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REVIEW ARTICLE

GREEN HOSPITAL IMPLEMENTATION FOR SUSTAINABLE AND RESILIENT HEALTH SYSTEMS IN LOW- AND MIDDLE-INCOME COUNTRIES: A SCOPING REVIEW

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ABSTRACT

INTRODUCTION

Health care both protects population health and drives environmental harm through energy use, waste, and greenhouse-gas emissions. The Green Hospital concept links environmental sustainability with hospital resilience, but evidence from low- and middle-income countries (LMICs) is fragmented.

OBJECTIVE

To map evidence on Green Hospital implementation in LMICs; identify enablers and barriers; characterize measurement approaches; quantify reporting of health, economic, and equity outcomes; and synthesize a conceptual framework of pathways from governance to population health.

METHODS

Scoping review following PRISMA-ScR, registered on the Open Science Framework (https://doi.org/10.17605/OSF.IO/F2BR5). PubMed/MEDLINE, Scopus, and ScienceDirect were searched for English-language peer-reviewed empirical studies published from January 2009 to October 2025 from countries classified by the World Bank (FY2025) as low-, lower-middle-, or upper-middle-income. Screening and charting were performed in duplicate.

RESULTS

Twenty-nine studies were included, concentrated in lower-middle-income settings (20/29), Sub-Saharan Africa (11/29), and South Asia (7/29). Implementation clustered in waste management, water and sanitation, energy efficiency, and green infrastructure, with limited resilience integration. Leading enablers were leadership commitment, regulatory support, and institutional awareness; leading barriers were financial constraints, weak technical capacity, fragmented governance, and non-standardized indicators. Life-cycle assessment and multi-criteria decision-making predominated. Three gaps were quantified: one study reported a population health outcome, and only as a cross-sectional association; three reported cost data and none a formal economic evaluation; none disaggregated findings by occupational group, rurality, or ownership.

CONCLUSION

The literature maps a Green Hospital agenda concentrated in foundational environmental domains and weakly connected to resilience-oriented governance and performance systems. Because studies were predominantly cross-sectional, pathways from intervention to resilience and health are presented as hypothesized propositions requiring testing. The next priority is to align harmonized environmental key performance indicators with hospital accreditation.

KEYWORDS

green hospital; sustainable health care; hospital resilience; climate change; environmental management; low- and middle-income countries; scoping review

INTRODUCTION

BACKGROUND

Global health systems face compounding pressures from climate change, pandemics, and socio-economic shocks, and are increasingly expected to become both resilient and sustainable. Hospital resilience is the capacity to adapt to, withstand, and recover from disruption while maintaining essential services [1,2]. The COVID-19 pandemic exposed how resource limits and weak coordination undermine it.[3]

Health care also contributes materially to greenhouse-gas emissions. Estimates vary with the system boundary and base year adopted, from about 4.4% of global emissions using 2014 input-output data to about 5.2% in more recent syntheses; across sources, hospital operations and their supply chains account for the largest share of the sector footprint.[4,5]
In response, the Green Hospital concept integrates energy efficiency, waste management, water conservation, and smart technologies into hospital management. Instruments such as environmental key performance indicators (EKPIs) and life-cycle assessment (LCA) support environmental evaluation, [5,6] while implementation-oriented tools for resource-constrained settings, such as the WHO/UNICEF WASH FIT, the WHO guidance on climate-resilient and environmentally sustainable facilities, and the PAHO Smart Hospitals Toolkit, provide a parallel measurement tradition.[7–9] Applying these principles can improve operational efficiency, reduce energy costs, and strengthen crisis capacity.[10]

Evidence remains fragmented, with heterogeneous indicators and limited synthesis of implementation and its constraints. This fragmentation is most acute in LMICs, where hospitals face high climate exposure and constrained investment capacity, and where the applicability of instruments developed in high-income settings has not been systematically examined. This review uses the term LMICs throughout, applying the World Bank country classification for fiscal year 2025, and reports sex- or gender-disaggregated data where available.[11,12] It addresses five objectives: 1) to map the concepts, models and implementation frameworks of Green Hospitals reported in LMICs; 2) to identify enabling and inhibiting factors; 3) to characterise the approaches used to measure sustainability, resilience and efficiency; 4) to quantify reporting of patient or population health outcomes, economic data and equity-relevant disaggregation; and 5) to synthesise an integrative conceptual framework that distinguishes evidenced from hypothesised pathways.

METHODS

REPORTING AND REGISTRATION

This scoping review follows the PRISMA extension for Scoping Reviews (PRISMA-ScR) and the methodological framework of Arksey and O'Malley as advanced by Levac and colleagues.[13,14] It was registered on the Open Science Framework (**https://doi.org/10.17605/OSF.IO/F2BR5**). The method was chosen to map the extent, range, and nature of the evidence rather than to estimate an effect. The PRISMA-ScR checklist is provided as Supplementary File S1.

DATA SOURCES AND SEARCH STRATEGY

Three electronic databases, PubMed/MEDLINE, Scopus, and ScienceDirect, were searched, last updated on 30 October 2025. The strategy combined three concept blocks corresponding to the PCC elements with the Boolean operator AND, with terms within each block combined using OR (Table 1). Truncation and phrase searching were applied; searches were restricted to title and abstract fields; MeSH descriptors were used in PubMed/MEDLINE; and free-text searching was used in Scopus and ScienceDirect. Filters covered publication date, document type, and language. The 2009 start date reflects the WHO and Health Care Without Harm discussion draft that introduced climate-friendly hospitals into institutional debate.[15] Supplementary file S2 provides full strings, run dates, and record counts. No hand-searching, citation tracking, or grey-literature searching was undertaken.

TABLE 1. CONCEPT BLOCKS, CONTROLLED VOCABULARY, AND BOOLEAN STRUCTURE OF THE SEARCH STRATEGY

PCC element	Free-text terms (title/abstract, OR within block)	Controlled vocabulary (MeSH, PubMed only)
Population	"health care system*" OR "healthcare facilit*" OR hospital* OR "health facilit*" OR "health-care facilit*"	Hospitals[Mesh]; Health Facilities[Mesh]; Delivery of Health Care[Mesh]
Concept	"green hospital*" OR "sustainable health care" OR "hospital sustainab*" OR "environmental sustainab*" OR "climate-resilient health facilit*" OR "hospital resilience" OR "life cycle assessment" OR "environmental management" OR "energy efficien*" OR "waste management" OR "sustainable health system*."	Conservation of Natural Resources[Mesh]; Medical Waste Disposal[Mesh]; Climate Change[Mesh]; Green Chemistry Technology[Mesh]
Context	"developing countr*" OR "low-income countr*" OR "middle-income countr*" OR LMIC* OR "least developed countr*" OR "resource-constrained" OR "resource-limited"	Developing Countries[Mesh]
Boolean structure	(Population block) AND (Concept block) AND (Context block), with date, document-type, and language filters applied at the end	-

ELIGIBILITY CRITERIA

Inclusion and exclusion criteria followed the PCC elements (Table 2). Eligible studies were peer-reviewed empirical articles or full conference papers addressing Green Hospital practice, environmental-sustainability domains (energy, waste, water and sanitation, buildings, procurement and supply chain) or resilience strategies with an environmental component, conducted in hospitals or health facilities in LMICs (World Bank FY2025) and published in English between 2009 and 2025. Eligibility focused on the unit of analysis rather than the topic: we included healthcare-waste studies that treated waste as a facility- or organization-level management problem and excluded those that examined it as a treatment process or product alone.

TABLE 2. ELIGIBILITY CRITERIA STRUCTURED BY THE PCC FRAMEWORK

PCC element	Inclusion criteria	Exclusion criteria
P (Population)	Health systems, health-care facilities and hospitals, including teaching, regional and district facilities, and mixed samples that include hospitals.	Studies confined to ambulatory or outpatient clinics only, or to non-health sectors.
C (Concept)	Green Hospital practice; environmental-sustainability domains (energy, waste, water	Product-level or clinical LCA with no organizational dimension; a waste-

	and sanitation, buildings, procurement and supply chain); environmental policy frameworks; or resilience strategies with an environmental component. Health-care-waste studies eligible where waste is a facility- or organization-level management problem; techno-economic studies eligible where facility-level environmental performance is reported.	treatment technology or laboratory process alone; only social or economic sustainability with no environmental dimension; engineering or financial analyses reporting no environmental performance.
C (Context)	Countries classified by the World Bank (FY2025) as low-, lower-middle- or upper-middle-income, including multi-country studies in which all or most settings fall within these categories.	Studies conducted exclusively in high-income countries.
Time and language	Published 1 January 2009 to 31 October 2025; full text in English.	Published outside this window; full text not available in English.
Publication type	Peer-reviewed original empirical research articles and full conference-proceedings papers.	Narrative reviews, systematic reviews, meta-analyses, editorials, commentaries, conference abstracts and study protocols.
Boundary rule	Eligibility turns on the unit of analysis, not the topic. Eleven included studies address health-care waste as a facility- or organization-level management problem with reported environmental performance.	Under the same rule, we excluded 20 full texts because they examined waste as a treatment process or product alone, and we excluded three device- or process-level techno-economic appraisals.

STUDY SELECTION AND DATA EXTRACTION

Records were imported into Rayyan (https://rayyan.qcri.org/) and de-duplicated. Two reviewers (AAL and AM) independently screened all titles, abstracts, and full texts in blinded mode; they resolved disagreements through discussion and, when needed, with a third reviewer (FM). Excluded studies and reasons were documented. The two reviewers charted data into a piloted spreadsheet covering study characteristics, implementation domains, resilience integration, policy frameworks, and LMIC contextual barriers, with dedicated fields for health-outcome, economic, and equity reporting. Screening and full-text disagreements were resolved by discussion and, where necessary, by adjudication with the third reviewer; no formal inter-rater agreement statistic (for example, Cohen's or Fleiss' kappa) was calculated.

DATA SYNTHESIS

Findings were synthesized narratively and thematically against four themes defined a priori from the objectives: concepts and implementation frameworks; enablers and barriers; measurement approaches; and policy implications. The themes were not mutually exclusive; each study was assigned to every theme on which it reported substantive data, so counts are reported against a denominator of 29 and sum to more than 29 (study-by-theme matrix in Supplementary File S3). A gap analysis quantified the reporting of health, economic, and equity outcomes across the included studies.

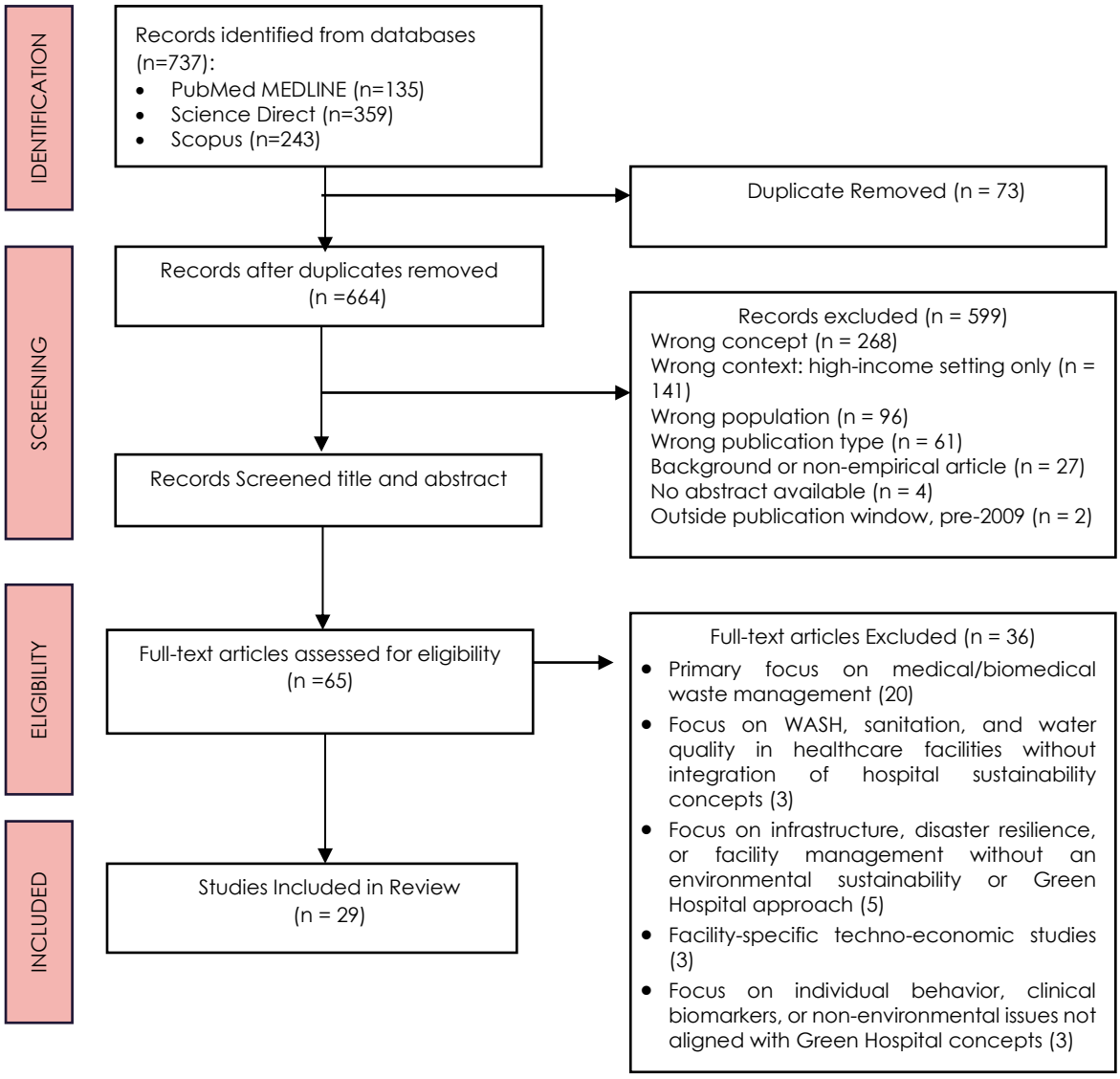
RESULTS

STUDY SELECTION

Database searching in PubMed/MEDLINE (n = 135), ScienceDirect (n = 359), and Scopus (n = 243) identified 737 records. After removal of 73 duplicates, 664 records were screened by title and abstract, and 599 were excluded; 65 full-text articles were assessed, and 36 were excluded, leaving 29 studies included (Figure 1). The 36 full-text exclusions comprised waste examined as a treatment process, technology or product alone (n = 20); settings confined to high-income countries (n = 5); device- or process-level techno-economic appraisals reporting no facility-level environmental performance (n = 3);

studies with no environmental dimension (n = 3); ineligible publication types (n = 4); and full text not available in English (n = 1). Figure 1 and Supplementary File S1 report the same six categories and the same totals.

FIGURE 1. PRISMA-SCR FLOW DIAGRAM FOR THE STUDY SELECTION PROCESS



CHARACTERISTICS OF THE INCLUDED EVIDENCE

The 29 studies were published between 2014 and 2025, with 19 (66%) from 2022 onward. The evidence base was geographically concentrated: Sub-Saharan Africa contributed 11 studies (38%), South Asia seven (24%), and Latin America and the Caribbean only two (7%). By income group, 20 studies (69%) were conducted in lower-middle-income, and eight (28%) in upper-middle-income countries; no single-country study was conducted in a low-income setting, which is represented only within one 46-country modeling study. Central Asia, the Pacific island states, and fragile or conflict-affected settings were absent. Modeling and multi-criteria decision-making dominated the designs (n = 8), followed by cross-sectional descriptive studies (n = 7). Sixteen studies (55%) focused exclusively on hospitals, and none reported findings separately for small or rural facilities (Tables 3 and 4).

TABLE 3. CHARACTERISTICS OF THE 29 INCLUDED STUDIES

Characteristic	n (%)	Detail
World Bank region		
Sub-Saharan Africa	11 (38)	Ghana 4, Nigeria 3, Kenya 2, Namibia 1, South Africa 1
South Asia	7 (24)	India 4, Bangladesh 1, Sri Lanka 1, Pakistan 1
Middle East and North Africa	4 (14)	Iran 3, Morocco 1
East Asia and Pacific	4 (14)	Indonesia 2, Thailand 1, Malaysia 1
Latin America and Caribbean	2 (7)	Colombia 1, Brazil 1
Multi-country	1 (3)	46 UN least-developed countries
World Bank income group (FY2025)		
Lower-middle income	20 (69)	India, Ghana, Nigeria, Kenya, Iran, Bangladesh, Sri Lanka, Pakistan, Morocco
Upper-middle income	8 (28)	Indonesia, Thailand, Malaysia, Colombia, Brazil, South Africa, Namibia
Low income (single country)	0 (0)	Represented only within the multi-country modeling study
Multi-country (low and lower-middle)	1 (3)	46 UN least-developed countries
Study design		
Modeling, MCDM or optimization	8 (28)	DEMATEL, ISM, MICMAC, fuzzy multi-objective, factor analysis, costing model
Cross-sectional descriptive quantitative	7 (24)	Survey, environmental assessment, waste characterization
Qualitative	4 (14)	Policy document review, interviews, document analysis
Life cycle assessment	3 (10)	Waste treatment alternatives
Case study or engineering design	3 (10)	Techno-economic and facility-design studies
Mixed methods	2 (7)	Sequential and concurrent designs
Tool or protocol development	2 (7)	Disaster-preparedness tool; waste-assessment protocol
Setting		
Hospitals only	16 (55)	Public, private, teaching and regional hospitals
Mixed hospital and primary care	6 (21)	Hospitals with clinics, health centers or health posts
Supply chain or off-site treatment	3 (10)	Healthcare supply-chain networks; common treatment facilities
Primary care only	2 (7)	Community health centers; rural dispensaries
System or policy level	2 (7)	National and sub-national policy analysis
Ownership		
Public facilities only	14 (48)	
Public and private facilities	9 (31)	
Not specified or not applicable	6 (21)	Sector- or network-level studies

TABLE 4. SUMMARY OF THE 29 INCLUDED STUDIES ON SUSTAINABILITY, RESILIENCE AND GREEN HOSPITAL IMPLEMENTATION IN LMICS

.	Author	Year	Country	Income group	Study design	Setting	Purpose	Key findings
1	Abu & Elliott [16]	2020	Kenya	Lower-middle	Qualitative policy document review	National and county health systems	Explore country-level commitment to WASH access in health-care facilities within a Universal Health Coverage pilot.	National policy documents lack comprehensive WASH indicators, which the UHC pilot neither measures nor monitors.
2	Lister et al. [17]	2025	Namibia	Upper-middle	Descriptive quantitative survey	Public, private and academic sectors	Identify professionals' knowledge, attitudes, and practices on environmental sustainability.	Professionals held basic knowledge and positive attitudes, but structural barriers prevented them from translating this into practice.
3	Chaitkin et al. [18]	2022	46 LDCs	Low and lower-middle	Modelling study	Public facilities, hospitals and non-hospital facilities, urban and rural	Estimate the cost of full basic WASH and waste-management coverage by 2030.	Full basic coverage requires an estimated US$6.5–9.6 billion, with waste management almost half of that cost.
4	Purwandari et al. [19]	2024	Indonesia	Upper-middle	Cross-sectional, national survey	Government, private, and specialized hospitals	Assess WASH via WASH FIT and its association with patient satisfaction and maternal mortality due to infection.	Most hospitals rated "good" for WASH but only 13% for waste management; specific WASH FIT indicators were associated with maternal mortality due to infection. This is the only study reporting a population health outcome.
5	Embrey et al. [20]	2024	Bangladesh	Lower-middle	Case study and policy analysis	Public and private secondary and tertiary facilities	Analyze integration of IPC and WASH into national quality-of-care guidelines.	National guidance covered only 55% of essential IPC/WASH subconditions; awareness was high, but budget, infrastructure, and training constrained implementation.
6	Chaudhary & Kumar [21]	2021	India (Bihar)	Lower-middle	Cross-sectional quantitative	Public and private hospitals	Examine how innovation and adopter	Relative advantage, simplicity, trialability, and compatibility

							characteristics influence the rate of adoption of environmental sustainability innovations.	significantly predicted adoption of eco-innovations, whereas innovativeness and environmental opinion leadership did not.
7	Regragui et al. [22]	2024	Morocco	Lower-middle	Framework development (fuzzy MCDM)	Public and private hospitals	Develop and test a multi-criteria methodology for hospital sustainability performance.	Thirty-two indicators across six dimensions were established; private hospitals outperformed public hospitals, and both were weakest on the environmental–social and learning–growth dimensions.
8	Rattan et al. [23]	2022	India	Lower-middle	Scale development (factor analysis)	Hospitals and clinics offering traditional medicine	Propose and validate a multidimensional sustainability scale aligned with the SDGs.	A 39-item, seven-dimension scale was validated; traditional medicine promoted low-cost access, but caste and gender exclusion persisted.
9	Ebekozien et al. [24]	2022	Nigeria	Lower-middle	Qualitative interviews	Public hospital buildings	Investigate barriers to green practice in public hospital buildings and propose solutions.	Green building was very limited, constrained by six barrier themes: policy, organizational/leadership, financial, technical, design team, and stakeholder behavior.
10	Sumrit [25]	2025	Thailand	Upper-middle	Hybrid MCDM (DEMATEL–ISM–MICMAC)	Hospitals, sector level	Analyze determinants of net-zero emissions in the health sector.	Top-management commitment and government regulation were the most influential drivers; green innovation and carbon-footprint monitoring were dependent outcomes.
11	Thakur & Anbanandam[26]	2016	India (Uttarakhand)	Lower-middle	Interpretive structural modeling	Facilities and common biomedical waste treatment facilities	Identify and prioritize barriers to health-care-waste management.	Twenty-five barriers formed a 12-level hierarchy; lack of motivation and poor infrastructure were the foundational drivers.

12	Nazari-Shirkouhi & Samadi [27]	2025	Iran	Lower-middle	Hybrid MCDM	Supply chains, hospitals, and pharmaceutical suppliers	Evaluate lean, agile, resilient, and green paradigms.	Green and resilient paradigms were primary causal factors driving supply-chain performance; lean and agile were effect factors.
13	Deepak et al. [28]	2022	India	Lower-middle	Life cycle assessment	Common biomedical-waste treatment facility	Evaluate the environmental burden of biomedical-waste practice.	Incineration was the principal contributor to impact (global warming, terrestrial ecotoxicity), driven by electricity use and direct emissions.
14	Vargas-Muñoz et al. [29]	2025	Colombia	Upper-middle	MCDM (DEMATEL)	Clinics and hospitals	Develop and validate a prioritization framework for circular supply-chain practice.	Management initiative and institutional/legal frameworks were the primary causal factors driving cleaner production and reverse logistics.
15	Sahamir & Zakaria [30]	2014	Malaysia	Upper-middle	Qualitative document analysis	Public hospital buildings	Identify green assessment criteria for public hospital building development.	The study identified six green criteria categories (energy, indoor environmental quality, site planning, materials, water, innovation), adapted for 24-hour operation.
16	Alighardashi et al. [31]	2024	Iran (Kermanshah)	Lower-middle	Cross-sectional environmental assessment	Eight teaching hospitals	Evaluate waste management against sustainable-development objectives.	Separation and collection scored highly, but reduction and disposal were insufficient, yielding moderate performance below circular-economy standards.
17	Munasinghe et al. [32]	2025	Sri Lanka	Lower-middle	Pilot, validation and implementation	Public tertiary and secondary hospitals	Develop and validate an all-hazards disaster-preparedness tool.	The tool was reliable and valid; hospitals scored highest on staffing and communication and lowest on logistics and human resources.
18	Alalade et al. [33]	2025	Nigeria	Lower-middle	Mixed methods	Public and private facilities	Evaluate facility-management approaches	A mixed facility-management approach predominated; inadequate funding, weak

							and maintenance challenges.	maintenance culture, and bureaucratic bottlenecks undermined efficiency.
19	Ala et al. [34]	2024	Iran	Lower-middle	Mathematical modeling and optimization	Supply-chain network: hospitals, laboratories, disposal centers	Develop a multi-objective model balancing cost, environmental impact, and social benefit.	The fuzzy multi-objective model reduced network cost and pollutants while increasing social welfare through accessibility and employment.
20	Asare et al. [35]	2025	Ghana	Lower-middle	Integrated LCA and systems thinking	Five teaching and regional hospitals	Evaluate the environmental impact of medical-waste treatment options.	Autoclaving with effective segregation was the most sustainable option, reducing emissions and terrestrial ecotoxicity relative to incineration.
21	Amos et al. [36]	2020	Ghana	Lower-middle	Sequential mixed methods	Public tertiary and secondary hospitals	Establish and model key performance indicators for waste-management service delivery.	Professional facility management, adequate resources, and defined KPIs (infection control, budget variance) improved waste-management outcomes.
22	Saddari et al. [37]	2025	Ghana (Sunyani)	Lower-middle	Techno-economic feasibility case study	Tertiary teaching hospital	Assess rooftop solar photovoltaic generation under net metering.	A 1,000 kWp grid-connected system could meet ~51% of annual demand with a 4.7-year payback and substantial emissions reduction.
23	Pramana et al. [38]	2023	Indonesia (Pekanbaru)	Upper-middle	Cross-sectional descriptive	Community health centers	Analyze ecological, economic, and social attributes of solid medical-waste management.	The ecological dimension was moderately sustainable, while the economic and social dimensions were less sustainable, indicating the need for a multidimensional model.
24	Oyebode & Otoko [39]	2022	Nigeria (Ado-Ekiti)	Lower-middle	Case study and engineering design	Multi-system teaching hospital	Assess waste practices and design a low-cost incinerator.	Waste generation was 1.15 kg per bed per day; a dual-chamber incinerator (1,200 °C) was

								designed to destroy hazardous waste with minimal emissions.
25	Machate et al. [40]	2021	South Africa (Ehlanzeni)	Upper-middle	Cross-sectional descriptive and inferential	Hospitals, clinics and community health centers	Identify factors influencing health-care-waste generation.	Patient and staff numbers were significant predictors of waste volume, with patient numbers most strongly correlated with daily waste weight.
26	Abu et al. [41]	2021	Kenya (Kisumu)	Lower-middle	Qualitative interviews	Rural dispensaries and an informal-settlement facility	Explore stakeholder experience of WASH implementation and management.	Despite improved access, poor water quality and inadequate sanitation persisted because of finance, climate variability, and corruption, compromising resilience.
27	Oduro-Kwarteng et al. [42]	2021	Ghana (Kumasi)	Lower-middle	Cross-sectional descriptive	Four hospitals and three health centers	Assessed generation rate, composition, and management of health-care waste.	Generation was 0.76–2.92 kg per bed-day with a high hazardous fraction (49.65%) and gaps in segregation, storage, and disposal.
28	Ahmad et al. [43]	2019	Pakistan (Swat)	Lower-middle	Life cycle assessment	Public and private secondary and tertiary hospitals	Compare environmental impact of solid-waste treatment alternatives.	Steam sterilization followed by landfilling was most favorable, outperforming incineration and direct landfilling across impact categories.
29	Moura et al. [44]	2018	Brazil (Rio de Janeiro)	Upper-middle	Protocol development and application	Public maternity hospital	Develop and apply a protocol for assessing health-care-waste management.	A four-phase protocol was validated; the hospital generated 3.39 kg per occupied bed-day, and poor segregation sent recyclables to infectious-waste streams.

CONCEPTS AND IMPLEMENTATION FRAMEWORKS (19 OF 29 STUDIES)

Nineteen studies described Green Hospitals as facilities that integrate environmental sustainability, resource efficiency, and climate resilience into planning, management, and service delivery, most often through green building, energy efficiency, health-care-waste management, and WASH. Three proposed transferable frameworks, rather than describing practice, are: six green assessment criteria for continuous hospital operation in Malaysia, [30] a 32-indicator, six-dimension sustainability model in Morocco, [22] and a validated 39-item, seven-dimension SDG-aligned scale in India. [23] Most others operationalized a single domain, most frequently health-care waste. [28,35]

ENABLING AND INHIBITING FACTORS (17 OF 29 STUDIES)

Common enablers included leadership commitment, supportive regulation, stakeholder engagement, and organizational awareness of environmental and climate risk. The clearest evidence identified top-management commitment and government regulation as the dominant driving factors in the Thai health sector, [25] and management initiative and institutional or legal frameworks as the principal cause-group factors for circular supply-chain practice in Colombia.[29] Reported barriers were high investment cost, limited financial and human resources, weak technical capacity and infrastructure, and weak monitoring: six barrier themes in Nigerian public hospital buildings, [24] a 12-level hierarchy of 25 waste-management barriers in India, [26] and inadequate funding, weak maintenance culture, and bureaucratic bottlenecks in Nigerian facility management. [33] A Study of health professionals in Namibia noted positive knowledge and attitudes alongside structural barriers that prevented translation into practice. [17] At the policy level, national documents neither specified nor monitored WASH indicators within a universal health coverage pilot. [16] Across the 29 included studies, no study applied an integrated framework spanning all five intervention domains; this is a mapping observation of the present review rather than a finding of any single study.

MEASUREMENT APPROACHES (13 OF 29 STUDIES)

Instruments ranged from environmental performance indicators and composite indices to LCA and multi-criteria decision-making (MCDM). LCA appeared in three studies, all applied to health-care-waste treatment alternatives; MCDM and structural modeling were used mainly to prioritize barriers, indicators, or practices rather than to measure performance over time. Only two studies produced an instrument for repeated facility-level application: a validated all-hazards disaster-preparedness tool, [32] and a four-phase waste-assessment protocol. [44] The disaster-preparedness tool is the only measure that directly addresses resilience, and it includes no environmental component; conversely, no environmental measure includes a resilience component.

POLICY IMPLICATIONS (11 OF 29 STUDIES)

Eleven studies argued that clear policy frameworks, institutional guidelines and performance-based monitoring are prerequisites for sustainability and resilience. One costing study estimated US$6.5–9.6 billion to achieve full basic WASH and waste coverage across 46 least-developed countries by 2030, with waste management accounting for nearly half of that total, [18] A Study in Bangladeshi national quality-of-care guidance addressed only 55% of essential infection-prevention and WASH subconditions. [20]

THREE QUANTIFIED EVIDENCE GAPS

A dedicated charting field showed that one of 29 studies (3%) reported a patient or population health outcome: associations between specific WASH FIT indicators and maternal mortality due to infection across Indonesian hospitals. [19] Because that study is cross-sectional, it cannot support attributing a health benefit to an intervention. Three studies (10%) reported quantified cost data, the only payback period, at 4.7 years for a rooftop photovoltaic installation, and none reported a formal economic evaluation.[18,34,37] No study disaggregated its findings by occupational group, rurality, facility size, or ownership; waste handlers, cleaners, informal waste pickers, and residents near disposal sites are absent as units of analysis, even where hazardous waste fractions and incineration emissions are characterized in detail. [28,42] Only one study reported social stratification directly, documenting exclusion by caste and gender. [23] These absences are principal mapping findings rather than review limitations.

DISCUSSION

PRINCIPAL FINDINGS

This review maps a Green Hospital literature in LMICs that is concentrated in foundational environmental domains: health-care waste, water and sanitation, energy efficiency, and green infrastructure, and only weakly connected to resilience-oriented performance and governance frameworks. Global normative guidance requires facilities to sustain essential services and reduce their footprint simultaneously, [7,17,46] but the mapped evidence does not yet operationalize that dual requirement: the single instrument that measures resilience contains no environmental component, and no environmental instrument contains a resilience component. Based on the available evidence, Green Hospital activity is pursued as an environmental program adjacent to, rather than integrated within, hospital resilience.

MEASUREMENT HETEROGENEITY AND THE CASE FOR HARMONIZED INDICATORS

A central contribution of this review is to document the heterogeneity of the indicators and tools applied, from LCA of waste-treatment options to MCDM models and composite indices. [29,35] These approaches yield context-specific insight but limit comparability across facilities and countries and constrain benchmarking. The most relevant comparison is with operational instruments already used in LMIC facilities: WASH FIT and the PAHO Green Checklist collect facility-level environmental data; the PAHO Hospital Safety Index collects resilience data, often in the same facilities; and no instrument spans both (Supplementary S4). A harmonized environmental key performance indicator set is therefore the missing measurement layer.

GOVERNANCE, LEADERSHIP AND FINANCING

Across the included studies, leadership commitment, clear regulation and institutional awareness were the conditions under which interventions were adopted. In contrast, fragmented governance, limited technical capacity and chronic underfunding were the dominant barriers, [24,25,33], consistent with the wider climate-resilient health-systems literature [47]. This should be read as a convergence of reported associations and expert-elicited priorities rather than a demonstrated causal ordering, because the leading analyses model expert judgment rather than implementation outcomes observed over time.

THREE QUANTIFIED EVIDENCE GAPS

Three gaps define the boundary of what this literature can currently support. First, the health consequences of Green Hospital investment are essentially unmeasured: one of 29 studies reported a population health outcome and did so as a cross-sectional association. Second, economic evidence is nearly as sparse: three studies reported cost data, and none provided a formal economic evaluation. Third, no study disaggregated its findings by occupational group, rurality, facility size, or ownership, so the distribution of the environmental health burden across exposed groups cannot be identified; this equity gap is examined in the following subsection. The first two gaps compound each other, because cost-effectiveness analysis requires an outcome to which cost can be referred. Until at least one is closed, the case for Green Hospital investment must rest on environmental and operational arguments.

EQUITY AND ENVIRONMENTAL JUSTICE

The absence of equity-relevant disaggregation is analytically significant, not a reporting deficiency. The environmental health burden of hospital operations falls disproportionately on waste handlers, cleaners and portering staff, on informal waste pickers, and on households near incineration and disposal sites. Studies here characterize hazardous fractions, incineration emissions, and terrestrial ecotoxicity in technical detail.[28,42], yet none identify the exposed population, and the evidence comes overwhelmingly from larger urban facilities. An environmental-justice lens is therefore a substantive requirement of the research agenda, not an optional framing.

AN INTEGRATIVE FRAMEWORK AND ITS TESTABLE PROPOSITIONS

The framework in Figure 2 links governance and system enablers (Band A), Green Hospital intervention domains (B), intermediate operational mechanisms (C), hospital resilience outcomes (D), and population health outcomes (E), with harmonized measurement and an equity lens as cross-cutting conditions. Five propositions follow, each stated with its

evidential status. P1 (evidenced): governance enablers predict intervention adoption, supported by 17 studies. P2 (partially evidenced): interventions produce operational mechanisms, but almost always as a single-domain output measured once rather than a facility-level mechanism observed over time. P3 (hypothesized): operational mechanisms improve resilience outcomes; no included study measures both in the same facility. P4 (hypothesized): resilience outcomes translate into health outcomes; no study addresses this link. P5 (single cross-sectional association): interventions affect health outcomes directly.[19] The evidence supports the front of the pathway, while the links to resilience and to health remain to be tested.

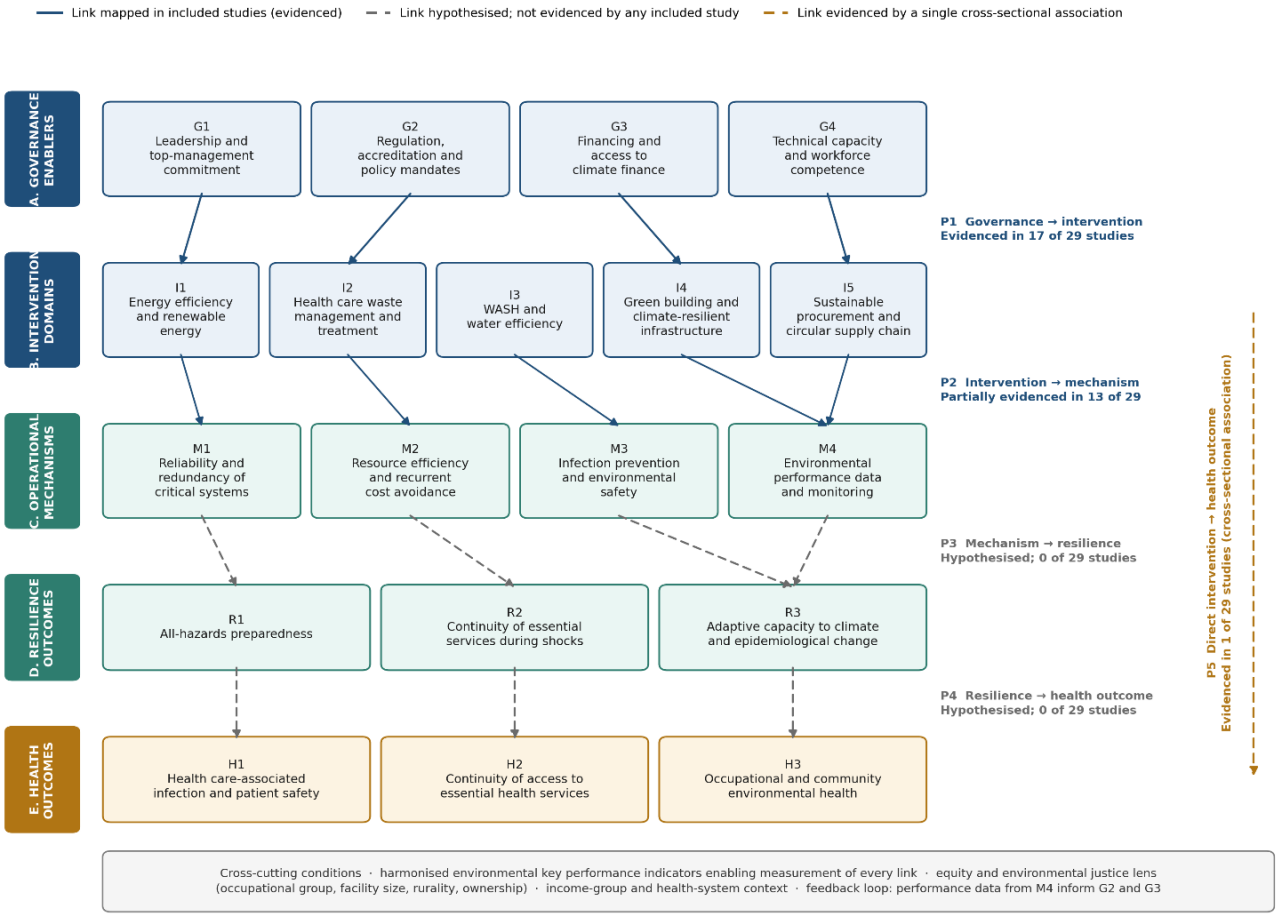


Figure 2. Integrative conceptual framework linking governance enablers, Green Hospital interventions, operational mechanisms, hospital resilience and population health outcomes in LMICs. Solid arrows denote links evidenced by the included studies; dashed arrows denote hypothesized links; a distinct style marks the single link evidenced only by a cross-sectional association (P5). Harmonized measurement and an equity and environmental-justice lens are cross-cutting conditions, with a feedback loop by which environmental performance data inform regulation, accreditation, and financing.

POLICY IMPLICATIONS

Three actions follow. First, embed a feasible minimum environmental indicator set in hospital accreditation the single decision point that already carries managerial accountability and a scoring cycle using data facilities already hold: monthly kilowatt-hours and cubic metres of water from utility invoices, sampled segregation audits, kilograms of waste per occupied bed-day from collection dockets, treatment-technology uptime, and the number of unplanned power or water interruptions, which also indexes the resilience construct at no extra data cost. Reporting should be phased through a voluntary baseline period before scoring any indicator, and facilities should be held accountable only for indicators within managerial reach. [8] Second, connect these indicators to climate finance: the Green Climate Fund, the Adaptation Fund and results-based lending require baseline inventories and monitoring, reporting and verification that most health ministries cannot yet produce, and the same indicator set can serve as that substrate. [4,48] Third, harmonize the environmental and resilience data already collected by WASH FIT, the PAHO Green Checklist and the Hospital Safety

Index into a common minimum core, led by WHO regional offices, making the mechanism-to-resilience link observable in routine data at lower cost than a new instrument.

STRENGTHS AND LIMITATIONS

Strengths include prospective registration, duplicate screening and charting, and an explicit framework distinguishing evidenced from hypothesized pathways. Consistent with the scoping-review method, the authors did not appraise individual studies for quality. The review was restricted to three databases, English-language records, and studies published from 2009. It excluded grey literature, reference-list checking, and citation tracking, so non-indexed LMIC studies are likely under-represented. Heterogeneity in design, outcomes, and tools precluded any comparison of effect sizes; most studies were cross-sectional or single-domain, limiting causal inference; and the evidence is skewed toward Sub-Saharan Africa, South Asia, and larger urban facilities, with no single-country low-income evidence and none from Central Asia, the Pacific, or fragile and conflict-affected settings, to which the findings should not be generalized. Screening and charting were performed in duplicate, but no formal inter-rater agreement statistic was calculated, so the reliability of the selection process is not quantified; this is a reporting limitation.

RESEARCH AGENDA

The priorities follow from the propositions and gaps: a prospective or interrupted-time-series study measuring both an operational mechanism and a resilience outcome such as downtime or service continuity during a documented shock (P3–P4); studies measuring health-care-associated infection, occupational exposure among waste handlers, or service continuity as outcomes; at least one full economic evaluation referring cost to a health or environmental outcome; and comparative research applying a harmonised indicator core across facility types and income groups, with disaggregation by occupational group and facility size as a design requirement.

CONCLUSION

This scoping review maps the Green Hospital literature in LMICs that is oriented toward foundational environmental domains: water and sanitation, health-care waste, energy efficiency, and green infrastructure, and only partially connected to explicit resilience and performance-management frameworks. Indicators and assessment tools are fragmented, with limited use of harmonized EKPIs, which constrains benchmarking, policy learning, and monitoring across facilities and countries. Three gaps are quantified: only one of 29 studies reported a population health outcome, and that as a cross-sectional association; three reported cost data and none a formal economic evaluation; and none disaggregated findings in a way that identifies who bears the environmental health burden. The integrative framework links governance enablers, interventions, operational mechanisms, resilience outcomes, and population health. It states explicitly that the evidence supports the front of that pathway while the links to resilience and health remain hypothesized. The immediate priority for LMIC health systems is not a new sustainability framework but a measurement and accreditation architecture that makes the pathway observable and aligns with national net-zero commitments and Sustainable Development Goals 3 and 13.

SUPPLEMENTARY MATERIAL

S1 PRISMA-ScR checklist with manuscript locators. **S2** Full executed search strategy per database. **S3** Study-by-theme matrix. **S4.** Assessment approaches identified in this review situated against operational sustainability and resilience frameworks used in LMIC health-care facilities

DECLARATIONS

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AUTHOR CONTRIBUTIONS.

Zakiah: Conceptualization; Methodology; Writing – original draft; Writing – review & editing. **Dumilah Ayuningtyas:** Conceptualization; Methodology; Writing – review & editing. **Farida Murtiani:** Methodology; Formal analysis; Writing – original draft; Writing – review & editing. **Annisa Ayu Lestari:** Data curation; Visualization; Writing – review & editing. **Fatimah Fatimah:** Data curation; Formal analysis; Writing – original draft; Writing – review & editing. **Ba'da Febriani:** Formal analysis; Visualization; Writing – original draft; Writing – review & editing. **Amelia Marisa:** Data curation; Writing – original draft. All authors read and approved the final manuscript.

DATA AVAILABILITY.

The completed data extraction for all 29 included studies (Table 4) is openly available on the Open Science Framework at https://doi.org/10.17605/OSF.IO/F2BR5. All other data supporting the findings of this review are contained within the article and its supplementary files.

USE OF GENERATIVE ARTIFICIAL INTELLIGENCE.

We used generative artificial intelligence tools for language editing and draft structuring, and Rayyan's AI features supported reference handling during screening. No tool generated data, charted or interpreted included studies, or made eligibility decisions; the named human reviewers performed all of these. The authors reviewed and edited all resulting text and take full responsibility for the content.

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