigma (GLSS) in healthcare	Adoption of GLSS to improve operational efficiency, environmental sustainability, and quality of care	N/A	- Participants acknowledged the potential for efficiency gains and waste reduction - Concerns included resource limitations and the need for training	Greece	The study highlights a cautious but optimistic outlook on GLSS in healthcare. Comprehensive training and resource allocation are necessary for effective implementation.
10	Wilkinson *et al.*, 2022	Multinational observational study	Approximately 2.5 million patients with respiratory diseases from seven ongoing studies	Quantification of the carbon footprint of respiratory care, including medications and healthcare resource utilization (HCRU)	N/A	The carbon footprint of inhaled, oral, and injectable medications will be assessed using life cycle assessment software (SimaPro, Ecoinvent® data)	40+ countries	The study aims to quantify GHG emissions in asthma and COPD care, highlighting the role of well-controlled treatment in reducing environmental impact.
11	Tu *et al.*, 2022	Qualitative	48 healthcare workers (HCWs) from 45 healthcare facilities (HCFs)	Thematic analysis of facilitators and barriers to infection prevention and control (IPC) practices	N/A	- Facilitators: Disinfection practices, patient education, and waste management procedures - Barriers: Lack of IPC training, and personal protective equipment (PPE) shortages	Malawi	Improved IPC policies and infrastructure support are needed to protect HCWs and patients from HAIs. Decision-makers should address systemic barriers to enhance IPC adherence.
12	Woo *et al.*, 2024	Survey and simulation-based	1065 public buildings, public health centers,	Evaluation of energy efficiency and living condition	N/A	- Average energy efficiency improvement of 30% across buildings	South Korea	Strategic adjustments needed to ensure uniform benefits. The study highlights the role of green remodeling in reducing

		evaluation study	and medical institutions	improvements after green remodeling		- Highest gains observed in public health centers - Regional variations in effectiveness		emissions and improving public health.
13	Toughzaoui *et al.,* 2024	Optimization and Simulation Study	Hospital energy systems	Development and optimization of an FC–CHP system powered by solar energy and hydrogen storage	N/A	- Efficient allocation of energy between electricity, hydrogen production, and storage - Reduction in grid electricity costs	France	Genetic algorithms are used for system optimization. The FC–CHP system enhances energy efficiency and sustainability in hospital settings.
14	Sundberg *et al.,* 2024	Qualitative study	24 postgraduate intensive care nursing students	Exploring experiences of environmental sustainability in intensive care units	N/A	-Identified barriers and facilitators to sustainability in ICUs -Nurses expressed a need for better education awareness	Sweden	- Sustainability in ICUs is challenging but possible - Education and hospital management support are crucial for success.
15	Seifert and Guenther, 2019	Qualitative content analysis (using MaxQDA)	31 environmental statements from EMAS-registered hospitals	Environmental management in hospitals under the Eco-Management and Audit Scheme (EMAS)	N/A	- Hospitals focus on structural changes, training, waste separation, and energy efficiency. - Challenges include prioritizing financially beneficial measures, and material consumption	Germany	- Employee awareness campaigns improve engagement. - Digitalization and eco-friendly procurement reduce environmental impact. - Hospitals focus more on waste & energy than water & emissions.
16	William *et al.,* 2019	Case study with energy simulation (Design Builder)	Hospitals in Egypt (Alexandria)	Energy efficiency assessment in hospitals using retrofit and energy-efficient techniques.	Baseline energy consumption	- 55% reduction in HVAC energy consumption. - 59% reduction in total hospital energy consumption.	Egypt	- Implementing energy-efficient techniques can significantly reduce hospital energy use. - The study recommends future hospital designs in Alexandria, Egypt, to improve energy efficiency.
17	McAlister *et al.,* 2022	Life Cycle Assessment	Imaging modalities in Australian hospitals	Assessment of CO2e emissions from five imaging modalities (MRI, CT, CXR, MCXR, US).	Baseline energy use and emissions from diagnostic imaging	- CO2e emissions per scan: MRI (17.5 kg), CT (9.2 kg), CXR (0.8 kg), MCXR (0.5 kg), US (0.5 kg). - Reduced emissions when excluding standby power: MRI (1.1 kg), CT (1.1 kg), CXR (0.6 kg), MCXR (0.1 kg), US (0.1 kg).	Australia	- Reduce unnecessary imaging orders and prioritize low-impact modalities (X-ray, ultrasound) over MRI and CT when possible. - Turn off scanners when not in use to reduce emissions from standby power.
18	Present study	carbon footprint reduction	hosptials	Approach for carbon footprint reduction	Carbon foorprint	-40 percent decrease through renewable energy -lower indirect emissions	Thailand	-High upfront costs, technical gaps, and resistance to change, especially in low-resource settings, hinder widespread implementation.

Ultimately, these interventions prove that environmental sustainability and patient safety are mutually reinforcing priorities rather than competing objectives (Faizan *et al.,* 2025). By adopting a data-informed approach, healthcare facilities can simultaneously reduce environmental impact and strengthen defenses against climate hazards (Münzel *et al.,* 2026). For global perspective challenges, sustainable healthcare interventions frequently trigger unintended trade-offs across operations and finance, while systemic differences make these models highly difficult to replicate globally. A stark disparity exists in global healthcare sustainability: high-income nations fund systemic decarbonization and supply chain emission reductions, whereas climate-threatened areas must prioritize resource-constrained budgets for critical infrastructure resilience and primary care survival (Chen *et al.,* 2026).

Study design

The study design subsection of the systematic review highlights a range of methodologies employed across the included studies. LCA was used in two studies (Keller *et al.,* 2021; McAlister *et al.,* 2022). Mixed methods approaches were adopted in two studies (Palmisano *et al.,* 2024; Woo *et al.,* 2024). Methodological focuses varied across the literature; a quality improvement assessment was utilized by Ilona and Amanda, (2024), whereas cost and environmental analyses were each executed in only a single study. Keil *et al.,* (2024) indicated that while hospitals preferred the greenhouse gas protocol for top-down organizational footprint, International Organization for Standardization (ISO) 14064 provided superior auditability. Conversely, micro-level clinical pathways required bottom-up LCAs, though current methodological inconsistency limits cross-study comparison. Bridging the gap between corporate carbon reporting and clinical workflows, investigators introduce a unified hybrid framework combining organizational and product-level sustainability standards. A cross-sectional design (Tordjman *et al.,* 2022) was employed in one study, and case studies were used in two studies (Badi *et al.,* 2019; William *et al.,* 2019). Qualitative studies were conducted in four studies (Gasciauskaite *et al.,* 2023; Sundberg *et al.,* 2024; Tu *et al.,* 2022; Vasileiou *et al.,* 2024), while qualitative content analysis was performed in one study (Seifert and Guenther, 2019). An observational study framework was utilized in a particular study (Wilkinson *et al.,* 2022). Additionally, a survey and simulation-based evaluation study was conducted in one of the included studies (Woo *et al.,* 2024), and an optimization and simulation study was carried out in another study (Toughzaoui *et al.,* 2024).

Evaluation of the quality of the studies

Table 4 outlines the comprehensive classification framework applied during the quality assessment of the selected literature. The seventeen studies evaluated with the MMAT demonstrated strong overall quality; sixteen met high-quality standards, while one was rated moderate. All studies that were part of the systematic review satisfied the essential quality benchmarks, with none being classified as inadequate. This systematic review explores key areas to improve sustainability in healthcare, including lowering the carbon footprint, energy management, waste management through circular economy approaches, and considering policy and economic considerations for sustainable hospitals. The outcomes underscore the ways in which healthcare facilities can markedly advance their sustainability efforts.

Carbon footprint reduction

The studies revealed significant opportunities to reduce carbon footprints in healthcare. Building infrastructure and catering were identified as primary contributors to environmental impacts, followed by heating and electricity, while waste, pharmaceuticals, and medical products had

Table 4: Assessment of the quality of the study

ID	Sources	General screening (Pass/Fail)	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Total "Yes" ratings	Quality
1	Keller *et al.,* 2021	Pass	✓	✓	✓	✓	✓	5	High
2	Palmisano *et al.,* 2024	Pass	✓	✓	✓	✓	x	4	High
3	Hale *et al.,* 2024	Pass	✓	✓	✓	✓	x	4	High
4	Benedetto *et al.,* 2024	Pass	✓	✓	✓	✓	x	4	High
5	Tordjman *et al.,* 2022	Pass	✓	✓	✓	x	x	3	Moderate
6	Badi *et al.,* 2019	Pass	✓	✓	✓	✓	x	4	High
7	Williams *et al.,* 2024	Pass	✓	✓	✓	✓	✓	5	High
8	Gasciauskaite *et al.,* 2023	Pass	✓	✓	✓	✓	x	4	High
9	Vasileiou *et al.,* 2024	Pass	✓	✓	✓	✓	x	4	High
10	Wilkinson *et al.,* 2022	Pass	✓	✓	✓	✓	x	4	High
11	Tu *et al.,* 2022	Pass	✓	✓	✓	✓	x	4	High
12	Woo *et al.,* 2024	Pass	✓	✓	✓	✓	✓	5	High
13	Toughzaoui *et al.,* 2024	Pass	✓	✓	✓	✓	✓	5	High
14	Sundberg *et al.,* 2024	Pass	✓	✓	✓	✓	✓	5	High
15	Seifert and Guenther, 2019	Pass	✓	✓	✓	✓	✓	5	High
16	William *et al.,* 2019	Pass	✓	✓	✓	✓	✓	5	High
17	McAlister *et al.,* 2022	Pass	✓	✓	✓	✓	✓	5	High

notable effects (Keller *et al.,* 2021; Cole *et al.,* 2025). To address these systemic challenges, targeted interventions must be implemented to curtail superfluous imaging orders. Specifically, clinical protocols should favour low-impact modalities such as X-rays and ultrasound as first-line diagnostics over resource-intensive alternatives like CT and MRI scans (McAlister *et al.,* 2022). Additionally, eliminating exam table paper demonstrated the potential for substantial cumulative savings in emissions, resources, and costs if implemented nationwide (Ilona and Amanda, 2024; Raihan *et al.,* 2025). The implementation of standardized operational practices—specifically the optimization of surgical preference cards—offers a highly effective mechanism for reducing material and resource waste during operative procedures (Palmisano *et al.,* 2024). By removing unnecessary or rarely used items from surgical checklists, hospitals can significantly reduce the volume of discarded, opened-but-unused supplies, ultimately lowering costs and surgical preparation time (Perez *et al.,* 2026). The data suggest that adopting a comprehensive, cross-operational approach to mitigation can drive meaningful reductions in institutional carbon footprints (Feigin *et al.,* 2023).

Energy management and hospital sustainability

Energy efficiency emerged as a critical area for improving hospital sustainability (Chen *et al.,* 2024). Studies highlighted the effectiveness of implementing energy-efficient techniques, such as HVAC retrofits, which led to a 55 percent reduction in HVAC energy consumption in Egyptian hospitals (William *et al.,* 2019). Furthermore, leveraging FC–CHP technology powered by renewable substrates has been shown to optimize system-wide energy efficiency, reduce reliance on external power grids, lower greenhouse gas emissions, decrease operational costs, enhance energy resilience, and support the long-term environmental sustainability of healthcare facilities through efficient resource utilization and cleaner energy production (Toughzaoui *et al.,* 2024). Green remodeling efforts improved energy efficiency by an average of 30%, with the highest gains observed in public health centers in South Korea (Woo *et al.,* 2024). Institutional sustainability can be further enhanced through operational policies that mandate the deactivation of idle imaging equipment, thereby curbing superfluous standby power emissions (McAlister *et al.,* 2022; Shokoohi *et al.,* 2025). To achieve long-term sustainability,

healthcare facilities should prioritize investments in renewable energy systems and conduct regular energy audits to identify further opportunities for optimization (Vovk *et al.,* 2025; Sarker *et al.,* 2025). Green certifications like Leadership in energy and environmental design (LEED), Building research establishment environmental assessment method (BREEAM), excellence in design for greater efficiencies (EDGE), and the WELL building standard give hospitals clear, data-backed standards to cut their heavy energy use and carbon emissions, turning them into sustainable, eco-friendly spaces (Ak, 2025).

Waste management and circular economy in hospitals

Effective waste management is essential for advancing a circular economy within healthcare (Zikhathile *et al.,* 2026; de Souza Lima Cano *et al.,* 2025). While sub-optimal waste segregation practices remain a primary driver of environmental liabilities within healthcare facilities, empirical evidence positions microwave technology as the most effective waste-remediation alternative to conventional methods such as incineration and landfilling (Badi *et al.,* 2019). Food service operations also offer opportunities for improvement; best practices such as modifying familiar dishes to be plant-forward (Fechner *et al.,* 2026; Yi *et al.,* 2026) and conducting plate waste studies can help reduce food waste while maintaining patient satisfaction (Williams *et al.,* 2024; Hoteit *et al.,* 2024). Prior studies underscore food waste reduction within healthcare facilities as a primary mechanism for mitigating institutional environmental degradation and curbing lifecycle greenhouse gas emissions (Chatzipavlou *et al.,* 2024; Thiel *et al.,* 2021; Yip *et al.,* 2025). Sustainable anaesthesia practices, including minimising the use of highly polluting anaesthetic gases, were also highlighted as impactful measures (Gasciauskaite *et al.,* 2023; Tordjman *et al.,* 2022). Emissions from healthcare-related anesthetic gases and respiratory inhalers have been heavily documented and targeted for systemic mitigation across key global medical studies and climate action frameworks (Provenzani *et al.,* 2025) such as identifying that major portion of nitrous oxide are lost to atmospheric leaks in centralized piping networks (Devlin-Hegedus *et al.,* 2022). To address the challenges of regulated medical waste, implementing non-monetary operational interventions—including targeted staff education, cross-departmental collaboration, and optimized receptacle placement—demonstrated a substantial reduction in the ecological footprint and disposal costs of interventional infectious waste. Hospitals should integrate comprehensive waste segregation policies, promote recycling initiatives, and explore innovative reuse strategies to close material loops (Shah *et al.,* 2026; Moshawih *et al.,* 2025). Evidence confirmed that circular economy methods—such as reprocessing devices, reusing surgical kits, and recovering materials—effectively lower hospital waste. As detailed in recent lifecycle assessments, the isolated implementation of reusable textiles curbed municipal solid waste volumes by over 90% and drove a concurrent decrease in carbon emissions (Iskandar Shah *et al.,* 2026).

Policy and economic considerations for sustainable hospitals

Policy frameworks and economic incentives play a pivotal role in driving sustainability initiatives (Zarghami, 2025; Schetinger and Lucena, 2025). Numerous investigations have highlighted a significant correlation between deficient clinician awareness and sub-optimal environmental outcomes, thereby demonstrating the urgency for targeted professional training in healthcare sustainability (Gasciauskaite *et al.,* 2023; Tordjman *et al.,* 2022; Sundberg *et al.,* 2024). For the leadership commitment, organizational culture, staff attitudes, awareness, and institutional readiness are key determinants for hospital sustainability strategies. The study highlights that active management, positive workforce attitudes, environmental education,

and structural capacity are crucial for effective implementation. Specifically, the deployment of staff-focused educational campaigns serves as an effective mechanism for fostering organizational alignment with broader ecological initiatives (Seifert and Guenther, 2019). Standardized indicators of carbon footprint reduction such as total absolute GHG emissions, carbon intensity, renewable energy share and emissions reduction factor (Yu *et al.,* 2024), are crucial for hospital performance frameworks to enable fair benchmarking, monitor development over time, and foster continuous quality enhancement (Dolcini *et al.,* 2025). To ensure long-term efficacy, future policy interventions should be engineered to dismantle systemic barriers, specifically inadequate infection prevention infrastructure and restricted access to personal protective equipment (Tu *et al.,* 2022; Houghton *et al.,* 2020). Financially, integrating sustainability into hospital operations can yield substantial cost savings (Dolcini *et al.,* 2025; Olawade *et al.,* 2025). For instance, mobile cancer screening units reduced travel costs by over 110,238 USD annually while cutting CO_2 emissions by 35 tons yearly (Benedetto *et al.,* 2024). Addressing institutional carbon footprints requires strategic policy interventions, namely the targeted funding of sustainable architectural modifications and the deployment of economic incentives to promote eco-friendly hospital procurement practices (Schwab *et al.,* 2025; Tomaselli *et al.,* 2026). Digitalizing hospital operations including telemedicine, AI-assisted triage, remote monitoring, and electronic medical records can also streamline resource use with the carbon footprint reduction while promoting sustainable supply chain practices (Seifert and Guenther, 2019; Bobini *et al.,* 2025). Regarding the issue of national healthcare policy, environmental regulations, and green procurement standards collectively drive hospital sustainability and carbon reduction, transforming voluntary ecological goals into mandatory, measurable operational requirements (Schwab *et al.,* 2025).

Quality of the studies

The quality assessment of the included studies, as summarized in Table 4, reveals a predominantly high methodological standard, with 16 out of 17 studies classified as high-quality, achieving at least four out of five "Yes" ratings. Notably, life cycle assessments (Liu *et al.,* 2024), mixed-method studies (Johnson *et al.,* 2020), and qualitative research designs (Ahmed, 2024) demonstrated the highest methodological rigor, with eight studies receiving a perfect score. These studies exhibited clear research frameworks, strong data validity, and well-structured analytical techniques, ensuring the reliability of their findings. In particular, mixed-method investigations offered an integrated paradigm for analyzing healthcare sustainability interventions, balancing statistical effectiveness data with qualitative evidence regarding stakeholder buy-in and organizational barriers (Rana and Chimoriya, 2025; Kagoma *et al.,* 2025). Additionally, the life cycle assessments included in the review employed comprehensive environmental impact analyses, strengthening the evidence base for sustainability strategies (Munir *et al.,* 2024). A comprehensive assessment of study quality indicates a low risk of methodological bias across the literature. Consequently, the synthesized data exhibit high credibility, substantiating the overarching conclusions of this systematic review.

Study strengths

Methodological rigor was safeguarded through adherence to PRISMA standards and systematic MMAT appraisal. Of the 17 studies selected for synthesis, 16 were evaluated as high quality (94.1%), and none were categorized as low quality. Its comprehensive scope, encompassing diverse sustainability interventions such as carbon footprint reduction, energy management, waste minimization, sustainable procurement, and green hospital infrastructure, provides a holistic understanding of environmentally sustainable hospital practices (Orsini *et al.,* 2024; Almukhtar *et al.,* 2024) and directly saves lives by minimizing

healthcare pollution, which currently drives up to 5% of global emissions (Schwab *et al.,* 2024). Evidence suggests that green healthcare initiatives foster health equity via clinical waste optimization, expanded digital health access, and renewable energy adoption. Nevertheless, operationalizing these measures creates significant ethical friction, forcing a reconciliation between institutional sustainability goals, fair resource distribution, and patient-centered care. By incorporating evidence from high-income and low- and middle-income countries (LMICs), the review identifies contextual disparities in policy adoption, financial constraints, and infrastructure readiness, offering globally relevant insights. Notably, the integration of mixed-methods evidence enhances this analysis, ensuring that statistical evaluations of environmental and economic efficacy are contextualized by qualitative assessments of prevailing policy challenges, stakeholder alignment, and systemic institutional barriers (Gao *et al.,* 2025; Iliopoulos *et al.,* 2026). This study evaluates the effectiveness of sustainability interventions and critically examines barriers to implementation, providing policy-relevant recommendations to enhance feasibility in diverse healthcare settings (Haregu *et al.,* 2025; Vasileiou *et al.,* 2024). Furthermore, by emphasizing the long-term economic viability of sustainability initiatives, the review contributes to the ongoing discourse on cost-effectiveness and strategic investment in green healthcare systems. These findings align with broader sustainability research demonstrating that environmentally responsible practices are increasingly influenced by stakeholder awareness, behavioral drivers, and digital transformation, reinforcing the need for integrated and adaptive sustainability strategies across sectors (Soulami *et al.,* 2026). By pairing pragmatic, policy driven recommendations with rigorous methodology, This study significantly enriches the theoretical framework of healthcare sustainability management and provides a blueprint for future institutional interventions and policy development.

Limitations

The limitations of the review primarily occur from the variability in study quality and design, as highlighted by MMAT. Substantial methodological heterogeneity across the included studies—specifically regarding sustainability metrics, research designs, and reporting frameworks—precludes the synthesis of uniform conclusions. Furthermore, the absence of longitudinal studies is a significant limitation, as it prevents a comprehensive understanding of the long-term sustainability impacts (Wang *et al.,* 2025), which are essential for evaluating the lasting effects of the interventions over time because the results were fragmented, the synthesis lacked a structured framework and failed to capture real-time dynamics, ultimately providing inadequate guidance for tackling hospital sustainability challenges (Mostepaniuk *et al.,* 2023). Furthermore, the interpretation of these environmental metrics is cross-cut by macro-level determinants—namely, disparities in facility capacity, patient volume, climate zones, national energy grid portfolios, and health economics frameworks—which complicate direct cross-study comparisons. These gaps in study design and reporting hinder the ability to assess the true sustainability of the interventions reviewed.

Future research

Accelerating hospital decarbonization requires regulatory policies that embed carbon accounting into institutional management, enforceable through mandatory emissions tracking, public reporting protocols, and standardized reduction benchmarks. Financial incentives, such as subsidies, carbon credits, carbon pricing, green taxation, financial incentives, sustainability funding mechanisms and public-private partnerships, should be introduced to help hospitals transition to low-carbon models, particularly in resource-constrained settings. To facilitate sector-wide compliance, future policy interventions must deploy structured governance systems capable of mitigating regulatory friction

while enforcing rigorous operational accountability. Future research should explore context-specific sustainability strategies tailored to hospitals in various socioeconomic settings, investigate innovative green technologies like AI-driven energy management and biodegradable medical supplies, and assess the effectiveness of policy interventions and financial models that facilitate sustainability adoption. Moreover, tracking carbon-neutral hospital trajectories via longitudinal methodologies is imperative for identifying optimal, scalable interventions, whereas institutionalizing capacity-building programs ensures a sustainable transition by embedding green operational skills throughout the healthcare workforce. These policy and research recommendations can transform healthcare institutions into environmentally responsible and sustainable entities.

CONCLUSION

The Hospital consumption requires the substantial portion of energy, water and natural resource and produce large volumes of waste generation, contributing to greenhouse gas emissions and environmental impact. Ultimately, global healthcare frameworks position medical sector decarbonization as a critical public health objective of the twenty-first century, thereby driving hospitals to systematically reduce greenhouse gas emissions and clip localized climate impacts. The sustainable practices would be achieved the significant environmental benefits, improve public health outcomes, and enhance economic efficiency. The sustainable building practices can significantly reduce energy consumption and improve efficiency with implementing renewable energy sources and co-generation systems. In transitioning toward environmental sustainability, modern hospitals simultaneously face acute resource and regulatory constraints alongside emerging pathways for financial and clinical co-benefits. This review underscores the need for integrated, policy-driven approaches to hospital sustainability. The studies reviewed indicate significant environmental impacts associated with healthcare practices with the potential for operational efficiency improvements. Nevertheless, these institutional barriers elucidate the critical imperative of mitigating educational deficits and optimizing resource allocation to cultivate a resilient, sustainable healthcare delivery model. For the carbon footprint reduction, the building infrastructure and catering of hospitals were presented as primary contributors of environmental impacts, followed by heating and electricity, while waste, pharmaceuticals, and medical products also had notable effects. Furthermore, hospitals can achieve substantial energy load reductions by powering down diagnostic imaging modalities during non-operational intervals, thereby mitigating the baseline carbon emissions associated with standby power consumption. While carbon footprint reduction, energy management, waste reduction, and sustainable procurement show promising results, their widespread adoption remains hindered by financial, regulatory, and organizational barriers. It is essential for governments, hospital administrators, and global health organizations to collaborate in order to establish scalable, context-specific sustainability models. Future studies should explore long-term impacts, financial viability, and new green technologies that can facilitate the worldwide shift towards environmentally sustainable healthcare systems.

AUTHOR CONTRIBUTIONS

T. Buadit designed the conceptualization and methodology with the role of project administration and funding acquisition. J. Bhatta conducted the data curation and analysis, and prepared the first draft of manuscript. P.J. provided the role of supervision for the direction and trend of manuscript. W. Ounsaneha assisted the formal analysis of data and the revised the manuscript draft. C. Rattanapan the corresponding author supervised the first and co-authors, conceived the manuscript concept, and finalized the manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy, have been completely witnessed by the authors.

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The author(s) declared that no AI tools or services were not used or not highly applied during the preparation of this work.

ABBREVIATIONS

%	Percent
BREEAM	Building research establishment environmental assessment method
CT	Computed tomography
EDGE	Excellence in design for greater efficiencies
FC–CHP	Fuel cell combined heat and power
GHG	Greenhouse gas
GLSS	Green lean six sigma
HVAC	Heating, ventilation, and air conditioning
ICU	Intensive care unit
ISO	International Organization for Standardization
Kg CO_2e	Kilogram carbon dioxide equivalent
LCA	Life Cycle Assessment
LEED	Leadership in energy and environmental design
LMICs	Low- and middle-income countries
MMAT	Mixed methods appraisal
MRI	Magnetic resonance imaging
NHS	National Health Service
Pico	Population, intervention, comparison, and outcome
PPE	Personal protective equipment
PRISMA	Preferred reporting items for systematic review and meta-analysis
PROSPERO	International Prospective Register of Systematic Reviews
RCTs	Randomized controlled trials
SFAR	Society of Anesthesia, Critical Care, and Perioperative Medicine
TCO_2e	Tan carbon dioxide equivalent
USD	United States dollar
WHO	World Health Organization
VA	Veterans affairs

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