Health policy 175 (2027) 105805

Contents lists available at ScienceDirect

Health policy

journal homepage: www.elsevier.com/locate/healthpol

Health systems' responses to climate change: an umbrella review of systematic reviews

Katarzyna Dubas-Jakóbczyk [a,*], Magdalena Mrożek-Gąsiorowska [a], Costase Ndayishimiye [b], Nsikakabasi Samuel George [c], Anna Bianca Pereyra [d], Gunda Waldmann [e], Wilm Quentin [e]

[a] Institute of Public Health, Faculty of Health Sciences, Jagiellonian University Medical College, Krakow, Poland
[b] IQ Health Department, Radboud University Medical Center (Radboudumc), Nijmegen, The Netherlands
[c] ZeroNOMA Africa Initiative, Kano, Nigeria
[d] Europubhealth Graduate at Institute of Public Health, Faculty of Health Sciences, Jagiellonian University Medical College, Krakow, Poland
[e] Chair of Planetary and Public Health, University of Bayreuth, Bayreuth, Germany

ARTICLE INFO

Keywords:
Climate change
Health system
Environmental sustainability
Climate resilience
Climate mitigation
Climate adaptation

ABSTRACT

Background: Climate change places increasing pressure on health systems. They must both reduce their negative impact on the environment and strengthen resilience to climate-related risks.
Objective: To synthesize and map the evidence from systematic reviews on the scope and effectiveness of climate change mitigation and adaptation actions in health systems.
Methods: An umbrella review of systematic reviews examining health system responses to climate change was conducted. The review followed the Joanna Briggs Institute methodological guidelines and adhered to the PRISMA checklist. The included systematic reviews had to meet two overarching criteria: at least two databases were searched, and a predefined instrument was used to assess the quality or risk of bias of the included studies.
Results: Forty-six systematic reviews published between 2020 and 2026 were included, covering 1,175 individual studies. Most reviews (41/46) focused exclusively on mitigation strategies, with evidence concentrated around major greenhouse gas emission hotspots: surgical procedures; radiology; pharmaceuticals; solid waste; and transportation of patients and staff. Across these areas, some mitigation strategies were associated with environmental and economic co-benefits, although the underlying evidence was heterogeneous and often of low to moderate quality. In contrast, only a small number of reviews addressed climate adaptation and health system resilience.
Conclusions: Existing evidence provides practical guidance on effective climate mitigation actions. The limited number of systematic reviews on climate adaptation highlights a gap in the evidence base. Translating mitigation evidence into clinical guidelines and policies and strengthening research on adaptation could support more systematic climate action in health systems.

Research in context

(1) What is already known about the topic?

A growing body of research examines climate mitigation and adaptation actions in healthcare, including interventions targeting energy use, clinical practices, waste management, procurement, and transport. Existing reviews often focus on specific clinical areas or single dimensions of climate action.

(2) What does this study add to the literature?

This umbrella review synthesizes evidence from 46 systematic reviews covering 1,175 primary studies. The evidence base is

* Corresponding author at: Health Economics and Social Security Department, Institute of Public Health, Jagiellonian University Medical College, Skawinska 8 St, 31-531 Krakow, Poland.
E-mail addresses: katarzyna.dubas@uj.edu.pl (K. Dubas-Jakóbczyk), magdalena.mrozek-gasiorowska@uj.edu.pl (M. Mrożek-Gąsiorowska), costase.ndayishmiye@radboudumc.nl (C. Ndayishimiye), nsikak.george@alumni.uj.edu.pl (N.S. George), pereyraannabianca@gmail.com (A.B. Pereyra), Gunda.Waldmann@uni-bayreuth.de (G. Waldmann), wilm.quentin@uni-bayreuth.de (W. Quentin).

https://doi.org/10.1016/j.healthpol.2026.105805
Received 14 March 2026; Received in revised form 12 October 2026; Accepted 16 October 2026
Available online 17 October 2026
0168-8510/© 2026 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

strongly concentrated on mitigation strategies – particularly in areas such as surgical care, radiology, pharmaceuticals, food waste, and transport – while systematic evidence on adaptation and climate resilience remains limited. Across several areas, mitigation actions appear capable of generating environmental and economic co-benefits.

(3) What are the policy implications?

Existing evidence provides practical guidance for reducing healthcare emissions in key hotspots and should be translated into clinical guidelines, procurement policies, and organisational sustainability strategies. The evidence base on climate adaptation and health system resilience needs strengthening, particularly in terms of outcome measures. Climate mitigation and adaptation topics should be integrated into health workforce education as well as into routine health system monitoring and reporting frameworks.

1. Background

Climate change is the most significant threat to human health globally [1–3]. It negatively affects population access to basic human needs, such as clean air and water, increases the burden of climate-related risk factors and diseases, and alters patterns of disease transmission [3,4]. At the same time, the increasing frequency of extreme weather events (e.g., floods, hurricanes) disrupts health care delivery [3]. Consequently, climate change impacts health systems by simultaneously increasing the demand for healthcare provision and impairing their ability to respond. Current prognoses predict that more severe climate risks will emerge sooner than previously expected [5], putting an enormous pressure on health systems to implement adequate response strategies [6].

The health system response to climate change comprises two closely related dimensions: 1) environmental sustainability, which aims to mitigate the negative impacts of health systems on the environment by reducing their greenhouse gas (GHG) emissions, and 2) climate resilience, which focuses on adaptation measures to better cope with the impacts of climate-related shocks and stresses [7]. While the formal definitions of both concepts adopted by the World Health Organisation (WHO) extend far beyond the scope of conventional climate change 'mitigation' and 'adaptation' actions[5], they are strongly related (Table 1)Within both dimensions, a variety of actions can be implemented at different levels of the health system, and their effectiveness can be assessed using diverse direct and indirect metrics (Table 1). The WHO's "Operational framework for building climate resilient and low carbon health systems" integrates both concepts into comprehensive guidance on health system transformation [7].

Health system responses to climate change have emerged as an important priority for health policy and research [12]. Under the auspices of the WHO, the Alliance for Transformative Action on Climate and Health has brought together over 100 countries whose ministers of health have committed to strengthening the climate resilience of health systems and/or reducing their GHG emissions [13,14]. Research on health system responses to climate change has expanded significantly, with numerous reviews published recently, including systematic [15–20], rapid [21,22], scoping[23–26], integrative [27,28] and/or narrative [29,30] reviews. However, important gaps remain: many systematic reviews focus on only a narrow aspect – for example environmental sustainability in a chosen medical discipline [15,20] or adaptation to heat related risks [19]. In contrast, rapid, scoping and narrative reviews typically cover a broader range of actions but they do not conduct quality and/or risk of bias assessments of the underlying evidence. For evidence-informed health policy, however, the quality of research evidence is crucial.

To address these limitations, we conducted an umbrella review of systematic reviews on environmental sustainability and climate resilience actions in health systems, focusing on reviews that included a quality and/or risk of bias assessment of their underlying primary studies. Umbrella reviews are particularly valuable when several recent and still up-to-date systematic reviews on the topic are available [31]. Our main goal was to offer decision makers a comprehensive and policy-relevant overview of the available evidence on environmental sustainability and climate resilience actions[32,33]. More specifically, the objectives were to: 1) characterize the main features of existing systematic reviews; 2) map the scope of available evidence on health system responses to climate change by geography, health system level, and type of response; and 3) synthesize evidence on the effectiveness of specific response strategies.

Table 1
Conceptual framework of health system's response to climate change.

Dimension	Health system's response to climate change	
	Environmental sustainability - MITIGATION	Climate resilience – ADAPTATION
Focus	reducing the negative impacts of health systems on the environment by reducing their greenhouse gas emissions	improving the capacity to cope with the impacts of climate change
WHO's definition	*Health system ability to "(…) improve, maintain or restore health, while minimizing negative impacts on the environment and leveraging opportunities to restore and improve the environment to the benefit of the health and well-being of current and future generations"* [8]	*Health system capability of "(…) anticipating, responding to, coping with, recovering from, and adapting to climate-related shocks and stress, to bring about sustained improvements in population health, despite an unstable climate"* [7]
Examples of actions	• changes in clinical practice to reduce greenhouse gas emission, • reducing low-value care, • investments in renewable energy sources, • implementing more sustainable waste management, • reducing patients and health workforce travel, • incorporating sustainability rules into procurement contracts	• implementing early warning systems, • planning backup systems for service delivery during climate-induced disasters, • investing in climate-proofing health infrastructure, • training the health workforce in disaster management • strengthening intersectoral collaboration for disaster preparedness
Examples of effectiveness measures	• reductions in waste generation or water use per patient/procedure, • reduction in greenhouse gas emission (total, in kilograms (kg) per year; per specific health care service/product; per patient)	• reduction in the number of deaths or people affected by climate-related causes, • reduction in climate-related healthcare utilization e.g. heat-associated hospitalisations • reduction in the frequency of disruption to healthcare provision or damage to infrastructure caused by climate-related disasters

Source: Authors' own compilation based on WHO works [1,8–11].

2. Methods

The work followed the Joanna Briggs Institute (JBI) methodological guidelines for evidence synthesis in umbrella reviews [32,33] and adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist [34]. The review was registered in PROSPERO (CRD420251052647) [35], while its protocol was published in a peer-reviewed journal [36].

2.1. Review questions

Three specific review questions were defined: 1) What are the main characteristics of the published systematic reviews?; 2) What is the scope of the available evidence on health system response to climate change (by geography, health system level, and type of response)?; 3) What evidence exists regarding the effectiveness of particular response strategies?

2.2. Inclusion and exclusion criteria

We defined the inclusion and exclusion criteria using the PICOS (Population, Intervention, Comparison, Outcomes, Study design) framework [37]. We operationalised the framework as follows (details are provided in Table S1 in Supplementary File): The population comprised health-system stakeholders and organisations at the micro level (individual health professionals and providers), meso level (regions and provider networks), or macro level (populations or entire health systems). Interventions included health-system responses addressing environmental sustainability and/or climate resilience, as defined by WHO (Table 1). No comparator was required. Eligible outcomes captured the effects of these responses on environmental sustainability or climate resilience. Regarding study design, we included peer-reviewed systematic or other evidence reviews that assessed the quality or risk of bias of their included studies. In addition, systematic reviews had to meet the following quality criterion: at least two databases were searched.

2.3. Search strategy

The searches were conducted in July 2025 and updated in July 2026. Five databases were searched: 1) MEDLINE via PubMed, 2) Scopus, 3) Web of Science Core Collection, 4) ProQuest Central, and 5) Cochrane Database of Systematic Reviews. The search strategy was developed in accordance with the PRESS guidelines [38] and combined multiple terms related to climate change AND health system AND systematic review. Where available, a dedicated filter for systematic reviews was applied. Terms were searched as keywords in the title and/or abstract fields, and, when appropriate, Medical Subject Headings (MeSH) terms were also used. Prior to finalization, the strategy was tested across all five databases to ensure accuracy and relevance. We included studies published from 2015 onwards, with full text available in English. Table S2 Supplementary File presents the full search strings for each database. In addition, the references of the included studies were screened to identify additional systematic reviews that met the inclusion criteria.

2.4. Selection of studies

All records were downloaded and deduplicated using Rayyan software[39], which also supported the study selection process. This process involved two stages: 1) screening of titles and abstracts and 2) full-text assessment. Two researchers independently participated in both stages and evaluated the records/full texts according to the predefined inclusion and exclusion criteria (Table S1 in Supplementary File). Any discrepancies were resolved through consensus between the two researchers.

2.5. Quality appraisal

The JBI critical appraisal checklist for systematic reviews and research syntheses[32,33] was used to assess the quality of the included reviews. This tool, applicable to both quantitative and qualitative studies, contains 11 items rated as 'yes', 'no', 'unclear', or 'not applicable'. A scoring guide specific to this umbrella review was developed, with 'yes' scored as 1.0, 'unclear' as 0.5, and 'no' as 0.0. Reviews scoring above 75% were considered high quality, 50–75% moderate, and below 50% low quality. Table S3 in Supplementary File presents details of the appraisal matrix. Two researchers independently conducted the assessments and resolved discrepancies through consensus.

2.6. Data extraction

The data extraction table was developed in a Microsoft Excel file following JBI recommendations for umbrella reviews [32]. It was pilot-tested on five included studies and revised as needed. The table included the following main sections: citation details; review questions; number of databases searched; date range of included studies; characteristics of included studies; quality appraisal; evidence certainty assessment; scope of climate action strategies; effectiveness of strategies; policy recommendations; additional notes. Two researchers independently extracted the data, compared their results, and resolved any discrepancies through discussion. In the case of missing data the corresponding authors of the included reviews were contacted with the request to provide relevant data.

2.7. Data synthesis

Data were summarized using both quantitative and qualitative methods. Thematic analysis (using both inductive and deductive approaches) was used to summarize and map the identified strategies. While our inclusion criteria covered strategies that fell within the formal WHO definitions of health system environmental sustainability and climate resilience (Table 1), we applied the short terms: 'mitigation' and 'adaptation' as the main classification codes. Specifically, the reviews were classified into those focusing on mitigation and those focusing on adaptation, with further subcategories based on their main topics (Table 2). For the former group, the existing classification of five types of mitigation actions as defined by Braithwaite et al [40] was also applied (Table 3). For reviews with multiple outcome measures, the findings were classified based on the authors' descriptions of their main results and conclusions. To assess the degree of overlap among primary studies included in the systematic reviews. the corrected covered area (CCA) was calculated following the method proposed by Pieper et al [41]. This ratio indicates the risk of double-counting shared data (with higher values indicating greater potential for double-counting shared evidence) and was calculated for all reviews, as well as separately for the two main groups: those focusing on mitigation and those focusing on adaptation. The results of the quality appraisal of the included systematic reviews, together with the extracted data on the certainty of the evidence (where available), were taken into consideration when drawing final conclusions and formulating policy recommendations [42].

3. Results

3.1. Search results

The search across the five scientific databases identified 5,538 records. After removing duplicates, 3,556 records were screened based on titles and abstracts, leading to 212 articles selected for full-text review. Of these, 44 publications met the inclusion criteria. The most common reason for exclusion was an inappropriate study design, usually related to the absence of quality appraisal of included studies in scoping reviews, or an unsuitable publication type – usually narrative reviews, where search results were not summarized (Fig. 1). Of the 168 excluded reviews, the vast majority (139) were focused solely on mitigation actions. Table S4 Supplementary File provides the full list of excluded studies along with the reasons for their exclusion. Two additional reviews were identified through reference list screening, resulting in a total of 46 included reviews (44 systematic reviews, one scoping review, and one integrative review—all meeting the criteria for study quality appraisal and reporting) (Table S5 in Supplementary File).

Table 2
General overview of the included systematic reviews (chronological order).

No	1st author and ref. no	Publication year	Dimension*	Review's topic	No of incl. stud.	Country of origin of incl. stud. (high- vs, middle, vs low-income countries)	The date range of incl. studies	Quality assessment result
1	Carino [43]	2020	M	food waste in hospitals (across supply chain)	80	Mixed, mostly high-income, with the highest no. of studies from: US (19), UK (8), Denmark (8), Australia (5)	1945–2018	high
2	Rizan [44]	2020	M	surgical operations (mix)	8	Mixed, mostly high-income: US (4), UK (2), Chile (1), India (1)	2011–2018	moderate
3	Mashallahi [45]	2022	M, A	mix - hospitals mitigations and adaptation	26	Mixed, mostly high-income, with the highest no. of studies from: US (5), Australia (4), UK (4)	2009–2020	high
4	Mohtady Ali [46]	2022	A	hospital disaster preparedness	22	Mixed, high-, middle and low-income countries. The highest no of studies from: US (4), Australia (3), China (3), UK (2), Sierra Leone (2)	2006–2021	high
5	Papadopoulou [47]	2022	M	surgical operations - minimally invasive surgery	16	Mixed, mostly high-income: US (9), Japan (2) +1 from Germany, Canada, France, India	2005–2021	moderate
6	Anudjo [48]	2023	M	radiology (mix)	14	High income: US (5), The Netherlands (2), Switzerland (2) +1 from UK, Germany, Ireland, Canada, Australia	2015–2023	high
7	Batcup [49]	2023	M	mix - behavioural change interventions (in clinical settings)	20	High income: UK (15), US (3), Australia (2)	2016–2021	high
8	Cook [50]	2023	M	food waste in hospitals	85	Mixed, mostly high-income, with the highest no. of studies from: US (37), Australia (15); Canada (9), UK (9)	2002–2020	high
9	Keil [51]	2023	M	single-use vs reusable healthcare products (mostly within surgical operations)	27	High income with the highest no of studies from: US (11), Australia (5), Germany (2), The Netherlands (2)	2008–2022	moderate
10	Lam [52]	2023	M	surgical operations (mix)	21	High income with the highest no of studies from: US (11), UK (7), Australia (5)	2012–2022	moderate
11	Perry [53]	2023	M	surgical operations (mix)	34	High income with the highest no of studies from: US (18), Australia (6), UK (5)	1994–2018	high
12	Pickard Strange [54]	2023	M	telemedicine	23	High income, with the highest no of studies from: UK (8), US (7), Spain (2)	1996–2021	high
13	Rodler [55]	2023	M	telemedicine	48	High income with the highest no of studies from: US (20); UK (12); Australia (5); Canada (3)	2013–2023	high
14	Wicklum [56]	2023	M	PHC - decarbonisation toolkits (mix)	20	Mixed, mostly high-income, with the highest no. of studies from: US (8), UK (7), Canada (4)	2007–2022	moderate
15	Blom [57]	2024	M	mix - different strategies / health system levels	22	Middle income, with the highest no of studies from India (6), China (3), Malaysia (2), Pakistan (2)	2000–2022	high
16	Braithwaite 2024 [40]	2024	M	mix - different strategies / health system levels	205	Mixed, mostly high income, with the highest no of studies from: US (27), UK (21), Australia (17), and Canada (14).	2005–2023	high
17	Chauvet [58]	2024	M	surgical operations - single vs multiuse laparoscopic instruments	14	High income: US (4), UK (3) + 1 from Australia, Canada, Belgium, France, Germany, Greece, Switzerland	1994–2022	moderate
18	Cohen [20]	2024	M	surgical operations – obstetrics and gynaecology (mix)	17	Mixed, mostly high income: US (11), Canada (2), UK (1), Netherlands (1), multi-country (2)	2004–2022	moderate
29	Davies [16]	2024	M	surgical operations (mix)	11	High income: US (8), Canada (2), multi-country (1)	2010–2021	moderate
20	Eussen [59]	2024	M	surgical operations - single vs multiuse instruments	53	Mixed, mostly high-income, with the highest no. of studies from: US (15), Germany (10), UK (7)	1991–2023	moderate
21	Gumera [60]	2024	M	surgical operations - single vs multiuse headwear	9	High income: US (8), the Netherlands (1)	2017–2022	high
22	Kloevekorn [17]	2024	M	surgical operations (mix)	18	High income: US (6), UK (3), Australia (2), Canada (2) + 1 from Turkey, France, Spain, Denmark, Ireland	2018–2024	moderate
23	Martins [61]	2024	M	surgical operations - single vs multiuse instruments in minimally invasive procedures	13	High-income: Denmark (3), US (3), Australia (2) + 1 from France, Ireland, Sweden, UK, Germany	2005–2023	high

(continued on next page)

Table 2 (*continued*)

No	1st author and ref. no	Publication year	Dimension*	Review's topic	No of incl. stud.	Country of origin of incl. stud. (high- vs, middle, vs low-income countries)	The date range of incl. studies	Quality assessment result
24	Nolan [62]	2024	M	surgical operations - behavioural interventions on anaesthetic agents	13	High income: UK (9), US (2) + 1 from Australia, New Zealand	2011–2022	high
25	Pickles [63]	2024	M	mix - different strategies / health system levels	21	High income, with the highest no of studies from: US (7), UK (6), Australia (3)	2011–2023	high
26	Roletto [64]	2024	M	radiology (mix)	16	High income: US (7), Switzerland (3), UK (2), + 1 from Ireland, Canada, Australia, Germany	2010–2023	moderate
27	van der Zee [65]	2024	M	telemedicine	28	High income with the highest no of studies from: UK (10); US (10); Australia (2)	2010–2022	moderate
28	Zurynski [18]	2024	A	health workforce preparedness	60	Mixed, mostly high-income, with the highest no. of studies from: US (29), Australia (6)	2004–2023	high
29	Vu [66]	2024	M	surgical operations (mix)	13	High income: US (7), Canada (3), France (2), Portugal (1)	2010–2023	moderate
30	Booth [67]	2025	M	surgical operations - single vs multiuse instruments	59	Mixed, mostly high-income, with the highest no. of studies from: US (22), Australia (7), UK (6)	1996-2024	moderate
31	Cunha [68]	2025	M	surgical operations - abdominal surgery	8	High income: US (5), UK (2), Italy (1)	2008–2023	moderate
32	Faizan [69]	2025	M	telemedicine and digital health	68	Mixed, mostly high-income countries (e.g., US, UK)	2020-2025	high
33	Iakovou [70]	2025	M	surgical operations - plastic surgery	15	High income: US (10), UK (3), Chile (1), Switzerland (1)	2017–2023	high
34	Johar [19]	2025	A	community-based heat adaptation	10	Mixed, mostly high income: Australia (2), Japan (2), China (2) + 1 from US, Canada, Italy, Pakistan	2000–2023	high
35	Hammer [71]	2025	M	surgical operations - anaesthetic agents	13	High income: France (3), US (4), Germany (2), Switzerland (1), Singapore (1), South Korea (1), Australia (1)	2019–2024	moderate
36	Lee-Smith [72]	2025	M	telemedicine – in orthopaedic	9	High income: UK (4), US (3), Germany (2)	2021-2025	high
37	Morris [73]	2025	A	disaster preparedness	20	Low income countries, with the highest no of studies from: India (4), Sri Lanka (3), Haiti (2), Pakistan (2), Tanzania (2)	2011-2025	moderate
38	Nunes [74]	2025	M	PHC – decarbonisation (mix)	15	High income: UK (5), Australia (3), US (2), Germany (2) +1 from France, Switzerland, Israel	2016–2023	high
39	Onasanya [75]	2025	M	pharmaceuticals - inhalers	64	Mixed, mostly high income with the highest no of studies from UK (24)	2014–2024	high
40	Peyrottes [76]	2025	M	surgical operations - single vs multiuse instruments in urological endoscopic procedures	10	High income: Australia (3), France (3) + 1 from Canada, Ireland, UK, US	2018–2024	high
41	Pitard [77]	2025	M	pharmaceutical - hospital pharmacy (mix)	17	Mixed, mostly high-income: France (4), US (4), Ethiopia (2), Saudi Arabia (2) + 1 from England, Italy, Netherlands, Brazil, Spain.	2014–2022	high
42	Shaw [78]	2025	M	hospital-led care (mix)	92	Mixed, mostly high-income, with the highest no. of studies from: UK (33), US (19), Germany (6), France (5)	2008-2023	high
43	Tozsin [15]	2025	M	surgical operations - single vs multiuse instrument in urological procedures	10	High income: France (3), US (2), Italy (2), Ireland (2), UK (1)	2018–2024	moderate
44	van Nieuwenhuizen [79]	2025	M	surgical operations (mix)	42	High-income, with the highest no. of studies from: US (20), Australia (4), UK (3)	2012–2023	high
45	McGushin [80]	2026	M	healthcare solid waste	107	Mixed, mostly high-income, with the highest no. of studies from: US (46), UK (11), Australia (7)	2008-2023	high
46	Wolf [81]	2026	M	dentistry (mix)	51	Mixed, mostly high-income, with the highest no of studies from: UK (11), Ireland (7), Saudi Arabia (5), US (4), India (4)	2012-2023	moderate

* M - mitigation, A - adaptation

Table 3
Reviews' themes and mitigation actions dimension matrix (R=42).

Review's theme / Mitigation dimension	Optimizing energy use in buildings & equipment	Changing clinical care to reduce impact on environment	Reducing waste and improving its management	Reducing travel and transport	Reducing supply chain emissions
Surgical operations: 21R, n=424	✓	✓	✓		
Food/solid waste: 3R, n=272			✓	✓	✓
Telemedicine and digital health: 5R, n=175				✓	✓
Radiology: 2R, n=30	✓	✓	✓	✓	
Pharmaceuticals: 2R, n=81		✓	✓		✓
PHC: 2R, n=35	✓	✓	✓	✓	✓
Hospital-led care: 1R, n=92	✓	✓	✓	✓	
Dentistry: 1R, n=51	✓	✓	✓	✓	✓
Behavioural interventions: 1R, n=20		✓	✓		
Mix - different strat. /system levels: 4R, n=274*	✓	✓	✓	✓	✓

* including 1R on both mitigation and adaptation

3.2. General overview of the included reviews

Table 2 presents a general overview of the included reviews. All 46 were published between 2020 and 2026. The vast majority (41/46) focused on environmental sustainability. Four reviews addressed climate adaptation actions, while one included primary studies examining both mitigation and adaptation strategies at the hospital level (Fig. S6 in Supplementary Material). The number of primary studies included in individual reviews ranged from 8 to 205, while the total number of studies across all 46 reviews was 1,567 (1,175 after eliminating overlapping ones). The majority of reviews (25/46) included relatively new research (published since 2010) and applied language limitation to studies published solely in English (32/46). With the exception of two [57,73], all reviews included studies conducted either exclusively (24/46) or predominantly in high-income countries (20/46) (Table 2). The overall corrected covered area (CCA) ratio is 0.74%, (0.88% and 0.75% for the mitigation and adaptation groups, respectively) indicating only slight overlap of primary studies across the included reviews.

3.3. Quality of the evidence base

More than half (27/46) of the included reviews were of high quality, while the remaining reviews were classified as being of moderate quality. Overall, the average quality score was 77%. The three most common quality problems were (1) lack of clearly and explicitly stated review question (33/46); (2) inclusion criteria not based on a dedicated framework (e.g., PICO) (27/46); and (3) searches conducted in fewer than five databases (25/46) (Table S3 in Supplementary File).

In 29 reviews, a single instrument/checklist was used to assess the quality and/or risk of bias of the included primary studies, while in the remaining 17 reviews, between two and four different instruments were used (depending on the type of primary studies). In most reviews, the results of quality appraisal/risk of bias assessment of individual studies varied considerably. In only two reviews [48,64], the pooled, overall quality score was above 80%, while in the vast majority of cases, the results were not pooled, only presented for each individual primary study and ranged from low or moderate to high quality/risk of bias. In two reviews [40,46], studies of low quality were excluded from the data synthesis. In four reviews [57,63,72,79], the certainty of evidence was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) [82,83] approach, and in all four cases the overall certainty of evidence was rated as low (Table S7 in Supplementary File).

3.4. Evidence on the scope and effectiveness of environmental sustainability actions

The 42 reviews on mitigation strategies (including one addressing both mitigation and adaptation) focused on 10 main themes (see Fig. S6 in Supplementary File). Half of them concentrated on different types of surgical operations (21/36). Other themes included: food/solid waste, telemedicine, radiology, pharmaceuticals, primary health care, hospital-led care, dentistry, behavioural interventions, and mixed strategies at different health system levels.

The identified mitigation strategies can be clustered into five main dimensions based on Braithwaite at al [40], including: 1) optimizing energy use in buildings and equipment (e.g., switching to renewable energy sources, turning off the equipment when not in use); 2) changing clinical care to reduce environmental impact (e.g., moving away from anaesthetic gases with high global warming potential; choosing medical pathways with lower environmental impact; reducing low-value care, implementing water saving measures); 3) reducing waste and improving its management (e.g., replacing single-use medical instruments and protective materials by multi-use options; waste reduction, reuse and recycling; recovering energy from waste); 4) reducing travel and transport (e.g., telemedicine, scheduling consultation to minimize patient travel, remote professional cooperation); and 5) reducing supply chain emissions (e.g., through local and green procurement) (Table 3).

Table 4 presents a general overview of the identified mitigation strategies (as classified in reviews) and the available evidence on their effectiveness. For the vast majority of identified strategies, the results clearly indicated a positive impact on the environment, manifested as reduced GHG emissions and/or reduced waste or water use. However, for two types of actions: 1) replacing single-use medical instruments (used mostly in surgical procedures) by reusable alternatives, and 2) selecting a surgical technique with lower emissions (mostly robot-assisted versus laparoscopic) – the evidence was mixed. While most high quality studies reported significant environmental advantages of reusable surgical instruments [44,52,61], some studies suggested the opposite [15] or found no differences in carbon footprint between single and multiuse instruments [76]. Similarly, some studies indicated lower GHG emissions from robot-assisted surgeries compared to laparoscopic ones [15,68], while others reported the opposite result [20,68].

Among 42 reviews on mitigation strategies, 18 also included financial costs and/or quality of care as additional outcomes of interest. Among these, five reviews evaluated all three aspects simultaneously (Table 5). The existing evidence indicated that mitigation actions were associated with improved environmental outcomes (reduced emissions, waste) and lower costs (costs savings), as well as positive or neutral effects on the quality of care (e.g., mortality, surgical site infection, asthma control). However, this evidence was derived from a limited

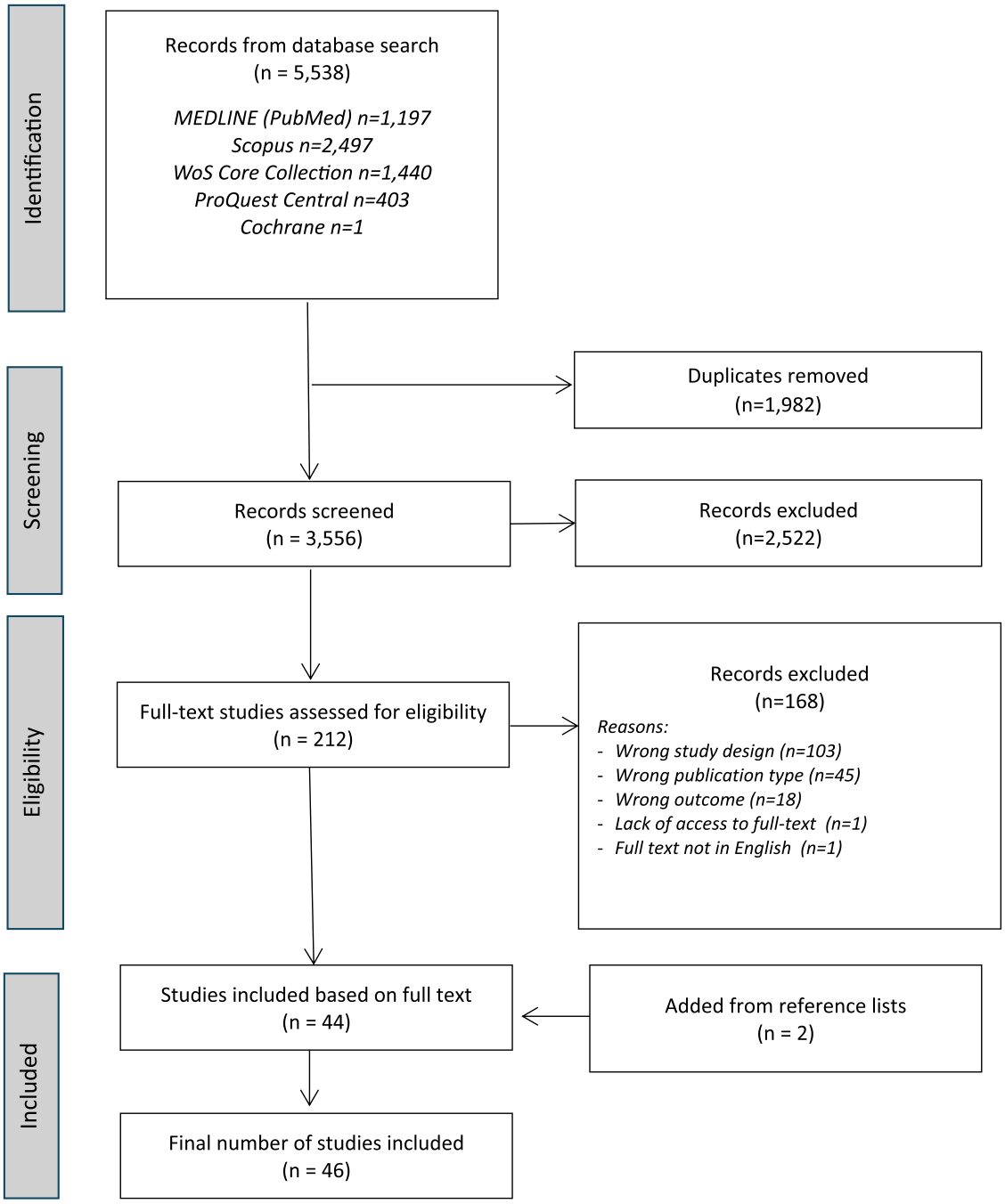


Fig. 1. PRISMA flow diagram, summarizing the search results and study selection process.

number of reviews using diverse methodologies and including primary studies that were often of low to moderate quality.

3.5. Evidence on the scope and effectiveness of climate resilience actions

Among the five reviews on climate resilience (including one addressing both mitigation and adaptation actions) three focused on disaster preparedness [73,45,46], one on the health workforce[18] and one on community heat adaptation actions [19]. Only the latter reported direct outcome measures (Table 6). Specifically, the review by Johar et al[19] showed that multicomponent educational interventions delivered in community settings could effectively improve heat literacy, adaptive behaviours, and direct health outcomes (e.g., reduce the number of heat-related health events). Consequently, the evidence on the effectiveness of specific climate adaptation actions is largely descriptive, showing, for example, that routine trainings allow for faster mobilization during climate disasters. In general, multicomponent educational activities, targeting both health professionals and patients, were the most commonly reported form of adaptation strategy.

4. Discussion

To the best of our knowledge, this is the first umbrella review synthesizing systematic reviews that included a quality appraisal of the evidence on health system responses to climate change, covering both environmental sustainability and climate resilience actions. Four main findings emerge. First, there is a large and rapidly growing evidence base: we identified 46 reviews published between 2020 and 2026,

Table 4
Synthesis of mitigation actions and their effectiveness as reported by 42 reviews (R) including 1,455 individual studies (n).

Review's theme	Strategy/Action	Evidence on effectiveness*	Impact on environment
Surgical operations: 21R, n=424	moving away from anaesthetic gases with high global warming potential (GWP)	✓ reduction of volatile anaesthetics, especially desflurane, lead to decrease in CO2e emissions between a 24% and a 98% [71] ✓ 12 out of 13 included studies reported reduced CO2e after application of educational interventions e.g., encouraging lowering fresh gas flow, applying intravenous anaesthesia [62] ✓ use of sevoflurane or propofol resulted in up to 60% reduced GHG emissions versus desflurane use [47] ✓ converting all suitable procedures from general to spinal anaesthesia can generate substantial CO2e savins [52]	positive
	optimizing energy use in operating theatres (OR)	✓ turning off airflow systems during nights and weekends can save up to 70% of total energy use [79] ✓ installing occupancy sensors, low-energy lighting, energy efficient air-conditioning systems and water cooling systems showed significantly reduced carbon emission [44] ✓ turning off idle sterilizers reduced electricity by 26% and water use by 13% [53] ✓ installing occupancy sensors in the OR let do decreased CO2 emissions by 234.2 tons [52]	positive
	replacing single-use medical instruments with multi-use options	✓ using reusable items showed a 70% waste reduction, 3 times lower water use, and 2.5 times lower energy consumption than disposables; disposable steel scissors had 99% higher environmental impact than reusable ones [44] ✓ hybrid devices in laparoscopic cholecystectomy emitted less CO2e than single-use devices (1.8 vs. 7.2kg) [68] ✓ 39 out of 47 studies directly comparing single-use and reusable devices showed lower carbon footprint of reusable option [67] ✓ 7 out of 8 studies showed lower environmental impact when using reusable endoscopic instruments [59] ✓ 3 high quality life cycle assessment studies (LCA) showed that multiuse instruments have a significantly lower (2-26 times) environmental footprint than their single-use counterparts in minimally invasive surgeries; several fair/poor quality studies favoured single-use [61] ✓ reusable equipment reduced CO2 emissions by 40-66% compared to single-use equivalents [52] ✓ single-use cystoscopes had lower emissions per procedure (2.4 kg) compared to their reusable counterparts (4.2 kg) but produced more waste; reusable cystoscopes, while having a lower cumulative waste per use, increased emissions due to energy-intensive reprocessing (the cumulative emissions results may depend on the sterilisation techniques and must be analysed by LCA) [15] ✓ in ureteroscopy, studies tend to show comparable carbon footprints for single-use and reusable instruments [76] ✓ minimal material and maximum reuse of equipment during hysterectomy resulted in 69% GHG emission reduction [47]	mixed
	minimising waste produced by instruments packaging	✓ repackaging of disposable instruments into packs of essential items customized to laparoscopic gynaecological surgery at their institution, resulting in waste reduction of 400 g per case [47] ✓ using 'green packs' for 'wide awake local anaesthesia no tourniquet' cases showed a significant waste reduction (2.3 kg per case)[70] ✓ redesigning of hand surgery packs led to a 2.8 tonnes waste decrease [70]	positive
	replacing single-use medical protective materials (e.g., headwear) by multi-use options	✓ reusable surgical head covers demonstrated a statistically significant lower carbon footprint, ozone depletion, fossil fuel depletion, terrestrial acidification, and fine particulate matter formation than disposable alternatives, while not impacting the surgical site infection rates [60]	positive
	changing surgical techniques to those with lower environmental impact	✓ robot-assisted surgery had a higher environmental impact than laparoscopic and open surgery [79] ✓ 2 studies on hysterectomy showed that robotic surgery had the highest emissions (12.0–40.3 kg CO2e) compared to laparoscopic (10.7–29.2 kgCO2e) and open surgery (7.1–22.7 kgCO2e); 1 study showed that laparoscopic prostatectomy produced more emissions than robotic option (59.7 vs. 47.3 kgCO2e) due to higher disposable devices, longer surgery time and length of stay [68]	mixed

(*continued on next page*)

Table 4 (*continued*)

Review's theme	Strategy/Action	Evidence on effectiveness*	Impact on environment
		✓ robotic prostatectomy produced lower emissions than laparoscopic methods [15]	
		✓ using alcohol-based scrub limits water use (18.5 litres per person per scrub) [53]	
		✓ increasing the lifetime of multi-use devices and fully loading autoclaves for their sterilization further decrease their environmental impact [51]	
		✓ reducing custom pack contents and replacing single-use items reduced caesarean procedure footprint by 22% [20]	
	improving waste management	✓ increasing recycling resulted in a 2% reduction in greenhouse gas emissions [52]	positive
		✓ waste segregation/recycling and minimising unused supplies reduced emissions [17]	
		✓ installing paper and cardboard recycling bins in anaesthetic room and operating theatre increased recycling (up to 50%-67% waste) [53]	
		✓ educational campaign reduced infectious medical waste by 75% [52]	
Food/solid waste: 3R, n=272	choosing local suppliers/procurement	✓ using local food (direct 'farm to hospital' procurement), which limits transport, is most environmentally beneficial [43]	positive
	using food ingredients and preparation techniques with lower environmental impact	✓ mediterranean-style diets and vegetarian menu generated lower GHG emissions and water use than the standard menu [43]	positive
		✓ using lean process tools reduced pre-service waste by 50%; fortified small portions decreases food waste by 5% [43]	
	adopting consumption methods that minimize waste	✓ using bulk trolley instead of plating food in the kitchen; enabling patient choice (e.g., room-service model) and using porcelain plates instead of plastic trays reduced food waste by 8% [43]	positive
	reusing medical items/equipment	✓ choosing reusable rather than single-use items/equipment (e.g., protective equipment, containers, non-invasive devices, surgical instruments) can significantly reduce emissions from waste[80]	positive
	improving food/solid waste management	✓ composting waste and donating surplus food substantially decreased total food waste volume [43,50]	positive
		✓ improving solid waste segregation (e.g., new waste streams, appropriate bins, a combinations of diverse staff trainings/competitions) can successfully reduce emissions from solid waste [80]	
		✓ most strategies that avoid and/or reduce sending food waste to landfill (e.g., industrial use, feeding animals, worm farms) helped to limit GHG emissions [43]	
Telemedicine and digital health: 5R, n=176	implementing remote (telephone, video, dedicated app) consultations/monitoring	✓ the majority of studies across all five reviews showed that telemedicine reduces GHG emissions due to limited travel (though not all included primary studies calculated telemedicine emissions) [54,55,65,69,72]	positive
		✓ although limited, the studies where complete LCA of telemedicine solutions was performed also showed GHG emission reduction due to replacing face-to-face visit with remote options [55]	
		✓ remote patient monitoring reduces hospital resource use and related emissions [69]	
		✓ telemedicine reduces transport-related emissions ranging by 20% to 70%, depending on the region and population size [69]	
Radiology: 2R, n=30	optimizing energy use	✓ turning off workstations/devices after hours saved a substantial part of total energy [48,64]	positive
		✓ choosing energy efficient radiological equipment [48]	
	reducing the use of consumables and radiopharmaceuticals	✓ limiting the use of diatrizoic acid (contrast agent) reduced environmental contaminations (e.g. in rivers) [48]	positive
	reducing patients' and staff travel	✓ investing in teleradiology/remote collaboration - online conferences (e.g., switching to online, the annual Radiological Society of North America conference can save 40 000 tons of CO2e due to travel) [48]	positive
Pharmaceuticals: 2R, n=81	reducing pharmaceutical waste	✓ diversity of actions described as effective, including e.g.: educational interventions (for both patients and staff); providing information (audit and feedback on waste values; monthly bulletins of waste production); reminders to return unused medicines; changing dispensing/distribution practice (dosage on demand; increased frequency of batches preparation), incorporating of environmental sustainability rules into procurement contracts [75,77]	positive
	switching to pharmaceuticals with lower carbon footprint	✓ switching inhalers from metered-dose (MDI) to dry powder inhalers (DPI) significantly lowered the carbon footprint	positive

(*continued on next page*)

Table 4 (*continued*)

Review's theme	Strategy/Action	Evidence on effectiveness*	Impact on environment
		while at the same time improved asthma control and adherence [75]	
PHC: 2R, n=35	delivering PHC's decarbonisation toolkits	✓ 11 toolkits were identified, all including educational materials for PHC staff, while 7 also included resources for patients; majority focused on clinical operations, procurement, energy use, and waste and recycling – although quantitative data were limited, the available evidence pointed towards a reduced environmental impact after toolkits implementation [84]	positive
	implementing mix of actions, incl.: reuse of resources, improving waste management, revising prescriptions; saving energy; promoting telemedicine and health education	✓ no quantitative data were provided and the identified strategies' results were not consistently reported; some strategies proved effective in reducing emissions (e.g., energy efficient solution; limiting patient travel by telemedicine and changes in appointment scheduling and prescription collection; social prescribing reduced further health care use, switching to dry powder inhalers reduced emissions) [85]	positive
Hospital-led care: 1R, n=92	reducing patient travel	✓ reductions in carbon emissions associated with the use of telemedicine/virtual appointments were consistent across all included studies [78]	positive
	reducing waste	✓ in gastroenterology, reusable equipment was associated with reduced carbon emissions; however in urology, disposable instruments were found to be associated with reduced carbon emissions [78]	mixed
Dentistry: 1R, n=51	switching to materials, equipment with lower environmental impact	✓ the use of reusable protective equipment, stainless steel sets, ceramic materials and water-saving technologies has the potential to significantly reduce emissions [81]	positive
Behavioural interventions: 1R, n=20	implementing a mix of behaviour change techniques, incl.: change in policy/protocols, email updates, announcements, presentations, personalised and team feedback, reminder notes	✓ some strategies, especially comprehensive ones that applied more than one behavioural technique proved effective in reducing emissions, with most evidence focused on interventions that targeted anaesthesia and pathology test ordering in hospital settings, e.g., educational intervention on anaesthetic gases flow rate in perioperative settings showed 105 kg of CO2e reduction per case; behavioural intervention to reduce biochemical test ordering showed 10 tons of CO2e reduction per year [49]	positive
Mix - different strat. /system levels: 4R, n=274**	changing clinical and surgical care pathways to reduce environmental impact	✓ interventions related to changing anaesthesia agent practices can lead to GHG reduction between 25% - 100% [63] ✓ targeting unnecessary resting (low-value care) limited emissions by 10%-37% [63] ✓ implementing multicomponent interventions to reduce low-value care (incl.: identifying and reducing unnecessary processes or procedures, minimising drug overprescription, encouraging a preventative care approach to reduce the need for health services) can successfully reduce emissions [40] ✓ implementing water use saving plans (e.g., automatic shut-off / low pressure valves, reporting water use to staff) can reduce water consumption [45]	positive
	reducing waste volume and improving waste managements	✓ multicomponent waste reduction intervention incl. clinician education, audit and feedback, recycling, relocation of landfill, and converting from single-use to reusable sharps containers led to reducing GHG emission by 32%-85% [63] ✓ systems integrating waste segregation, composting and material recycling with simultaneous transport optimisation generated greatest emission reductions, ranging from 47%–114% [57]	positive
	reducing travel and transport	✓ numerous studies examining different approaches to reduce travel and transportation (telemedicine, local care options, shared transport options, scheduling face-to-face appointment to minimize travel needs, reducing health professional's business trips) showed positive results in terms on GHG emission reductions [40]	positive
	optimizing energy use (in buildings and equipment)	✓ using mixed energy sources or fully renewable ones, led to CO2 emission reductions of 25%–233% [57] ✓ conserving energy by optimizing equipment use (switching off when not used, sleep-mode) can reduce emissions[40] ✓ investing in infrastructural solutions that maximise use on natural light (windows exposure) and minimizes the need for air-conditioning (insulation, reflective materials) [45]	positive
	decarbonising the supply chain	✓ numerous studies showed that green procurement (e.g., using sustainable or local sources of food supply, or using supply chains with low emissions) can reduce emissions [40]	positive

* if available, quantitative data are presented; otherwise a descriptive information is used
** including one R on both mitigation and adaptation

Table 5
Results of the 18 reviews on mitigation, with multiple outcome measures, including 615 individual studies.

1st author and ref. no	Review's topic	Mitigation action's association with*		
		Environment	Costs	Quality of care
Batcup [49]	mix - behavioural change interventions	positive	positive	n/a
Blom [57]	mix - different strategies / health system levels	positive	mostly positive	mostly positive
Carino [43]	food waste (across hospital supply chain)	positive	positive	n/a
Chauvet [58]	surgical operations - single vs multiuse laparoscopic instruments	positive	positive	mixed
Eussen [59]	surgical operations - single vs multiuse instruments	positive	positive	neutral
Gumera [60]	surgical operations - single vs multiuse headwear	positive	positive/ neutral	neutral
Iakovou [70]	surgical operations - plastic surgery	positive	positive	n/a
Onasanya [75]	pharmaceuticals - inhalers	positive	n/a	positive
Papadopoulou [47]	surgical operations - minimally invasive surgery (robotic vs laparoscopic)	mixed	positive	n/a
Pickard Strange [54]	telemedicine	positive	positive	n/a
Pickles [63]	mix - different strategies / health system levels	mostly positive	mostly positive	neutral
Pitard [77]	pharmaceuticals - hospital pharmacy (mix)	positive	mostly positive	n/a
Rodler [55]	telemedicine	positive	positive	n/a
Roletto [64]	radiology (mix)	positive	positive	n/a
Vu [66]	surgical operations (mix)	positive	positive	n/a
Faizan [69]	telemedicine and digital health	positive**	n/a	positive**
Lee-Smith [72]	telemedicine	positive	positive	n/a
McGushin [80]	healthcare solid waste	positive	mostly positive	n/a

* a positive association means reduced environmental impact, reduced costs and improved quality of care
** not compared at the level of individual studies

Table 6
Synthesis of the identified adaptation actions reported by five reviews (R) including 138 individual studies (n).

Review's theme	Strategy/Action
Disaster preparedness: 3R, n=68*	✓ continuous education of healthcare professionals on disaster preparedness, including multi-professional, scenario-based educational trainings [46] ✓ routine workforce training exercises (e.g. for cyclones) enable faster mobilization and more effective patient triage during actual disasters [73] ✓ availability of disaster response protocols (including additional supplies availability patterns) developed and updated by the dedicated emergency preparedness committee [46] ✓ institutional coordination with external partners, such as NGOs, government agencies, and volunteer groups strengthens mobilization during disasters [73] ✓ early warnings/ outbreaks detection IT systems [46] ✓ investing in climate-proof infrastructure solutions (e.g., insulation, reflective materials to reduce heat gain inside buildings; architectural design to reduce risk of flooding, or damages due to strong winds) [45] ✓ functional preparedness (portable equipment) strengthens the resilience of care delivery during disasters [73]
Workforce preparedness: 1R, n=60	✓ disaster preparedness training (incl. actionable protocols, drills, evacuation plans and interprofessional collaboration) [18] ✓ planning for staff surge capacity (scheduling and contingency plans, effective mobilisation strategies, role flexibility and adequate incentives structure) [18] ✓ psychological support (counselling during and after climate events) [18]
Community heat adaptations: 1R, n=10	✓ multicomponent educational interventions delivered in community settings (e.g., written and digital media, individual communication) can be effective in improving heat literacy, behavioural adaptation, and health outcomes (incl. reduced number of hospital visits, reduced heat related health events) [19]

* including one R on both mitigation and adaptation

covering 1175 individual studies, mostly originating from high-income countries. Second, the literature is strongly concentrated on mitigation strategies, while evidence on adaptation and climate resilience remains comparatively scarce. Most research focuses on actions implemented at the level of individual healthcare providers or clinical practices, with half addressing mitigation actions in surgical care, whereas other themes – including solid waste, telemedicine and transport, radiology, pharmaceuticals, primary health care, hospital-led care, dentistry behavioural interventions, and mixed strategies across health system levels – are each covered by a relatively smaller number of reviews. Third, the available evidence indicates that many mitigation actions might generate environmental and economic co-benefits, although much of the underlying research is of low to moderate quality. Only a few reviews (with primary studies of varying quality) analysed the associations between mitigation actions and quality of care, showing positive or neutral association. Finally, several findings – particularly regarding reusable instruments and specific surgical techniques – appear to be highly context dependent.

Our findings are in line with results of previous evidence syntheses focusing on climate mitigation strategies within health systems, e.g., Braithwaite et al [40] and Seppänen & Or [23]. However, our work covers a broader literature base, reports on quality appraisal of both the systematic reviews and the underlying primary studies, provides more details on the effectiveness of particular strategies, and draws attention to (potential) co-benefits of interventions for environmental sustainability and costs. It provides the most comprehensive overview of the available literature to date.

However, before discussing the implications for policy and research, several limitations should be noted. First, the evidence base shows substantial methodological heterogeneity. Across the included reviews, effectiveness data were reported in different formats (quantitative versus descriptive) and at different levels of aggregation (individual studies, pooled results, or fragmented summaries). Reviews also applied a wide range of quality appraisal and risk-of-bias tools – more than 30 different tools were used, up to four in a single review (Table S7 in Supplementary File). This limited comparability prevented a quantitative synthesis or overall grading of evidence certainty. Second, many underlying primary studies were assessed as having low to moderate methodological quality, which reduces the reliability of the results. Third, our inclusion criteria focused on reviews primarily addressing health system actions, while climate resilience often depends on intersectoral measures involving urban planning, transport, agriculture and food systems, energy, and housing [7,86]. Relevant evidence from these areas may therefore not be fully captured, as reviews on intersectoral

climate adaptation strategies, without a primary focus on health system activities were excluded. Fourth, our focus on effectiveness of mitigation and adaptation measures, might have led to the identification of a higher number of reviews on mitigation actions, for which the outcome measures are relatively straightforward and well established in the literature – namely, direct GHG emission reductions. In contrast, the outcome indicators for activities aimed at strengthening health system climate resilience may be much more difficult to capture [11,87], resulting in a limited number of available studies. Fifth, the CCA ratio was calculated only for the two main types of reviews, and not within narrower thematic groups (which would most probably show a higher degree of overlapping publications). Finally, only a subset of mitigation reviews included life-cycle assessment (LCA) studies, which are considered the gold standard for evaluating environmental impacts [88,89]; summary statistics for the available evidence could not be calculated across all reviews, as methodological details about the included studies were not always provided. These limitations highlight the need for more standardized methodologies and reporting practices in future research.

Nevertheless, our findings have important implications for policymakers and researchers. First, the large body of available evidence provides practical guidance for reducing the environmental footprint of healthcare in several well-identified emission hotspots, including surgical care, pharmaceuticals, radiology, patient and staff transport, and food/solid waste:

- ✓ Surgery is highly resource-intensive: it uses three to six times more energy than other hospital wards [90], accounts for 30% to 50% of hospital waste, including mostly single-use plastic products and packaging [53,91], and represents up to 60% of total hospital emissions [92]. Reducing the use of high-emission anaesthetic gases, improving operating room energy management, optimising surgical pathways, and increasing the use of reusable instruments can make a substantial contribution to environmental sustainability [53,91,93].
- ✓ Pharmaceuticals account for about 25% of health system emissions [94,95], with certain medicines having a disproportionate impact. For example, inhalers generate about 3% of total NHS emissions in England. Key mitigation approaches include reducing pharmaceutical waste and selecting medicines with a lower environmental impact, such as switching from metered-dose to dry-powder inhalers where clinically appropriate.
- ✓ Clinical radiology and radiotherapy contribute about 10% of the healthcare carbon footprint [48]. The major drivers are energy-intensive equipment, large data storage needs, and waste from consumables, including radiological contrast agents [96,97]. Existing evidence suggests that 40% to 91% of energy use occurs during idle time, when devices are switched on but not operating [64]. In addition, there is growing evidence on low-value diagnostic imaging – including, for example, MRI and CT scans that are unnecessarily performed [98], thus the potential for emission reduction is substantial.
- ✓ Food waste represents approximately 20% to 30% of total hospital waste, with plate waste averaging around 30%-40% [99], although this varies depending on the type of ward. When decomposed in landfills, food waste emits methane which has a global warming potential 28 times greater than carbon dioxide [100]. Mitigation actions for food waste in hospitals cover all areas of the general food recovery hierarchy[101], with the prevention of waste generation being the most effective approach. Similarly, reducing emissions from other types of healthcare solid waste can be achieved through a variety of actions within the “reduce, reuse, reprocess, recycle, replace and improve waste segregation” framework [80].
- ✓ Transport and travel account for 14% to 22% of healthcare emissions [95,102]. Much of the existing mitigation evidence in this area focuses on telemedicine as an effective way to limit travel by both patients and health professionals.

To achieve a system-wide impact, these insights need to be translated into formal policy instruments such as clinical guidelines, procurement standards, and organisational sustainability strategies. Some examples already exist, *The Green Surgery Report* [103] by the UK Health Alliance on Climate Change, *The Greening the Operating Room and Perioperative Arena guidelines* [104] by the American Society of Anaesthesiologists, the *Intensive Care Environmental Sustainability Recipe Book* [105] by the Intensive Care Society, and the *NHS Net Zero Supplier Roadmap* by the National Health Service[106].

Second, the strong concentration of the literature on mitigation underlines the need for greater attention to health system climate resilience. Climate change is already affecting health systems through heatwaves [107], extreme weather events [108], and changing disease patterns[109], yet only a small number of systematic reviews have addressed adaptation actions. While effective health system adaptation often requires coordination with other sectors - including urban planning, energy systems, and food systems [7] - the limited number of rigorous systematic reviews assessing the quality or certainty of the underlying evidence on heat adaptation, climate-resilient infrastructure, or green resilience approaches within healthcare is notable. Strengthening the evidence base in this area is therefore an important priority for both research and policy. Further research is needed to better understand which adaptation and resilience strategies are most effective, under what conditions, and how their impact can be measured across different health system contexts. As mentioned in the limitations of this study, the outcome measures for health system climate resilience might be more difficult to capture, than those for mitigation actions. The WHO proposes a set of indicators for measuring health system climate resilience at the macro/system level [11,110], including, for example, population health outcomes and metrics of health services disruptions (Table 1). However, different structural measures, focusing more narrowly on technical adaptation dimensions might be more relevant at the individual provider and/or professional levels (e.g., the existence of routine climate disaster preparedness training, surge capacity/mobilization protocols, backup systems). Future studies should move beyond descriptive assessments towards rigorous evaluations of implemented adaptation interventions, using comparable methodologies.

Third, the geographical distribution of the identified evidence is heavily concentrated in high-income countries. Only two of the 46 reviews focused explicitly on low- and/or middle-income countries. Review by Blom et al [57] focused primarily on mitigation and synthesized evidence from 22 studies, covering 11 countries, while the work by Morris et al [73] focused on climate disaster preparedness and included 20 studies from 12 countries. In both reviews, the quality of the included studies was often low (Table S7 in Supplementary File). These findings indicate important gaps in research-based knowledge, that could hinder evidence-informed policy decisions. Overall, the geographical imbalance in the available evidence is particularly striking as climate change is expected to have more severe impacts on low-income countries [3,5]. More studies using robust and replicable methodologies are needed that analyse specific aspects of climate mitigation and resilience in these low-resource settings.

Fourth, the evidence on environmental and economic co-benefits provides an important argument for policy action. Many mitigation strategies appear capable of reducing greenhouse gas emissions while also being associated with lower costs (generating cost savings). Future studies, using rigorous and replicable methodologies should investigate these associations in greater detail. Similarly, the association between mitigation actions and quality of care requires further research attention. Our work identified just a few reviews [59,60,63] – suggesting that the mitigation actions investigated may have a neutral or even positive effect on quality of care. For example, reviews by Eussen et al [59] and Gumera et al [60] showed that reusable medical instruments and reprocessed single use instruments (e.g., scissors, trocars, forceps, Veress needles) as well as reusable surgical headwear, offer significant environmental advantages and lower costs, while maintaining comparable

performance and safety to disposable alternatives. Similarly, the review by Onasanya et al [75] showed that switching to inhalers with much lower emissions was associated with improved inhaler adherence and asthma control. In summary, although the evidence is limited to only a few reviews with mixed quality appraisal scores, it suggests that policies prioritizing mitigation interventions may align climate objectives with broader health system goals, including cost containment and value-based care. Further research could usefully explore these co-benefits more systematically and examine the environmental implications of other cost-saving care strategies, such as shifting care to ambulatory settings and reducing low-value interventions. Existing efforts to incorporate environmental sustainability criteria (e.g. carbon emissions) into clinical trials [111,112], and health technology assessments [113,114] and to prioritise services that can provide the same health effect with a lower environmental impact [115] point in the right direction.

Fifth, the environmental performance of specific interventions may vary considerably depending on local conditions such as energy sources, sterilization practices, reuse rates, or the organization of clinical pathways. For example, the relative environmental advantage of reusable versus single-use medical instruments depends on a range of factors [44,51,61], including the efficiency of sterilisation techniques (e.g., related to packing of autoclaves), the number of reuse cycles, and the proportion of renewable sources in the energy mix. Consequently, a similar mitigation action can be effective in one context but not in another. For example, the carbon footprint of reusable surgical instruments may be much higher in Australian settings (with mostly coal-based electricity) than in European ones (with a higher share of renewable energy sources) [44]. These findings suggest that policy guidance should combine general principles with context-specific assessments. Health systems may therefore benefit from integrating environmental impact evaluations into local decision-making processes, procurement strategies, and clinical pathway redesign.

Sixth, our findings highlight the need to strengthen methodological standards and implementation capacity. The heterogeneity of environmental impact assessment methods across studies limits the comparability and synthesis of results. The wider use of standardized approaches – particularly LCAs – would improve the robustness of the evidence base. LCAs are based on dedicated ISO standards (ISO 14040–14044) [88,89] and allow for a comprehensive product assessment, from 'cradle to grave' (material extraction, production, use, and waste management). Furthermore, incorporating environmental impact indicators into standard health information and reporting systems would enable a more systematic assessment of the environmental performance of healthcare activities, moving beyond the current reliance on ad hoc analyses conducted as part of individual studies.

Translating evidence into practice will require stronger integration of climate and sustainability topics into health professional education, clinical training, and continuing professional development programs. We found two reviews underlining the crucial role of educational activities, training and skill development for climate mitigation and adaptation efforts [18,49]. However, current training programs often do not cover climate action topics [116–118]. For example, in 2020 climate change topics were taught in only 15% of medical schools worldwide (survey by The International Federation of Medical Students Associations) [116]; and surveys among intensive care professionals indicate that many lack formal training on environmentally sustainable practices [119]. Strengthening education and training in this area is therefore an important step towards enabling health professionals to incorporate climate mitigation and adaptation practices into routine decision-making. At the same time, growing engagement among medical students and health professionals suggests increasing interest in this topic, providing a promising foundation for integrating climate and sustainability competencies into future health workforce training [120,121].

Overall, our findings provide a strong argument for incorporating the dimensions of environmental sustainability and climate resilience dimensions into health system performance assessment frameworks [110,122]. This could strengthen routine data collection and enable the regular generation of robust research evidence, which is especially important for monitoring progress in health system climate adaptation.

5. Conclusions

There is a substantial and rapidly growing body of research on health system responses to climate change. The literature is strongly concentrated in high-income countries and mitigation strategies implemented at the level of individual providers, particularly in surgical care. Across several areas, mitigation actions appear capable of generating environmental and economic co-benefits, while some individual reviews also point to positive or at least neutral associations with quality of care. In contrast, the evidence on the effectiveness of health system climate resilience actions remains limited. Only a few available reviews have appraised the quality of the primary studies. Multicomponent educational activities are the most commonly reported form of response strategy.

These findings have important implications for policymakers and researchers. The existing evidence base provides practical guidance for reducing the environmental impact of healthcare in key emission hotspots, which can be incorporated into clinical guidelines, procurement standards, and organisational strategies. The strong focus on mitigation highlights the need to strengthen the evidence base on health system climate resilience. Particular attention should be given to developing and validating robust indicators of climate resilience, as outcomes such as preparedness, adaptive capacity, continuity of care, and the protection of vulnerable populations are often complex and difficult to quantify. While climate mitigation and resilience are conceptually distinct, they are closely interrelated. Both dimensions should be incorporated into health workforce education and training as well as into health system performance assessment frameworks.

Declaration of generative AI use

During the preparation of this work, the authors used ChatGPT to proofread and improve the flow of the text. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Funding

No dedicated funding.

CRediT authorship contribution statement

Katarzyna Dubas-Jakóbczyk: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Magdalena Mrożek-Gąsiorowska:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis. **Costase Ndayishimiye:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Data curation. **Nsikakabasi Samuel George:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis. **Anna Bianca Pereyra:** Writing – review & editing, Validation, Investigation, Formal analysis. **Gunda Waldmann:** Writing – review & editing, Validation, Investigation, Formal analysis. **Wilm Quentin:** Writing – review & editing, Validation, Investigation, Formal analysis.

Declaration of competing interest

Given their roles as editors, Katarzyna Dubas-Jakóbczyk, Gunda Waldmann and Wilm Quentin had no involvement in the peer review of

this article and have no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.healthpol.2026.105805.

References

[1] WHO. WHO guidance for climate resilient and environmentally sustainable health care facilities. Accessed May 2, 2025, https://www.who.int/publications/i/item/9789240012226; 2020.
[2] WHO. Climate change. Accessed May 2, 2025, https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health; 2023.
[3] Health and climate change. Accessed January 21, 2026. https://www.worldbank.org/en/topic/health/brief/health-and-climate-change.
[4] Rocque RJ, Beaudoin C, Ndjaboue R, et al. Health effects of climate change: an overview of systematic reviews. BMJ Open 2021;11(6):e046333. https://doi.org/10.1136/BMJOPEN-2020-046333.
[5] IPCC. AR6 synthesis report: climate change 2023 — IPCC. Accessed May 2, 2025, https://www.ipcc.ch/report/sixth-assessment-report-cycle/; 2023.
[6] Health at the heart of national adaptation planning: a global review of national adaptation plans and health national adaptation plans. Accessed January 21, 2026. https://www.who.int/publications/i/item/9789240118447.
[7] World Health Organization. Operational framework for building climate resilient and low carbon health systems. Published online, https://iris.who.int/bitstream/handle/10665/373837/9789240081888-eng.pdf; 2023.
[8] WHO. Environmentally sustainable health systems: a strategic document. Accessed August 2, 2026, https://www.who.int/publications/i/item/WHO-EURO-2017-2241-41996-57723; 2017.
[9] WHO. WHO global strategy on health, environment and climate change : the transformation needed to improve lives and well being sustainably through healthy environments. Published online 2020.
[10] WHO. Safe, climate-resilient and environmentally sustainable health care facilities. Published online November 7, 2024. doi:10.2471/B09119.
[11] World Health Organization. Measuring the climate resilience of health systems. World health organisation. Published online, https://www.who.int/publications/i/item/9789240048102; 2022.
[12] Smith CL, Rojas C, Zurynski Y, Partington A, Braithwaite J. From policy to practice: building a resilient, climate aware health system from the ground up. Clim Chang 2025;178(4):69. https://doi.org/10.1007/S10584-025-03914-7. -.
[13] Countries and areas - the community of practice for climate resilient and low carbon sustainable health systems. Accessed January 21, 2026. https://www.atachcommunity.com/atach-community/countries-and-areas/.
[14] Bowie K. Are our health systems following through on their climate targets? BMJ 2025;391:r2235. https://doi.org/10.1136/BMJ.R2235.
[15] Tozsin A, Aydin A, Silay S, et al. Environmental sustainability in urologic practices: a systematic review. World J Urol 2025;43(1):152. https://doi.org/10.1007/S00345-025-05522-7.
[16] Davies JF, Ikin B, Francis JJ, McGain F. Implementation approaches to improve environmental sustainability in operating theatres: a systematic review. Br J Anaesth 2024;133(6):1383–96. https://doi.org/10.1016/j.bja.2023.05.017.
[17] Kloevekorn L, Roemeling O, Fakha A, Hage E, Smailhodzic E. Decarbonizing surgical care: a qualitative systematic review guided by the congruence model. BMC Health V Res 2024;24(1). https://doi.org/10.1186/S12913-024-11929-6.
[18] Zurynski Y, Fisher G, Wijekulasuriya S, et al. Bolstering health systems to cope with the impacts of climate change events: a review of the evidence on workforce planning, upskilling, and capacity building. Int J Health Plann Manag 2024;39(3):781–805. https://doi.org/10.1002/HPM.3769.
[19] Johar H, Abdulsalam FI, Guo Y, et al. Community-based heat adaptation interventions for improving heat literacy, behaviours, and health outcomes: a systematic review. Lancet Planet Health 2025;9(7):101207. https://doi.org/10.1016/S2542-5196(25)00007-5.
[20] Cohen ES, Kouwenberg LHJA, Moody KS, et al. Environmental sustainability in obstetrics and gynaecology: a systematic review. BJOG 2024;131(5):555–67. https://doi.org/10.1111/1471-0528.17637;JOURNAL:JOURNAL:14710528;PAGE:STRING:ARTICLE/CHAPTER.
[21] Mani ZA, Naylor K, Goniewicz K. Essential competencies of nurses for climate change response in Saudi Arabia: a rapid literature review. J Adv Nurs 2025;81(12):8116–31. https://doi.org/10.1111/JAN.16372.
[22] Nayna Schwerdtle P, Moo E, Pae C, et al. Learning from practice - a rapid review of climate resilient and low carbon health systems - case studies in six western pacific countries. J Clim Chang Health 2025;22:100376. https://doi.org/10.1016/J.JOCLIM.2024.100376.
[23] Seppänen AV, Or Z. A scoping review of interventions to reduce the environmental footprint of healthcare. Value Health 2025;28(7):1110–25. https://doi.org/10.1016/J.JVAL.2025.01.021.
[24] Ghotra SS, Champendal M, Flaction L, Ribeiro RT, Sá dos Reis C. Approaches to reduce medical imaging departments' environmental impact: a scoping review. Radiography 2024;30:108–16. https://doi.org/10.1016/j.radi.2024.08.002.
[25] Chatzipavlou M, Karayiannis D, Chaloulakou S, Georgakopoulou E, Poulia KA. Implementation of sustainable food service systems in hospitals to achieve current sustainability goals: a scoping review. Clin Nutr ESPEN 2024;61:237–52. https://doi.org/10.1016/j.clnesp.2024.03.030.
[26] Brink N, Mansoor K, Swiers J, et al. Scoping review of climate change adaptation interventions for health: implications for policy and practice. Int J Env Res Public Health 2024;21(12):1565. https://doi.org/10.3390/IJERPH21121565.
[27] Mulu MM, Kivuva MM. Climate change education for environmental sustainability among health professionals: an integrative review. SAGE Open Nurs 2025;11. https://doi.org/10.1177/23779608251351117;SUBPAGE:STRING:FULL.
[28] Almazan JU, Manabat A, Kavashev Z, et al. Sustainability in education and healthcare field: an integrative review of factors, barriers, and the path forward for informed practices. Health Prof Educ 2024;10(4):3. https://doi.org/10.55890/2452-3011.1299.
[29] Kjelle E, Brandsæter I, Andersen ER, Hofmann B. Sustainability in healthcare by reducing low-value imaging – a narrative review. Radiography 2024;30:30–4. https://doi.org/10.1016/j.radi.2024.05.014.
[30] Leivaditis, V., Sepetis, A. Digital transformation as a catalyst for sustainable health care systems: a narrative review of current evidence. https://doi.org/10.1142/S1363919625400092. 2025;29(5-6). 10.1142/S1363919625400092.
[31] Belbasis L, Bellou V, Ioannidis JPA. Conducting umbrella reviews. BMJ Med 2022;1(1):e000071. https://doi.org/10.1136/BMJMED-2021-000071.
[32] Aromataris E, Fernandez R, Godfrey C, Holly C, Khalil H, Tungpunkom P. Umbrella reviews. JBI Man Evid Synth 2024. https://doi.org/10.46658/JBIMES-24-08. Published online.
[33] Aromataris E, Fernandez R, Godfrey CM, Holly C, Khalil H, Tungpunkom P. Summarizing systematic reviews: methodological development, conduct and reporting of an umbrella review approach. Int J Evid Based Heal 2015;13(3):132–40. https://doi.org/10.1097/XEB.0000000000000055.
[34] Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. https://doi.org/10.1136/BMJ.N71.
[35] PROSPERO. Accessed May 18, 2025. https://www.crd.york.ac.uk/PROSPERO/view/CRD420251052647.
[36] Dubas-Jakóbczyk K, George NS, Ndayishimiye C. Health systems' adaptations to climate change: an umbrella review of global evidence protocol. BMJ Open 2025;15(10):e105492. https://doi.org/10.1136/BMJOPEN-2025-105492.
[37] Stern C, Jordan Z, Mcarthur A. Developing the review question and inclusion criteria. Am J Nurs 2014;114(4):53–6. https://doi.org/10.1097/01.NAJ.0000445689.67800.86.
[38] McGowan J, Sampson M, Salzwedel DM, Cogo E, Foerster V, Lefebvre C. PRESS peer review of electronic search strategies: 2015 guideline statement. J Clin Epidemiol 2016;75:40–6. https://doi.org/10.1016/J.JCLINEPI.2016.01.021.
[39] Rayyan: AI-powered systematic review management platform. Accessed May 3, 2025. https://www.rayyan.ai/.
[40] Braithwaite J, Smith CL, Leask E, et al. Strategies and tactics to reduce the impact of healthcare on climate change: systematic review. BMJ 2024;387:e081284. https://doi.org/10.1136/BMJ-2024-081284.
[41] Pieper D, Antoine SL, Mathes T, Neugebauer EAM, Eikermann M. Systematic review finds overlapping reviews were not mentioned in every other overview. J Clin Epidemiol 2014;67(4):368–75. https://doi.org/10.1016/j.jclinepi.2013.11.007.
[42] Fernandez RS, Sharifnia AM, Khalil H. Umbrella reviews: a methodological guide. Eur J Cardiovasc Nurs 2025;24:996–1002. https://doi.org/10.1093/EURJCN/ZVAF012.
[43] Carino S, Porter J, Malekpour S, Collins J. Environmental sustainability of hospital foodservices across the food supply chain: a systematic review. J Acad Nutr Diet 2020;120(5):825–73. https://doi.org/10.1016/J.JAND.2020.01.001.
[44] Rizan C, Steinbach I, Nicholson R, Lillywhite R, Reed M, Bhutta MF. The carbon footprint of surgical operations: a systematic review. Ann Surg 2020;272(6):986–95. https://doi.org/10.1097/SLA.0000000000003951.
[45] Mashallahi A, Ardalan A, Nejati A, Ostadtaghizadeh A. Climate adaptive hospital: a systematic review of determinants and actions. J Env Health Sci Eng 2022;20(2):983–1013. https://doi.org/10.1007/S40201-022-00810-5.
[46] Mohtady Ali H, Ranse J, Roiko A, Desha C. Investigating organizational learning and adaptations for improved disaster response towards "resilient hospitals:" an integrative literature review. Prehosp Disaster Med 2022;37(5):665–73. https://doi.org/10.1017/S1049023X2200108X.
[47] Papadopoulou A, Kumar NS, Vanhoestenberghe A, Francis NK. Environmental sustainability in robotic and laparoscopic surgery: systematic review. BJS 2022;109(10):921–32. https://doi.org/10.1093/BJS/ZNAC191.
[48] Anudjo MNK, Vitale C, Elshami W, et al. Considerations for environmental sustainability in clinical radiology and radiotherapy practice: a systematic literature review and recommendations for a greener practice. Radiography 2023;29(6):1077–92. https://doi.org/10.1016/j.radi.2023.09.006.
[49] Batcup C, Breth-Petersen M, Dakin T, et al. Behavioural change interventions encouraging clinicians to reduce carbon emissions in clinical activity: a systematic review. BMC Health Serv Res 2023;23(1):384. https://doi.org/10.1186/S12913-023-09370-2.
[50] Cook N, Goodwin D, Porter J, Collins J. Food and food-related waste management strategies in hospital food services: a systematic review. Nutr Diet 2023;80(2):116–42. https://doi.org/10.1111/1747-0080.12768.
[51] Keil M, Viere T, Helms K, Rogowski W. The impact of switching from single-use to reusable healthcare products: a transparency checklist and systematic review of

life-cycle assessments. Eur J Public Health 2023;33(1):56–63. https://doi.org/10.1093/EURPUB/CKAC174.
[52] Lam K, Gadi N, Acharya A, Winter Beatty J, Darzi A, Purkayastha S. Interventions for sustainable surgery: a systematic review. Int J Surg 2023;109(5):1447–58. https://doi.org/10.1097/JS9.0000000000000359.
[53] Perry H, Reeves N, Ansell J, et al. Innovations towards achieving environmentally sustainable operating theatres: a systematic review. Surgeon 2023;21(3):141–51. https://doi.org/10.1016/j.surge.2022.04.012.
[54] Strange MP, Booth A, Akiki M, Wieringa S, Shaw SE. The role of virtual consulting in developing environmentally sustainable health care: systematic literature review. J Med Internet Res 2023;25(1):e44823. https://doi.org/10.2196/44823.
[55] Rodler S, Ramacciotti LS, Maas M, et al. The impact of telemedicine in reducing the carbon footprint in health care: a systematic review and cumulative analysis of 68 million clinical consultations. Eur Urol Focus 2023;9(6):873–87. https://doi.org/10.1016/j.euf.2023.11.013.
[56] Wicklum SC, Nuique K, Kelly MA, Nesbitt CC, Zhang JJ, Svrcek CP. Greening family medicine clinic operations and clinical care, where do we start? a scoping review of toolkits and aids. Fam Pr 2023;40(3):473–85. https://doi.org/10.1093/FAMPRA/CMAD006.
[57] Blom IM, Eissa M, Mattijsen JC, Sana H, Haines A, Whitmee S. Effectiveness of greenhouse gas mitigation intervention for health-care systems: a systematic review. Bull World Health Organ 2024;102(3):159–175B. https://doi.org/10.2471/BLT.23.290464.
[58] Chauvet P, Enguix A, Sautou V, Slim K. A systematic review comparing the safety, cost and carbon footprint of disposable and reusable laparoscopic devices. J Visc Surg 2024;161(2):25–31. https://doi.org/10.1016/j.jviscsurg.2023.10.006.
[59] Eussen MMM, Moossdorff M, Wellens LM, et al. Beyond single-use: a systematic review of environmental, economic, and clinical impacts of endoscopic surgical instrumentation. Int J Surg 2024;110(12):8136–50. https://doi.org/10.1097/JS9.0000000000002141.
[60] Gumera A, Mil M, Hains L, Fanshaw SR, Dunne B. Reusable surgical headwear has a reduced carbon footprint and matches disposables regarding surgical site infection: a systematic review and meta-analysis. J Hosp Infect 2024;152:164–72. https://doi.org/10.1016/j.jhin.2024.07.017.
[61] Martins RS, Salar H, Salar M, et al. Making minimally invasive procedures more sustainable: a systematic review comparing the environmental footprint of single-use versus multi-use instruments. World J Surg 2024;48(9):2212–23. https://doi.org/10.1002/WJS.12286.
[62] Nolan BC, Hoskins MJ, Phillips B, Evans KL. Promoting behavioural change by educating anaesthetists about the environmental impact of inhalational anaesthetic agents: a systematic review. Anaesth Intensive Care 2024;52(6):356–68. https://doi.org/10.1177/0310057X241263113.
[63] Pickles K, Haas R, Guppy M, et al. Clinician and health service interventions to reduce the greenhouse gas emissions generated by healthcare: a systematic review. BMJ Evid Based Med 2024;29(5):300–12. https://doi.org/10.1136/BMJEBM-2023-112707.
[64] Roletto A, Zanardo M, Bonfitto GR, Catania D, Sardanelli F, Zanoni S. The environmental impact of energy consumption and carbon emissions in radiology departments: a systematic review. Eur Radiol Exp 2024;8(1). https://doi.org/10.1186/S41747-024-00424-6.
[65] van der Zee C, Chang-Wolf J, Koopmanschap MA, van Leeuwen R, Wisse RPL. Assessing the carbon footprint of telemedicine: a systematic review. Health V Insights 2024;17. https://doi.org/10.1177/11786329241271562.
[66] Vu C, Ibarra-Vega A, Yang CD, et al. Interventions to reduce surgical waste burden: a systematic review. Plast Reconstr Surg Glob Open 2024;12(8):e6085. https://doi.org/10.1097/GOX.0000000000006085.
[67] Booth A, Chowaniec M, Goyal S, Faulkner S, Shaw S. The carbon footprints of single-use and reusable medical devices: a systematic review. BMJ Open 2025;15(12):e108446. https://doi.org/10.1136/BMJOPEN-2025-108446.
[68] Cunha MF, Neves JC, Roseira J, Pellino G, Castelo-branco P. Green surgery: a systematic review of the environmental impact of laparotomy, laparoscopy, and robotics. Updates Surg 2025;77(5):1683–92. https://doi.org/10.1007/S13304-025-02221-1.
[69] Faizan M, Han C, Lee SW. Policy-driven digital health interventions for health promotion and disease prevention: a systematic review of clinical and environmental outcomes. Healthcare 2025;13(18):2319. https://doi.org/10.3390/HEALTHCARE13182319.
[70] Iakovou D, Sousi S, Glynou SP, et al. A systematic review of sustainability practices in plastic surgery. J Plast Reconstr Aesthet Surg 2025;102:104–13. https://doi.org/10.1016/j.bjps.2025.01.027.
[71] Hammer S, Eichlseder M, Klivinyi C, et al. Effects of departmental green anaesthesia interventions on carbon dioxide equivalent emissions: a systematic review. Br J Anaesth 2025;135(1):79–88. https://doi.org/10.1016/J.BJA.2025.03.038.
[72] Lee-Smith L, Andrews J, Lee-Smith L, Andrews J. Examining the carbon footprint of orthopaedic outpatient care and comparing the emissions from in-person versus virtual models of care: a systematic review. Cureus 2025;17(12). https://doi.org/10.7759/CUREUS.100475.
[73] Morris K, Pasha A, Li X, Qiao S. Disaster preparedness of health systems in LMICs in the face of climate change: a systematic mapping review of vulnerabilities and response strategies. BMC Public Health 2025;26(1):217. https://doi.org/10.1186/S12889-025-25873-5.
[74] Nunes AR, Karaba F, Geddes O, et al. Implementation of decarbonisation actions in general practice: a systematic review and narrative synthesis. BMJ Open 2025;15(2):e091404. https://doi.org/10.1136/BMJOPEN-2024-091404.
[75] Onasanya AA, Haider Y, Peaston G, Ignatowicz A, Turner AM. Inhaler sustainability in asthma and COPD care: a systematic review. BMJ Open 2025;15(7):e098052. https://doi.org/10.1136/BMJOPEN-2024-098052.
[76] Peyrottes A, Long-Depaquit T, Pradère B, et al. Environmental impact of current endoscopic technology in urological procedures: a systematic review on reusable vs. disposable scopes. World J Urol 2024;43(1). https://doi.org/10.1007/S00345-024-05317-2.
[77] Pitard M, Rouvière N, Leguelinel-Blache G, Chasseigne V. Contribution of hospital pharmacists to sustainable healthcare: a systematic review. Eur J Hosp Pharm 2025;32(2):100–5. https://doi.org/10.1136/EJHPHARM-2024-004098.
[78] Shaw L, Orr N, Lawal HM, et al. Effectiveness of interventions to reduce carbon-emissions within secondary healthcare: systematic review and evidence and gap map. Campbell Syst Rev 2025;21(4):e70077. https://doi.org/10.1002/CL2.70077;ISSUE:ISSUE:DOI.
[79] Van Nieuwenhuizen KE, Michels CTJ, Both I, Guinée JB, Jansen FW. Evidence-based integration of environmental sustainability into clinical guidelines for operating rooms: a systematic review. Ann Surg 2026;283:593–607. https://doi.org/10.1097/SLA.0000000000006756. Published online.
[80] McGushin A, Okokon E, Haddock RE, et al. Interventions to reduce greenhouse gas emissions from health-system solid waste: a systematic review. Lancet Planet Health 2026;10(2):101418. https://doi.org/10.1016/j.lanplh.2025.101418.
[81] Wolf TG, Müßig L, Paulmann K, Lamloum D, Campus G. Green dentistry and sustainability in oral healthcare: a systematic review. Dent J 2026;14(6):377. https://doi.org/10.3390/DJ14060377.
[82] Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008;336(7650):924–6. https://doi.org/10.1136/bmj.39489.470347.ad.
[83] GRADE Book. Accessed February 4, 2026. https://book.gradepro.org/.
[84] Wicklum SC, Nuique K, Kelly MA, Nesbitt CC, Zhang JJ, Svrcek CP. Greening family medicine clinic operations and clinical care, where do we start? A scoping review of toolkits and aids. Fam Pr 2023;40(3):473–85. https://doi.org/10.1093/FAMPRA/CMAD006.
[85] Nunes AR, Karaba F, Geddes O, et al. Implementation of decarbonisation actions in general practice: a systematic review and narrative synthesis. BMJ Open 2025;15(2):e091404. https://doi.org/10.1136/BMJOPEN-2024-091404.
[86] Elements of climate-resilient healthcare. Health care without harm - global. https://global.noharm.org/resources/elements-climate-resilient-healthcare-2023; 2023.
[87] Doubleday A, Errett NA, Ebi KL, Hess JJ. Indicators to guide and monitor climate change adaptation in the US pacific northwest. Am J Public Health 2020;110(2):180–8. https://doi.org/10.2105/AJPH.2019.305403.
[88] ISO 14040. Environmental management — life cycle assessment — principles and framework. https://www.iso.org/standard/37456.html; 2006.
[89] ISO 14044. Environmental management — life cycle assessment — requirements and guidelines. https://www.iso.org/standard/38498.html; 2006.
[90] MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. Lancet Planet Health 2017;1(9):e381–8. https://doi.org/10.1016/S2542-5196(17)30162-6.
[91] Mulier H, Rex S, Teunkens A. Greening the operating room: a narrative review of existing initiatives and future opportunities in anaesthesia. Best Pr Res Clin Anaesthesiol 2024;38(4):372–8. https://doi.org/10.1016/j.bpa.2025.04.003.
[92] Dargent J. Reducing greenhouse gas emissions in a bariatric surgical unit is a complex but feasible project. Sci Rep 2024;14(1):1252. https://doi.org/10.1038/s41598-024-51441-9.
[93] Environmental impact of inhaled anesthetics | greening the operating room and perioperative arena. Accessed February 11, 2026. https://www.asahq.org/about-asa/governance-and-committees/asa-committees/environmental-sustainability/greening-the-operating-room/inhaled-anesthetics.
[94] Caron C, Sajwani S, Bateman K, et al. Environmentally sustainable opportunities for health systems: metered-dose inhaler prescribing, dispensing, usage, and waste at the ottawa hospital. Lancet Planet Health 2024;8:S5. https://doi.org/10.1016/S2542-5196(24)00070-6.
[95] Greener NHS » areas of focus. Accessed February 8, 2026. https://www.england.nhs.uk/greenernhs/a-net-zero-nhs/areas-of-focus/.
[96] Buckley, B.W., MacMahon, P.J. Radiology and the climate crisis: opportunities and challenges—radiology in training. https://doi.org/10.1148/radiol.20212 10851. 2021;300(3):E339-E341. 10.1148/radiol.2021210851.
[97] Dekker HM, Stroomberg GJ, Prokop M. Tackling the increasing contamination of the water supply by iodinated contrast media. Insights Imaging 2022;13(1). https://doi.org/10.1186/s13244-022-01175-x.
[98] Kjelle E, Andersen ER, Krokeide AM, et al. Characterizing and quantifying low-value diagnostic imaging internationally: a scoping review. BMC Med Imaging 2022;22(1):73. https://doi.org/10.1186/s12880-022-00798-2.
[99] Carino S, Porter J, Malekpour S, Collins J. Environmental sustainability of hospital foodservices across the food supply chain: a systematic review. J Acad Nutr Diet 2020;120(5):825–73. https://doi.org/10.1016/j.jand.2020.01.001.
[100] Quantifying Methane Emissions from Landfilled Food Waste | US EPA. Accessed February 5, 2026. https://www.epa.gov/land-research/quantifying-methane-emissions-landfilled-food-waste.
[101] Wasted Food Scale | US EPA. Accessed February 12, 2026. https://www.epa.gov/sustainable-management-food/wasted-food-scale.
[102] Pichler PP, Jaccard IS, Weisz U, Weisz H. International comparison of health care carbon footprints. Environ Res Lett 2019;14(6):064004. https://doi.org/10.1088/1748-9326/ab19e1.

[103] Green surgery – uk health alliance on climate change. Accessed February 5, 2026. https://ukhealthalliance.org/sustainable-healthcare/green-surgery-report/.
[104] Greening the operating room and perioperative arena. Accessed February 5, 2026. https://www.asahq.org/about-asa/governance-and-committees/asa-committees/environmental-sustainability/greening-the-operating-room.
[105] Intensive care society | intensive care environmental sustainability recipe book. Accessed March 10, 2026. https://ics.ac.uk/guidance/sustainability/ic-environmental-sustainability-recipe-book.html.
[106] NHS England » Sustainable procurement. Accessed August 15, 2026. https://www.england.nhs.uk/nhs-commercial/sustainability/?utm_source=chatgpt.com.
[107] Psistaki K, Kouis P, Yiallouros PK, Paschalidou A. Heatwave characteristics and health impacts: a review of epidemiological evidence and implications for heatwave response plans. Environ Res: Health 2025;3(4):042003. https://doi.org/10.1088/2752-5309/ae1861.
[108] Valente M, Del Prete C, Facci G, et al. The impacts of extreme weather events on health services and systems: a systematic review of reviews. Public Health 2026;250:106049. https://doi.org/10.1016/j.puhe.2025.106049.
[109] Wright AKA, Ezugwu CI, Iregbu JK, et al. Climate change and emerging infectious diseases: a global review of shifting patterns, pathogens, and public health risk. Epidemiol Health Data Insights 2025;1(3):ehdi009. https://doi.org/10.63946/ehdi/16744.
[110] (WHO) WHO. Indicators of climate resilience and GHG emissions in health systems. Accessed August 4, 2026, https://www.who.int/publications/m/item/indicators-of-climate-resilience-and-ghg-emissions-in-health-systems; 2026.
[111] Nordberg LB, Pohl H, Haavardsholm EA, Lillegraven S, Bretthauer M. Carbon-footprint analyses in RCTs — toward sustainable clinical practice. N Engl J Med 2024;390(24):2234–6. https://doi.org/10.1056/nejmp2402018.
[112] Petersen JJ, Hemberg L, Thabane L, et al. Integrating environmental outcomes in randomised clinical trials: a call to action. Lancet 2025;405(10477):446–8. https://doi.org/10.1016/S0140-6736(24)02666-7.
[113] Williams JTW, Bell KJL, Morton RL, Dieng M. Methods to include environmental impacts in health economic evaluations and health technology assessments: a scoping review. Value Health 2024;27(6):794–804. https://doi.org/10.1016/j.jval.2024.02.019.
[114] Desterbecq C, Tubeuf S. Inclusion of environmental spillovers in applied economic evaluations of healthcare products. Value Health 2023;26(8):1270–81. https://doi.org/10.1016/j.jval.2023.03.008.
[115] Identifying, measuring and reducing low-value care in the context of health system performance assessment - public health. Accessed February 12, 2026. https://health.ec.europa.eu/publications/identifying-measuring-and-reducing-low-value-care-context-health-system-performance-assessment_en.
[116] Climate change & medical schools | IFMSA. Accessed February 14, 2026. https://ifmsa.org/climate-change-medical-schools/.
[117] Bevan J, Blyth R, Russell B, et al. Planetary health and sustainability teaching in UK medical education: a review of medical school curricula. Med Teach 2023;45(6):623–32. https://doi.org/10.1080/0142159X.2022.2152190.
[118] Luo OD, Carson JJK, Sanderson V, Wu K, Vincent R. Empowering health-care learners to take action towards embedding environmental sustainability into health-care systems. Lancet Planet Health 2021;5(6):e325–6. https://doi.org/10.1016/S2542-5196(21)00059-0.
[119] Iliopoulou K, Leone M, Hunfeld N, et al. Environmental sustainability in intensive care: an international survey of intensive care professionals'views, practices and proposals to the European society of intensive care medicine. J Crit Care 2025;88(3):155079. https://doi.org/10.1016/j.jcrc.2025.155079.
[120] Létourneau S, Roshan A, Kitching GT, et al. Climate change and health in medical school curricula: a national survey of medical students' experiences, attitudes and interests. J Clim Change Health 2023;11(10):100226. https://doi.org/10.1016/j.joclim.2023.100226.
[121] Hampshire K, Ndovu A, Bhambhvani H, Iverson N. Perspectives on climate change in medical school curricula—a survey of U.S. medical students. J Clim Change Health 2021;4(12):100033. https://doi.org/10.1016/j.joclim.2021.100033.
[122] OECD. Rethinking health system performance assessment. Published online 2024. doi:10.1787/107182C8-EN.