Delivering on Commitments to Sustainable Healthcare in Kenya: the role of the healthcare system in mitigating and adapting to climate change.

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Abstract

Climate change poses significant threats to human health through direct impacts, such as extreme weather events, and indirect pathways, including shifting disease patterns, exacerbated mental health challenges, and undernutrition. Healthcare systems, essential for addressing these challenges, paradoxically contribute approximately 5% of global greenhouse gas emissions. This dual role necessitates urgent action to reduce healthcare's environmental footprint while enhancing its resilience to climate-related risks. Integrating mitigation and adaptation strategies within healthcare systems presents opportunities to improve health outcomes, strengthen resilience, and achieve co-benefits such as enhanced energy security and cost savings. The disproportionate impact of climate change on low- and middle-income countries (LMICs) underscores the need for contextually appropriate approaches. Kenya exemplifies ambitious climate leadership with its commitment to achieving a net-zero, resilient healthcare system by 2030.

This thesis explores pathways to transform healthcare systems into sustainable, resilient systems, using Kenya as a case study. It investigates the interactions between mitigation and adaptation strategies, focusing on synergies, co-benefits, conflicts, and trade-offs to inform actionable transformation pathways. The research evaluates global commitments to healthcare system sustainability, synthesises evidence on mitigation interventions in LMICs, and develops policy recommendations tailored to Kenya. It also examines the role of education in empowering health workers as agents of change. Employing a multi-method approach, the study integrates a global policy analysis, a systematic review, stakeholder interviews, a Delphi process, a questionnaire, and a focus group. These methods collectively identify barriers, opportunities, and priorities for action, considering alignment with Kenya's healthcare needs and offering insights applicable to broader contexts.

Unexpected findings from this research challenge prevailing assumptions about climate action in LMICs. In particular, political will and cautious optimism among diverse stakeholders including Kenyan healthcare workers regarding the 2030 net-zero target demonstrate a strong foundation for transformation. These insights suggest that LMICs may offer greater opportunities for climate-health leadership than often recognised by international funders and policymakers.

Evaluation of progress of global commitments to sustainable, resilient healthcare systems reveals inconsistent outcomes, with significant gaps in accountability and data transparency. The policy analysis highlights the risks of greenwashing and emphasises the need for robust, outcome-oriented indicators to track tangible health system transformations. In Kenya's context, the lack of appropriate indicators for healthcare emissions and resilience highlights a critical barrier that must be addressed to sustain momentum and evidence tangible progress over time. Lessons from global efforts, particularly the integration of healthcare into national climate strategies, provide critical insights for Kenya. By addressing

governance, financing, and data challenges, Kenya can lead in implementing sustainable healthcare practices while avoiding emission-intensive models.

The systematic review identifies evidence-based mitigation interventions in LMIC healthcare systems, highlighting potential reductions in emissions through energy solutions, waste management, and operational interventions. Renewable and hybrid energy systems show promise for rural areas, with the potential of addressing both adaptation and mitigation needs. However, gaps in evidence regarding supply chain emissions and long-term outcomes warrant further research.

Stakeholder interviews and a Delphi process in Kenya reveal critical strategic themes, including infrastructure, competing priorities, financial constraints, awareness, and strategic coordination. Findings highlight the tension between immediate healthcare needs and long-term sustainability goals, emphasising the importance of aligning policies with near-term co-benefits, such as cost savings and improved health outcomes. Notably, the Delphi process revealed a conviction among participants regarding the importance of mitigation, indicating that support for climate action is deeply rooted and can be harnessed to accelerate progress. Nevertheless, bridging the gap between strategic ambitions and practical implementation remains an urgent task, particularly through strengthening accountability frameworks and operational planning. Prioritised actions include clean energy implementation, evidence-driven policy development, and local stakeholder engagement.

Health workers are identified as pivotal to achieving Kenya's net-zero healthcare goals. A mixed-methods approach, including a questionnaire and focus group, identifies a broad awareness of climate change's health impacts and the healthcare system's role in emissions reduction. However, limited training, financial constraints, and a disconnect between national policies and local realities hinder their ability to act. Recommendations include co-created educational programs, peer-led workshops, and embedding sustainability modules in curricula. Despite widespread awareness, there is currently no systematic education on sustainable healthcare in Kenya's health workforce training, representing both a critical gap and a major opportunity for embedding climate resilience and sustainability into health education at scale. Education emerges not just as a support tool but as a cornerstone for systemic change, empowering health workers to bridge structural barriers and lead in advancing sustainable practices.

This thesis concludes by emphasising the urgency of transforming healthcare systems to address the interconnected imperatives of health, climate mitigation, and adaptation. It underscores the importance of human agency, cross-sector collaboration, and international financial support in driving this transformation. It also argues that LMICs like Kenya are uniquely positioned to leapfrog high-carbon healthcare development pathways through strategic alignment of mitigation and adaptation, provided that education, data systems, governance structures, and financing mechanisms are strengthened in tandem. By aligning immediate healthcare needs with long-term climate goals, the research provides a roadmap for achieving sustainable and resilient healthcare systems, offering relevant insights for implementation and recommendations for future research.

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Table of Contents

Tables

Figures

Boxes

Table of Abbreviations

Table 1 List of Abbreviations

Abbreviation	Full Form
COP	Conference of Parties
DALY	Disability-Adjusted Life Year
GHG	Greenhouse gas
G7	Group of Seven
G20	Group of Twenty
HICs	High-income countries
HNAP	Health National Adaptation Plan
IPCC	Intergovernmental Panel on Climate Change
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NOx	Nitrogen Oxides
PM	Particulate matter
LMICs	Low- and middle-income countries
LT-LEDS	Long-Term Low Emission Development Strategy
SO2	Sulphur dioxide
UHC	Universal Health Coverage
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

Glossary

Table 2 List of key definitions relevant to sustainable healthcare systems, adapted from Blom et al. 2024 (1)

Concept	Source	Definition
Adaptation	WHO	Adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to the expected climate and its effects. (2)
Climate-resilient health systems	WHO	Those capable 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. (3)
COP26 Health Programme Commitment to Climate resilient health systems	WHO	• Commit to conduct climate change and health vulnerability and adaptation assessments (V&As) at population level and/or health care facility level by a stated target date; • Commit to develop a health National Adaptation Plan (HNAP) informed by the health V&A, which forms part of the National Adaptation Plan (NAP) to be published by a stated target date; • Commit to use the V&A and HNAP to facilitate access to climate change funding for health (e.g. project proposals submitted to the Global Environmental Facility (GEF), Green Climate Fund (GCF) or Adaptation Fund (AF) or GCF Readiness programme). (4)
COP26 Health Programme Commitment to Sustainable, low-carbon health systems	WHO	• Commitment to deliver a baseline assessment of greenhouse gas emissions of the health system (including supply chains) • Commitment to develop an action plan or roadmap by a set date to develop a sustainable low-carbon health system (including supply chains) which also considers human exposure to air pollution and the role the health sector can play in reducing exposure to air pollution through its activities and its actions. (4)
COP26 Health Programme Commitment to net-zero emissions	WHO	• Commitment to set a target date by which to achieve health system net-zero emissions (ideally by 2050). (4)
Environmentally sustainable health systems	WHO	A health system that improves, maintains or restores health, while minimising negative impacts on the environment and leveraging opportunities to restore and improve it, to the benefit of the health and well-being of current and future generations. (5)
Greenwashing	Nemes et al.	Greenwashing is an umbrella term for a variety of misleading communications and practices that intentionally or not, that induce false positive perceptions of an organization, product or service environmental performance. (6)
Health National Adaptation Plan	WHO	Plan led by the Ministry of Health as part of the national adaptation plan (NAP) process. The HNAP sets out a range of actions to address the health impacts of climate change and build climate resilient health systems at all levels of planning. It contributes to comprehensive health adaptation planning to respond to the health risks of climate change. It is based on the best available evidence and is informed by a comprehensive V&A assessment. (2)
Healthcare Systems	WHO	The institutions, people and resources involved in delivering healthcare to individuals. (7)
Health Systems	WHO	Ensemble of all public and private organizations, institutions and resources mandated to improve, maintain or restore health and incorporate disease prevention, health promotion, and efforts to influence other sectors to address health concerns in their policies. (8)

Mitigation	Intergovernmental Panel on Climate Change	A human intervention to reduce emissions or enhance the sinks of greenhouse gases. (9)
National Adaptation Plan	United Nations Environment Programme	The NAP process seeks to identify medium- and long-term adaptation needs, informed by the latest climate science. Once major vulnerabilities to climate change have been identified, the NAP process develops strategies to address them. (10)
Net-zero greenhouse gas emissions	Intergovernmental Panel on Climate Change	The condition in which metric weighted anthropogenic greenhouse gas emissions are balanced by metric-weighted anthropogenic greenhouse gas removals over a specified period. (9)
Low-carbon health systems	WHO	Those capable of implementing transformative strategies towards reducing GHG emissions in their operations, reducing short- and long-term negative impacts on the local and global environment. (3)
Sustainable health systems	Lancet Commission on Sustainable Healthcare	Health systems that provide universal access to appropriate care that optimizes health and wellbeing for today's patients and communities, as well as for future generations, by delivery of care that is needed, wanted, clinically effective, affordable, equitable, responsible in its use of resources, and functioning within planetary boundaries. (1)
Universal Health Coverage	WHO	That all people have access to the full range of quality health services they need, when and where they need them, without financial hardship. (11)
Vulnerability and Adaptation Assessment	WHO	A tool that allows countries to evaluate which populations and specific geographies are most vulnerable to different kinds of health effects from climate change; to identify weaknesses in the systems that should protect them; and to specify interventions to respond. (2)

Chapter 1: Introduction

Climate change is having and is expected to have a profound negative impact on human health through a wide range of direct and indirect pathways (12–18). The direct consequences of climate change include increased frequency and intensity of extreme weather events, such as floods, droughts, wildfires, and heatwaves. These events are exacerbating water scarcity, food insecurity, and triggering changes in the growing seasons, which further aggravate undernutrition and poverty. Indirectly, climate change is increasing the spread of allergens and contributing to changes in the distribution of vector-borne and zoonotic diseases (e.g., malaria, dengue, and other insect-borne illnesses). It is also associated with heightened risks of mental health issues such as depression, anxiety, and stress-related disorders, driven by stress, displacement, migration, and conflict exacerbated by climate-related disruptions (19).

These broad-ranging effects have significant implications for nearly every sector, but healthcare systems are particularly affected in two critical ways. Firstly, climate change will have direct impacts on population health, placing additional strain on health systems already managing existing health challenges. Rising temperatures, changing disease patterns, and increasing disaster-related injuries and illnesses will drive demand for health services. Secondly, climate change will challenge the resilience and capacity of healthcare systems to adequately respond to both existing and emerging health threats. This will be particularly challenging for systems already under pressure due to resource constraints or fragile infrastructure. Conversely, healthcare systems themselves are major contributors to the climate crisis, accounting for a substantial share of global greenhouse gas (GHG) emissions. The systems' significant GHG emissions underscore the need for health systems to reduce their environmental impact by striving toward net-zero GHG emissions. At the same time, healthcare systems must adapt to the inevitable consequences of a warming planet and proactively plan for climate resilience. (20)

A health system is defined by the World Health Organization (WHO) as follows: "A health system consists of all organisations, people and actions whose primary intent is to promote, restore or maintain health" (21). In particular, the healthcare system refers to "the institutions, people and resources involved in delivering healthcare to individuals" (7). These definitions emphasize that healthcare systems are fundamental not only in treating illnesses but also in maintaining and promoting population health. As such, healthcare systems are pivotal in responding to the health impacts of climate change. However, their own operations contribute significantly to the problem, presenting a complex paradox where healthcare must simultaneously address and mitigate climate change.

Healthcare systems, in addition to managing climate-exacerbated health issues, have a substantial environmental footprint. A global assessment found that in 2020, healthcare systems contributed approximately 4.6% of global GHG emissions (17). In some high-income countries (HICs), such as the

United States of America and the Netherlands, more than 5% of the national GHG emissions come from the healthcare system. Across countries that committed to climate action in their healthcare systems, the healthcare system of the United States contributes the highest burden of air pollution, resulting in an estimated annual loss of 470,000 Disability-Adjusted Life Years (DALYs) through exacerbating respiratory and cardiovascular diseases. Japan follows with 140,000 DALYs lost annually (17). In Europe, healthcare systems in Germany (71,000 DALYs), France (29,000 DALYs), and the United Kingdom (46,000 DALYs) also contribute notable burdens of air pollution-related health impacts (17). These figures reflect the pressing need to reduce emissions and associated air pollution, which further strains the healthcare system itself.

An earlier assessment, which examined healthcare systems between 2000 and 2015, detailed that healthcare was responsible for 4.4% of global GHG emissions, along with 2.8% of particulate matter (PM), 3.4% of nitrogen oxides (NOx), and 3.6% of sulphur dioxide (SO_2) emissions (22). These pollutants largely come from the combustion of fossil fuels which are also the main contributor to climate change, creating a feedback loop where healthcare systems, by contributing to pollution, indirectly increase the burden of disease they are required to treat (23,24). Despite growing awareness of the healthcare systems' environmental impact, emissions continue to rise globally (23), highlighting the need for systemic changes to reduce emissions across healthcare operations, energy use, and supply chains.

At the United Nations Framework Convention on Climate Change 26th Conference of Parties (UNFCCC COP26) in November 2021, 14 countries initially committed to reaching net-zero GHG emissions within their health systems, with targets to be achieved between 2030 and 2050 (25). Eleven of these countries were low- and middle-income countries (LMICs), as defined by the World Bank (25,26). Kenya, Indonesia, and Malawi set ambitious targets, committing to achieving net-zero health systems by 2030. These countries, despite their challenges, are leading the way in setting short-term goals for climate mitigation in their healthcare systems.

As of December 2024, 45 countries have committed to achieving net-zero health systems, with 30 LMICs aiming for full net-zero emissions by 2060 at the latest (25). 83 countries have pledged to establish sustainable low-carbon health systems, with 59 of them being LMICs (25). Additionally, the number of countries that have committed to developing climate-resilient health systems has risen to 92, with 66 of these coming from LMICs (25). In June 2022, the Group of Seven (G7) included a net-zero commitment for their health systems by 2050 in their Leaders' Communique (27) followed by the Group of Twenty (G20) launching a roadmap to decarbonising healthcare in 2023 (28).

To bring these commitments to reality, evidence-based mitigation interventions, including specifically in LMICs must be identified, disseminated, implemented and further evaluated. Although LMICs have demonstrated remarkable leadership by setting ambitious targets, the challenge now lies in operationalising these commitments. There are, however, currently few examples of successful healthcare system transformations towards environmental sustainability and resilience in LMICs (29,30). By taking a comprehensive approach including reducing emissions in electricity, travel and the supply chain, there is a unique opportunity for LMICs to advance the healthcare system whilst achieving environmental sustainability. These approaches could also offer the potential for co-benefits, such as reducing air pollution, lowering energy costs, and improving resilience in healthcare infrastructure. (31)

It is critical to recognize that pursuing net-zero targets in healthcare systems LMICs must not be framed as a mechanism to absolve HICs for their historical emissions. Instead, these efforts should be grounded in a context-specific approach that prioritises the expansion of Universal Health Coverage (UHC). For LMICs, achieving UHC remains a paramount challenge. By understanding the potential co-benefits of mitigation and adaptation actions, strategies could aim to support resilience, emissions reduction and immediate healthcare priorities. Benefits extend beyond emissions reduction to include enhanced energy security, improved healthcare resilience, and long-term futureproofing of health systems. By focusing on these tangible, localized outcomes, climate targets can align more closely with the immediate health priorities of LMICs including UHC, ensuring that sustainability efforts contribute directly to improved health outcomes and strengthened system capacities.

The commitment and implementation of LMICs to climate mitigation can help challenge unconscious biases that sometimes devalue research and innovation originating from lower-income countries (32). LMICs are uniquely positioned to lead the global transformation to sustainable healthcare systems, particularly due to their ability to adopt low-emission solutions and leapfrog conventional, high-emission healthcare models. This shift can contribute to reducing inequities in global research recognition, elevating LMICs as influential contributors to solving both health and climate challenges. By synthesising this evidence, it is possible to foster cross-pollination of ideas that elevates the value of research from all regions.

Efforts by healthcare systems to mitigate GHG emissions may also lead to more cost-effective healthcare which can also help to build system resilience. A successful example of increased quality care, cost-effectiveness and reduction of emissions is the 'Aravind Eye Care System' in Southern India that manages to deliver cataract surgery to over 3.8 million patients annually at about 10% of the cost, 10% of the waste and 5% of the carbon emissions as compared to cataract surgery in HICs (33).

Nations worldwide were aiming for no more than 1.5°C global mean temperature increase above pre-industrial levels (34). This target seems no longer within reach and rapid and decisive action with concerted efforts across all sectors is vital to ensure no more than 1.8°C global mean temperature increase. It is essential to note that today many direct effects are already felt and even at the 1.5°C global mean temperature increase, significant health effects would have been faced (15,16,35). LMICs, although historically contributing less to the total global GHG emissions, are expected to experience the most extreme impacts of climate change whilst being the least resilient and least able to afford recovery (36). This underlines the urgency with which healthcare system must adapt and transform into resilient health systems, defined by the WHO as "capable to anticipate, respond to, cope with, recover from and adapt to climate-related shocks and stress, to bring sustained improvements in population health, despite an unstable climate." (37). It is, therefore, vital to consider the interaction of mitigation interventions with those actions taken to adapt to climate change impacts and promote system resilience, and whether synergies can be identified and promoted. Most action in LMICs is correctly around adaptation, especially in those settings with less ability and capacity to react to impacts and mitigate emissions. Even so, successful development of climate vulnerability and adaptation strategies – essential towards informing health system officials for successful health system transformation - requires greater capacity building on all levels (38). There are opportunities in various settings to cut emissions with potential positive implications for future health. Identifying synergies and co-benefits between mitigation and adaptation actions could create significant opportunities for LMICs to adapt their health systems whilst ensuring mitigation of emissions to avoid adverse feedback loop in the future and worsening the climate crisis (31).

To successfully achieve a transformation to sustainable healthcare systems in LMICs further research is needed to investigate what specific actions are required and how these actions interact with efforts to adapt to the impacts from climate change. Throughout this process, knowledge from different contexts, including low- and middle-income contexts, must be bridged since diverse types of experience, opportunity, and progress can provide inspiration and potential multidirectional learning across income and resource levels. In the long-term, overall healthcare system reform including a major shift towards prevention could significantly decrease GHG emissions.

Kenya, in particular, stands out as a leader in this effort due to its central role in the region and its ambitious commitment to achieving net-zero emissions in its healthcare system by 2030 (25). Kenya's leadership and forward-thinking climate policies place it at the forefront of healthcare transformation in LMICs, making it an ideal case study for understanding how climate mitigation and adaptation can be successfully integrated.

In summary, there is increasing recognition and engagement at global levels, such as within the WHO and other key institutions, to develop net-zero healthcare systems. At the same time, these efforts face scepticism, particularly regarding their prioritization amidst pressing healthcare access and development challenges. However, integrating climate mitigation with healthcare system strengthening and climate adaptation offers a unique opportunity to address these concerns and leverage potential synergies. By aligning mitigation efforts with the immediate priorities of improving healthcare access, resilience, and equity, net-zero healthcare systems could support broader development goals. This PhD will respond to this opportunity by investigating the climate mitigation of healthcare systems, with a particular focus on Kenya, and its interactions with adaptation in the context of climate change.

Chapter 2: Background

2.1 Definitions & Key Concepts

The relationship between healthcare systems and climate change is shaped by several interrelated concepts, which are crucial for understanding both mitigation and adaptation strategies within healthcare. These concepts provide the foundation for the analysis of healthcare systems' responses to climate change.

Adaptation is a central concept in the discussion of climate change and health. As defined by the WHO, adaptation involves adjusting to actual or expected changes in climate. In human systems, adaptation seeks to reduce harm or seize opportunities created by shifting environmental conditions (2). Within the healthcare context, adaptation is crucial for ensuring that health systems can cope with the evolving health risks posed by climate change. These risks range from the increasing prevalence of vector-borne diseases to the more frequent occurrence of extreme weather events that strain healthcare infrastructure.

The concept of climate resilience is closely linked to adaptation. The WHO defines climate-resilient health systems as those capable of anticipating, responding to, and recovering from climate-related shocks and stresses, while continuing to deliver essential health services (3). Building such resilience is particularly vital in LMICs, where healthcare systems often face the dual challenges of limited resources and heightened vulnerability to climate-related disasters. The ability of a health system to maintain functionality in the face of climate change is a key component of both public health strategy and climate policy.

As part of the global response to these challenges, the COP26 Health Programme outlined several key aspects to help countries integrate climate resilience into their healthcare systems. Governments committed to conducting vulnerability and adaptation assessments to identify which populations and geographic areas are most at risk from climate change's health impacts. These assessments also form the basis for developing Health National Adaptation Plans (HNAPs), which guide the integration of health into broader national climate adaptation strategies (2). Such commitments are essential for countries, especially LMICs, to access climate funding and implement meaningful health system reforms. (4)

In parallel to adaptation, mitigation - the reduction of GHG emissions—is an equally important objective for healthcare systems. The Intergovernmental Panel on Climate Change (IPCC) Working Group III defines mitigation of climate change as 'a human intervention to reduce emissions or enhance the sinks of greenhouse gases' (39). For healthcare systems, mitigation involves strategies such as reducing energy use, transitioning to renewable energy sources, and minimising waste and emissions throughout healthcare operations and supply chains.

Low-carbon health systems, as defined by the WHO, focus on implementing strategies to significantly reduce GHG emissions from their operations, aiming for reductions that contribute both locally and globally to environmental sustainability (4). More ambitiously, net-zero health systems can be defined as health systems that cut all emissions the health system controls and those it influences across all three emission scopes, including operations, energy and supply chains, and finally offset remaining emissions that cannot be cut (40). The IPCC Working Group III defines net-zero GHG emissions as 'the condition in which metric weighted anthropogenic GHG emissions are balanced by metric-weighted anthropogenic GHG removals over a specified period', where in practice natural systems are taking up less CO2 emissions which will imply that anthropogenic emissions need to be reduced to zero or close to zero and that short lived climate pollutants such as methane also need to be addressed (39).

Beyond the direct scope of their operations, acting across the other two scopes provide significant potential for healthcare systems' to be able to lever a wider impact across sectors through actions and decisions impacting their energy and supply chains related to buildings, transport, energy and food procurement (20). Further, committing to a net-zero health system might enable health workers to more strongly catalyse wider change in moving the broader economy towards net-zero through advocating with local and national governments. Countries that committed to net-zero health systems during COP26 agreed to set a target date by which they would achieve this goal across all healthcare-related emissions (4), although a WHO definition tied to the commitment is lacking.

The broader ambition of creating environmentally sustainable health systems goes beyond just reducing emissions. The WHO describes environmentally sustainable health systems as those that not only minimize harm to the environment but also contribute to its restoration and improvement (5). Overarching, sustainable healthcare systems improve population health without exceeding planetary boundaries, and they seek to deliver equitable, effective, and affordable care for both current and future generations (41). In this context, sustainable healthcare systems represent a vision of healthcare that is both resilient to climate change and actively contributing to its mitigation.

However, in pursuing these goals, there is a risk of greenwashing, a term used to describe misleading claims about environmental sustainability (6). In the context of healthcare, greenwashing can manifest when healthcare systems or institutions claim to be reducing emissions or becoming more sustainable without making meaningful changes to their operations. Ensuring transparency and accountability in healthcare climate commitments through independent research is therefore crucial for avoiding such pitfalls and ensuring that efforts truly contribute to environmental and health goals.

2.2 Sustainable UHC in LMICs

LMICs face unique challenges in their pursuit of sustainable healthcare systems amidst increasing climate pressures and the imperative to expand UHC. While healthcare systems globally have started addressing both climate mitigation and adaptation, the literature reveals that LMICs are both leading and lagging in different aspects of this effort (31). On the one hand, the urgency of the climate crisis has spurred innovative practices in resource-constrained settings; on the other hand, the scale of these innovations is often limited by systemic challenges, including financial constraints, infrastructural vulnerabilities, and the lack of benchmarking and accounting for progress year on year.

One major area of focus has been the development of climate-resilient health systems. The WHO Operational framework for building climate resilient and low carbon health systems has laid out extensive guidelines for building these systems, emphasising that health systems must remain operational under the strain of climate-related disruptions. This framework particularly underscores the necessity for "climate-transformative" governance, workforce development, and integrated health service delivery in building climate-resilient infrastructures in LMICs (3).

At the same time, climate mitigation - aiming to reduce healthcare's contribution to GHG emissions - has been a growing area of research. The healthcare sector globally contributes around 5% of total GHG emissions, but LMICs have a much lower per capita emission than high-income countries (17). However, as these countries develop, their emissions from healthcare are expected to rise unless proactive steps are taken to build low-emission health systems (31). Imposing net-zero frameworks in LMICs risks shifting the responsibility for global emissions reduction disproportionately onto countries with historically lower contributions to climate change. Therefore, these frameworks need to be appropriately contextualized, offering significant opportunities for LMICs to simultaneously address pressing healthcare challenges and advance sustainability goals. In particular, framing net-zero targets around other benefits - such as resilience-building, energy security, and reductions in air pollution - provides a pathway to align climate action with immediate health priorities in LMICs.

The WHO's guidance highlights the role of sustainable infrastructure, energy efficiency, and procurement policies in reducing emissions from healthcare services (3,42). Successful examples in LMICs show the potential of climate mitigation in healthcare through renewable energy solutions, such as solar-powered hospitals in rural settings, which simultaneously improve service delivery and cut emissions.

However, the literature also points to significant barriers. Many LMICs still lack the technical capacity and financial resources to implement large-scale mitigation initiatives (31). For example, while there is growing interest in reducing emissions from the healthcare supply chain, many LMICs depend heavily on imported medical goods and technologies from countries with higher carbon footprints. Moreover, the current healthcare infrastructure in LMICs is often not resilient enough to withstand both climate shocks and increased patient loads during extreme weather events, further complicating the implementation of sustainable practices. In addition to financial and infrastructural challenges, healthcare system transitions in

LMICs could encounter "soft" system barriers such as limited awareness and engagement among healthcare staff, insufficient cross-sector dialogue, and inadequate institutional support for change (43).

Despite these challenges, LMICs present unique opportunities for implementing low-emission healthcare strategies. The healthcare systems in these regions can leapfrog traditional carbon-intensive practices through the adoption of context-appropriate, low-emission technologies. Furthermore, the literature consistently highlights the co-benefits of mitigation and adaptation efforts in LMICs. Interventions aimed at reducing emissions, such as cleaner energy sources and efficient waste management systems, can directly improve public health outcomes by reducing air pollution and minimising disease transmission in healthcare settings. Synergies and co-benefits between climate and health outcomes are critical in contexts where healthcare systems are stretched thin and are highly vulnerable to environmental stresses (31,37). Importantly, Appendix I brings attention to the need for national policies to strike a contextual balance between these twin goals of mitigation and adaptation while leveraging both bottom-up and top-down approaches to policy implementation (44).

While research into sustainable healthcare systems is growing, there remains a need for comprehensive studies that evaluate the effectiveness of different interventions in these settings. Much of the current literature focuses on small-scale pilot programs in HICs, leaving gaps in understanding relevance in different contexts and how to scale these initiatives to national levels.

2.3 Conceptual Framework

Building on the foundation of sustainable healthcare in LMICs, it is essential to utilize a structured conceptual framework to guide the integration of climate mitigation and adaptation interventions within healthcare systems. This framework, presented in Blom et al. 2024 and detailed in Annex VII.ii (45), adapted from Rasheed et al. (31), centrally considers climate mitigation of healthcare systems and its interaction with adaptation to climate-related impacts, specifically in LMIC contexts. In shaping the approach to building a sustainable healthcare system, the conceptual framework recognizes that healthcare systems' sustainability efforts will only be meaningful if they are based on robust, comparable data, as emphasized in Appendix II (46).

The problem statement that guides this framework is that climate change affects health systems both as a direct source of risk and indirectly through its contributions to public health burdens. Simultaneously, healthcare systems themselves are significant contributors to GHG emissions. This creates an inherent paradox in which health systems, tasked with safeguarding human health, are also exacerbating climate change, leading to more health crises. The conceptual framework frames this paradox by addressing both the emissions of healthcare systems and related climate change vulnerability considerations in LMICs. This approach supports that mitigation and adaptation are pursued together, rather than as separate or conflicting objectives.

Impact and Aim

The central impact of the conceptual framework is to reduce GHG emissions in healthcare systems in LMICs while enhancing their climate resilience. It builds on the premise that healthcare systems in LMIC have the opportunity to integrate mitigation and adaptation as synergistic strategies rather than treating them as independent or conflicting objectives. While the global emphasis on net-zero targets often raises scepticism about their applicability to LMIC contexts, this framework repositions mitigation as a driver of resilience, adaptation, and energy security if approached appropriately. The framework acknowledges the historical inequities in climate contributions and solutions, emphasising that mitigation efforts in LMICs should not be framed as an obligation to compensate for inaction in HICs but as opportunities for advancing health system resilience, understanding that context-specific mitigation strategies can unlock broader socio-economic benefits, such as cost savings and health improvements, while inspiring global shifts toward equity-driven climate action. The framework posits that by implementing targeted interventions, healthcare systems in these settings can:

1. Transform toward more sustainable, low-emission healthcare, thus contributing less to climate change.
2. Achieve multiple benefits (or "co-benefits" depending on the primary purpose) with adaptation interventions, thereby reducing climate risks for health.
3. Act as change agents, indirectly fostering broader national and international climate action.

This conceptual model highlights the importance of both delivery assumptions and effects assumptions. The delivery assumptions include the availability of relevant mitigation interventions, the political will of policymakers, and the necessary resources and capacities to implement changes. On the other hand, the effects assumptions posit that these interventions can lead to improved health outcomes, adaptation synergies, and increased awareness that can drive more comprehensive climate actions across sectors.

Process and Outcomes

The framework organizes mitigation efforts across the three scopes of emissions, each corresponding to different scopes of emissions, alongside a key focus on the potential co-benefits or synergies with adaptation:

1. Scope 1: Healthcare operations (e.g., direct fuel consumption on site).
2. Scope 2: Emissions associated with the energy used by healthcare facilities (e.g., electricity from the grid, often dependent on fossil fuel sources).

3. Scope 3: Emissions from the production and transportation of healthcare-related products and services.

For each category, the framework proposes interventions to reduce emissions, improve energy efficiency, promote the use of renewables, and create incentives for adopting low-emission technologies. Examples include:

- Energy Efficiency: Transitioning to energy-efficient technologies such as LED lighting in healthcare facilities and using renewable energy sources like solar power for rural hospitals.
- Sustainable Procurement: Requiring suppliers to meet environmental standards, such as providing low-emission medical products, or using plant-based, locally sourced food in hospital cafeterias.
- Digital Health Solutions: Promoting teleconsultations to reduce patient travel and thus lower emissions from healthcare-related transport.

These emissions-reduction strategies are also intended to contribute to adaptation co-benefits. For example, by building energy-efficient infrastructure, healthcare systems not only lower their GHG emissions but also become more resilient to climate-related energy disruptions. Similarly, by promoting active transportation (e.g., walking and cycling), systems reduce air pollution and GHG emissions while simultaneously promoting healthier lifestyles providing the risk of road injury is not increased.

Theory of Change

The framework is based on a theory of change that envisions healthcare systems transforming through iterative steps of adaptation and mitigation. It recognizes that the healthcare system can serve as a powerful catalyst for broader societal change by advocating for and exemplifying sustainable practices. The theory highlights the dynamic nature of the healthcare system's role in addressing climate challenges, allowing for a living document approach in which interventions are continuously refined based on emerging evidence and feedback from LMIC experiences.

Potential Risks and Unintended Consequences

A critical aspect of the framework is acknowledging the potential unintended consequences of prioritising mitigation over adaptation, especially in resource-constrained settings where the immediate need for adaptation is pressing. The framework cautions against overemphasising GHG reduction at the cost of compromising urgent adaptation needs, such as improving healthcare infrastructure to withstand extreme weather events.

Overall, this conceptual framework presents a comprehensive and dynamic model for integrating climate mitigation and adaptation in healthcare systems, especially in LMICs. By linking emissions reduction with health resilience, the framework aims to offer a direction of thinking towards sustainable, climate-responsive healthcare that aligns with global climate goals while safeguarding public health. (45)

2.4 Kenya's Climate and Health Policy Context

Having established the broader conceptual framework for integrating climate mitigation and adaptation within healthcare systems, it is essential to examine how this framework is applied in specific contexts. Kenya serves as an important case study for understanding the dynamics of implementing sustainable healthcare practices in LMICs. With its ambitious climate goals, Kenya is not only tackling the direct impacts of climate change on public health but also striving to reduce the environmental footprint of its healthcare system (25).

Kenya is a lower-middle-income country with a diverse healthcare landscape that includes public, private, faith-based, and NGO-operated facilities (26). The country faces significant healthcare challenges, including a low doctor-to-patient ratio, disparities in healthcare access, and limited per capita healthcare spending (47). Despite these constraints, Kenya has made remarkable progress in creating policy around the intersecting challenges of climate change and health.

Kenya's policy framework is deeply rooted in its response to climate change, starting with the National Climate Change Response Strategy (2010) and followed by the National Climate Change Action Plan in 2013 (48,49). These documents provided the foundation for Kenya's climate resilience and sustainability efforts and have since been updated to reflect the evolving landscape of climate risk and adaptation. In 2016, the National Adaptation Plan (NAP) and the Climate Change Act further solidified Kenya's commitment to mainstreaming climate change across all sectors, including healthcare (50,51).

A major milestone in Kenya's climate-health paper journey was its commitment to achieving a net-zero emissions healthcare system by 2030 as part of the UNFCCC COP26 Health Programme (25). This pledge aligns with Kenya's broader national climate goals, as outlined in its Nationally Determined Contribution (NDC), which targets a 32% reduction in GHG emissions by 2030 (52). In response to these commitments, the Climate Change and Health Strategic Working Group was established by the Ministry of Health in 2017. Kenya's leadership in climate policy is underpinned by a commitment to harmonising climate mitigation, adaptation, and healthcare delivery, positioning the country at the forefront of global climate action in the health system.

Moreover, Kenya's ambition is reinforced by its engagement with global initiatives and partnerships. The country has worked closely with international organizations such as the WHO, the World Bank, and the Aga Khan Development Network to secure support for its climate-health agenda. Kenya's collaboration with these organizations has been critical in advancing its commitment to a net-zero healthcare system and securing resources for implementation (53)(Appendix X). The country's Long-Term Low Emission Development Strategy (LT-LEDS), submitted to the UNFCCC in 2023, envisions a net-zero future by 2050 (54). Through these policy instruments, Kenya aims to build a sustainable, resilient healthcare system that not only reduces its emissions but also improves health outcomes, particularly in vulnerable communities affected by climate change.

2.5 Kenya's Climate Vulnerability

Kenya's diverse topography and reliance on natural resources make it highly vulnerable to the effects of climate change, with serious implications for public health. As climate patterns shift, the country faces an increasing burden of climate-sensitive health outcomes, from vector-borne diseases to undernutrition. Understanding these vulnerabilities is essential for designing sustainable, climate-resilient healthcare systems, particularly in the context of the country's commitment to net-zero emissions by 2030.

To gain a better understanding of Kenya's climate-sensitive health outcomes, a scoping review was conducted (Appendix III) that examined the relationship between environmental exposures and health outcomes from 2000 to 2023 (55). The review used a rigorous two-stage screening process across nine bibliographic databases, eventually including 353 relevant studies. The focus of the review was on environmental exposures such as temperature, rainfall, and air quality, and their associated health impacts.

Key Climate-Sensitive Health Outcomes in Kenya

Vector-Borne Diseases

Climate variability in Kenya has a significant impact on the spread of vector-borne diseases, particularly malaria. Rising temperatures and changes in precipitation patterns create favourable conditions for the growth and spread of mosquito populations, particularly in the Lake Victoria Basin and Rift Valley regions. Malaria remains the most studied vector-borne disease in Kenya, and its incidence is closely tied to seasonal and geographic variations in climate. Other vector-borne diseases such as dengue and Rift Valley fever are also influenced by shifting environmental conditions, although they are less frequently studied. (55)

Waterborne Diseases and Water Access Disorders

Changes in rainfall patterns, especially increased frequency of floods and droughts, have exacerbated waterborne diseases such as cholera and diarrhoea. These diseases are particularly prevalent in regions affected by extreme weather events, where access to clean water is disrupted. In the coastal regions and parts of the Rift Valley, waterborne diseases pose a serious public health threat during periods of heavy rainfall and flooding, as well as during prolonged droughts when water scarcity leads to contamination of available sources. (55)

Undernutrition and Food Security

Droughts and unpredictable rainfall patterns in Kenya's northern and arid regions have had a large impact on food security. Undernutrition, particularly among children, is a growing concern in these regions, where agricultural productivity is severely affected by climatic stress. As food scarcity worsens, undernutrition rates increase, leading to long-term health consequences, especially for vulnerable populations such as infants and pregnant women. (55)

Heat Exposure and Respiratory Disorders

Rising temperatures, particularly in certain urban areas, are contributing to an increase in heat-related illnesses and exacerbating respiratory conditions. Air pollution, combined with higher temperatures, creates an environment where respiratory disorders, including asthma and chronic obstructive pulmonary disease, are more likely to occur. While studies on heat-related health outcomes are relatively scarce in Kenya, the scoping review highlights this as an area of growing concern, especially as urbanization accelerates. (55)

Broader Implications for Health Resilience

The findings from this scoping review illustrate the complex interactions between climate change and health outcomes in Kenya. As the country continues to experience increasingly extreme weather patterns, the vulnerability of its healthcare system to climate shocks becomes more evident. Regions such as the northern arid and semi-arid lands, which are home to some of Kenya's most marginalized communities, face heightened risks due to their reliance on natural resources and limited access to healthcare. In these regions, food insecurity, waterborne diseases, and vector-borne diseases are likely to worsen as climate change progresses. (55)

By furthering understanding the localized impacts of climate change, policymakers can prioritize climate adaptation measures that address the most urgent health risks. While the scoping review provides valuable insights into Kenya's climate-sensitive health outcomes, it is by no means a comprehensive account of the full spectrum of health impacts related to climate change in the country. Nevertheless, the evidence highlights key vulnerabilities - particularly in vector-borne and waterborne diseases, undernutrition, and heat-related illnesses - that must be addressed to build a more climate-resilient healthcare system.

Chapter 3: Aim and Objectives

3.1 Aim

This thesis addresses the critical challenge of transforming healthcare systems into sustainable, resilient systems, with a focus on Kenya. The research explores the interactions between climate mitigation and adaptation strategies, identifying synergies, co-benefits, conflicts, and trade-offs. The aim is to provide deeper understanding of how climate mitigation interventions can be effectively implemented in the Kenyan healthcare system while contributing towards a resilient healthcare system through exploring the following questions:

1. How can healthcare system climate mitigation be achieved across operations, energy, and supply chains (scope 1-3) in Kenya?
2. How do mitigation strategies interact with adaptation efforts, and what potential synergies, co-benefits, conflicts, or trade-offs exist between these actions?
3. What are the effective pathways and roles of various stakeholders, including specifically healthcare workers, in implementation of the healthcare system transformation to achieve sustainable and resilient healthcare in Kenya?

By identifying the gaps and opportunities in progress under the COP26 Health Programme, these questions seek to explore how LMICs like Kenya avoid replicating emissions-intensive healthcare models and instead chart a path that delivers increased access to quality care, resilience, cost savings, and energy security alongside emissions reductions. By addressing these questions, this thesis aims to offer insights into evidence-based pathways that inform strategies for integrating climate mitigation and adaptation within the healthcare system.

3.2 Objectives

This thesis is structured around four main objectives, each tied to specific research questions. These objectives guide the progression of the research, leading to a deeper understanding of climate mitigation in healthcare systems, with a particular focus on Kenya. Table 3 provides an overview of the objectives, research questions, and the knowledge gained for each.

Table 3 Overview of objectives, research questions and knowledge gained per objective.

Objectives	Research Questions	Knowledge Gained
1. Evaluate the current indicators and accountability mechanisms for tracking progress in sustainable, low-carbon, and resilient healthcare systems globally, as part of the COP26 Health	1. What is the current progress towards sustainable healthcare systems per the COP26 Health Programme global commitments?	A detailed analysis of global progress in developing low-carbon and climate-resilient healthcare systems under COP26 commitments, highlighting gaps in accountability and measurement.
	2. What gaps in data and evidence exist that limit progress and understanding of progress toward sustainable healthcare systems?	

Objectives	Research Questions	Knowledge Gained
Programme, to identify insights that can guide climate mitigation efforts in Kenya.	3. How can the lessons learned from global efforts be applied to improve healthcare system's transformation?	
2. Identify all relevant peer-reviewed literature on GHG mitigation interventions in healthcare systems in LMICs to inform pathways towards net-zero healthcare systems.	1. What is the evidence on interventions towards climate mitigation in healthcare systems in LMICs?	An overview of existing evidence and gaps of interventions towards healthcare system mitigation in low- and middle-income countries, including their impact and context.
	2. What are practical or theoretical examples of mitigation interventions across healthcare operations, energy, and supply chains towards GHG mitigation in the context of LMICs?	Conceptual framework of GHG mitigation in healthcare systems in LMICs was expanded based on findings.
	3. How do these interventions interact with actions contributing to climate change adaptation, including through potential synergies, co-benefits, conflicts, or trade-offs?	
	4. How do these interventions vary contextually and what aspects are applicable across different contexts?	
3. Develop policy recommendations based on a qualitative overview and understanding of barriers and opportunities related to the pathway towards a net-zero healthcare system in Kenya, including a prioritization of actions.	1. In Kenya which GHG mitigation interventions in the healthcare system are designed, planned, implemented, and/or evaluated and how is this done? Which are most important? Which are most feasible?	An overview of current efforts in Kenya is created and gaps are identified. A prioritization of most important and most feasible next actions is presented.
	2. What opportunities are identified and what barriers are faced and how have these been, or can these be overcome?	Opportunities, challenges, and barriers are better understood, including approaches to them.
	3. What stakeholders are important to get to a net-zero healthcare system in Kenya?	A further understanding of the integration of adaptation within mitigation interventions is gained.
	4. How do the interventions consider and/or interact with adaptation?	
4. An exploration of the role of education for the healthcare workforce in Kenya to enhance their understanding of climate change's health impacts and empower them to implement effective interventions in their practice.	1. What specific climate change knowledge do (different types of) health workers in Kenya need to effectively build sustainable and resilient healthcare?	Identification of specific knowledge gaps and learning needs concerning climate change and health among health workers.
	2. Which educational components are needed for enhancing health workers' capabilities in climate change mitigation and adaptation?	Insights into the components necessary for effective education for health workers on climate change.
	3. How can existing policies and frameworks be leveraged to support the integration of climate change education into healthcare professional development?	Exploration of alignment of climate change education with existing policies and frameworks.

3.3 Role of the Candidate

As the principal investigator of this research, I played a central role in conceptualising, designing, and executing the study. My responsibilities included developing the research framework, designing the methodology, and conducting data collection, which involved reviewing global and national literature, gathering qualitative data through stakeholder interviews, facilitating a workshop with stakeholders in Kenya, coordinating outreach of a questionnaire, and holding a focus group with Kenyan health workers. I led the analysis and interpretation of the results, integrating findings from multiple sources to formulate policy recommendations. In addition to the research activities, I was responsible for writing all drafts of the manuscripts and this thesis, with the support and guidance of my supervisory team, my advisory committee and partners. I also actively engaged with key stakeholders, including Kenyan policymakers, health workers, and international experts, to ensure the research remained contextually relevant and had practical implications for the Kenyan healthcare system's transformation.

3.3.1 Reflections on Researcher Positionality and Background

As a researcher and medical doctor from the Global North, I recognize that my perspective and background may shape both the approach to this research and its interpretation. While my training has equipped me with the tools to investigate healthcare systems and climate change, I acknowledge the inherent differences in healthcare priorities, systems, and challenges between high-income settings and middle-income countries like Kenya. These differences necessitated a conscious effort to adopt an inclusive, locally informed lens throughout the research process.

Collaborations with Kenyan institutions and stakeholders were foundational to ensuring that this research was grounded in local realities and aligned with national priorities. Partnerships with the Ministry of Health in Kenya, the University of Eldoret, the Eastern Africa Planetary Health Hub, and the Kenyan Medical Association played a critical role in contextualising the research framework and developing relevant recommendations. Through these collaborations, I was able to integrate Kenyan expertise and experiences into the study, mitigating the risk of external perspectives overshadowing local needs and priorities.

However, I also acknowledge the structural dynamics and power imbalances that often accompany research led by Global North scholars in LMICs. These dynamics can inadvertently shape research questions, methodologies, and interpretations of findings. While the partnerships established in this study sought to address these concerns, the conditions of funding, access, and collaboration inevitably create considerations for how the findings are interpreted. For example, the emphasis on net-zero healthcare systems reflects a global agenda that may not fully align with the immediate priorities of all stakeholders in Kenya, such as healthcare access and infrastructure development. This underscores the importance of framing mitigation strategies as tools for advancing resilience, energy security, and co-benefits, rather than as obligations to meet global targets.

Throughout this process, I strived to balance my positionality by fostering dialogue, centring Kenyan voices in data collection and analysis, and critically reflecting on the implications of my own perspective. This approach aimed to ensure that the findings are both scientifically robust and contextually meaningful.

Nevertheless, the interpretation of this thesis should consider the influence of my background as a researcher from the Global North and the conditions under which the study was conducted. Such considerations are critical to advancing equitable research practices and ensuring that this work contributes meaningfully to Kenya's journey toward a sustainable, climate-resilient healthcare system.

3.4 Collaborating Institutions

This research was conducted in close collaboration with several key institutions that provided vital support and expertise throughout the project. The Ministry of Health in Kenya played a crucial role by facilitating access to national health data and providing insights into ongoing healthcare and climate initiatives. Additionally, the University of Eldoret, the Eastern Africa Planetary Health Hub, and the Africa Community of Planetary Partners for Health and Environment were instrumental in providing local research capacity and expertise on climate change and health systems in the region. The Kenyan Medical Association supported outreach efforts and connected the research with health workers, enhancing the practical relevance of the study's findings. The Commissioners of The Lancet Commission on Sustainable Healthcare supported global contextualisation. A large number of individuals and organizations supported and engaged as participants of the qualitative research projects. These collaborations were essential to ensuring the research was contextually grounded, scientifically robust, and aligned with national and regional health priorities.

3.5 Funding

Four grants partially supported this PhD: The first grant was from the Prince Bernhard Culture Fund with grant number 40037327 awarded on the 15th of September 2021. The second grant was from Stichting VSBFonds with grant number VSB.21/00168 awarded on the 17th of May 2021. The third grant was from the Stichting dr Hendrik Muller's Vaderlandsch Fonds without grant number which was awarded on the 9th of December 2021. The fourth grant was a Doctoral Project Traveling Scholarship which was awarded on the 28th of June 2023 by the London School of Hygiene & Tropical Medicine in support of the Candidate's travel to Kenya.

Chapter 4: Methods

4.1 Overview of Methods

This chapter provides an in-depth explanation of the methods employed to achieve the four objectives of this PhD, which collectively address the urgent challenge of climate mitigation and adaptation in healthcare systems, with a particular focus on Kenya. The overall approach is designed to systematically investigate global progress in sustainable and resilient healthcare systems, identify relevant interventions, and assess Kenya's specific pathways toward achieving a net-zero, resilient healthcare system. The interconnected nature of these objectives ensures that findings from one phase directly inform subsequent research steps.

Figure 1 illustrates how the methods for each objective are linked, creating a cohesive methodological framework that integrates insights from global policy landscapes, a systematic literature review, and localised, context-specific data from Kenya. Each method supports the overall aim of this research: to identify and evaluate climate mitigation interventions across healthcare operations (Scope 1), energy use (Scope 2), and supply chains (Scope 3), assess their interactions with adaptation strategies in Kenya, and explore their implementation towards transforming the healthcare system. This thesis considers the framing of mitigation strategies not as externally imposed obligations but as opportunities to strengthen healthcare systems in ways that resonate with local needs. By exploring potential benefits - such as enhanced energy security, cost savings, and improved health outcomes - this work reframes the pursuit of sustainable healthcare systems as a pathway to greater resilience and equity. This framing is especially critical for LMICs like Kenya, where healthcare transformation must align with immediate service delivery priorities while building long-term climate resilience. The methodological approach was designed to explore these synergies and ensure that mitigation strategies are positioned as tools for addressing Kenya's healthcare challenges rather than as obligations to meet global targets or competing priorities.

The first two objectives focus on understanding the international landscape of sustainable and resilient healthcare systems and synthesising global evidence on GHG mitigation interventions, particularly in LMICs, and their interaction with adaptation. The methods for these objectives include an analysis of global commitments from the COP26 Health Programme and a systematic review of peer-reviewed literature.

The third objective shifts to the Kenyan context, employing qualitative research methods to gather in-depth insights from stakeholders within Kenya's healthcare system. Semi-structured interviews, combined with a Delphi process, are used to prioritise GHG mitigation interventions and understand the barriers and opportunities for implementing these interventions in Kenya.

Finally, the fourth objective focuses on exploring role of health workers in Kenya in the transformation of the healthcare system. This objective is achieved through a questionnaire and a focus group amongst a range of health workers to assess knowledge and identify needs for integrating sustainability and resilience into healthcare practices.

While recognizing the importance of situating healthcare systems within the broader context of planetary health including a broad environmental footprint beyond GHG emissions, this thesis narrows its focus to healthcare systems and climate change. This specificity reflects the time-bound nature of this PhD and the aim to align with actionable priorities. Healthcare systems serve as a concentrated domain where measurable interventions can address significant greenhouse gas emissions and enhance climate resilience. Furthermore, this focus supports global initiatives, such as the COP26 Health Programme, by providing directly applicable findings that contribute to the transformation of healthcare systems into sustainable, low-carbon, and climate-resilient systems.

Each of the subsequent sections will describe the methods for each specific objective in more detail.

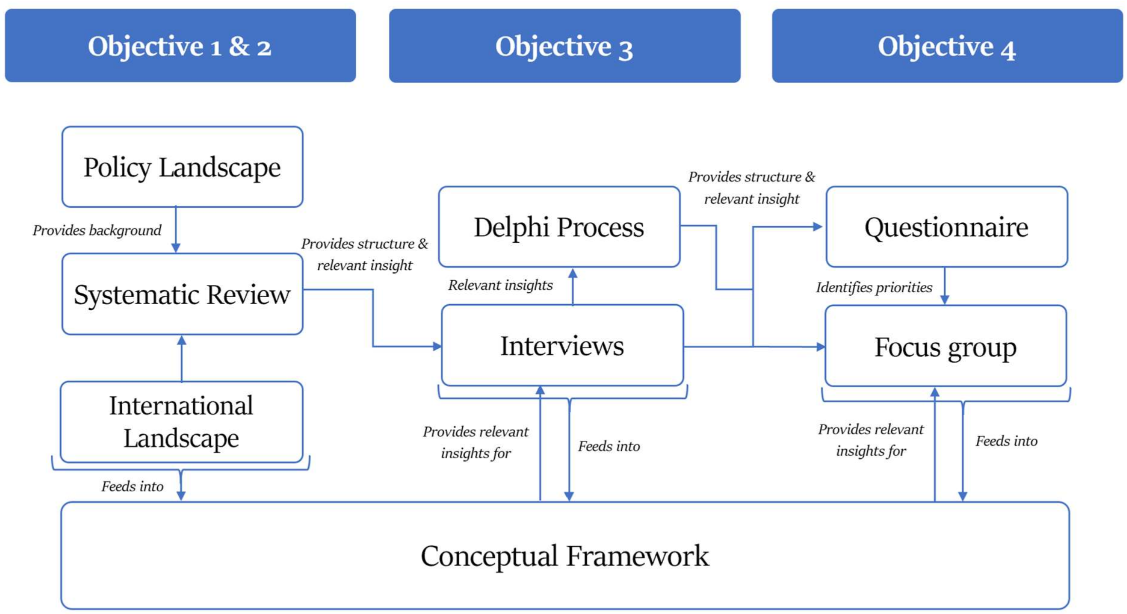

Figure 1 Overview of methods per objective of this thesis including the connections between each phase.

4.2 Methods for Objective 1

The first objective of this PhD focuses on evaluating the global progress toward sustainable healthcare systems under the COP26 Health Programme, particularly to derive insights that can inform Kenya's pathway to net-zero healthcare. This objective aligns with the broader research framework by contributing to an understanding of global trends, challenges, and gaps in data and accountability mechanisms, which can be directly applied to Kenya's healthcare system context.

To achieve this, a multi-step approach was employed, involving the systematic collection and analysis of publicly available data from international databases. The overarching goal was to assess the progress of

COP26 Health Programme signatory countries in achieving climate-resilient, sustainable, and net-zero healthcare systems, as well as to identify gaps in existing indicators and data that are relevant for tracking such progress.

Data Collection and Indicator Assessment

A comprehensive review of COP26 Health Programme country commitments, using publicly available data on the WHO website, was first conducted. These commitments were categorized into three distinct types as defined by the COP26 Health Programme: climate-resilient healthcare systems, sustainable low-carbon healthcare systems, and net-zero healthcare systems.

A review of both WHO-proposed indicators and other internationally available indicators was conducted to assess global progress. Indicators were evaluated based on their relevance to healthcare system sustainability and resilience, public data availability, and the quantifiability of their measurements. This involved extracting data from several global databases, such as the WHO Global Health Observatory, the WHO Global Health Expenditure Database, and the Lancet Countdown on Health and Climate Change, among others.

The extracted data from these sources were thematically grouped to align with the four areas relevant to sustainable healthcare systems: resilience, sustainability, finances, and governance. These four thematic areas were identified through a two-step process. Initially, the first two areas were derived directly from the types of commitments made under the COP26 Health Programme, which focus on the development of climate-resilient and sustainable, low-carbon healthcare systems. However, recognising that these two categories alone did not fully encompass the broader ambitions of the Paris Agreement or the realities of implementing systemic transformation, the analysis was intentionally expanded. Two additional areas were included: financial resources, to reflect the priorities identified by the ATACH working group on financing, and governance, to capture healthcare system integration into national climate strategies and broader governance mechanisms. This thematic grouping ensured that the data was directly applicable to Kenya's healthcare context by suggesting where gaps in progress or data exist globally, and how Kenya might address these through policy development or targeted interventions.

The methods for this objective provide essential background for understanding the international landscape of sustainable healthcare systems, which directly informs the strategies and policy recommendations to be developed for Kenya. These methods also acknowledge the need to frame global commitments like those under the COP26 Health Programme in terms of their local relevance and practical benefits. By identifying gaps in global accountability mechanisms, this thesis highlights opportunities for Kenya to define its leadership in climate-health action through approaches that prioritize resilience, health equity, and sustainable development.

4.3 Methods for Objective 2

Objective 2 is designed to systematically review and analyse evidence-based climate mitigation interventions in healthcare systems across LMICs. As part of the overall thesis, this objective is critical in identifying interventions that can reduce the healthcare system's emissions while considering specific contexts.

Given the complexity and breadth of this research, a detailed protocol for the systematic review has been published and peer-reviewed in Wellcome Open Research (Chapter 6.4). The protocol outlines a comprehensive strategy for identifying, extracting, and synthesising data from peer-reviewed literature on healthcare GHG mitigation interventions in LMICs.

The systematic review is a foundational component of this thesis as it directly addresses the gap in knowledge regarding evidence-based interventions that LMIC healthcare systems can implement to mitigate their GHG emissions. The review focuses on interventions targeting scope 1 (healthcare operations), scope 2 (energy from the grid), and scope 3 (supply chains), providing a structured evaluation of their effectiveness in reducing emissions.

As part of the data extraction, it is noted if and how the articles considered linkages with adaptation of the mitigation actions. The importance of considering dimensions beyond mitigation has been recognised in the literature to understand and prioritize potential co-benefits or avoid conflicts (56). Mitigation aims to reduce emissions, while adaptation is meant to reduce the effects of climate change. Specifically, many researchers have suggested that recognising and addressing interlinkages between mitigation and adaptation is vital in national climate policies to ensure a systematic and effective response (57–63). Historically, most funding available for climate policies has been allotted to mitigation efforts without consideration of adaption (62). Table 4 illustrates differences between adaptation and mitigation across different domains, as adapted from Grafakos et al. and Dang et al. (62,64).

Table 4 Mitigation and adaptation differences in policies as adapted from Grafakos et al. and Dang et al. (62,64)

	Mitigation policy	**Adaptation policy**
Sectoral focus	All sectors can reduce GHG emissions	Selected ones related to particular climate impacts
Geographical scale of effect	Global	Local, regional
Temporal scale of effect	Long term	Short to medium term
Level of governance	International, national	Regional, local
Effectiveness	Relatively certain if effective approaches are used and no leakage of emissions (concerning GHG emissions)	Less certain

Co-benefits	Multiple co-benefits possible	Often direct or co-benefits, depending on the primary purpose of the action
Monitoring	Relatively easy (measurement of GHG emissions)	More complex (measurement of climate risk)

Grafakos et al. identified four areas to consider to adequately define the interlinkages between mitigation and adaptation. The first type of interlinkages are co-benefits, defined as "when a plan, policy or measure that aims to enhance an adaptation (mitigation) objective leads simultaneously to the enhancement of mitigation (adaptation) objective". The second type are synergies, defined as "an interaction between an adaptation and a mitigation plan, policy, strategy or practical measure that produces an effect greater than the constituent components". The third type are conflicts, defined as "a plan, policy or measure that counteracts or undermines one or more planning goals between adaptation and mitigation". And finally, the fourth type are trade-offs defined as "a situation that necessitates choosing (balancing) between one or more desirable, but sometimes conflicting, plans, policies or measures" (62). Table 5 shows examples for each of these four categories, as adapted from Grafakos et al. (62).

Table 5 Examples within the four different categories of interlinkages between adaptation and mitigation, as adapted from Grafakos et al. (62)

Type of interlinkage	**Definition**	**Action**	**Primary objective**	**Interlinkage explained**
Co-benefit	"When a plan, policy or measure that aims to enhance an adaptation (mitigation) objective leads simultaneously to the enhancement of mitigation (adaptation) objective"	Hospital-wide passive heating and cooling system	Mitigation	Cooling can also be used in warm months to adapt to high temperatures
Synergy	"An interaction between an adaptation and a mitigation plan, policy, strategy or practical measure that produces an effect greater than the constituent components"	Green hospital rooftops	Adaptation and mitigation	Increase in energy efficiency of the hospital and a decrease in water runoff
Conflict	"A plan, policy or measure that counteracts or undermines one or more planning goals between adaptation and mitigation"	Individual air conditioning in hospital rooms	Adaptation	Increased use of individual, unsustainable air condition units to adapt to increased heat cause increased emissions
Trade-off	"A situation that necessitates choosing (balancing) between one or more desirable, but	Medical supply chain	Adaptation or mitigation	Challenges to set priorities in the supply chain due to reducing and reusing (mitigation) versus

	sometimes conflicting, plans, policies or measures”			increasing supplies in preparation for health emergencies (adaptation)

By understanding these interlinkages, the findings from this systematic review aims to feed into the analysis of how mitigation and adaptation can be integrated within Kenya’s healthcare system. As Kenya strives toward net-zero healthcare emissions by 2030, it is vital that mitigation strategies do not undermine critical adaptation efforts. Conversely, there may be opportunities to enhance adaptation through well-designed mitigation actions. This knowledge may support policy recommendations, ensuring that Kenya can develop a healthcare system that not only reduces emissions but also builds resilience to climate-related shocks.

4.4 Methods for Objective 3

Objective 3 focuses on understanding the barriers, opportunities, and priorities for achieving a net-zero healthcare system in Kenya. This objective is particularly important for identifying practical steps that the Kenyan healthcare system can take to mitigate GHG emissions while considering local context, stakeholder priorities, and interactions between mitigation and adaptation efforts. It builds directly on the insights gathered from the global landscape analysis (Objective 1) and the systematic review of GHG mitigation interventions (Objective 2). Objective 3 shifts the focus specifically to Kenya, employing qualitative methods to understand the unique barriers and opportunities for healthcare system mitigation.

Study Setting

Kenya, a lower-middle-income country in East Africa with a population of approximately 56 million, presents a unique healthcare landscape that includes public, private, and faith-based systems (65). Annual healthcare expenditure was 95 USD per capita in 2021, compared to Canada which holds the highest UHC Index and has an annual health expenditure of around 6500 USD per capita (66–68). There is significant variation in standards of care across regions and types of healthcare facilities, with the highest quality services concentrated in major cities like Nairobi and Mombasa. Kenya’s commitment to achieving a net-zero healthcare system by 2030 positions it as a regional leader in GHG mitigation (25). This commitment, backed by strong government leadership and international partnerships with organizations like the Aga Khan Development Network and the WHO, makes Kenya a critical case study. Lessons learned from Kenya’s journey could potentially be applied across the region and inform global mitigation and adaptation strategies, particularly in LMICs.

Data collection for this objective was centred in Nairobi, with additional stakeholders engaged from across Kenya. Interviews and workshops were designed to capture a wide range of perspectives from health workers, government representatives, and other key stakeholders.

To ensure a comprehensive exploration of perspectives within Kenya's healthcare system, a purposive quota sampling strategy was employed following Robinson's sampling guide. This approach was specifically designed to capture a heterogeneous set of perspectives from key stakeholders, aiming to identify commonalities across diverse viewpoints. The sample universe was defined to include individuals involved in or influencing the planning, implementation, or evaluation of greenhouse gas mitigation actions in Kenya's healthcare system. Eligibility criteria required participants to be over 18 years of age and either situated in or actively involved with healthcare-related climate mitigation and adaptation efforts in Kenya.

Sampling was guided by the need to ensure representation across key categories, including national and county government representatives, intergovernmental organizations, development agencies, health workers, supply chain managers, building designers, and healthcare services. A target sample size of 25 individuals was established, with flexibility to range between 15 and 35 participants depending on recruitment progress and the point of theoretical saturation. Recruitment involved direct outreach through networks in collaboration with local researchers, utilising a snowballing technique to identify additional relevant stakeholders throughout the interview process.

A sample of 21 stakeholders was selected for semi-structured interviews, ensuring a broad representation across key sectors. The sampling strategy allowed for flexibility, enabling the inclusion of additional stakeholders as needed to achieve theoretical saturation. The sample included stakeholders with decision-making or advisory roles in the planning, implementation, or evaluation of GHG mitigation efforts in Kenya's healthcare system. Participants were recruited through expert advice from intergovernmental, governmental, and non-governmental organizations with expertise in GHG mitigation in Kenya's healthcare system.

The interviews were designed to gather insights on several key topics, including current mitigation interventions, barriers to implementation, and opportunities for improving healthcare system sustainability. Participants were also asked to discuss how mitigation actions interacted with adaptation strategies, identifying any synergies, co-benefits, conflicts, or trade-offs between these efforts. This consideration of both mitigation and adaptation mirrors the thesis's broader framework, ensuring that Kenya's healthcare system can address climate risks holistically.

The interviews followed a standardized topic guide that allowed for flexibility depending on the participant's expertise and responses, ensuring that each conversation could delve deeper into relevant areas. All interviews were recorded, transcribed verbatim, and analysed thematically using NVivo software (69). This structured thematic analysis helped identify recurring patterns, barriers, and potential solutions, which were then synthesized into key recommendations for Kenya's healthcare system.

Following the interviews, a Delphi method was employed to facilitate consensus-building among key decision-makers in Kenya's healthcare system. This process was conducted through a workshop that involved 12 high-level stakeholders. The Delphi process consisted of multiple rounds of voting and discussion. Participants first reviewed the findings from the semi-structured interviews, then engaged in structured discussions to identify and rank priority actions for GHG mitigation.

Objective 3 serves as a critical bridge between the global evidence synthesized in Objective 2 and the practical, context-specific solutions needed for Kenya's healthcare system. The qualitative insights gathered through interviews and the Delphi process provide a rich understanding of the real-world challenges and opportunities that the Kenyan healthcare system faces in transforming to net-zero emissions. The qualitative methods employed in this objective are particularly suited to capturing the nuanced perspectives of stakeholders in Kenya's healthcare system.

4.5 Methods for Objective 4

After having been identified as key stakeholder, objective 4 focuses on understanding the role of health workers in Kenya's transformation to a net-zero healthcare system. The objective seeks to explore the role of health workers and to identify the educational components required to empower them to act.

While Objectives 1 to 3 deal with policy, systemic interventions, and conceptual frameworks for GHG reduction and adaptation, Objective 4 focuses on a specific stakeholder group key to implementation: how health workers can engage with and contribute effectively to climate mitigation and adaptation of the healthcare system. This objective directly informs the practical application of strategies by contributing to eventually addressing the gaps in knowledge, education, and engagement that health workers face.

A mixed-methods approach was employed to comprehensively explore the roles and perceptions of health workers in Kenya regarding climate change mitigation. This approach consisted of two phases: an online questionnaire to capture baseline knowledge, attitudes, and practices, followed by a focus group discussion to explore key themes in greater depth.

The focus on health workers in this objective also reflects a broader commitment to ensuring that mitigation and adaptation strategies are locally relevant and actionable. By exploring the educational gaps and needs of health workers, this research emphasizes their pivotal role in implementing climate solutions that improve healthcare delivery while addressing environmental challenges. Importantly, this objective explores health workers as agents of change, capable of driving improved patient outcomes, reduced environmental footprints, and increased resilience to climate shocks.

Phase 1: Structured Questionnaire

A structured online questionnaire was distributed to health workers, including doctors, nurses, pharmacists, dentists, and community health workers. The questionnaire aimed to assess the respondents' awareness of climate change and its impacts, their understanding of the healthcare system's contribution to GHG emissions, and their engagement in climate mitigation and adaptation practices. The questionnaire also explored the barriers health workers face in implementing sustainable practices and their willingness to participate in the transformation towards a net-zero healthcare system.

The questionnaire was distributed virtually via professional networks such as the Kenya Medical Association (KMA) and through hospital systems, ensuring a broad reach across various types of health workers. The quantitative data collected through the questionnaire provided a foundational understanding of the knowledge and attitudes among health workers, which was crucial for shaping the more in-depth discussions in the focus group.

Phase 2: Focus Group Discussion

Following the questionnaire, a focus group was conducted to deepen the exploration of health workers' roles in Kenya's net-zero healthcare transformation. Participants were drawn from professional healthcare associations and their student and young professional networks. This purposive sampling approach was chosen to ensure diverse representation of healthcare stakeholders within the constraints of the study. Given the time and financial limitations, it was not feasible to randomly identify and recruit participants from a broader sample of health workers across Kenya.

The focus group was conducted online to overcome geographic challenges and reduce costs. While an in-person format might have facilitated more dynamic interactions and potentially included participants without stable digital access, the online format enabled participation from multiple regions, maximising inclusivity within the available resources. The structure of the discussion was informed by the themes identified in the questionnaire, providing continuity between study phases and focusing on generating preliminary insights.

The focus group aimed to offer an initial exploration of health workers' perspectives on climate mitigation and adaptation in healthcare systems, emphasising educational needs and actionable strategies. This approach reflects a pragmatic response to logistical constraints while initiating critical discussions on sustainable healthcare practices.

The methodological design of the focus group drew from established frameworks in planetary health and sustainable healthcare education. Drawing on educational praxis for planetary health, the discussion incorporated inclusive and transformative approaches, exploring the role of local information systems and community co-creation. These principles shaped the focus group's structure, encouraging participants to reflect on lived experiences and propose contextually relevant solutions for embedding climate change education into healthcare practices (70).

The focus group questions were designed to explore participants' perspectives on education. Participants were encouraged to discuss practically, aiming to identify approaches that are both feasible and context sensitive. The discussions also included reflections on fostering reflective practice and addressing ethical challenges in climate action within healthcare, guided by the principles outlined in the relevant literature (71).

These theoretical foundations guided the objectives and content of the focus group. By linking systemic and individual dimensions of education for climate action, the study addressed a first exploration of critical aspects of empowering health workers to support Kenya's transformation to sustainable healthcare.

4.6 Ethics

The proposal for this thesis was approved by the Kenya Medical Research Institute (KEMRI, Ref. 4662) and the Research Ethics Committee of the London School of Hygiene & Tropical Medicine (Ref. 28210), and licensed by the National Commission for Science, Technology and Innovation (NACOSTI, Ref. 519115 and extension Ref. 285069)(see Appendix IV Ethics Approvals). The ethical approach of this thesis also includes a commitment to exploring climate mitigation strategies as opportunities for healthcare system development and adaptation synergies or co-benefits. This perspective aims to ensure that the research remains sensitive to the priorities and realities of Kenya's healthcare system while contributing meaningfully to the dialogue on sustainable healthcare transformations.

Chapter 5: Global Progress and Accountability in Sustainable Healthcare

5.1 Introduction

This chapter focuses on the first objective of this thesis: to evaluate global progress toward sustainable, low-carbon, and climate-resilient healthcare systems under the COP26 Health Programme. The COP26 Health Programme introduced international commitments aimed at transforming health systems.

To track progress on these commitments, it is essential to apply robust, transparent indicators that monitor both the development of climate-resilient systems and the reduction of healthcare footprints. This research assesses the current state of global commitments under the COP26 Health Programme, evaluates existing indicators, and identifies gaps that could lead to accountability challenges and the risk of greenwashing. Through a review of publicly available data, this paper presents an in-depth analysis of how far signatory countries have progressed toward their climate and health system goals and the effectiveness of the indicators used to monitor this progress.

This paper was prepared as an effort to support the international community in understanding the current state of healthcare system sustainability and resilience, as well as to guide future policy developments. The findings will provide valuable lessons for countries, including Kenya, which is the central case study of this thesis.

5.2 Aims and Objectives

The primary aim of this chapter is to evaluate the progress of global healthcare systems in transforming towards sustainability, low-carbon operations, and climate resilience, as outlined by the commitments of the COP26 Health Programme. This analysis serves as a critical step toward understanding how Kenya and other LMICs can enhance their own climate mitigation and adaptation strategies within the healthcare system. By assessing global progress, this study identifies key gaps in data, evidence, and accountability mechanisms that hinder the realization of climate-resilient and sustainable healthcare systems.

The specific objectives of this analysis are:

1. Evaluate the current progress toward sustainable healthcare systems as per the COP26 Health Programme commitments. This includes reviewing the actions taken by countries in terms of reducing greenhouse gas emissions and developing climate-resilient healthcare.
2. Identify gaps in data and evidence that limit the global understanding of progress. This involves assessing the availability, quality, and relevance of current indicators used to track healthcare system transformation.

3. Apply lessons from global efforts to improve Kenya's pathway to achieving a climate-resilient and net-zero healthcare system. The goal is to leverage insights from international commitments to shape Kenya's approach to climate mitigation in healthcare.

5.3 Research Paper Cover Sheet

SECTION A – Student Details

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Thesis Title	PhD – Epidemiology & Population Health		
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SECTION B – Paper already published

Where was the work published?	The Lancet Planetary Health		
When was the work published?	1st of October, 2024		
Have you retained the copyright for the work?*	**Yes**	Was the work subject to academic peer review?	**Yes**

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SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper.	IMB, JDS, AJM, FNR, and MR conceptualised the Review. IMB and MJE curated the data. IMB conducted formal analysis of the data with support from MJE, JS, and XN. IMB was responsible for data collection. All authors developed the methodology. IMB was responsible for project administration, with support from JCY. JDS and AJM provided supervision for the Review. IMB, JDS, AJM undertook validation of results. JCY, supported by IMB, prepared the figure. IMB wrote the original manuscript draft, and all authors contributed to further review and editing.

SECTION E

Student Signature	
Date	10/12/2024

Supervisor Signature	
Date	16/12/2024

The Lancet Planetary Health

5.4 Evaluating progress and accountability for achieving COP26 Health Programme international ambitions for sustainable, low-carbon, resilient health-care systems

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Abstract

A global initiative to develop low-carbon, resilient health systems—the COP26 Health Programme—launched at the UN Framework Convention on Climate Change 26th Conference of the Parties (COP26) in 2021. As of May 2024, 83 nations have committed to participate in this initiative. This analysis evaluates the effectiveness of existing and proposed indicators towards public monitoring and accountability to these commitments. Our findings reveal substantial gaps in data availability and indicator relevance, with many countries reporting process indicators that do not reflect actual progress towards achieving sustainable health-care systems. We found a dearth of suitable indicators and an urgent need to develop robust ones that are adaptable to different health-care system contexts. These indicators should be designed to capture tangible outcomes, support policy making, and prevent greenwashing. Integration of more robust indicators into independent scientific monitoring can support systematic inclusion of healthcare in global climate strategies, thereby enhancing the overall effectiveness of the COP26 Health Programme.

5.4.1 Introduction

At the UN Framework Convention on Climate Change (UNFCCC) 26th Conference of the Parties (COP26) in 2021, the global health community launched the COP26 Health Programme, building on the goal of the 2015 Paris Agreement to limit global temperature rise (4,72). The Agreement calls for countries to submit periodic Nationally Determined Contributions (NDCs), outlining their plans and progress towards reducing greenhouse gas (GHG) emissions and adapting to climate change. The COP26 Health Programme emphasises the crucial role of health systems in achieving the Paris Agreement's goals through adaptation and emission reductions (4). The COP26 Health Programme includes three levels of national commitments to develop sustainable health systems: climate-resilient health systems; sustainable, low-carbon health systems; and net-zero health systems within a designated timeframe (Table 6)(4).

To support these commitments, WHO, in partnership with the COP26 and COP27 presidencies, launched the Alliance for Transformative Action on Climate and Health (ATACH) in 2022 (73). In November 2023, WHO updated its Operational Framework for building climate-resilient and low-carbon health systems. For each of the 10 framework building blocks (Figure 2), WHO proposed 12 to 20 indicators intended to guide and measure health-care system transformation (3). Although some efforts are in place for the collection and reporting of indicators by nations, there are currently no independent measurement or accountability structures to ensure adherence to commitments. There is, therefore, a need to develop strategies to evaluate and monitor progress and direct efforts towards areas of greatest need.

In this Review, author members from the Lancet Commission on Sustainable Healthcare aim to build on ATACH efforts to achieve sustainable health- care systems (Table 6) through a scientific analysis of the COP26 Health Programme commitments by identifying, applying, and evaluating relevant indicators (41). We review WHO-proposed and existing indicators, evaluate their suitability for independent progress monitoring on the basis of publicly available data, and highlight performance assessment gaps (3). A crucial challenge in monitoring the COP26 Health Programme commitments is the potential for greenwashing—that countries might report data that give the appearance of progress without actually achieving substantial outcomes. The absence of robust, outcome-oriented indicators (e.g., emission reductions or surge capacity and system adaptability) increases the risk of greenwashing, which not only undermines accountability but also misleads stakeholders about the true extent of progress towards achieving sustainable health systems. This Review could serve as a foundation for independent scientific assessment of progress, harnessing the expertise of the scientific community for innovative indicator development to guide actions that can most effectively deliver sustainable health-care systems (defined in Table 6).

Table 6 List of key concept definitions relevant to sustainable health-care systems.

	Source	Definition
Adaptation	WHO	Adjustment to actual or expected climate and its effects; in human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities; in some natural systems, human intervention may facilitate adjustment to the expected climate and its effects (2)
Climate-resilient health systems	WHO	Those capable 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 (3)
COP26 Health Programme: commitment to climate resilient health systems	WHO	Commit to conduct climate change and health vulnerability and adaptation assessments at population level, health-care facility level, or both, by a stated target date; commit to develop a HNAP informed by the health vulnerability and adaptation assessment, which forms part of the National Adaptation Plan to be published by a stated target date; commit to use the vulnerability and adaptation assessments and HNAP to facilitate access to climate change funding for health (egg, project proposals submitted to the Global Environmental Facility, Green Climate Fund, Adaptation Fund, or Green Climate Fund Readiness programme) (4)
COP26 Health Programme: commitment to sustainable, low-carbon health systems	WHO	Commitment to deliver a baseline assessment of greenhouse gas emissions of the health system (including supply chains); commitment to develop an action plan or roadmap by a set date to develop a sustainable low-carbon health system (including supply chains) that also considers human exposure to air pollution and the role the health sector can play in reducing exposure to air pollution through its activities and actions (4)
COP26 Health Programme: commitment to net-zero emissions	WHO	Commitment to set a target date by which to achieve health system net-zero emissions (ideally by 2050) (4)
Environmentally sustainable health systems	WHO	A health system that improves, maintains or restores health, while minimising negative effects on the environment and leveraging opportunities to restore and improve it, to the benefit of the health and wellbeing of current and future generations (5)
Greenwashing	Nemes et al	Greenwashing is an umbrella term for a variety of misleading communications and practices that, intentionally or not, induce false positive perceptions of an organisation, product, or service's environmental performance. (6)
Health National Adaptation Plan (HNAP)	WHO	Plan led by the Ministry of Health as part of the National Adaptation Plan process; the HNAP sets out a range of actions to address the health impacts of climate change and build climate resilient health systems at all levels of planning, contributes to comprehensive health adaptation planning to respond to the health risks of climate change, is based on the best available evidence, and is informed by a comprehensive vulnerability and adaptation assessment (2)
Health systems	WHO	Ensemble of all public and private organisations, institutions, and resources mandated to improve, maintain, or restore health and incorporate disease prevention, health promotion, and efforts to influence other sectors to address health concerns in their policies (8)
Mitigation	United Nations Environment Programme	Any procedure or action undertaken to reduce the adverse impacts that a project or activity might have on the environment (74)
National Adaptation Plan	United Nations Environment Programme	The National Adaptation Plan process seeks to identify medium-term and long-term adaptation needs, informed by the latest climate science; once major vulnerabilities to climate change have been identified, the National Adaptation Plan process develops strategies to address them (10)
Net-zero	Science Based Target initiative	Reducing scope 1, 2, and 3 emissions to zero or a residual level consistent with reaching net-zero emissions at the global or sector level in eligible 1·5°C-aligned pathways, and permanently neutralising any residual emissions at the net-zero target year and any greenhouse gas emissions released into the atmosphere thereafter (75)
Low-carbon health systems	WHO	Those capable of implementing transformative strategies towards reducing greenhouse gas emissions in their operations, reducing short-term and long-term negative effects on the local and global environment (3)
Sustainable health-care systems	Lancet Commission on Sustainable Healthcare	Health-care systems that provide universal access to appropriate care that optimises health and wellbeing for today's patients and communities, and for future generations, by delivery of care that is needed, wanted, clinically effective, affordable, equitable, responsible in its use of resources, and functioning within planetary boundaries (41)
Vulnerability and Adaptation Assessment	WHO	A tool that allows countries to evaluate which populations and specific geographies are most vulnerable to different kinds of health effects from climate change, to identify weaknesses in the systems that should protect them, and to specify interventions to respond (2)

		Indicator quantifiability					
		Not quantifiable	Quantifiable				
		Data availability					
WHO operational framework building blocks	Total number of WHO-proposed indicators	No data available (Not quantifiable)	No data available (Quantifiable)	No data available (%)	Limited data	Detailed data	Indicators
Climate-transformative leadership and governance	18	4	8	66·7%	2	4	1·1·2, 1·1·3, 1·2·2, 1·2·3
Climate-smart health workforce	17	10	7	100·0%	..	..	
Assessments of climate and health risks and GHG emissions	18	10	4	77·8%	2	2	3·2·1
Integrated risks monitoring, early warning, and GHG emissions tracking	14	6	8	100·0%	..	..	
Health and climate research	19	15	2	89·5%	2	..	
Climate-resilient low-carbon infrastructures, technologies, and supply chain	20	16	4	100·0%	..	..	
Management of environmental determinants of health	10	6	4	100·0%	..	..	
Climate-informed health programmes	14	12	2	100·0%	..	..	
Climate-related emergency preparedness and management	12	9	3	100·0%	..	..	
Sustainable climate and health financing	13	7	6	100·0%	..	..	

Indicators by UNFCCC-aligned thematic area

- Resilient health-care systems
- Sustainable, low-carbon health-care systems
- Access to financial resources
- Inclusion in governance and NDCs

Figure 2 Summary analysis of the 155 WHO-proposed indicators across the 10 building blocks of the WHO Operational Framework for climate-resilient and low-carbon health systems.

Limited data availability is defined as only one case study identified. Detailed data availability is defined as the existence of a corresponding international database. Indicators lacking data are visualised via heatmap in red and identified in grey by proportion of total indicators per WHO-derived building block. Number of quantifiable indicators for which detailed data are available for at least a quarter of committed countries are denoted by numerical classifiers referenced in the WHO Operational Framework,4 and categorised by colour per our identified key themes (with the exception of Access to financial resources, as no WHO-proposed indicators reflected this).

5.4.2 Methods

First, we created a comprehensive summary of COP26 Health Programme country commitments through May 31, 2024, using publicly available data on the WHO website, categorising the commitments into the three types as defined by the Programme: climate- resilient health systems; sustainable, low-carbon health systems; and net-zero health systems. Next, we systematically assessed country commitments using WHO-proposed and existing indicators. These were then organised into four themes, reflecting UNFCCC processes.

Search strategy and selection criteria

We evaluated each of the 155 proposed indicators from the updated WHO Operational Framework on the basis of quantifiability and public availability of national-level data. To identify other relevant indicators, we further reviewed the University of Exeter's statistical database guide, and extracted all health-related indicators available from key global sources known for their relevance to healthcare (76). These sources include the WHO Global Health Observatory, WHO Global Health Expenditure Database, ATACH Baselines, EuroStat, Lancet Countdown on Health and Climate Change, Organisation for Economic Co-operation and Development Data Explorer, World Bank Data, UN Data, UN Data Commons, Sustainable Development Goals indicators, International Monetary Fund Data, and Our World in Data (17,47,77–86). The extraction process involved reviewing each database and cataloguing all health-related indicators. Duplicates were removed, each indicator was 5 reviewed independently by two authors (IMB and XN) for relevance, with disputes resolved by a third author (JDS). Indicators were included if they had clear definitions and measurement methods, measured aspects directly affecting health-care system sustainability, reflected areas where health-care systems could implement changes, and were supported by publicly available national-level data.

Data supporting the identified indicators were extracted and analysed for countries that had made any commitment under the COP26 Health Programme. We identified gaps in public assessment methods to inform the development of robust accounting mechanisms.

Thematic groupings in alignment with UNFCCC

To facilitate a more targeted analysis of sustainable health-care system progress in alignment with the UNFCCC and ATACH, we grouped indicators into four thematic areas. The first two areas—indicators monitoring progress towards resilient health-care systems and those monitoring progress towards sustainable, low-carbon health-care systems—directly reflect the COP26 Health Programme commitment types. However, the types of commitments do not fully reflect the opportunity for more comprehensive integration of healthcare into the goals of the Paris Agreement. To bridge this gap, we expanded our analysis to include two additional areas: indicators that measure access to financial resources, reflecting the priori- ties of the ATACH working group on financing, and indicators that evaluate how well health-care considerations are integrated into governance (including NDCs), thereby ensuring consideration of the WHO conceptual framework building blocks of health systems reflecting governance and leadership (87).

5.4.3 Current status of COP26 Health Programme commitments

Commitments to climate-resilient health systems

As of May 2024, with one exception (Chile), all countries committed to the COP26 Health Programme have pledged to achieve climate-resilient health systems, defined by WHO as "those capable 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"(Table 6)(3). Low-income and middle-income countries (LMICs) represent 58 of the 82 commitments to resilient health systems (appendix pp 2–8)(26). This commitment requires vulnerability and adaptation assessments to be conducted, either at the population level or health-care facility level, and the development of a Health National Adaptation Plan (HNAP) based on the findings of the vulnerability and adaptation assessments (Table 6). This commitment further calls for leveraging these HNAPs to access climate financing to achieve climate-resilient health system goals (4).

Commitments to sustainable, low-carbon health systems

Of the 83 COP26 Health Programme signatory countries, 76 have committed to developing sustainable, low-carbon health systems, defined by WHO as "those capable of implementing transformative strategies towards reducing GHG emissions in their operations, reducing short- and long-term negative impacts on the local and global environment."(3). LMICs account for 54 of these 76 countries (Appendix V). The primary intent of low-carbon commitments is to reduce the estimated 4·6% of global GHG emissions attributable to health-care systems, and their negative effects on health (17). According to the COP26 Health Programme, all committed countries must calculate their baseline national health system emissions and devise an action plan to reduce both GHG emissions and health sector air pollution (4).

Commitments to net-zero health systems

38 (46%) of 83 COP26 Health Programme signatory countries have committed to the more ambitious target of achieving net-zero health-care emissions between 2030 and 2060, of which 24 are LMICs (Appendix V). We were unable to find an official WHO definition of a net-zero health system, and it is therefore unclear if this commitment entails reducing all health-care system GHG emissions across scope 1 (health-care operations), scope 2 (energy), and scope 3 (supply chain) to near-zero, and counterbalancing remaining emissions with removals from the atmosphere.

5.4.4 Review of WHO-proposed and existing indicators

In our review of WHO-proposed indicators, difficulties in identifying specific metrics arose for 61% (95/155). These difficulties stemmed from lack of specificity of what indicators were trying to measure, or their inherent complexity suggesting multifaceted data points would be required. Of the 60 indicators deemed readily quantifiable—meaning they could be measured directly or through single-source data—seven are supported by publicly available, international databases (Figure 2, Appendix V). One of these seven indicators was the "Proportion of population with primary reliance on clean fuels and technology", which we excluded as it pertains to household instead of healthcare system fuel; thus, six proposed indicators were analysed.

In addition to WHO-proposed indicators, a total of 6257 indicators were retrieved from the 12 international databases. After screening, 12 relevant indicators were identified, for a total of 18 indicators that support our four identified themes (Table 7).

The results are organised around four key thematic areas: resilient health-care systems, low-emission or net-zero health-care systems, financial resources towards resilient and low-emission health-care systems, and the inclusion of health-care systems in governance and NDCs. For each theme, we first describe the relevant indicators identified and then present analysis of the progress made by the countries committed to the COP26 Health Programme.

Table 7 Overview of existing national-level data-driven indicators by key theme.*

	Indicator source	**Data source**	**Type**	**Most recent data (year)**
		Resilient health-care systems		
Country commitment to a resilient health-care system	(P) WHO Operational Framework: component 1, objective 1, indicator 2 (1.1.2)	WHO Alliance for action on climate change and health	Binary (yes or no) process indicator	2024
Vulnerability and adaptation assessments	Partial relevance to WHO Operational Framework (3.1.1)	WHO Alliance for action on climate change and health	Binary (yes or no) process indicator	2024
National Adaptation Plan health-care integration	(P) WHO Operational Framework (1.2.2)	WHO review	Binary (yes or no) process indicator	2020
Health National Adaptation Plan	WHO Alliance for action on climate change and health	WHO Alliance for action on climate change and health	Binary (yes or no) process indicator	2024
Health surveillance system with or without considering meteorological information	Partial relevance to WHO Operational Framework (4.1)	WHO Health and climate change global survey	Binary (yes or no) process indicator	2021
		Sustainable, low-carbon health-care systems		
Country commitment to a sustainable, low-carbon health-care system	(P) WHO Operational Framework (1.1.3)	WHO Alliance for action on climate change and health	Binary (yes or no) process indicator	2024
Country commitment to a net-zero health-care system	(P) WHO Operational Framework (1.1.3)	WHO Alliance for action on climate change and health	Binary (yes or no) process indicator	2024

	Indicator source	Data source	Type	Most recent data (year)
Greenhouse gas emissions assessed	(P) WHO Operational Framework (3.2.1)	WHO Alliance for action on climate change and health	Binary (yes or no) process indicator	2024
National health sector greenhouse gas emissions	Partial relevance to WHO Operational Framework (3.2.1)	*Lancet* Countdown on Health and Climate Change	Quantitative outcome indicator	2020
Low-carbon, sustainable health-care system action plan for health system developed	WHO Alliance for action on climate change and health	WHO Alliance for action on climate change and health	Binary (yes or no) process indicator	2024
Disability-adjusted-life-years from $PM_{2.5}$ and ozone pollution associated with health-care delivery and supply chains	*Lancet* Countdown on Health and Climate Change	*Lancet* Countdown on Health and Climate Change	Quantitative outcome indicator	2020
Access to financial resources				
Health expenditure including domestic, private, or external sources	WHO Global health expenditure database	WHO Global health expenditure database	Quantitative process indicator	2020
Universal Health Coverage Service Coverage Index (SDG 3.8.1)	WHO Global health observatory	WHO Global health observatory	Quantitative process indicator	2021
Inclusion in governance and Nationally Determined Contributions				
The Global Climate and Health Alliance Nationally Determined Contributions Scorecard	(P) WHO Operational Framework (1.2.3)	Global Climate and Health Alliance	Quantitative process indicator	2023 and 2021*
Climate Change and Health Agreements Ministry of Health	Partial relevance to WHO Operational Framework (1.3.1)	WHO Health and climate change global survey	Binary (yes or no) process indicator	2021
Designation of a key person responsible for health and climate change within the Ministry of Health	Partial relevance to WHO Operational Framework (1.1.1)	WHO Health and climate change global survey	Binary (yes or no) process indicator	2021
Existence of a multi-stakeholder mechanism on health and climate change	Partial relevance to WHO Operational Framework (1.3.2)	WHO Health and climate change global survey	Binary (yes or no) process indicator	2021
National health and climate change plan or strategy developed	Partial relevance to WHO Operational Framework (1.2.1)	WHO Health and climate change global survey	Binary (yes or no) process indicator	2021

**Overview of national-level data-driven indicators categorised by key themes. Where a partial relevance is indicated, the WHO Operational Framework describes details that are not fully reflected in the existing indicator. P=proposed. *Two evaluations have been conducted on updated Nationally Determined Contributions, and the most recent analysis has been included for each evaluated country.*

5.4.5 National-level data-driven indicators by key theme

Indicators of progress towards resilient health-care systems

Vulnerability and adaptation assessments are intended to help identify health-care system vulnerabilities to climate-related hazards and to inform adaptation strategies. Committed countries report to ATACH on whether they have conducted or updated these vulnerability and adaptation assessments, using binary (yes or no) data (80).

National Adaptation Plans are not mentioned by the COP26 Health Programme, however the WHO Operational Framework includes a proposed indicator with integration of health adaptation planning into the National Adaptation Plan process. Under the UNFCCC, National Adaptation Plans are formulated to guide countries in identifying and addressing their medium-term and long-term adaptation needs. WHO evaluated health integration within National Adaptation Plans in 2020 and 2023 (88,89). The 2020 evaluation included country-specific, binary data providing insight into countries' adaptation plans including their health-care systems (88).

HNAPs are not specified in the WHO Operational Framework or recognised in UNFCCC processes, however standalone HNAPs provide detailed health-specific adaptation plans. Committed countries report to ATACH on whether they have completed or updated HNAPs since 2020 (80).

Health surveillance systems enhance the capacity of health systems to adapt to climate-sensitive disease risks. Through the WHO Global Health Observatory's 2021 Health and Climate Change Global Survey, countries reported on whether they have a health surveillance system in place, including those measuring effects on health-care systems, and whether they include meteorological information (79).

Indicators of progress towards low-emission or net-zero health-care systems

Committed countries report to ATACH whether they have assessed their health system's GHG emissions. It is unclear whether these assessments include emissions across all three GHG protocol scopes (80).

Through ATACH, countries also report with binary data on whether they have developed an action plan since 2020 for creating a sustainable, low-carbon health-care system (80).

The Lancet Countdown on Health and Climate Change reports annually on country-level health sector GHG emissions using national health expenditures (as reported to WHO) combined with environmentally extended multi-region input–output models to facilitate tracking of emissions associated with economic activities in health sectors of countries studied. The models also incorporate emissions from domestic sources and global health-care supply chains, accounting for international trade. This approach yields total and per capita health-care GHG emissions, with the most recent results based on 2020 health-care expenditure data. (17)

Reported by the Lancet Countdown on Health and Climate Change, national health expenditures (as reported to the WHO) and environmentally extended multi-region input–output models are also used to estimate the health effects of air pollution ($PM_{2\cdot5}$ and ozone pollution) from health-care delivery and supply chains, expressed as disability-adjusted-life-years (DALYs), combining years of life lost and years lived with disability (17).

Indicators of financial resources towards resilient and low-emission health-care systems

The WHO Global Health Expenditure Database aggregates data from national reports, Ministries of Finance, central banks, and international bodies to provide an overview of health expenditures (domestic, private, or external) and their sources across countries. These data elucidate the relative responsibilities of financial stakeholders in implementing solutions necessary to meet the COP26 Health Programme commitments. (47)

Scored on a scale of 0 to 100 by the WHO Global Health Observatory, the Universal Health Coverage Service Coverage Index reflects access to essential health services among the general population and the most disadvantaged populations, thereby monitoring national progress towards universal health coverage. (66)

Indicators of inclusion of health-care systems in governance and NDCs

NDCs are a key policy instrument for mobilising state actors in GHG mitigation and climate adaptation. The Global Climate and Health Alliance evaluated the representation of healthcare within countries' NDCs in 2021 and 2023. NDCs were then assigned a score out of 18 across six health categories: integrated governance, health effects, health sector action (including national planning of mitigation and adaptation), health co-benefits (including identifying health benefits of actions in other sectors), economics and finance, and monitoring and implementation. This scorecard is a potential aid for evaluating the COP26 Health Programme by examining progress on country-level implementation. (90,91)

Extracted from the WHO Health and Climate Change Global Survey, binary data indicate the presence of cross-sectoral collaboration through tracking of formal agreements between Ministries of Health and other sectors, such as agriculture and energy.

The WHO Health and Climate Change Global Survey collects self-reported data on whether countries have: a designated key person responsible for health and climate change within the Ministry of Health, an operational multi-stakeholder mechanism on health and climate change, and a national health and climate change plan. These three indicators on policies and engagement highlight the organisational and strategic mechanisms supporting efforts towards achieving sustainable healthcare.

5.4.6 Analysis of COP26 Health Programme progress using identified indicators

The COP26 country commitments are presented in the Appendix V alongside the 18 identified indicators across the four themes described previously and are summarised in Table 8. Each of the indicators and their significance in monitoring COP26 Health Programme progress in alignment with the UNFCCC process are discussed in the following sections.

Table 8 Summary of extracted data relevant to the COP26 Health Programme, by indicator with description.

	Climate resilient health systems (n=82)		Sustainable, low-carbon health systems (n=76)		Net-zero commitment (n=38)	
	n	**%**	**n**	**%**	**n**	**%**
Vulnerability and adaptation assessment as per the Alliance for Transformative Action on Climate and Health (2024)						
Completed or updated since 2020 (self-reported)	25	30	24	32	13	34
National Adaptation Plans as per the Review of Health in National Adaptation Plans (2020)						
Health sector recognised as a vulnerable sector	9	11	10	13	3	8
Health National Adaptation Plan as per the Alliance for Transformative Action on Climate and Health (2024)						
Completed or updated since 2020 (self-reported)	21	26	21	28	11	29
Health Surveillance System as per the Global Health Observatory (2021, self-reported)						
Surveilling impacts on health-care facilities	13	16	10	13	4	11
Surveilling impacts on health-care facilities including meteorological information	4	5	3	4	0	0
Surveilling impact on mortality and morbidity	8	10	6	8	4	11
Surveilling impact on mortality and morbidity including meteorological information	0	0	0	0	0	0
Disability-adjusted-life-years from $PM_{2.5}$ and ozone pollution associated with health-care delivery and supply chains (2020)						
>1000	50	63	48	66	25	69
Greenhouse gas emissions assessment and strategy as per the Global Health Observatory (2021, self-reported)						
Greenhouse gas emissions assessed for health system since 2020	9	11	9	12	6	16
Low-carbon, sustainable health-care system action plan for health system developed since 2020	6	7	6	8	0	0
Total greenhouse emissions per capita (total CO_2 equivalent/capita) (2019)						
≥400 kg CO_2e/cap	13	16	12	16	8	22
<400 kg CO_2e/cap	66	84	61	84	28	78
Income status as per the World Bank (2022)						
High income	24	29	22	29	14	37
Upper-middle income	17	21	16	21	4	11
Lower-middle income	26	32	24	32	12	32
Low income	15	18	14	18	8	21
Global health expenditure database (2020)						
Domestic general government ≥50%	45	57	41	56	19	53
Domestic general government <50%	34	43	32	44	17	47
Domestic private ≥25 %	55	70	51	70	22	61
Domestic private <25%	24	30	22	30	14	39
External sources ≥25 %	13	16	12	16	7	19
External sources <25%	59	82	54	82	25	78
Universal health coverage index as per the Global Health Observatory (2021)						
>80 out of 100	18	22	19	25	19	50
Integration of health categories as per the National Determined Contributions Scorecard (2021 or 2023, maximum score)						

	Climate resilient health systems (n=82)		Sustainable, low-carbon health systems (n=76)		Net-zero commitment (n=38)	
Integrated governance	0	0	0	0	0	0
Health impacts	12	29	12	32	8	42
Health sector action	13	50	12	57	5	56
Health co-benefits	16	38	15	39	7	37
Economics and finance	0	0	0	0	0	0
Monitoring and implementation	5	19	5	24	2	22
Climate change and health agreements as per Ministry of Health (2021, self-reported)						
Environment	21	26	17	22	7	18
Transportation	8	10	6	8	4	11
Agriculture	10	12	7	9	5	13
Education	7	9	5	7	4	11
Energy	11	13	9	12	5	13
National meteorological and hydrological services	15	18	13	17	7	18
Social services	2	2	1	1	2	5
Urban development and housing	7	9	5	7	5	13
Water, sanitation, and hygiene	18	22	15	20	6	16
Policies and engagement as per the Global Health Observatory (2021, self-reported)						
Designation of a key person responsible for health and climate change within the Ministry of Health	42	51	38	50	15	39
Existence of a multistakeholder mechanism on health and climate change	25	30	23	30	9	24
National health and climate change plan or strategy developed	25	30	23	30	23	61

**N is the number of countries in the WHO COP26 Health Program Commitments. Detailed overview per country in the Appendix V. Percentages shown as total of measured committed countries unless otherwise indicated. Year given for each indicator indicates the most recent data. CO2-e/cap= CO2 equivalent per capita.*

Resilient health-care systems

According to ATACH data, only 30% (25/82) of countries committed to the COP26 Health Programme have conducted a vulnerability and adaptation assessment.

The 2020 WHO assessment of National Adaptation Plans identified that only 11% (9/82) of countries committed to achieving resilient health systems under the COP26 Programme had identified health as a vulnerable sector in a total of 19 published National Adaptation Plans (88). Although a 2023 assessment found that 63% of all NDCs had identified health adaptation as a priority, this assessment did not provide country-specific data, nor was it specific to healthcare (89).

Only 25% (21/82) of countries committed to achieving resilient health systems report having completed or updated their HNAPs since 2020.

Data on health surveillance systems from the Global Health Observatory (2021) revealed varied levels of implementation among countries committed to the COP26 Health Programme. Specifically, only 16% (13/82) of countries committed to resilient health-care systems reported having surveillance systems in place to monitor the effects of climate change on health-care facilities. Notably, only 5% (4/82) of countries (Bahrain, Brunei, Cabo Verde, and the Dominican Republic) had surveillance systems that included meteorological information.

Low-emission or net-zero health-care systems

Only 9 (12%) of 76 countries committed to sustainable, low-carbon health systems, and 6 (16%) of 38 countries committed to net-zero health systems, have assessed their health system's GHG emissions following their commitment. These nine countries are France, Germany, Guinea, Madagascar, Nepal, the Netherlands, New Zealand, Norway, and the UK.

Only 6 (8%) of 76 countries committed to sustainable, low-carbon health-care systems—and none of the countries committed to net-zero health-care systems— have developed sustainable, low-carbon health-care system action plans following their commitment. These six countries are France, Mauritania, Morocco, the Netherlands, New Zealand, and the UK; of these, only France, the Netherlands, New Zealand, and the UK have performed baseline GHG assessments essential for evidence-based action plans.

Health-care systems from all committed high-income countries (HICs) emitted on average 8-fold more GHGs per capita (n=25, M=619 kg CO_2 equivalent [CO_2 e], SD=438) compared with health-care systems from committed LMICs (n=55, M=74 kg CO_2 e, SD=74), with Israel having the highest per capita health-care emissions at 1910 kg CO_2 e in 2020 (Appendix V).32 Several HICs such as Russia and South Korea, and high-emitting LMICs such as China and India, are conspicuously absent from the commitments (92). Notably, the 51 LMICs committed to sustainable, low-carbon health systems for which data is available contributed only 7·5% (171 Mt CO_2 e) of total global health-care emissions in 2020, whereas the 22 committed HICs contributed 38% (861 Mt CO_2 e).

Although the USA is a COP26 Health Programme signatory, and responsible for 21% of total global healthcare emissions and 45% of committed country emissions (474·1 Mt CO_2 e), its commitment represents a small fraction of its national health sector emissions. The USA low-carbon commitment falls under Presidential Executive Order (EO 14057), and thus applies only to federal health systems, including the Military Health System, Veterans Health Administration, and Indian Health Service, which represent approximately 4% of total USA health-care GHG emissions, meaning that most USA health-care emissions fall outside its commitment (93). Altogether, assuming all other countries' commitments comprehensively cover their entire national health sectors, only around 26% (587 Mt CO_2 e) of emissions from global healthcare are presently represented in the COP26 Health Programme commitments. 12% (287 Mt CO_2 e) of global health-care emissions are accounted for by countries that have committed to net-zero health systems.

Across COP26 committed countries, the USA contributes the highest burden of air pollution (PM2·5 and ozone, associated with health-care delivery and supply chains), with an annual loss of 470 000 DALYs. Japan follows with 140 000 DALYs. In Europe, the health-care systems in Germany (71 000 DALYs), France (29 000 DALYs), and the UK (46 000 DALYs) contribute a notable burden.

Financial resources towards resilient and low-emission health-care systems

According to the WHO Global Health Expenditure Database, in 43% (34/83) of countries committed to the COP26 Health Programme, less than 50% of 2020 health expenditures originated from the domestic central government (47). In 55 countries, more than 25% of health expenditures came from domestic private healthcare, and in 13 countries, more than 25% came from external sources such as international governmental and nongovernmental charities (47).

Among countries committed to the COP26 Health Programme, 18 (22%) achieved a Universal Health Coverage Service Coverage Index score above 80, indicating a high level of service coverage. High scorers included Canada (91), Germany (88), Norway (87), Australia (87), and the UK (88). However, several countries received substantially lower scores, such as the Central African Republic (32), Somalia (27), and Ethiopia (35), highlighting disparities in health-care service coverage across different regions.

Inclusion of health-care systems in governance and NDCs

Of 26 countries committed to the COP26 Health Programme for which an updated NDC (which, as detailed in the Paris Agreement, should take place every 5 years) was available, 13 achieved the maximum Global Climate and Health Alliance NDC score for health sector action across process indicators, meaning they included a combination of key measures such as vulnerability and adaptation assessments, resilience and preparedness actions, or mitigation strategies in the health sector, or they outlined an HNAP (Table 6

Table 6)(90,91).

Ministries of Health from committed countries reported agreements with other Ministries, including environment (26%), transportation (10%), agriculture (12%), education (9%), energy (13%), national meteorological and hydrological services (18%), social services (2%), urban development and housing (9%), and water, sanitation, and hygiene (22%).

With regard to the three indicators on policies and engagement, a total of 42 (51%) of 83 committed countries reported having designated a key person responsible for health and climate change within the Ministry of Health. Only 25 (30%) of 83 committed countries indicated the existence of a multistakeholder mechanism on health and climate change, such as a task force or committee. Similarly, only 25 (30%) of 83 committed countries had developed a national health and climate change plan or strategy.

5.4.7 Discussion

The COP26 Health Programme and ATACH are landmarks in coordinating global efforts towards sustainable, resilient health systems. The UNFCCC COP28 in December, 2023, further reinforced these global efforts with a Declaration on Climate and Health, signed by 150 countries, which included a commitment to reduce health sector emissions and waste (94). These collective efforts underscore the crucial intersection of climate, health, and care, and suggest promising actions toward health-care system transformation.

The WHO Operational Framework aims to guide countries in systematically addressing climate-related health risks while reducing the health sector's carbon footprint. This Review concludes that, to strengthen this effort with independent scientific monitoring, there is a need for broader consideration of existing indicators and overall indicator refinement.

Our analysis found that WHO-proposed indicators and other existing indicators for which data are publicly available did not effectively capture the extent and ambition of different COP26 Health Programme commitment types, nor were they sufficiently comprehensive to capture health-care mitigation and adaptation progress. The supporting public data for 13 of 18 indicators are limited to binary (yes/no) process measures, which provide no insight into health-care quality or outcomes.

The paucity of completed national vulnerability and adaptation assessments (30%), infrequent inclusion of health in National Adaptation Plans or completed HNAPs (26%), and unknown quality of these assessments and plans highlight gaps in the building of health-care system resilience. Analysis of health surveillance systems highlights further gaps, with only 16% of countries committed to resilient health systems under the COP26 Health Programme reporting surveillance systems for effects on health-care facilities, and even fewer (5%) incorporating meteorological information essential for prospective health-care system planning in a rapidly changing climate.

Traditionally, Ministries of Environment, which might not always prioritise health-care system vulnerabilities due to a disconnect with Ministries of Health, have spearheaded the development of National Adaptation Plans (95). To deliver COP26 Health Programme commitments, countries must embed health-care system resilience within their national climate strategies. Toward this end, incorporating HNAPs into National Adaptation Plans could improve collaboration between Ministries of Environment and Health.

Furthermore, a detailed understanding of the vulnerability and adaptation content, which is crucial to inform these adaptation plans, is lacking. There is an urgent need for more health-care-specific metrics within existing vulnerability and adaptation frameworks to drive evidence-based planning, guide investments, and enable monitoring of progress and accountability to build capacity sustainably. Previously published WHO quality criteria could be considered in the development of indicators (96). A recent systematic analysis highlights seven crucial areas for strengthening health-care system resilience to climate effects that should be considered when refining indicators: workforce, tools and frameworks, infrastructure and urban planning, communication, surge capacity and increased system burden, service interruption, and financial costs (97). Employing the RESILIENT framework, as detailed in a recent review on health-care facility resilience, to report facility-level interventions could help standardise the way assessments, risks, population impacts, facility capabilities, and climate solutions are documented (98).

One major finding of this analysis is the lack of substantial commitment from high-emitting countries. Despite commitments from 83 countries, 74% of global health-care emissions (~1667 Mt CO2 e) are not currently encompassed by the COP26 Health Programme. According to fair share principles, which advocate for an equitable distribution of the remaining carbon budget and health benefits, it would be anticipated that the bulk of low-carbon or net-zero commitments would come from the countries that are contributing the highest per capita emissions, leveraging HICs' relatively greater resources for comprehensive emissions tracking and innovation, including making accounting and reporting systems less onerous. Instead, LMICs have embraced a disproportionate role, comprising a distinct majority in all commitment categories. (99)

There is a dearth of baseline data to inform evidence-based decarbonisation, as only 11% of all countries committed to low-carbon health systems and none of the countries with net-zero commitments reported to have assessed their health-care emissions. Furthermore, the absence of clear definition tied to the net-zero health system commitment is concerning, as it could lead to a narrow focus on scope 1 and 2 emissions, neglecting the more substantial scope 3 emissions, which are estimated to account for 70–80% of total health sector emissions (17). However, some countries, such as Egypt, Iran, Morocco, and the UK, have started to measure scope 3 emissions, indicating progress towards comprehensive emissions reporting (53,80). Published in June, 2024, WHO's checklist for setting sustainable, low-carbon health system targets does include scope 3 emissions (42). This checklist provides a structure for further indicator development, and a WHO net-zero health system definition is required to match this. Sectors such as energy and manufacturing have developed comprehensive approaches to tracking and reporting emissions, offering valuable lessons for the health-care sector (100,101). Engaging relevant actors such as the private sector, non-profit entities, and municipalities via environmental, social, and governance (ESG) reporting could be particularly effective in advancing health-care sustainability (102). For example, National Health Service England mandates ESG reporting for its supply chain vendors (103). The EU's Corporate Sustainability Due Diligence Directive further supports this trend, with potential implications for expanding these practices across Europe (104).

The Lancet Countdown on Health and Climate Change reports health-care emissions against measures of health-care access and quality to track health system performance and ensure that care standards are not compromised in the pursuit of pollution mitigation. Results show that emissions tend to rise with health-care quality to an inflection point of 400 kg CO_2 e per person (105). The observation that emissions increase with health-care quality up to a certain efficiency threshold suggests that achieving high-quality care does not inherently necessitate high emissions. Given that health-care access and quality are expected to expand in LMICs to address unmet needs, investment in sustainable solutions is crucial to ensure development of low-carbon health services rather than replication of carbon-intensive models of care currently in widespread use in HICs (31,106). HICs must reduce excessive material and energy consumption in the delivery of health-care services (92). Considering the indicator's limitations of relying on reported economic activities, improving accuracy through bottom-up data collection by countries and supply chain vendors can help refine reporting and drive evidence-based strategic management.

The loss of DALYs from $PM_{2·5}$ and ozone pollution associated with health-care delivery and supply chains highlights substantial health effects across countries committed to the COP26 Health Programme. A broader understanding is warranted following this first assessment, including use of fossil fuels by health-care facilities, which can disproportionately affect populations susceptible to pollution-related health effects in surrounding communities. The WHO Operational Framework emphasises the importance of mitigating environmental health risks, including air pollution, to protect public health and reduce the health-care sector's carbon footprint (3), which underscores the need for comprehensive pollution mitigation strategies that include scope 3 emissions.

Although GHG emissions and DALYs from air pollution serve as crucial indicators of environmental and health effects of health-care delivery, the sector's contribution to other environmental emissions, water consumption, material extraction, land use, and waste generation are also of concern. Although beyond the remit of the COP26 Health Programme, ensuring a holistic approach to sustainable healthcare requires expanding the current indicator set to capture the broader health-care system environmental footprint in tandem with health-care access and quality (107,108). Research is needed to quantify and compare the environmental effects of alternative healthcare interventions and strategies.

Within COP26 Health Programme countries there is a broad spectrum of public and private financing models. Country commitments could be more readily actionable within publicly funded health systems, owing to inherently stricter regulatory oversight and stewardship of common resources. The UK's National Health Service exemplifies the rapid progress possible within a publicly funded system, facilitated by strong national leadership and legal decarbonisation mandates through the UK Climate Change Act of 2008, which subsequently led to embedding implementation support into the Health and Care Act 2022 (109). In France in 2020, through the Ségur de la Santé, a cadre of advisors was established to improve health-care facility energy management and emission reductions (110). The intricacies of maintaining commitments and implementing similar actions across varying health-care system funding models remain largely unexplored.

Reliance on the WHO Global Health Expenditure Database for financial insights poses a risk of oversimplification. Although this database consolidates data from various sources, it might not capture the full dynamics and disparities of health-care financing within and across countries. This gap underscores the need for a more detailed assessment of health-care financing mechanisms and their implications for transitioning to sustainable health-care delivery.

Countries with higher Universal Health Coverage Service Coverage Index scores might have better infrastructure and resources to implement sustainable and low-emission health-care practices or, conversely, those with lower coverage might use sustainability solutions while expanding coverage. Understanding the correlation between universal health coverage and the ability to meet COP26 Programme commitments might help tailor strategies that address both health-care access and sustainability, ensuring that no country is left behind in the global effort to transform health systems.

Self-reported climate change and health agreements by Ministries of Health indicate varying levels of cross-sectoral collaboration, which are essential for integrating health into climate policy, as reflected in the WHO Operational Framework's emphasis on comprehensive, multisectoral approaches to building sustainable health systems (3). Only half of countries committed to the COP26 Health Programme have a designated key person for health and climate change within their Ministry of Health, and just 30% had national health and climate change plans. The absence of multistakeholder mechanisms in 70% of countries indicates insufficient cross-sectoral collaboration. Furthermore, it is unclear to what extent these indicators specifically consider healthcare delivery.

Although the Global Climate and Health Alliance NDC scorecard shows progress in integrating health into NDCs, particularly with respect to health effects and health co-benefits, it also exposes ongoing deficiencies in parameters crucial for the practical implementation of sustainable health-care delivery. These deficiencies are reflected in low scores in integrated governance and finance, potentially translating into practical challenges in cross-sectoral coordination and financing. A more in-depth evaluation of NDCs could provide more understanding of the integration of health-care systems into global climate negotiations.

Low scores for implementation and monitoring highlight the disparity between COP26 Health Programme commitments and actual reported actions. A grey literature review of international policy and practice in 2022 found substantial gaps in the integration of healthcare within any type of national climate strategy. Of 60 country commitments to the Programme at that time, only 13% (8/60) referenced health-care decarbonisation, and 32% (19/60) mentioned adaptation or resilience in NDCs (111). These gaps underscore the need for meaningful consideration of healthcare in national strategies and NDCs to ensure effective climate action and progress towards achieving sustainable health-care systems at the national level (90,91). The use of NDCs for gauging countries' health–climate integration has inherent limitations. The voluntary nature of plans outlined in NDCs, and insufficient data standards could result in selective reporting, with countries emphasising their strengths while downplaying areas needing improvement.

The reliance on publicly available data—with a majority being binary and lacking quality assessments—limited the scope and depth of analysis possible in this Review, potentially affecting the robustness of our findings and the ability to capture nuanced progress. Additionally, our systematic search of 12 key global databases, although comprehensive, was not exhaustive and might have excluded less widely recognised sources. An in-depth survey of national policies for countries committed to the COP26 Health Programme would complement the current analysis but was outside the scope of this Review.

A more detailed examination of national policies, including stratification by income status and further qualitative analysis, can offer additional understanding of the challenges faced by countries at different income levels. Despite these limitations, this Review provides a valuable, comprehensive assessment of the current landscape of indicators and identifies crucial gaps. The systematic approach used in selecting and analysing indicators ensures that the findings are relevant and aligned with global priorities, thereby contributing to ongoing efforts towards monitoring progress under the COP26 Health Programme.

5.4.8 Conclusion

Our analysis of the COP26 Health Programme highlights the need for transparent, standardised reporting of data to understand progress, guide policy making, and better ensure accountability. Developing robust indicators through targeted research is essential to capture these crucial aspects and prevent greenwashing. Greenwashing not only poses a technical challenge but also raises ethical concerns, as current commitments could allow countries to report progress without delivering meaningful outcomes, potentially obscuring the true state of global efforts towards achieving resilient health-care systems within planetary boundaries.

To effectively address these challenges, it is important to adopt a comprehensive approach that not only focuses on resilience and environmental sustainability but also considers the social foundations in the broader context of economic development and governance as presented in this Review. By grounding efforts more broadly in the context of the Paris Agreement, better monitoring can be achieved to track and guide the transition to sustainable health-care systems that are equipped to meet both current and future challenges.

Immediate steps towards these grounding efforts include the establishment of governance structures and implementation of standardised metrics to set baselines and track progress, fostering transparency and aligning actions with science-based targets. Indicators should include tangible health-care outcomes to ensure that quality and access are maintained or improved (108). Standardisation will simplify data management and enhance comparability, contributing to an evidence base that will allow identification of best practices and guide systemic transformation. The Lancet Commission on Sustainable Healthcare aims to support global efforts by developing and refining data-driven indicators to enhance transparency and effectiveness in achieving COP26 Health Programme goals and beyond.

5.5 Discussion and Implications

The findings from this paper provide crucial insights into global progress towards achieving climate-resilient, low-carbon, sustainable healthcare systems under the COP26 Health Programme. The gaps identified in data availability, indicator relevance, and accountability mechanisms point to significant areas that must be addressed to enhance the effectiveness of global climate mitigation and adaptation strategies in healthcare. An important observation arising from this analysis is that while initial steps towards governance and standardisation have been initiated through structures such as the WHO ATACH, progress at the national level has been uneven. Governance structures dedicated specifically to healthcare decarbonisation remain rare, and reporting often relies on self-assessments rather than independent verification. Similarly, although WHO has proposed a large set of indicators, many remain process-focused and lack publicly available, outcome-oriented data. This limited operationalisation suggests that global frameworks alone are insufficient to drive transformation without dedicated national mechanisms that ensure transparent, verifiable, and outcomes-based reporting. While these insights have broad relevance, they hold particular significance for Kenya as it undertakes its ambitious effort to create a net-zero healthcare system by 2030.

Although the COP26 Health Programme has catalysed important commitments, its primary focus on carbon emissions leaves broader environmental impacts, such as water use, material extraction, and waste generation, less thoroughly addressed, highlighting an area for future development. The paper also emphasises the importance of taking a holistic approach that integrates both mitigation and adaptation efforts. In Kenya's case, its dual focus on climate mitigation and healthcare system resilience positions it as a potential leader in this field, particularly within LMICs. The global analysis highlights that synergies between mitigation and adaptation are essential to achieving long-term sustainability. The commitment to a net-zero healthcare system offers a unique opportunity to design systems that leapfrog emission-intensive models, and it is recognized that international collaboration and equitable climate financing are vital to ensure these efforts are supported without compromising development goals.

Another critical lesson drawn from the global analysis is the need to better integrate healthcare into national adaptation and mitigation planning. The paper reveals that many countries have not sufficiently incorporated healthcare into their NAPs, nor have they developed comprehensive HNAPs. This presents a strategic opportunity for Kenya to strengthen its climate policies by ensuring that healthcare is central to its adaptation and mitigation strategies. By doing so, Kenya can access important climate financing opportunities and enhance its capacity to deliver on its commitment to a net-zero healthcare system.

While high-income countries have struggled to achieve net-zero commitments, Kenya has the chance to avoid replicating emission-intensive healthcare models by proactively implementing sustainable policies.

Kenya's early commitment to sustainable healthcare practices positions it well to address this issue and lead the way in demonstrating how countries can mitigate healthcare-related emissions without compromising development goals. Understanding the correlation between countries' Universal Health Coverage Service Coverage Index and their capacity to implement sustainable healthcare policies is crucial. Countries with higher UHC scores often benefit from more established healthcare infrastructure, stronger governance, and greater financial capacity, potentially facilitating the rollout of low-emission and climate-resilient healthcare strategies. However, countries with lower UHC coverage, such as many LMICs, may possess a unique opportunity: the potential to integrate sustainability principles from the outset as they expand services. This could allow them to leapfrog carbon-intensive healthcare trajectories traditionally followed by high-income countries. Recognising and leveraging this dynamic enables the tailoring of strategies that simultaneously strengthen healthcare access and embed sustainability. For Kenya, this could align its universal health access ambitions with climate goals, ensuring a development trajectory that is both equitable and climate resilient.

Finally, the paper's discussion of financing models and governance mechanisms highlights the need for strong cross-sectoral collaboration and clear financial pathways to support healthcare decarbonisation. Kenya's commitment to a net-zero healthcare system could be strengthened by enhancing governance structures and securing international financial and technical support. Partnerships with global health organizations, such as WHO, will be crucial in providing the resources and expertise necessary to achieve these ambitious targets.

This paper underscores the importance of developing robust, transparent, and outcome-oriented indicators for tracking progress towards sustainable healthcare systems. For Kenya, the lessons drawn from global efforts provide a valuable framework for refining its healthcare system's transformation. By addressing gaps in data, strengthening healthcare's integration into national climate strategies, and leveraging international financing, Kenya can set a powerful example of how to successfully transform to a net-zero healthcare system that is both sustainable and resilient to the impacts of climate change.

Chapter 6: Mitigation Interventions in LMIC Healthcare Systems

6.1 Introduction

The protocol and systematic review presented in this chapter serve as a foundational element of the thesis, identifying evidence-based interventions that reduce GHG emissions in healthcare systems, particularly within LMICs. LMICs face distinct challenges in balancing their healthcare development needs with climate goals.

This review was conducted to evaluate and summarize the current evidence on GHG mitigation interventions in LMIC healthcare systems. The focus is on identifying actionable interventions across critical areas such as energy, waste management, healthcare operations, and building design, with an emphasis on understanding their effectiveness, feasibility, and co-benefits. Importantly, the review also considers how these interventions interact with climate adaptation strategies where reported, given the heightened vulnerability of LMICs to climate change impacts.

By systematically analysing available data, the review seeks to shed light on existing evidence and gaps, as well as contribute to the growing body of knowledge on sustainable healthcare practices in LMICs, aligning with global efforts such as the COP26 Health Programme.

6.2 Aims and Objectives

The aim of this chapter is to conduct a systematic review of peer-reviewed literature to identify GHG mitigation interventions within healthcare systems in LMICs, providing evidence-based insights that inform pathways toward achieving net-zero healthcare systems. As LMICs face unique challenges in addressing climate change due to their geographical, economic, and infrastructural contexts, this review is critical for identifying practical, scalable, and context-specific strategies that contribute to global climate goals while also considering healthcare and adaptation needs.

The objectives of the review are:

1. To identify the current evidence on interventions towards GHG mitigation in healthcare systems in LMICs.
2. To identify practical and theoretical examples of mitigation interventions across key areas such as healthcare operations, energy use, and supply chains, exploring their potential to reduce GHG emissions in LMIC contexts.
3. To examine how these interventions interact with climate change adaptation efforts, identifying synergies, co-benefits, conflicts, or trade-offs that may arise when implementing mitigation strategies alongside adaptation measures.

4. To explore the contextual variability of these interventions across different LMIC settings, highlighting which aspects of mitigation strategies are applicable universally and which require local adaptation based on specific healthcare, environmental, and socio-economic conditions.

By addressing these objectives, the systematic review aims to support the development of comprehensive, actionable strategies for reducing GHG emissions in LMIC healthcare systems.

6.3 Research Paper Cover Sheet

SECTION A – Student Details

Student ID Number	2100667	**Title**	Dr
First Name(s)	Iris Martine		
Surname/Family Name	Blom		
Thesis Title	PhD – Epidemiology & Population Health		
Primary Supervisor	Dr Sarah Whitmee		

SECTION B – Paper already published

Where was the work published?	Wellcome Open Research		
When was the work published?	12^{th} of June, 2023		
Have you retained the copyright for the work?*	**Yes**	Was the work subject to academic peer review?	**Yes**

*If yes, please attach evidence of retention. If no, or if the work is being included in its published format, please attach evidence of permission from the copyright holder (publisher or other author) to include this work.

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	IMB conceptualized and designed the protocol, including the development of the research questions, methodology, and systematic review framework. IMB led the drafting of the original manuscript, incorporating feedback and suggestions from all authors. All authors contributed by reviewing and refining the draft to enhance clarity and accuracy. SW and AH served as supervisors, providing oversight and guidance throughout the conceptualization, methodology design, and manuscript preparation phases.

SECTION E

Student Signature	IBB.
Date	10/12/2024

Supervisor Signature	SWhitmee
Date	16/12/2024

Wellcome Open Research

6.4 A systematic review protocol for identifying the effectiveness of greenhouse gas mitigation interventions for healthcare systems in low- and middle-income countries

Blom IM, Asfura JS, Eissa M et al. A systematic review protocol for identifying the effectiveness of greenhouse gas mitigation interventions for healthcare systems in low- and middle-income countries [version 2; peer review: 3 approved, 3 approved with reservations]. Wellcome Open Res 2023, 7:202 (https://doi.org/10.12688/wellcomeopenres.18005.2) (112)

Corresponding Author: Iris Martine Blom

Competing Interests: No competing interests were disclosed.

Grant Information: This work was supported by Wellcome (EPPHZT91/10, to SW and AH; a Pathfinder Initiative grant [221284]); IMB declares having received three partial grants for her studies. A Prince Bernhard Culture Fund grant number 40037327 was awarded on 15 September 2021; Stichting VSBFonds grant number VSB.21/00168 was awarded on 17 May 2021; dr. Hendrik Mullerfonds without grant number was awarded on 9 December 2021. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

First Version Published: 04 Aug 2022, **7**:202 (https://doi.org/10.12688/wellcomeopenres.18005.1)
Latest Version Published: 12 Jun 2023, **7**:202 (https://doi.org/10.12688/wellcomeopenres.18005.2)

[1] Evidence of retention of copyright.

Abstract

Background: Climate change is predicted to be our century's most significant health threat. In 2021, 46 countries committed to environmentally sustainable low carbon healthcare systems. Of those, 34 were from low- and middle-income countries (LMICs). Currently, health systems are responsible for 4.4% of global greenhouse gas (GHG) emissions, with health systems in high-income countries (HICs) contributing the largest proportion to the sector's GHG emissions. However, future increases are predicted in LMICs in the absence of robust GHG mitigation. This systematic review aims to identify evidence-based GHG mitigation interventions to guide the transformation of healthcare systems towards net zero, specifically in LMICs. Additionally, potential synergies between interventions that aid adaption to climate change and mitigate GHG emissions will be investigated.

Methods: This protocol will follow the 'Preferred Reporting Items for Systematic review and Meta-Analysis Protocols (PRISMA-P) checklist of recommended items to address in a systematic review protocol'. A comprehensive search will be conducted on electronic databases identified as relevant. Search terms were identified to capture all relevant peer-reviewed, primary research published between 1990 and 2022. The risk of bias will be assessed, and the quality of evidence graded. The eventual narrative synthesis will feed into a theory of change framework on GHG mitigation of healthcare systems in LMICs.

Discussion: This systematic review will synthesise the existing evidence around GHG mitigation interventions across all scopes of emissions, including scope 1 (healthcare operations), scope 2 (energy), and scope 3 (supply chains). It can be used to inform recommendations on how healthcare systems in LMICs can reduce emissions while prioritising which actions to take to gain the most significant reductions in GHG emissions, considering ease of implementation, scope and cost. Finally, this can catalyse further research in this area which is urgently needed.

Amendments from Version 1

Following the reviewers' valuable feedback, several amendments have been made to our manuscript to enhance its clarity and methodology. Firstly, the critical appraisal tool intended for individual articles was revised. Originally, we planned to use the Joanna Briggs Institute (JBI) Critical Appraisal Tools, but given the non-clinical, diverse, and policy-focused nature of the interventions in the included articles, these tools were deemed inappropriate. In response, and in consultation with experts, we developed a custom appraisal tool better suited for our specific research needs. Secondly, we revised the introduction section to clarify a particular sentence and enhance its understanding. Thirdly, to ensure a comprehensive review, we have adjusted the timeline of our study to include articles published up until March 2023. Lastly, we have elaborated on the rationale behind our selection of the ten databases, providing an explanation for each and detailing their individual contributions to our study.

6.4.1 Introduction

Without action to reduce global greenhouse gas (GHG) emissions, climate change is predicted to be the biggest threat to global public health in the 21st century due to many direct and indirect health effects, including extreme weather, the spread of vector-borne diseases, lack of access to clean water and mental health impacts (19). Although healthcare systems will have to deal with the health impacts of this looming public health crisis, they are also responsible for 4.4% of GHG emissions globally, thereby contributing to it (23). At the United Nations Framework Convention on Climate Change 26th Conference of Parties (UNFCCC COP26) in November 2021, 46 countries committed to a transition to sustainable, low carbon health systems defined by the WHO as systems that improve, maintain or restore health while minimising negative impacts on the environment and leveraging opportunities to restore and improve it, for the benefit of the health and well-being of current and future generations (5,25). Furthermore, 14 countries committed to achieving net-zero health systems between 2030 and 2050 (25). Among the countries pledging, many were low- and middle-income countries (LMICs), namely 34 and 11, respectively (25). Even though healthcare systems in LMICs have lower GHG emissions than high-income countries (HICs), as healthcare systems in many LMICs advance, an increase in these emissions is expected unless action is taken to identify, quantify and reduce them. (25). Even though healthcare systems in LMICs have lower GHG emissions than high-income countries (HICs), as healthcare systems in many LMICs advance, an increase in these emissions is expected unless action is taken to identify, quantify and reduce them. In addition, LMICs are expected to experience the negative impacts on health from climate change both earlier and most severely due to geographical location and exposure, whilst being the least equipped to deal with them because of lack of resources to cope and recover (36). It is vital to ensure that any adaptation actions undertaken by healthcare systems do not also exacerbate the sector's GHG emissions, locking them into higher-emission trajectories. However, there is a current gap in knowledge on transforming healthcare systems in LMICs to adapt to climate change while transitioning to low carbon. Therefore, to bring the COP26 commitments to reality, evidence-based GHG mitigation interventions towards more sustainable healthcare systems in LMICs must be identified across all scopes of emissions including scope 1 (healthcare operations), scope 2 (energy), and scope 3 (supply chains). This article will describe a systematic review protocol towards this aim following the Preferred Reporting Items for Systematic review and Meta-Analysis Protocols (PRISMA-P) checklist of recommended items toa address in a systematic review protocol (113).

Aims, objectives and research questions

This systematic review aims to identify practical and theoretical GHG mitigation interventions for healthcare in LMICs. The following research questions guide this study and summarise its objectives:

1) What practical or theoretical GHG mitigation interventions across healthcare operations, energy, and supply chains can be identified that decrease greenhouse gas emissions in the context of low- and middle-income countries?

2) What are the implementation processes to reach the desired outcomes, including goal setting, determining roles and responsibilities, delegating tasks, execution and monitoring of tasks, and the evaluation; and what are enablers of and barriers to implementation?

3) How do the GHG mitigation interventions interact with actions to promote adaptation and resilience, including possible synergies, co-benefits, conflicts or trade-offs?

4) How do these interventions vary contextually, and what aspects are applicable across different contexts? Contextual variables include the economic context (*e.g.* economic growth, unemployment rate), the socio-cultural context (*e.g.* social values, religion), and the political-legal context (political stability, legal framework).

6.4.2 Methods

A systematic review will be undertaken to collate, critically appraise and synthesise existing evidence on practical or theoretical GHG mitigation interventions across healthcare operations, energy and supply chains in the context of LMICs. Various aspects will be explored, including the implementation process. Furthermore, the relation of these interventions with adaptation will be analysed where reported. Within the following paragraphs, different aspects of the methodology will be discussed.

Eligibility criteria

Table 9 shows the areas considered in screening the articles and the related inclusion and exclusion criteria.

Table 9 Inclusion and exclusion criteria of the systematic review.

Area	Criteria
Publication type	Only peer-reviewed primary research will be included, including analytical cross-sectional studies, case-control studies, case reports, cohort studies, diagnostic test accuracy studies, and randomised controlled trials. Any other articles, such as protocols, guidelines, (systematic) reviews, perspectives, commentaries, or editorials, will be excluded. However, relevant reviews will be screened for primary references.
Language	Articles written in English, Spanish, Italian, Portuguese, French and Arabic will be included for screening. All other languages will be excluded.
Context	Only articles will be included from which the context of the research is in LMICs. It will be excluded if the research context is in HICs, or general and not specific to a country, group of countries or region.
Topic	Only articles will be included that mention any theoretical or practical GHG mitigation intervention across healthcare operations, energy and supply chains towards a decrease of GHG emissions. Articles that do not report such a mitigation intervention will be excluded.
Metrics	Only articles that report a quantified change in GHG emissions from the intervention as mentioned above will be included. If a measurable outcome is not reported, the article will be excluded.
Timeline	Only articles published between 1990 and 17 March 2023, will be included. 1990 is chosen as a starting point for the inclusion of articles since it is the start of a significant research movement supporting the climate change and health connection (114). Articles that were written before 1990 are excluded.

Information sources

This systematic review will make use of electronic databases as information sources. The electronic databases that have been evaluated to be relevant and intended to be searched for the systematic review are Ovid MEDLINE, Ovid EMBASE, Global Health, SCOPUS, Web of Science, AfricaPortal, Africa-Wide Information, LILACS, Global Index Medicus, GreenFILE and ELDIS. The first five databases provide access to healthcare and global health-related literature across different indices and the latter five specialize in LMIC-specific literature across different regions.

Search strategy

A broad and sensitive search strategy has been designed, which will be repeated across the identified relevant databases. Table 10 includes a specific example of the search strategy that has been drafted for the electronic database Ovid MEDLINE.

Table 10 Search strategy of the systematic review drafted for the electronic database Ovid MEDLINE.

Search line	Content of search
1	(netzero or net zero).mp.
2	Carbon Footprint/
3	Greenhouse Effect/
4	exp Climate Change/
5	(carbon or CO2 or methane or CH4 or nitrous oxide or nitrus oxide or N2O or hydrofluorocarbon* or HFC* or perfluorocarbon* or PFC* or F-gas or fluorinated gas or sulfur hexafluoride or SF6 or nitrogen trifluoride or NF3 or emission* or greenhouse or GHG or climat* change* or global warming or footprint or eco-friendly or climate friendly or environment* friendly or eco-efficient or environment* responsible or environment* sound or energy-efficient or energy-saving or green initiative* or environmental impact or short-lived climate pollutant or black carbon).mp.
6	(environment* and sustainab*).mp.
7	1 or 2 or 3 or 4 or 5 or 6
8	exp "Delivery of Healthcare"/
9	exp Health Facilities/
10	(health system* or health-care or health-care or health sector or health supply chain* or health service* or delivery of health or health delivery or health facilit* or health cent* or hospital or hospitals or clinic or clinics or emergency room* or operat* room* or operat* theat* or patient care or ward* or urgent care or primary care or secondary care or tertiary care or quaternary care or telemedicine or medical cent* or diagnostic care or rehabilitative care or preventative care or palliative care or home care).mp.
11	8 or 9 or 10
12	7 and 11
304	or/13-303 [ALL LOW AND MIDDLE-INCOME COUNTRIES (expert search)]
305	12 and 304
306	limit 305 to yr="1990 - 2022"

Study records

Data management. The references of the articles identified through the search strategies on the relevant electronic databases will be uploaded to the software Rayyan QCRI which allows simultaneous collaboration between all screeners. The inclusion and exclusion criteria will be applied in every step of the screening process as outlined below. Citation, abstracts and full articles will be uploaded to be used at the different, relevant screening steps. Every screener unfamiliar with the software will receive a training session from the first author to gain familiarity with its use.

Selection process. After removing duplicates, papers will be initially screened by title, following Mateen *et al.*'s recommendations to improve the screening process's efficiency (115). Then, articles will be screened by abstract and shortlisted articles will be screened through full-text analysis against eligibility criteria using the software Rayyan QCRI. At least two reviewers will perform each screening step, and any disagreements regarding inclusion will be discussed. If there is no consensus between two screeners, a third author will be consulted until an agreement is reached.

Data collection process. Data from eligible articles will be collated independently using a tailored data collection form with a detailed instruction manual trialled before use. As part of the pilot phase, four reviewers will extract data from the same five articles, after which the form will be discussed and adjusted based on experience and feedback. This will also contribute to improved consistency of data collection between different reviewers.

Data items. Table 11 shows an overview of the data items for which data will be sought.

Table 11 List of variables for which data will be sought as part of the systematic review.

Data item	Definition
Article identifiers	Basic identifiers of the article will be extracted, including name, authors, date, journal, article type and article design.
Methodology	The methodology used in the article will be identified and extracted.
Geographical scale	The geographical scale, namely if it was conducted at the local, regional, national or international level.
Location	The article's location will be extracted by identifying the relevant town/city, region, country and/or countries where the research was conducted.
Emission scope	If a particular emission scope was researched, this will be extracted, and it will be identified whether the research interacts with scope 1 (healthcare operations), scope 2 (energy), scope 3 (supply chains) or multiple scopes.
Part of the healthcare system	If a particular aspect of the healthcare system was researched, this will be extracted, (*e.g.* a primary healthcare clinic, a rural hospital).

Data item	Definition
GHG mitigation intervention(s)	The GHG mitigation intervention(s) are the interventions that lead towards a decrease in GHG emissions, including its details.
Measurable impact of the GHG mitigation intervention(s)	The quantified impact of the identified intervention(s) of the research on mitigation, including a specification of GHG or GHG equivalent and whether it is a practical or theoretical impact.
Implementation process	The implementation process will be extracted, including enablers and barriers that were faced and how these were or will be approached.
Implementation timeline	The timeline around the implementation will be extracted in terms of length around the implementation process.
Economic analysis	If included, the economic aspects such as cost effectiveness, cost benefit or cost consequences will be extracted.
Linkage with adaptation or resilience	If the intervention is directed at both mitigation and adaptation or specifically resilience is described, this will be extracted. These interactions can be synergies, co-benefits, conflicts, trade-offs or co-harms (62).
Health impact	If the intervention has a measured impact on health outcomes or exposures, this will be extracted.
Funding source	The source of funding for the authors will be extracted to identify potential conflicts of interest.
Conflicts of interest	Further potential conflicts of interest will be extracted, including relationships with relevant parties other than financial relationships.
Summary	Each article will be summarised in under 100 words on the extraction sheet.

Outcomes and prioritisation

The primary outcome is the identification of GHG mitigation interventions undertaken with the aim of reducing GHG emissions within healthcare systems in the context of LMICs and the quantified emission reductions associated with each mitigation action. The main objective of the research is to identify these interventions as there is a lack of overview of evidence-based interventions towards environmental sustainability in this context.

Secondary outcomes include identifying links with climate change adaptation actions, including climate resilience, the emission scope of the intervention, and the implementation process, including the timeline and enablers or barriers faced. The collection of other secondary outcomes is pertinent to inform policy recommendations regarding which interventions will be easiest to implement and in which context, and where actions can be scaled or translated between different contexts.

Risk of bias in individual studies

For each included article, the risk of bias will be assessed using specifically designed questions applicable across different study types using a simple judgement of low risk, high risk of unclear risk on different axes as endorsed by the Cochrane Collaboration. These questions span different areas including reporting bias, and clarity in the definitions, methods, results and discussion. An assessment will be 'unclear' if relevant information is missing from the assessed article. The assessments will be made independently by at least two authors, after which they will be compared. Any disagreements will be discussed, and a third author will be consulted if no consensus is found. The risk of bias in each included article will be reported in the eventual manuscript of the systematic review (116).

Data synthesis

It is unlikely that extracted data from included articles in this systematic review will be appropriate for quantitative synthesis because of the diversity of contexts, types and scale of intervention and possible outcomes. A narrative synthesis will present the identified data of the included articles. A table will be provided to summarise the included articles and their findings to facilitate this synthesis. Findings will be grouped by type of intervention where possible. Through narrative analysis, these findings will be further explored and compared between articles. Furthermore, the identified data will feed into a theory of change theoretical framework on GHG mitigation interventions for healthcare systems in LMICs.

Meta-bias(es)

Reporting bias will be investigated by recording whether included articles are proceeded by a protocol published before the article's publication. If selective reporting of the results is identified while comparing the protocol to the eventual article, this will be reported.

Confidence in cumulative evidence

To assess the overall strength of the body of evidence created from the synthesis of the included articles, the evidence will be graded using the approach developed by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) Working Group. This tool includes the domains 'Risk of Bias', 'Imprecision', 'Inconsistency', 'Indirectness', and 'Publication Bias'. The eventual evidence will be graded using four different categories. As described by Siemieniuk *et al.*, these categories are that the certainty of the evidence is 1) very low (the true effect is probably very different from the estimated effect), 2) low (the true effect might be very different from the estimated effect), 3) moderate (the authors believe that the true effect is probably close to the estimated effect) or 4) high (the authors are confident that the true effect is similar to the estimated effect) (117).

Dissemination of information

The findings and outcomes of this study will be published in peer-reviewed scientific journals and presented at conferences and meetings related to planetary health, climate change and health, and health systems. The findings will also be disseminated to the broader public using a social media dissemination strategy.

Amendments

This protocol is the first publication. In case of important protocol amendments following review, they will be tracked, dated and published as such on Wellcome Open Research.

6.4.3 Discussion

Climate change is expected to have a major impact on health (19). While healthcare systems need to become prepared to deal with these health effects, they must also move to sustainable practice to halt their contribution to this health emergency. Most countries committed to sustainable healthcare systems at COP26 are LMICs, yet there is a lack of structured evidence to inform policy (25). Furthermore, health system research rarely considers the interaction between these GHG mitigation interventions and adaptation, which is especially important in vulnerable locations. To respond to this emergency, this protocol describes the approach to a systematic review which will provide an overview of the current existing peer-reviewed evidence on interventions towards GHG mitigation of healthcare systems in LMICs. To the authors' knowledge, this will be the first attempt to create this overview. Given the urgency around climate change and its impact on health, it is also a timely one. It will provide the first step in the direction of evidence-based guidance toward GHG mitigation of healthcare systems in LMICs.

Several potential sources for biases for this review, common to this methodology, could impact the quality of the evidence presented in the eventual synthesis. First, the risk of publication bias must be considered for three reasons. The first reason is that GHG mitigation research is a recent area of research that is rapidly developing and expanding, considering the topic's urgency. It could be regarded as likely that not all successful mitigation interventions are indeed published in peer-reviewed journals due to the perceived lengthy publication process. The second reason is that interventions with a measured impact are more likely to be published than those with lesser or no significant impact on decreasing GHG emissions. The final reason that might contribute to publication bias is that certain areas of mitigation, such as those that produce scope 1 and 2 emissions, might receive more research funding than emissions from scope 3. The publication bias will be assessed as part of the synthesis during the systematic review.

A second potential bias to consider is the reviewer bias which can be caused by varied interpretations of inclusion criteria by different reviewers. To reduce this risk of bias, all reviewers will be trained and familiarized with the program before starting. Furthermore, each article will be screened by at least two reviewers during every step of article screening. Any disputes will be discussed, and a third reviewer will be involved if no consensus can be reached.

Finally, a third potential bias to be aware of during the process of this systematic review is the existence of inconsistent terms and definitions. In the relatively young area of research into GHG mitigation, terms are used interchangeably and often not clearly defined. To reduce this risk of bias, the search strategy is broad and includes a wide range of terms that can be relevant to the research topic.

As outlined above, the search strategy aims to be comprehensive. Therefore, a challenge during the synthesis might be that heterogeneity of reporting styles is observed between the selected articles: for example, using various metrics and units across contexts. The authors will aim to translate heterogeneous results to allow for quantitative synthesis and interpretation, where possible.

In conclusion, this protocol describes a systematic review methodology that aims to provide an urgently needed overview of interventions toward GHG mitigation in healthcare systems. Furthermore, any connections with climate change adaptation by healthcare systems will also be synthesised. Through that, the review will have the opportunity to contribute to ongoing GHG mitigation and adaptation efforts. Furthermore, doing so will also contribute to identifying areas where more research is needed to guide future efforts in an evidence-based manner.

Data availability

Underlying data

No data are associated with this article.

Reporting guidelines

Medicine: PRISMA-P Checklist for 'A Systematic Review Protocol for Identifying the Effectiveness of Greenhouse Gas Mitigation Interventions for Healthcare Systems in Low- and Middle-Income Countries', https://doi.org/10.17037/DATA.00002988

6.5 Research Paper Cover Sheet

SECTION A – Student Details

Student ID Number	2100667	**Title**	Dr
First Name(s)	Iris Martine		
Surname/Family Name	Blom		
Thesis Title	PhD – Epidemiology & Population Health		
Primary Supervisor	Dr Sarah Whitmee		

SECTION B – Paper already published

Where was the work published?	Bulletin of the World Health Organization		
When was the work published?	1st of March, 2024		
Have you retained the copyright for the work?*	**Yes**	Was the work subject to academic peer review?	**Yes**

*If yes, please attach evidence of retention. If no, or if the work is being included in its published format, please attach evidence of permission from the copyright holder (publisher or other author) to include this work.

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper.	IMB played a central role in the conceptualization, design, and execution of this systematic review, including the development of the research questions, selection criteria, and methodology. IMB led the systematic literature search and data extraction process. IMB, ME, JCM and HS screened the records. IMB synthesized and analysed the findings and drafted the manuscript. All authors contributed through reviewing, refining, and ensuring methodological rigor. SW and AH acted as supervisors, providing guidance and support throughout the research and writing processes.

SECTION E

Student Signature	IBB.
Date	10/12/2024

Supervisor Signature	SWhitmee
Date	16/12/2024

Bulletin of the World Health Organization

6.6 Effectiveness of greenhouse gas mitigation intervention for health-care systems: a systematic review

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 Mar 1;102(3):159-175B. doi: 10.2471/BLT.23.290464. Epub 2023 Jan 31. PMID: 38420573; PMCID: PMC10898283. (45)

Correspondence to Iris Martine Blom (email: iris.blom@lshtm.ac.uk).

Received 2023 Jun 27; Revised 2023 Oct 9; Accepted 2023 Nov 6.

[2] Evidence of retention of copyright.

Abstract

Objective

To identify evidence-based interventions that reduce greenhouse gas emissions in health-care systems in low- and middle-income countries and explore potential synergies from these interventions that aid climate change adaptation while mitigating emissions.

Methods

We systematically searched 11 electronic databases for articles published between 1990 and March 2023. We assessed risk of bias in each article and graded the quality of evidence across interventions in health-care operations, energy and supply chains.

Findings

After screening 25 570 unique records, we included 22 studies published between 2000 and 2022 from 11 countries across six World Health Organization regions. Identified articles reported on interventions spanning six different sources of emissions, namely energy, waste, heating and cooling, operations and logistics, building design and anaesthetic gases; all of which demonstrated potential for significant greenhouse gas emission reductions, cost savings and positive health impacts. The overall quality of evidence is low because of wide variation in greenhouse gas emissions measuring and reporting.

Conclusion

There are opportunities to reduce the greenhouse gas emissions from health-care systems in low- and middle-income countries, but gaps in evidence were identified across sources of emissions, such as the supply chain, as well as a lack of consideration of interactions with adaptation goals. As efforts to mitigate greenhouse gas intensify, rigorous monitoring, evaluation and reporting of these efforts are needed. Such actions will contribute to a strong evidence base that can inform policymakers across contexts.

6.6.1 Introduction

In the absence of actions to rapidly reduce global greenhouse gas emissions, climate change is predicted to be the biggest threat to human health in the 21st century. Direct and indirect health effects from climate change include exposure to extreme weather, undernutrition, the spread of vector-borne diseases, lack of access to clean water, and mental health effects (118). Health-care systems are facing the challenge of treating these impacts, but they also emit about 4.4% of global greenhouse gas emissions with projected increases in emissions (23,92). Since the United Nations Framework Convention on Climate Change 26th Conference of Parties in 2021 (UNFCCC COP26), 75 (54 low- and middle-income) countries have committed to transitioning to sustainable, low-carbon health systems, with 29 (22 low- and middle-income) countries aiming to reach net-zero emissions in their health-care systems (5,25).

Health-care systems in low- and middle-income countries emit lower per capita greenhouse gas emissions compared to those in high-income countries (23,92), but as health-care systems in many low- and middle-income countries advance, an increase in emissions is likely unless steps are taken to identify, measure and control them. Low- and middle-income countries are also predicted to experience the harmful effects of climate change with greater intensity and at an earlier stage due to their geographical location, exposure and vulnerability, while being less equipped to handle these effects due to a shortage of resources to cope and recover (16,36). Any adaptation actions undertaken by health-care systems should not exacerbate the health sector's greenhouse gas emissions, creating negative feedback loops and locking them into higher emission trajectories.

To fulfil the commitments undertaken at, and since, COP26, it is necessary to identify evidence-based strategies for reducing the greenhouse gas emissions of health-care systems in low- and middle-income countries (119). We undertook a systematic review to identify modelled and implemented greenhouse gas mitigation interventions and their relationship with adaptation, applicable within the context of low- and middle-income countries, to provide evidence on which interventions are most feasible to implement and where actions can be scaled to provide significant reductions in emissions within health-care facilities and across the sector.

6.6.2 Methods

We followed a protocol published on 4 August 2022 following the Preferred reporting items for systematic review and meta-analysis protocols checklist (online repository) (112,113,120). The protocol underwent one methodological amendment, namely the removal of the Joanna Briggs Institute Critical Appraisal Tools for evaluation, as they were not relevant to the types of interventions we analysed (116). We searched the database Ovid MEDLINE®, Ovid Embase®, Global Health, Web of Science, Africa-Wide Information, LILACS, Global Index Medicus, ELDIS, SCOPUS, AfricaPortal and GreenFILE on 17 March 2023. We predetermined the inclusion and exclusion criteria, which are detailed in Box 1.

Publication types

Peer-reviewed primary research including analytical cross-sectional studies, case-control studies, case reports, cohort studies, diagnostic test accuracy studies, and randomized controlled trials. We excluded other types of publications, such as protocols, guidelines, (systematic) reviews, perspectives, commentaries or editorials. We screened relevant reviews for primary research references.

Languages

No restriction.

Context

Findings of research in one or more low- and middle-income countries.

Topic

Any implemented or modelled greenhouse gas mitigation intervention across health-care operations, energy and supply chains.

Outcome

Reporting a quantified change in greenhouse gas emissions from the intervention.

Timeline

Published between 1990 and 17 March 2023. Year 1990 was chosen as a starting point for the inclusion of articles, as a significant number of publications supporting a connection between climate change and health started to appear in the early 1990s.[a]

Box 1 Inclusion criteria for articles on greenhouse gas mitigation interventions for health-care systems.

[a](114,121)

Search strategy

Our search strategy consisted of three main elements: (i) the health-care system; (ii) greenhouse gases; and (iii) low- and middle-income countries (Box 2 and online repository)(Appendix VII)(112,122). To further structure our strategy, we devised a conceptual theory of change framework. We used approaches outlined by the United Nations Sustainable Development Group Latin America and the Caribbean and the New Philanthropy Capital and insights from a previous publication to develop this framework (31,123). The framework is defined in (Box 3; available at: https://www.who.int/publications/journals/bulletin/) and detailed descriptions of each section can be found in our online repository (Appendix VII)(122).

1: (netzero or net zero).mp.

2: carbon footprint/

3: greenhouse effect/

4: exp climate change/

5: (carbon or CO2 or methane or CH4 or nitrous oxide or N2O or hydrofluorocarbon* or HFC* or perfluorocarbon* or PFC* or F-gas or fluorinated gas or sulfur hexafluoride or SF6 or nitrogen trifluoride or NF3 or emission* or greenhouse or GHG or climate change* or global warming or footprint or eco-friendly or climate friendly or environment* friendly or eco-efficient or environment* responsible or environment* sound or energy-efficient or energy-saving or green initiative* or environmental impact or short-lived climate pollutant or black carbon).mp.

6: (environment* and sustainable*).mp.

7: 1 or 2 or 3 or 4 or 5 or 6

8: exp "delivery of healthcare"/

9: exp health facilities/

10: (health system* or health care or healthcare or health sector or health supply chain* or health service* or delivery of health or health delivery or health facility* or health cent* or hospital or hospitals or clinic or clinics or emergency department* or operating* room* or operating* theatre* or patient care or ward* or urgent care or primary care or secondary care or tertiary care or quaternary care or telemedicine or medical cent* or diagnostic care or rehabilitative care or preventative care or palliative care or home care).mp.

11: 8 or 9 or 10

12: 7 and 11

304: or/13–303 [ALL LOW AND MIDDLE-INCOME COUNTRIES (expert search)]

305: 12 and 304

306: limit 305 to yr = "1990–2023"

Box 2 Search strategy, search line and content of search parameters to identify articles on greenhouse gas mitigation interventions for health-care systems.

Problem statement

Climate change is and will continue to affect human health through many different direct and indirect health outcomes. Less well-known is that health-care systems themselves contribute 4.4 % of global greenhouse gas emissions. Health-care systems, referring to the institutions, people and resources involved in delivering health care to individuals, need to implement mitigation interventions to ensure an adequate, effective and systematic response to these health effects while aiming for synergies or co-benefits with adaptation and, specifically, climate resilience. Since UNFCCC COP26, countries have committed to a more environmentally sustainable, low-carbon health-care system – out of which the majority are low- and middle-income countries. There is a lack of robust evidence guiding efforts towards environmentally sustainable health-care systems, particularly in low- and middle-income countries.

Impact and aim

If measures are taken to mitigate greenhouse gas emissions produced by health-care systems in low- and middle-income countries effectively, then:

1. the health-care systems could advance while contributing less to climate change;

2. a knock-on effect could potentially lead to a reduction in climate risk for health due to synergies or co-benefits for adaptation; and

3. raising awareness can indirectly help achieve local and national climate goals. This happens as people, communities, and other sectors, including high-income countries, become more informed about how climate change affects health. This knowledge can lead to better climate actions as well as improving climate plans by combining them with health strategies. Furthermore, the health-care sector can significantly guide and shape the actions of these various groups.

Delivery assumptions:

1. Relevant interventions can be identified in the literature

2. Sufficient interest and dedication from policymakers

3. Skills, abilities and resources are present.

Assumptions about effects:

1. Improved health outcomes through interventions

2. Potential positive knock-on effect on adaptation

3. Potential indirect effect on awareness and local and national climate action.

Possible unintended consequences

1. Conflict or trade-off mitigation intervention with adaptation or prioritization mitigation over adaptation when there is an urgent need to adapt.

Theory of change process assumptions

1. Robust data and experts consulted

2. Theory of change is a living document.

Outcomes, outputs and potential risk and barriers

1. Reduction of greenhouse gas emissions produced by health-care operations (emission scope 1).

Key Indicator: percent reduction in greenhouse gas emissions.

- Stimulate low carbon prescriptions
- Increase efficiency and minimize patient travel, that is, through strategic planning and multidisciplinary consults
- Transition to a health-care system of community-based health promotion and disease prevention with a prominent role of primary health care
- Shift towards higher usage of eHealth, including teleconsultations
- Stimulate the use of low carbon transport alternatives for operations, including low emission ambulances
- Health workforce barriers including lack of adequately trained health workers might prevent multidisciplinary consults, a transition to preventive, primary health care

- Lack of access to technology might prevent eHealth
- Soft issues such as lack of support and awareness among staff, open dialogue and proper infrastructure to implement change.

Note: Financial barriers or other accessibility barriers including patents might prevent low-carbon prescriptions or low-carbon transport alternatives.

2. Reduction of greenhouse gas emissions from energy used in health care (emission scope 2).

Key Indicator: Percent of reduction in greenhouse gas emissions.

- Transition to clean energy through renewable energy sources and low carbon grids
- Use of batteries to expand the renewable energy supply
- Use energy efficiently, such as light-emitting diode (LED) fixtures
- Soft issues, including lack of support and awareness among staff or suppliers, lack of open dialogue, and lack of proper infrastructure to implement change.

Note: Financial barriers or other accessibility barriers including lack of expertise might prevent a transition to clean and renewable energy, use of battery power energy efficient products such as LED lighting.

3. Reduction of greenhouse gas emissions of health-care supply chains (emission scope 3).

Key Indicator: Percent of reduction in greenhouse gas emissions.

- Reuse of medical devices and supplies
- Reduce the acquisition of non-reusables and high-emission alternatives and increase the use of low-emission alternatives
- Transition to a predominantly plant-based hospital menu with locally produced foods (e.g. for staff and visitors)
- Stimulate health and care workers and patients to minimize transport and, when necessary, use active transport or electric, shared vehicles
- Use low-emission alternatives for transportation and distribution
- Encourage low-emission travel options for business travels
- Procure from net-zero suppliers or suppliers with a strategy to move to net-zero
- Food system effects or food availability might prevent a transition to plant-based hospital menus with locally produced food
- Soft issues, including lack of support and awareness among staff or suppliers, lack of open dialogue, and lack of proper infrastructure to implement change.

Note: Financial barriers or technological limitations might prevent reuse of supplies, low-emission prioritization in acquisitions, low-emission alternatives for transportation or distribution, low-emission travel options, and procuring from net-zero suppliers.

4. Co-benefit or synergy of the mitigation intervention with actions contributing to climate change adaptation.

Key Indicator: Percent of reduction in loss of life or disability.

- Hospital-wide passive heating and cooling system
- Agriculture on hospital rooftops
- Soft issues, including lack of support and awareness among staff and/or leadership, lack of open dialogue, and lack of proper infrastructure to implement change.

Note: Financial barriers due to specified or allocated funding, lack of flexibility of funding and gaps in knowledge.

COP: Conference of Parties; LED: light-emitting diode; UNFCC: United Nations Framework Convention on Climate Change.

Note: Adapted from Rasheed et al., 2021.[a]

Box 3 Conceptual framework according to the theory of change on greenhouse gas mitigation interventions in health-care systems in low-and middle-income countries.

[a](31)

Selection process and data extraction

We uploaded records using Rayyan QCRI software (Rayyan, Cambridge, United States of America), and the aforementioned inclusion and exclusion criteria were applied throughout the screening process. Following published efficiency guidelines (115), we removed duplicates, screened titles and analysed abstracts and full texts against eligibility criteria using Rayyan QCRI. Two reviewers performed each step separately, after which any disagreements were discussed. If no consensus was reached, a third author was consulted for resolution. Two reviewers independently extracted all relevant data from eligible articles using a pre-tested form with detailed instructions (Box 4). This extracted data was used to generate a 100-word or less summary on the extraction sheet.

We assessed risk of bias using specifically designed questions intended to be applicable across different study types using a simple judgement of low risk, high risk or unclear risk on different axes as endorsed by the Cochrane Collaboration (124). Independent assessments were made by at least two authors.

We assessed the overall strength of evidence resulting from article synthesis using the Grading of recommendations assessment, development, and evaluation (GRADE) approach. The collated evidence was graded using four different categories: (i) very low (we believe the true effect is probably very different from the estimated effect); (ii) low (we believe the true effect might be very different from the estimated effect); (iii) moderate (we believe that the true effect is probably close to the estimated effect); or (iv) high (we are confident that the true effect is similar to the estimated effect) (117). We used GRADEpro Guideline Development Tool (McMaster University and Evidence Prime, Hamilton, Canada) for the analysis.

Article identifiers:

Basic identifiers including name, authors, date, journal, article type and article design

Methods:

Types of research methods used in the article

Geographical scale:

Whether the study was conducted at a local, regional, national or international level

Location:

Relevant town or city, region, country and/or countries where the research was conducted

Emission scope:

Health-care operations (scope 1), energy (scope 2), supply chains (scope 3)

Part of the health-care system:

A particular aspect of the health-care system such as a primary health-care facility or a rural hospital

Greenhouse gas mitigation intervention(s):

Intervention details that lead to a decrease in greenhouse gas emissions

Measurable effects of the greenhouse gas mitigation intervention(s):

Quantified effects of the identified intervention(s) on mitigation, including a specification of greenhouse gas or carbon dioxide equivalent and whether it was measured or modelled

Implementation process:

A description of the implementation process, including enablers and barriers and how these were approached

Implementation timeline:

Timeline of the implementation process

Economic analysis:

Any provided economic information such as cost–effectiveness, cost–benefit or cost consequences

Linkage with adaptation or resilience:

Whether the intervention was directed at both mitigation and adaptation or if resilience was described. These interactions can be synergies, co-benefits, conflicts, trade-offs or co-harms[19]

Health effects:

Measured effects on health outcomes or exposures

Funding source:

Source of funding for the authors

Conflicts of interest:

Further potential conflicts of interest, including relationships with relevant parties other than financial relationships

Box 4 Data extracted for each article identified in the systematic review on greenhouse gas mitigation interventions for health-care systems.

6.6.3 Results

Our search yielded 25 570 records. After removing duplicates and screening the titles, abstracts and full texts, 22 articles met the inclusion criteria (Figure 3) (125–146). The 22 studies were published between 2000 and 2022, with 77% (17) of studies published between 2016 and 2022, and 36% (eight studies) between 2020 and 2022. They cover 11 countries across all World Health Organization (WHO) regions, primarily in the Western Pacific Region (seven studies) and South-East Asia Region (seven studies). India is the most-reported country (six studies; Figure 4). Countries range from lower- to upper-middle-income countries, as per World Bank classification, with no low-income countries represented (26). Study settings vary from regional systems to urban areas, hospitals and rural centres (Table 12).

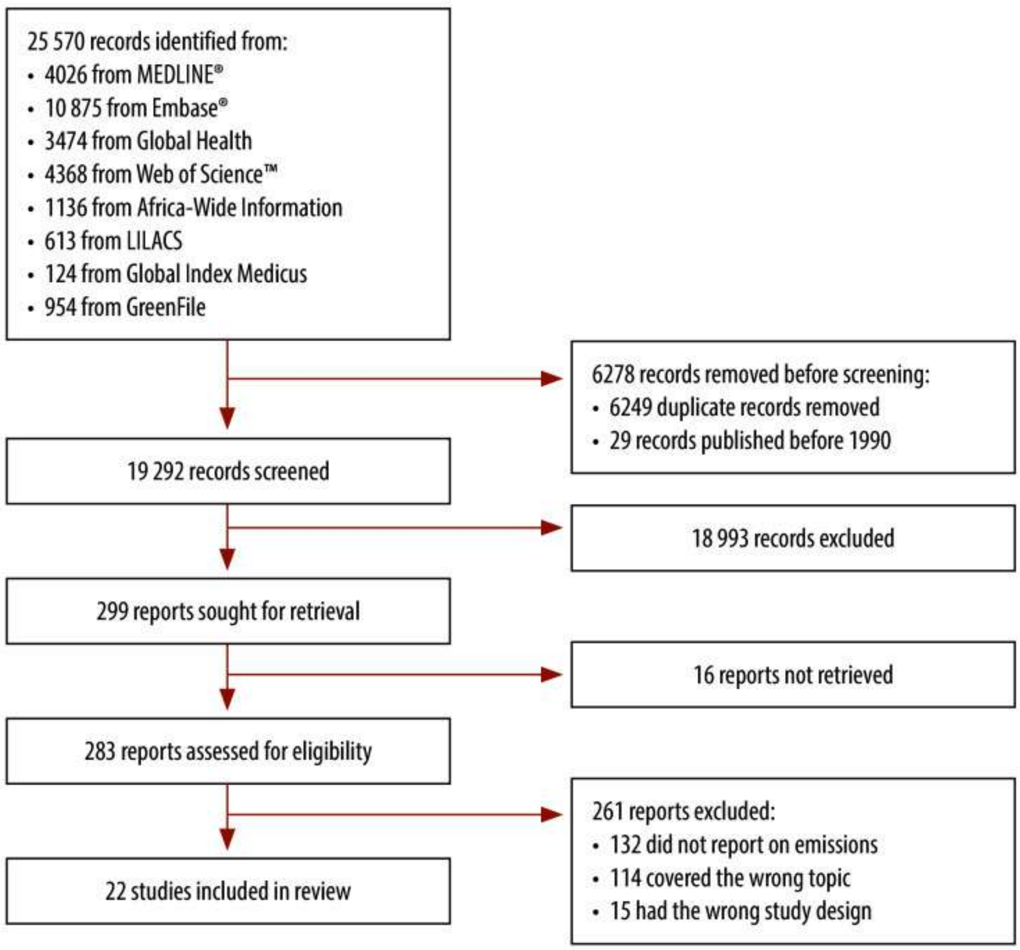

Figure 3 Flowchart of the selection of studies on greenhouse gas mitigation interventions for health-care systems.

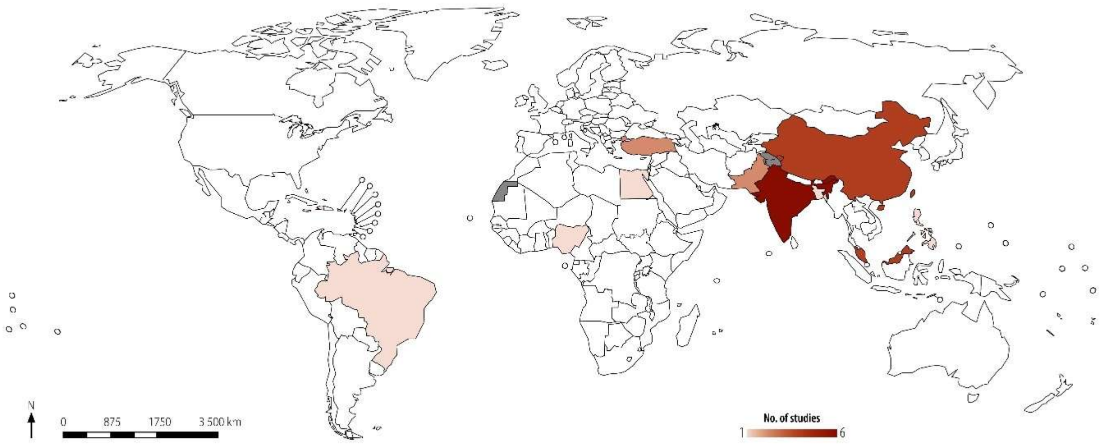

Figure 4 Geographical distribution of the included studies on greenhouse gas mitigation interventions for health-care systems.

Table 12 Detailed summary of included studies on greenhouse gas mitigation interventions for health-care systems.

Study	Study design	Year of intervention	Country, WHO region	Income level	Health system level	Study site(s)
Ahmadzadehtalatapeh & Yau, 2011 (135)	Analytical and modelling	NR	Malaysia, Western Pacific Region	Upper-middle-income	Hospital ward	One orthopaedic ward
Ali et al., 2016 (127)	Descriptive: cross-sectional	2014–2015	Pakistan, Eastern Mediterranean Region	Lower-middle-income	Hospital	Tertiary hospital
Chowdhury et al., 2021 (125)	Descriptive: case report	NR	Bangladesh, South-East Asia Region	Lower-middle-income	Health-care facility	One temporary rural health-care centre on an island
Ciplak, 2015 (128)	Descriptive: cross-sectional	NR	Türkiye, European Region	Upper-middle-income	Region within country	One region
Datta et al., 2016 (136)	Analytical: experimental	2015	India, South-East Asia Region	Lower-middle-income	Outpatient surgery	Paediatric eye examinations at one hospital
Duraivelu & Elumalai, 2021 (126)	Descriptive: case report	2019	India, South-East Asia Region	Lower-middle-income	Hospital	One urban hospital
Isa et al., 2016 (137)	Analytical and modelling	NR	Malaysia, Western Pacific Region	Upper-middle-income	Hospital	One university hospital
Khan et al., 2019 (129)	Descriptive: case series	2016–2017	Pakistan, Eastern Mediterranean Region	Lower-middle-income	Clinic	371 private clinics
Khor et al., 2020 (130)	Analytical: observational: case-control	2017	Malaysia, Western Pacific Region	Upper-middle-income	Hospital	One hospital
Lemence & Tamayao, 2021 (140)	Analytical and modelling	NR	Philippines, Western Pacific Region	Lower-middle-income	Health-care facility	One rural health-care facility
Liu et al., 2022 (131)	Analytical and modelling	2050	China, Western Pacific Region	Upper-middle-income	Health-care system	Hospitals, community health service centres,

Study	Study design	Year of intervention	Country, WHO region	Income level	Health system level	Study site(s)
						township health centres, and village clinics
Narang et al., 2017 (141)	Descriptive: case report	2015–2016	India, South-East Asia Region	Lower-middle-income	Clinical laboratory	One laboratory
Olatomiwa et al., 2018 (142)	Descriptive: case series	NR	Nigeria, African Region	Lower-middle-income	Clinic	Six rural clinics in six different regions
Paksoy et al., 2000 (143)	Descriptive: case report	NR	Türkiye, European Region	Upper-middle-income	Hospital	One university hospital
Panwar et al., 2013 (144)	Analytical and modelling	2011–2012	India, South-East Asia Region	Lower-middle-income	Health-care system (subnational)	One city
Pina et al., 2021 (145)	Analytical and modelling	NR	Brazil, Region of the Americas	Upper-middle-income	Hospital	One university hospital
Raghuwanshi & Arya, 2020 (146)	Descriptive: case report	NR	India, South-East Asia Region	Lower-middle-income	Health-care facility	One remote health-care centre
Raila & Anderson, 2017 (132)	Analytical: experimental	2014	Haiti, Region of the Americas	Lower-middle-income	Health-care system (subnational)	Five health-care waste incinerators
Sun & Huang, 2017 (138)	Analytical and modelling	NR	China, Western Pacific Region	Upper-middle-income	Outpatient surgery	Lobby of outpatient department of a hospital
Thiel et al., 2017 (139)	Descriptive: case series	2014	India, South-East Asia Region	Lower-middle-income	Surgery	2 tertiary care centres
Zakaria et al., 2005 (133)	Descriptive: cross-sectional	NR	Egypt, Eastern Mediterranean Region	Lower-middle-income	Health-care system (subnational)	Six hospital waste incinerators
Zhao et al., 2021 (134)	Analytical and modelling	NR	China, Western Pacific Region	Upper-middle-income	Health-care system (subnational)	One city

NR: not reported; WHO: World Health Organization.
Note: Income level follows the classification of the World Bank.(26)

Interventions

Of the selected articles, we identified six primary intervention areas: energy (10 studies); waste (eight studies); heating and cooling (one study); operations and logistics (one study);building design (one study); and anaesthetic gases (one study). All articles detailed implementation; 14 discussed costs; 13 reported health effects; and one considered adaptation to the effects of climate change.

Twenty articles included data on carbon dioxide reduction whereas only two articles reported on other greenhouse gases or pollutants (Table 13). For one article, we could only extract percent reduction of emissions[20] and for five others no percentage could be calculated as original emissions were not provided (126,128,129,138,143). Three articles only reported decreases in electricity usage, which was converted to carbon dioxide equivalent using the national grid emission factor (135,138,141,147,148). Two articles included a 100% reduction of carbon dioxide emissions and in this case the supply chain, installation of the system and relevant upkeep were not considered (141,144). Three articles indicated more than 100% reduction due to zero-emission electricity generation and selling the surplus (129,135,145). The intervention areas of energy and waste are outlined below, and the other four areas are described in Box 5.

Table 13 Interventions and outcomes in studies on greenhouse gas mitigation interventions for health-care systems.

Country, reference	Scope and intervention type	Summary of intervention	Type of outcome measurement	Reduction CO_2(equivalent) kg/year unless otherwise stated (%)	Reduction of other greenhouse gases per year unless otherwise stated
Bangladesh (125)	Electricity: Energy	A hybrid photovoltaic-converter-wind-battery-generator energy generation system for a temporary health centre is compared to: System A: a hybrid wind-generator-converter-battery system; and System B: a hybrid photovoltaic generator-converter-battery system	Modelled	Compared to: System A: NR (27) System B: NR (25)	Compared to system A: CO: 20 496 kg PM: 124 kg Unburned hydrocarbon: 895 kg SO_2: 6 569 kg[b] NOx: 19 254 kg
India (126)	Electricity: Energy	A 5-kWp on-grid solar photovoltaic rooftop system for one urban hospital is compared to solely grid-provided electricity	Modelled	11 287 (NR)	SO_2: 8.86 kg[b] NOx: 18.50 kg Ash: 485.792 kg
Malaysia (137)	Electricity: energy and heating	A grid-connected photovoltaic-fuel cell-battery system for energy and heating of one university hospital building is compared to a standard, standalone diesel system	Modelled	71 004 (74)	CO: 239 kg Unburned hydrocarbon: 26.4 kg PM: 18 kg SOx: 83 kg NOx: 2075.5 kg
Philippines (140)	Electricity: energy	A solar photovoltaic panel energy system with and without grid connection for a rural health-care facility is compared to a grid-only system	Empirical	With: 19 598 (59) Without: 62 776 (72)	NR
India (141)	Electricity: energy	A solar photovoltaic panel for a laboratory is compared to electricity from the grid	Modelled	13 860 (100)[a]	NR
Nigeria (142)	Electricity: energy	Optimal hybrid renewable system configurations for electricity generation (photovoltaic-wind-diesel-battery hybrid system configuration and photovoltaic-diesel-battery hybrid system configuration depending on the location) for six rural clinics from six different areas are compared to a diesel generator system	Modelled	20 113 (83)	NR
Türkiye (143)	Electricity: energy, heating and cooling	Using solar energy in combination with aquifer thermal energy storage for electricity generation for heating and cooling for one university hospital is compared to using oil and the electricity grid	Modelled	2 100 000	SOx: 7 000 kg NOx: 8 000 t
India (144)	Electricity: energy	A solar photovoltaic tunnel dryer for surgical cotton for one city is compared to a dryer on: light diesel oil or liquefied petroleum gas	Modelled	Compared to: Diesel: 12 150 (100) Gas: 6 720 (100)	NR

Country, reference	Scope and intervention type	Summary of intervention	Type of outcome measurement	Reduction CO_2(equivalent) kg/year unless otherwise stated (%)	Reduction of other greenhouse gases per year unless otherwise stated
Brazil (145)	Electricity: energy	A hybrid polygeneration system for the provision of electricity to a hospital under four legal scenarios is compared to standard usage of the electricity grid. The legal scenarios are: 39.1: Purchase only: no sale of electricity allowed; 39.2: Annual consumer: purchase and sale are allowed with the condition of purchasing more electricity than sales annually; 39.3: Unrestricted sale: purchase and sale are allowed with no restraints; and 39.4: Excess electricity production is injected into the distribution network, creating energy credits in kWh, by means of a free loan.	Modelled	39.1: 4 852 036 (63) 39.2: 6 844 207 (90) 39.3: 17 774 491 (233) 39.4: 17 774 491 (233)	NR
India (146)	Electricity: energy	A photovoltaic-diesel-battery energy system for energy generation for a remote health-care centre is compared to a diesel-battery energy system	Modelled	1813 (46)	CO: 4.48 kg Unburned hydrocarbons: 0.496 kg PM: 0.337 kg SO_2: 3.64 kg[b] NO: 40 kg
Pakistan (127)	Supply chain: waste	An integrated system of hospital solid waste treatment and disposal consisting of composting, incineration, and material recycling is compared to the standard scenario of incineration and landfill or incineration only	Empirical	Compared to: Standard: 2 806 (62) Incineration only: 2 610 (47)	NR
Türkiye (128)	Supply chain: waste	A regional health-care waste management scenario of a centralized autoclave coupled with an incinerator is compared to: Scenario 1: an incinerator; Scenario 2: decentralized autoclaving coupled with an incinerator	Modelled	Compared to: Scenario1: 1 544 000 Scenario 2: 1 767 000	NR
Pakistan (129)	Supply chain: waste	Segregation into medical waste (which is incinerated with transportation by motorbikes and then sent to landfill), and general waste (from which material is recovered or composted and then sent to landfill), is compared to: Scenario 1: segregation with landfilling of general waste and incineration of medical waste, then landfilling, and Scenario 2: incineration and then landfilling of all waste	Empirical	Compared to: Scenario 1: 538 per tonne of waste (114) Scenario 2: 1 110 per tonne of waste (106)	NR
Malaysia (130)	Supply chain: waste	Segregation and recycling of waste of phacoemulsification surgery is compared to no segregation and recycling in one hospital	Empirical	0.139 per case	NR
China (131)	Supply chain: waste	Plastic recycling in the health-care system is compared to no recycling	Modelled	868 700 000 (57)	NR

Country, reference	Scope and intervention type	Summary of intervention	Type of outcome measurement	Reduction CO_2(equivalent) kg/year unless otherwise stated (%)	Reduction of other greenhouse gases per year unless otherwise stated
Haiti (132)	Supply chain: waste	Mainstreaming the use of cardboard sharps health-care waste containers instead of plastic containers at five health-care waste incinerators	Empirical	NR	Black carbon: 61.68%
Egypt (133)	Supply chain: waste	Comparing a newer incinerator including a high-performance scrubber control system and good practice processes by an experienced operator, with an older incinerator without specified processes	Empirical	NR	CO: 3 358 mg/m^3 (86.8)
China (134)	Supply chain: waste	Medical waste management in a city through microwave sterilization with landfill medical waste disposal technology is compared to rotary kiln incineration; pyrolysis incineration; plasma melting and steam sterilization with landfill	Modelled	Compared to: Per disposal rotary kiln: 285 (68) Pyrolysis: 52 (28) Plasma melting: 551 (80) Steam sterilization: 30 (18)	NR
Malaysia (135)	Electricity: heating and cooling	An eight-row pipe heat exchanger system added to the air conditioning system in one orthopaedic ward in a university hospital is compared to a standard air conditioning system	Modelled	314 (147)[b]	NR
India (136)	Health-care operations: anaesthetic gases	Induction dose only sevoflurane during paediatric eye examination for children aged 1–5 years at one hospital is compared to standard low-flow sevoflurane	Empirical	7700 (22) per day of 10–12 procedures	CO_2 equivalent includes a reduction of N_2O of 3.75 L/case
China (138)	Electricity; building design	The energy consumption of an outpatient hospital lobby building design of a lobby of 16 m^2 with two exterior walls, south oriented at the same height as the rest of the hospital is compared to lobby designs that have a different number of exterior walls, a different orientation, and a different height. Then, different window–wall ratios and skylight ratios are compared	Modelled	186–1011[a]	NR
India (139)	Health-care operations, electricity and supply chain: operations and logistics	Usage of multiuse vial for pharmaceuticals, a short surgical duration, and a quick turnaround time during cataract surgery is compared to the standard practice in a British hospital	Empirical	124 (95) per case	NR

CO: carbon monoxide; CO2: carbon dioxide; kWp: kilowatt peak; N2O: nitrous oxide; NOx: nitrogen oxides; NR: not reported; PM: particulate matter; SO2: sulfur dioxide; SOx: sulfur oxides.
a Emissions calculated using national emission factors.(147,148)
b SO2 is a cooling aerosol, so reduced SO2 emissions partly offset the reduction of the heating effect from mitigation of greenhouse gas emissions.

Heat exchanger system, Malaysia

A hospital ward in Malaysia incorporated an eight-row heat pipe heat exchanger into its air conditioning system, yielding savings equivalent to approximately 314 kg of carbon dioxide each year. This system also provides an economic benefit of about US$ 42 000 annually with a payback period of 1.6 years, and offers the added advantage of preventing *Legionella* growth in the ducting system.[a]

Sevoflurane use, India

Using only the induction dose of sevoflurane for brief paediatric eye examinations in children aged 1–5 years reduced emissions in comparison to the traditional continuous low flow. Despite the high global warming potential of sevoflurane, this reduction in usage amounts to a modest climate benefit and cost savings of US$ 10 per day across 8–12 patients, enhancing health equity and affordability of this vital anaesthetic for children in low-resource settings.[b]

Building design, China

A hospital's new outpatient lobby design in a colder region of China, featuring two south-facing exterior walls over a 16 m^2 area, is expected to achieve a significant reduction in carbon dioxide emissions, between 186 and 1011 kg annually, due to the decreased need for heating.[c]

Multiuse pharmaceuticals and reusing surgical supplies, India

Cataract surgery at the Aravind Eye Care Centre in India, when compared with similar procedures in the United Kingdom of Great Britain and Northern Ireland, showed that implementing multiuse pharmaceuticals and reusing surgical supplies led to a substantial 95% relative reduction in emissions. The centre also optimized surgical duration and turnaround times, running two adjacent operating rooms simultaneously, which contributed to better patient outcomes and lower complication rates. Nonetheless, the assessment acknowledged methodological limitations, including variance in greenhouse gas measurement techniques and a lack of life cycle inventories specific to India. The researchers advocated for the expansion of such interventions, suggesting new vision centres and the integration of telemedicine, supported by rigorous training and strict sterilization protocols. They highlighted that policy changes, particularly those allowing multiuse pharmaceuticals in more countries, are essential to mitigate the environmental impact of health-care practices.[d]

US$: United States dollars.

Box 5 Other greenhouse gas mitigation interventions in health-care systems.

[a](135); [b](136); [c](138); [d](139)

Energy interventions

We identified reports on hybrid energy systems using a combination of non-renewable and renewable energy sources (125,126,137,142,143,145,146) or fully renewable sources (140,141,144); achieving carbon dioxide emission reductions of 25%–233% as compared to alternative scenarios (Table 13) where the reductions higher than 100% are attributed to surplus electricity generation exported to the grid. All reported energy systems featured solar photovoltaic electricity generation paired with various other sources, such as wind or diesel. Greenhouse gas emissions from production and installation were generally not considered, and no unintended consequences were reported. One article compared legal contexts and concluded that flexibility to sell or export electricity to the grid maximizes annual carbon dioxide emission savings (145).

Implementation

We found that all study authors recognized hybrid energy systems as acceptable interventions when considering various factors such as electricity generation, environmental impact and economic feasibility. Photovoltaic electricity generation was also found to be environmentally, technically and economically feasible (125,126,137,145).

The authors of two studies noted that these energy forms are scalable in rural health-care facilities in disparate geographical locations provided that local energy costs and climate parameters are considered during the pre-planning stages (125,140–142,145). Scalability could extend to commercial buildings and agricultural industries as well (126,144).

Initial capital costs and access to sufficient finance may act as a barrier to implementation of hybrid energy systems, but hybrid energy systems were seen as a solution to enhance energy reliability and reduce energy costs over time (140). Suggested solutions included government funding, international climate-related financing and renewable energy purpose obligations; with one article suggesting a 25-year implementation period (126,137,140). Wind and solar potential significantly influence their implementation, as areas with high potential (for example, those with strong insolation for solar energy), are more conducive to successful deployment than low-potential areas.

Economic analysis

Eight articles reported details on costing, including their Net Present Costs (ranging from 3658 to 146 284 United States dollars, US$), payback periods (ranging from 3.38 to 9.9 years), and return metrics, which vary across different systems and locations (Table 14).

Table 14 Studies reporting economic outcomes for greenhouse gas mitigation interventions for health-care systems.

Country	Intervention	Initial capital, US$	Net present cost, US$	Payback period, year	Return on investment, %	Initial rate of return, %
Bangladesh (125)	Photovoltaic Converter-Wind-Battery-Generator energy generation system	NR	69 377 300	7	NR	NR
India (141)	Solar panel	12 000	NR	NR	NR	NR
India (144)	Solar photovoltaic tunnel dryer for surgical cotton	NR	10 660	3.38	86 to 150	NR
India (146)	Photovoltaic-diesel-battery energy system	NR	13 523	9.9	NR	NR
India (126)	5-kWp on-grid solar photovoltaic rooftop system	3 658	NR	7.1	NR	NR

Country	Intervention	Initial capital, US$	Net present cost, US$	Payback period, year	Return on investment, %	Initial rate of return, %
Malaysia (137)	Grid-connected photovoltaic fuel cell-battery system	NR	98 318	NR	NR	NR
Nigeria (142)	Optimal hybrid renewable system configurations for electricity generation	NR	71 210 to 108 920	NR	NR	NR
Philippines (140)	A solar photovoltaic panel energy system with or without grid connection	NR	With: 87 139 Without: 146 284	With: 9.7 Without: 4.5	With: 6.10; Without: 15.90	With: 9.0 Without: 20.8

kWp: kilowatt peak; US$: United States dollars.

Health and health equity

Five articles qualitatively estimated potential health effects, noting that reliable hybrid energy systems can prevent power interruptions and address the lack of access to reliable electricity in rural areas. Without continuous access to electricity, the lack of essential medical equipment – such as incubators, ventilators and basic lighting, critical for safe childbirth and neonatal care – leads to a high rate of maternal and perinatal mortality; spoilage of medication; and the inability to sterilize medical equipment used in operating rooms. In addition to the negative effects noted above, lack of coordination and communication (hindered by lack of reliable access to electricity or broadband wireless networks) was also found to disproportionately affect the healthcare of women and children. Reliable electricity access can reduce these effects by increasing operating hours, attracting a larger health workforce, improving cold-chain for vaccines and medicines, and enhancing communication among health workers and between patients and health workers. (140–142,149)

Other important actions such as replacing diesel generators with hybrid systems can act to reduce harmful exposure to pollutants including unburned hydrocarbons and particulate matter; potentially reducing risks for lung cancer, asthma and bronchitis (146); as well as contributing to a safer work environment particularly in laboratory settings (141).

Adaptation

Authors of one study examined the intersection of mitigation and adaptation in the context of a solar photovoltaic energy system with and without grid-connection for a rural health-care facility in the Philippines. They defined a climate-resilient energy system as providing “reliable, safe, and secure electricity during short-term disasters and events and as longer-term climate changes occur”, and found that this solar photovoltaic energy system could enable continued provision of care during both short- and longer-term climate change effects. (140,150)

Waste interventions

Of the eight studies on waste that we identified; one study covered plasma melting; used for melting medical waste. Plasma melting appears to have the highest overall relative greenhouse gas emissions as compared to alternative waste interventions (134). Four studies covered stand-alone incineration and a mix of incineration with landfilling or autoclaving, which have the second highest emission (127–129,134). Relative emission reductions can be achieved by centralising the autoclave, ensuring efficient transportation and having well-trained operators (128,133). One article also considered water usage, and found that combining autoclaving with incineration may conserve 38 967 m^3 of water annually compared to incineration alone (Table 13). (128)

Systems integrating waste segregation, composting and material recycling, all while optimising transport, achieved the greatest emission reductions, ranging from 47%–114% (127,129–131). Any further reductions in emissions were achieved through material recovery (129). For example, cardboard sharps containers were found to reduce black carbon emissions by 62% compared to plastic sharps containers in an incineration-only system (132).

Reported methodological limitations around waste management data include: (i) neglecting heat recovery (127,134); (ii) lack of accurate waste data (129); (iii) inability to measure electricity during operations and autoclaving (130); (iv) foreign emission factors (130); and (v) omission of transportation (131,134). Unintended negative consequences of waste management include ineffective segregation leading to exposure to hazardous items (127), and generation of toxic dioxin during recycling (131).

Implementation

Appropriate waste management also acts to improve health and safety while reducing greenhouse gas emissions (129). Three articles recommended scaling up the proposed waste management systems within their respective cities and regions (127–129), one more broadly across low- and middle-income countries (128), while another recommended a global ban on plastic sharps containers (132). For example, composting of biodegradable waste in Pakistan was easy to implement because of low management and operation costs (129). In Türkiye, incineration on its own was not feasible due to high costs (128). Ultimately, widespread segregation and material and energy recovery was recommended but funding may be a barrier to implementation (129).

Factors contributing to successful interventions include introduction of new technology (such as a well-performing scrubber control system), capacity-building and carbon tax policies (129,131,133). Barriers to successful implementation include unskilled operators, ineffective segregation and illegal removal of waste for recycling. Several policy interventions were suggested by the authors to deal with these potential barriers (127,131,133).

Economic analysis

In a study from China, authors estimated that appropriate plastic recycling in the health-care system would lead to a cumulative economic benefit of about US$ 450 million in 2050 (131). In another article, a cost–benefit analysis indicates that electricity generation from waste can cover a large portion of the fuel expenses of transportation and incineration of medical waste. (129)

Health and health equity

Reducing black carbon and sulfur emissions from incineration can reduce health risks, such as respiratory infections, low birth weight, premature deaths and asthma, in localities where incineration is happening nearby (132,133). Although waste burning is a relatively small contributor to black carbon globally, it is a substantial contributor to health-related illnesses in locations with high black carbon exposure such as in China, India, Nigeria and Republic of Korea (149).

Critical appraisal and risk of bias

Definitions of relevant methodological terms in the included studies were generally clear, but details on methods were missing in nine out of 22 (41%) articles. Fourteen studies (64%) reported on modelled outcomes, and eight (36%) reported on empirical outcomes. Some outcomes lacked transparency (missing data, time frames or units; six studies, 27%) and/or lack of confounding (eight studies, 36%). Seven articles (32%) did not clearly state assumptions, and 14 (64%) did not clearly state limitations. We did not note a conflict of interest partly because 12 articles (55%) did not include a conflict-of-interest statement. Funding sources included health ministry funds, government funds, national foundations and institutes, university grants, corporations (140), research councils and national programmes (Table 15).

Table 15 Critical appraisal of studies included in the systematic review on greenhouse gas mitigation interventions for health-care systems.

	Definition			Methods		Results		Confounding	Discussion	
Country, reference	**Clear definition of the objective**	**Clear definition of intervention or exposure?**	**Clear definition of outcome?**	**Is/are the control(s) appropriate?**	**Methods applied consistently?**	**Data reported transparently?**	**Type of outcome measurement used?**	**Addressed in design or analysis?**	**Assumptions clearly stated?**	**Limitations clearly stated?**
Energy										
Bangladesh (125)	Yes	Yes	Yes	Yes	Yes	Yes	Modelled	Yes	Yes	No
India (126)	Yes	Yes	Yes	Yes	Yes	Yes	Modelled	Yes	Yes	No
Malaysia (137)	Yes	Yes	Yes	Yes	Yes	No	Modelled	Yes	Yes	No

	Definition			Methods		Results		Confoun ding	Discussion	
Country, reference	**Clear definition of the objective**	**Clear definition of intervention or exposure?**	**Clear definition of outcome?**	**Is/are the control(s) appropriate?**	**Methods applied consistently?**	**Data reported transparently?**	**Type of outcome measurement used?**	**Addressed in design or analysis?**	**Assumptions clearly stated?**	**Limitations clearly stated?**
Philippines (140)	Yes	Yes	Yes	Yes	Yes	Yes	Modelled	Yes	Yes	Yes
India (141)	No	Yes	Yes	Yes	No	No	Empirical	No	No	No
Nigeria (142)	Yes	Yes	Yes	Yes	Yes	Yes	Modelled	Yes	Yes	No
Turkey (143)	Yes	Yes	Yes	Yes	NA	No	Modelled	Yes	No	No
India (144)	Yes	Yes	Yes	No	NA	Yes	Modelled	No	Yes	No
Brazil (145)	Yes	Yes	Yes	Yes	Yes	Yes	Modelled	Yes	Yes	No
India (146)	Yes	Yes	Yes	Yes	Yes	Yes	Modelled	Yes	Yes	No
Waste										
Pakistan (127)	Yes	Yes	Yes	Yes	Yes	No	Empirical	Yes	Yes	Yes
Türkiye (128)	Yes	Yes	Yes	Yes	Yes	Yes	Modelled	Yes	Yes	No
Pakistan (129)	Yes	Yes	Yes	Yes	Yes	Yes	Empirical	No	No	Yes
Malaysia (130)	Yes	Yes	Yes	Yes	NA	Yes	Empirical	No	No	Yes
China (131)	Yes	Yes	No	Yes	NA	Yes	Modelled	Yes	No	Yes
Haiti (132)	Yes	Yes	Yes	Yes	Yes	Yes	Empirical	No	Yes	No
Egypt (133)	No	No	Yes	Yes	Yes	Yes	Empirical	No	Yes	No
China (134)	Yes	Yes	Yes	Yes	Yes	No	Modelled	Yes	Yes	Yes
Others										
Malaysia (135)	Yes	Yes	Yes	No	NA	Yes	Modelled	No	No	No
India (136)	Yes	Yes	Yes	Yes	Yes	Yes	Empirical	Yes	No	Yes
China (138)	Yes	Yes	Yes	Yes	Yes	No	Modelled	Yes	Yes	No
India (139)	Yes	Yes	Yes	No	No	Yes	Empirical	No	Yes	Yes

NA: not applicable.

As no protocols were published in advance, we could not compare and identify selective reporting for any of the articles. None of the articles self-reported potential meta-biases.

Confidence in cumulative evidence

We evaluated confidence in the available evidence regarding the effect size of greenhouse gas emission reductions using the GRADE certainty assessment (Table 16), which is described in detail in the online repository (Appendix VII)(122). Across all 10 articles on energy, outcomes were assessed, as they spanned a variety of hybrid energy systems that included renewable energy resources. Regarding waste, we assessed four separate outcomes based on the different interventions described in the articles. The four remaining articles were assessed as separate outcomes in the text.

Table 16 Certainty of evidence for interventions to mitigate greenhouse gases for health-care systems, low- and middle-income countries.

Outcome	Impact	No. of studies	Certainty of evidence[a]
Greenhouse gas mitigation through hybrid energy systems	A variety of hybrid energy systems, including renewable energy sources adjusted to contexts, reported reductions in carbon dioxide emissions ranging from 25% to a theoretical 233%	10 observational studies	Low
Greenhouse gas mitigation of health-care system waste through waste management systems with composting or recycling	Relative emission reductions are reported ranging between 46%–114% in systems that include waste segregation, composting, and material recycling while considering efficient low-emission transportation options	Four observational studies	Low
Greenhouse gas mitigation of health-care system waste through incineration and autoclave process efficiency	Relative emission reductions in waste management systems are reported to take place through centralising the autoclave (reduces electricity needed), considering efficient transportation, and ensuring incinerators are up to date with a clear process and well-trained operator	Two observational studies	Very low[b]
Greenhouse gas mitigation of health-care system waste through replacing plastic sharps containers by cardboard sharps containers	Using cardboard sharps containers instead of plastic sharps containers led to a reported 62% reduction in black carbon emissions	One observational study	Very low[b]
Greenhouse gas mitigation of health-care system waste through microwave sterilization and landfilling	Urban medical waste management through microwave sterilization with landfill medical waste disposal technology reduces relative emissions as compared to rotary kiln incineration (68%), pyrolysis incineration (28%), plasma melting (80%) and steam sterilization with landfill (18%)	One observational study	Low
Greenhouse gas mitigation of health-care facility heating and cooling through heat exchangers	An eight-row heat pipe heat exchanger system added to one hospital ward was assessed to reduce carbon dioxide emissions compared to the regular air conditioning system by 147%, because of heat generation	One observational study	Low
Greenhouse gas mitigation of anaesthetic gases through induction dose only sevoflurane	Induction dose only sevoflurane during paediatric eye examination for children aged 1–5 years at one hospital reduces 22% of emissions compared to standard low-flow sevoflurane	One RCT	High
Greenhouse gas mitigation of a hospital building through lobby design	In this cold-climate region, a lobby with two exterior walls, south-oriented at the same height as the rest of the hospital, emits the least with a relative reduction of 0.014–0.074 kg CO_2/m^2 depending on the comparison design	One observational study	Very low[c]
Greenhouse gas mitigation of operations and logistics of cataract surgery	Multiuse pharmaceuticals, reusing surgical supplies, a short surgical duration and quick turnaround time resulted in a relative reduction of emissions of 95% as compared to the same surgery in the United Kingdom	One observational study	Very low
Climate adaptation from mitigation interventions	A solar photovoltaic panel energy system with and without grid-connection for a rural health-care facility in the Philippines may contribute to the resilience of a health-care facility to short-term disasters and events and as longer-term climate changes occur	One observational study	Very low[d]

CO_2: carbon dioxide; RCT: randomized controlled trial.

[a] *We used the Grading of Recommendations Assessment, Development, and Evaluation approach.*

[b] *Results (partially) based on visual observation of pollution.*

[c] *Outcomes in electricity generated in carbon dioxide equivalent using national emission factors.*

[d] *Adaptation was a consideration in the article and not measured.*

6.6.4 Discussion

Here we provide an overview of peer-reviewed evidence on greenhouse gas mitigation interventions for health-care systems in low- and middle-income countries. The eligible studies show reductions in greenhouse gas emissions, cost savings as well as potential positive health effects. Because the overall health sectoral emissions contribute to about 5% of global greenhouse gas emission, successful mitigation efforts need to be urgently scaled up to affect overall emissions. For example, in 2015, Chinese health-care systems emitted an estimated 302 megatonnes (Mt) of carbon dioxide, while the Kenyan and Malaysian systems emitted an estimated 2 Mt and 6 Mt of carbon dioxide, respectively (23). In our identified studies, the maximum reductions were approximately 0.9 Mt of carbon dioxide equivalent annually for a sustainable waste approach in China; and 0.02 Mt of carbon dioxide equivalent for a hybrid polygeneration energy system in a Brazilian hospital (131,145). However, due to the limited identified records and inconsistent methods, the overall quality of evidence is low and supports the conclusion that rigorous research, publication and dissemination is needed.

Fully renewable energy with battery storage, or hybrid energy systems including renewable and conventional sources provide a reliable and sustainable source of electricity, especially in areas with intermittent or unreliable grid electricity supply; and require decision-makers interested in implementing renewable energy systems to consider local conditions, such as energy prices, solar and wind parameters, and temperature to optimize performance and sustainability. A primary barrier to implementation is the high initial cost to purchase, install and maintain such systems or interventions. Irrespective of these barriers, we identified seven articles that reported positive returns, suggesting that the long-term benefits of implementing renewable energy systems outweigh the initial costs of implementation. Adequate funding is therefore crucial to support the initial setup of these mitigation interventions.

Our results highlight actions such as waste segregation, composting and material recycling as means to reduce greenhouse gas emissions, which is consistent with evidence from other sectors and high-income country settings (151,152). Waste-to-energy technologies such as incineration, autoclaving and microwave sterilization could contribute more to greenhouse gas emission reductions than plasma melting or landfilling. We recommend that health-care facilities prioritize waste reduction, segregation and recycling, and address identified barriers through capacity-building and incentives before considering waste-to-energy technologies. However, identifying potential unintended negative consequences for the local community from waste produced by health-care facilities is essential, including pollution from incineration, when designing waste-management policies. Context-specific strategies to mitigate some of these effects need to be developed that are also sensitive to local socioeconomic and environmental conditions. Limited information on costs and potential benefits of waste management interventions in this systematic review underscores the need for further economic analysis.

There is evidence to suggest that building design optimization and improved surgical processes can lead to reductions in greenhouse gas emissions; however, there is a dearth of data on the implementation, costing and health impacts of these interventions (135,136,138,139). Although we have reviewed several promising interventions to reduce greenhouse gas emissions in health-care settings, there are gaps in our current knowledge of the implementation and sustainability of mitigation interventions and their potential scalability. These gaps restrict our understanding of the effects on overall sectoral emission reductions. Detailed information is lacking on the workforce required, the amount of implementation-related greenhouse gas emissions, and the time and resources needed for installation and deployment. Moreover, there is little information on other important issues such as long-term maintenance and upkeep.

This study has some limitations. First, the findings may not encompass all pertinent factors leading to successful implementation because of a lack of descriptive details. Second, the absence of consistent reporting methods in the literature restricts the comparability and generalizability of the results and impedes further in-depth analysis. Third, the GRADE approach is designed for single interventions, which creates challenges in the interpretation of systemic change. To overcome these limitations, further research is necessary to obtain more comprehensive evidence on the effectiveness, scalability and durability of mitigation interventions in health-care systems in low- and middle-income countries using standard approaches; for example by adapting guidelines for evaluation of complex interventions to the planetary health agenda (153,154).

We found that the types of interventions reported in the literature are limited to a few areas that contribute to emissions, namely energy, waste, heating and cooling, operations and logistics, building design and anaesthetic gases. We also noted a lack of reported interventions in other subject areas including equipment efficiency; inhalers; food; manufacturing and efficient use of pharmaceuticals and chemicals; production, reduction and circularity of medical supplies and devices; partnerships, purchasing and finance; information and communication technologies; telemedicine; community-based care; and supply-chain management (119). Further, interventions focusing on systemic efficiencies of delivery of high-quality care were not identified and improving the efficiency of health-care provision could provide another opportunity to reduce emissions (Box 3).

There is a lack of data on how to consider context-specific adaptation and mitigation measures, particularly in low- and middle-income countries. Future research and interventions should consider a wider range of contexts, including low-income countries, all scopes of emissions and adaptation. While efforts are increasing to mitigate greenhouse gas emissions from health-care systems, such as through WHO's Alliance for Transformative Action on Climate Change and Health (4), it is essential to robustly monitor, evaluate, record and report outcomes in a standardized manner. An example of a tool that could support such efforts is the recently launched HealthcareLCA database, which contains assessments focused on the environmental impact of healthcare (155). In addition, reviewing grey literature such as reports from nongovernmental organizations, local organizations and community-based initiatives could provide valuable insights into the implementation and sustainability of interventions in low- and middle-income countries. Adding grey literature can complement findings from academic research and fill gaps in knowledge, particularly in resource-constrained settings where formal research may be limited. Such evidence will, however, require critical assessment because of the potential for methodological weaknesses and conflicts of interest leading to biased findings.

In conclusion, this review illustrates a wide range of interventions to mitigate greenhouse gas emissions in health-care systems in low and middle-income countries. We also highlight important gaps in the research-based knowledge. Further research, monitoring and evaluation are necessary to establish a robust evidence base and inform future policy decisions and interventions towards successful greenhouse gas mitigation and adaptation of health-care systems in the context of climate change.

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Competing interests:

None declared.

6.7 Discussion and Implications

The systematic review of GHG mitigation interventions across LMIC healthcare systems provides important insights that directly inform the broader goals of this thesis. As outlined in Chapter 3, this thesis seeks to identify practical and scalable pathways toward net-zero healthcare systems, with a focus on Kenya's unique context. The findings from this review offer evidence-based lessons on what interventions are most relevant and feasible for reducing healthcare-related emissions in LMICs, which is particularly applicable as Kenya develops its own strategy to achieve net-zero emissions in the healthcare system by 2030. While Kenya's net-zero commitment exemplifies ambitious leadership, the responsibility for healthcare-related GHG emissions cannot rest primarily on LMICs. HICs, with historically higher emissions, have an obligation to provide technical and financial support to ensure equitable progress. Kenya's efforts should be seen as a beacon of innovation, fostering global cooperation rather than a redistribution of burdens.

A key contribution of the review is the identification of interventions with the highest potential for reducing emissions in healthcare operations, energy use, and supply chains. Energy interventions, particularly those involving hybrid systems that incorporate renewable energy sources, demonstrate significant reductions in emissions and could be particularly relevant for Kenya, where healthcare facilities often face unreliable electricity supplies. These solutions offer both climate mitigation and adaptation benefits by increasing energy security, especially in rural areas that are most vulnerable to power outages and climate-related disruptions. This dual impact aligns with Kenya's broader sustainability agenda, illustrating how mitigation and adaptation can work in tandem to enhance healthcare quality and accessibility.

The review also underscores the importance of waste management interventions, which are crucial for addressing emissions from healthcare supply chains. Although waste-to-energy technologies like incineration can reduce waste-related emissions, the findings suggest that segregation, recycling, and composting are more effective and scalable options in LMICs. These interventions could be adapted to Kenya's healthcare system, especially given the growing emphasis on circular economy principles within the country's broader sustainability agenda. By reducing waste and optimising material recovery, Kenya's healthcare system can lower emissions while improving health and safety for patients and staff, particularly in resource-constrained settings.

However, one of the most critical findings is the gap in evidence around the broader supply chain emissions, which accounts for a significant portion of healthcare-related GHGs globally. This gap highlights a key area for further research and policy development in Kenya, as addressing emissions in supply chains is essential for achieving net-zero goals. It also emphasizes the need for comprehensive data collection and monitoring systems, which this thesis advocates for as part of Kenya's transformation to a sustainable healthcare system.

In terms of methodological and research implications, the low overall quality of evidence found in the review points to a pressing need for more rigorous studies that track long-term outcomes of GHG mitigation interventions. This is directly relevant to Kenya's net-zero strategy, as robust evidence on the effectiveness and scalability of interventions will be critical for informing national policies and ensuring that Kenya's healthcare system transformations in a sustainable, evidence-based manner.

Moreover, the review highlights the importance of contextualising GHG mitigation interventions to local conditions. This is particularly pertinent to Kenya, where regional disparities in healthcare infrastructure, resource availability, and energy access present challenges to implementing one-size-fits-all solutions. The findings suggest that Kenya must tailor interventions based on local needs, particularly in rural areas that may benefit from hybrid energy systems or decentralized waste management solutions. This reflects the thesis's focus on developing context-specific pathways that account for Kenya's healthcare system heterogeneity.

Chapter 7: Stakeholder Insights on Kenya's Net-Zero Healthcare Transformation

7.1 Introduction

Kenya's healthcare system is at a critical juncture as it works towards its commitment to achieving net-zero GHG emissions by 2030, as part of the UNFCCC COP26 Health Programme. This ambitious target is situated within Kenya's broader climate policy, including the National Climate Change Action Plan and Kenya's Long-Term Low Emission Development Strategy. As highlighted in previous chapters, Kenya's healthcare system must navigate both mitigation and adaptation efforts, which are made more challenging by existing systemic health vulnerabilities, such as resource constraints and regional disparities in healthcare access.

Building on these broader themes, this chapter specifically examines the perspectives of key stakeholders in Kenya's healthcare system regarding the transformation to a net-zero, resilient system. Unlike the broader global policy review and analysis from earlier chapters, this study zooms in on stakeholder experiences and insights to understand the practical realities, opportunities, and challenges on the ground. This includes understanding how national policies are interpreted and operationalized within the healthcare system, the readiness to adopt mitigation interventions, and the key barriers that need to be overcome.

Kenya presents a unique case, not just because of its ambitious climate goals, but because of its diverse and decentralized healthcare system, which complicates coordination efforts. This study uses qualitative research methods, specifically semi-structured interviews and a Delphi consensus process, to capture a range of stakeholder voices - from health workers and managers to policymakers and development agency representatives. By doing so, it offers a detailed understanding of how mitigation strategies can be implemented in a context where competing priorities, financial constraints, and infrastructural challenges are common.

7.2 Aims and Objectives

This chapter intends to provide a comprehensive, qualitative assessment of the opportunities and barriers related to the pathway towards achieving a net-zero healthcare system in Kenya. Through stakeholder perspectives, the aim is to develop informed policy recommendations that can support Kenya's ambitious climate goals, with a focus on the healthcare system's contribution to reducing GHG emissions.

Specifically, this chapter has the following objectives:

1. To identify and explore the GHG mitigation interventions that are being designed, planned, implemented, or evaluated within Kenya's healthcare system. This includes assessing which

interventions are considered most important for reducing emissions and which are deemed most feasible for implementation given current resources and constraints.

2. To understand the key barriers and opportunities identified by stakeholders on the pathway towards a net-zero healthcare system. This objective seeks to uncover how these barriers have been, or could be, overcome and what opportunities exist for advancing climate action within the healthcare system.
3. To identify the key stakeholders involved in the transformation to a net-zero healthcare system in Kenya. This includes mapping out their roles, levels of influence, and the importance of their engagement in driving forward GHG mitigation efforts.
4. To assess how GHG mitigation interventions within Kenya's healthcare system interact with climate adaptation strategies. The objective is to examine how mitigation actions can complement or create synergies with adaptation efforts, as well as to identify any potential trade-offs or conflicts between the two.

These objectives guide the qualitative analysis in this chapter and contribute to the broader aim of informing practical and actionable policy recommendations that support Kenya's transformation to a resilient, net-zero healthcare system.

7.3 Research Paper Cover Sheet

SECTION A – Student Details

Student ID Number	2100667	**Title**	Dr
First Name(s)	Iris Martine		
Surname/Family Name	Blom		
Thesis Title	PhD – Epidemiology & Population Health		
Primary Supervisor	Dr Sarah Whitmee		

SECTION C – Prepared for publication, but not yet published

Where is the work intended to be published?	The Journal of Climate Change and Health
Please list the paper's authors in the intended authorship order:	Iris Martine Blom, Melvine Anyango Otieno, Susannah Mayhew, Neil Spicer, Andy Haines, Sarah Whitmee
Stage of publication	**In press**

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	IMB was responsible for the conceptualization of the study and design of the methodology, supported by all authors. IMB handled the software and data curation aspects of the research. Validation and formal analysis were conducted by IMB with support from all authors. IMB also led the investigation with outreach supported by MO and provided the necessary resources for the study. The original draft of the manuscript was written by IMB, and all authors contributed to reviewing and editing the manuscript. Visualization was carried out by IMB. SW and AH, supported by SM, provided supervision throughout the project. IMB managed the project administration and, supported by SW and AH, was involved in funding acquisition.

SECTION E

Student Signature	[redacted]
Date	10/12/2024

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7.4 Towards a Net-Zero Healthcare System in Kenya: Stakeholder perspectives on opportunities, challenges and priorities

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Abstract

Introduction

Kenya's healthcare system, committed to achieving net-zero greenhouse gas emissions by 2030 as part of the UNFCCC COP26 Health Program. To turn these ambitious commitments into outcomes and share learnings with other nations, a comprehensive assessment of the perspectives of key stakeholders likely to be involved in implementing the transition of the healthcare system is needed.

Methods

This study employs qualitative methods, including 21 semi-structured interviews with key stakeholders and a Delphi consensus process, to explore stakeholder perspectives on Kenya's journey to a net-zero healthcare system.

Results

Stakeholders identified and validated 14 process components crucial for this transformation, ranging from leadership and financing to behavioural change and monitoring. Critical barriers, such as infrastructure limitations, competing health priorities, financial constraints, and gaps in strategy coordination, were highlighted. Stakeholders ranked three interventions as the highest priority: implementing clean energy solutions in healthcare facilities, developing national sustainable healthcare policies that are informed by existing evidence on climate benefits, and generating localized data to guide actionable policies. Ranking interventions based on feasibility, however, produced different results that favoured simpler, more immediately actionable measures like hospital vegetable gardens and the creation of guidelines for health facilities.

Conclusion

While the transition to net-zero poses challenges, stakeholders expressed optimism about the potential of current strong leadership, strategic partnerships, and the growing momentum for action on climate change and health. This research provides actionable insights and recommendations to guide Kenya's transition to a sustainable, resilient healthcare system, while offering valuable lessons for other countries facing similar challenges.

Highlights

- Kenya targets a net-zero healthcare system by 2030.
- Barriers include infrastructure, financial constraints, and strategy coordination gaps.
- Strong leadership, partnerships, and climate-health momentum offer key opportunities.
- Delphi consensus identified clean energy, policy, and data as most important for achieving net-zero.
- Tension exists between high-impact interventions and more feasible ones due to resource and capacity constraints.

7.4.1. Introduction

Climate change poses a critical challenge to healthcare systems worldwide. Healthcare systems themselves account for approximately 5% of global greenhouse gas (GHG) emissions (17), requiring a dual approach of mitigation and adaptation to safeguard health outcomes. In Low- and Middle-Income Countries (LMICs), the burden of climate change intersects with existing systemic health vulnerabilities, such as inadequate healthcare infrastructure, limited access to essential medicines, and shortages of health workforce, driving an urgent need for resilient, strengthened and expanded healthcare infrastructures that can operate sustainably (156).

Kenya, a lower-middle-income country with a growing population of approximately 56 million, is characterized by a diverse healthcare system encompassing public (47% of facilities) and non-state actors such as private (46% of facilities), faith-based and non-governmental organization (NGO)-operated facilities (8% combined) (65,157). The country faces diverse healthcare challenges, including a low doctor-to-patient ratio estimated at approximately one doctor per 5,000 inhabitants and an annual healthcare expenditure of 95 USD per capita in 2021, compared to Canada which holds the highest Universal Health Coverage Index at 12 doctors per 5,000 inhabitants and an annual health expenditure of around 6500 USD per capita (47,66–68,158,159). These factors contribute to significant disparities in healthcare quality and accessibility across different regions and facility types. Kenya has committed to establishing a net-zero emissions healthcare system by 2030 as part of the UNFCCC COP26 Health Program in 2021 (160). The pledge sits within a broader climate policy framework for Kenya including the National Climate Change Response Strategy (2010), the National Climate Change Action Plan (2013, 2023) which recognizes health as a key sector, a National Adaptation Plan (2016), the Climate Change Act (2016), Kenya's Nationally Determined Contribution (NDC) to the UNFCCC (2020), and Kenya's amended Long-Term Low-Emission Development Strategy with the goal of a net-zero emissions future by 2050 (2023), which collectively underscore Kenya's commitment to climate action (48,50–52,54,161).

The establishment of the Climate Change and Health Strategic Working Group by the Kenyan Ministry of Health in 2017 marked a pivotal moment, bolstering Kenya's progress towards a comprehensive health system approach to climate action. Subsequent years have seen significant progress, such as the execution of the first Health, Environment & Climate Change Conference by the Kenya Medical Research Institute in 2019 and the incorporation of environmental health into the COVID-19 response in 2020 (162,163). Kenya's ambitious target is supported by high-level engagements with international partners, including the World Bank, the Aga Khan Development Network and the World Health Organization. Beyond potential benefits of improving provision of healthcare, the implications of Kenya's transition toward a net-zero healthcare system could potentially extend beyond national borders, offering valuable lessons for similar LMICs facing parallel challenges. Successes in this area could unlock further international support and funding, while also providing global inspiration to adopt innovative approaches to sustainable healthcare. This study setting, therefore, provides a critical backdrop for understanding the dynamics of integrating climate action nationally with healthcare planning and execution in a complex, multi-layered health system environment.

This study critically analysed the progress and prospects of Kenya's commitment to a net-zero, resilient healthcare system. Adopting a health policy and systems research approach, the study used qualitative methods, including in-depth interviews and a Delphi consensus process with workshop, to gather diverse stakeholder perspectives. We examined the integration of interventions within Kenya's healthcare system, focusing on the design, implementation, and evaluation of interventions. The study also assessed key barriers and identifies facilitators of the process. Finally, we provided actionable recommendations aimed at informing both national policy and practical steps for advancing Kenya's transition to a sustainable, resilient healthcare system.

7.4.2 Material and Methods

This study explored synergies, co-benefits, conflicts, and trade-offs between climate adaptation and mitigation actions to operationalize net-zero health system commitment of Kenya (160). We employed semi-structured interviews and a Delphi consensus process to gather diverse stakeholder perspectives on healthcare system mitigation strategies.

Participants were purposively sampled based on Robinson's guide to ensure theoretical saturation and diverse representation across Kenya's healthcare system (164). Stakeholders were selected through expert consultations and a mapping exercise of key actors, targeting individuals aged 18 and above with significant roles or influence in healthcare sustainability and climate change mitigation. Stakeholder groups included representatives from government, academia, development agencies, health workers, and supply chain managers.

Semi-Structured Interviews

We conducted 21 interviews (June 2023–January 2024) with stakeholders, including 9 women and 12 men (Table 17). Interview guides were informed by a theory of change framework for GHG mitigation in LMIC healthcare systems (45). Topics covered included intervention planning, implementation, and evaluation; barriers and opportunities; and adaptation strategy interactions. Interviews (45–60 minutes) were conducted in person (10) and virtually (11), recorded, transcribed verbatim, and analysed using NVivo software. Thematic analysis included coding, theme identification, and narrative synthesis to ensure findings reflected participant insights.

Table 17 Participant numbers and their respective affiliation and gender.

Participant number	Affiliation	Gender
01	Academia	Man
02	Academia	Man
03	Building design	Man
04	Building design	Man
05	County government representative	Man
06	Development agency	Woman
07	Development agency	Woman
08	Environmental researcher	Man
09	Faith based health services	Man
10	Health workforce	Woman
11	Health workforce	Woman
12	Health workforce	Man

Participant number	Affiliation	Gender
13	Intergovernmental organization	Man
14	Intergovernmental organization	Woman
15	National government representative	Man
16	National government representative	Woman
17	National government representative	Man
18	NGO providing health services	Woman
19	Supply chain	Man
20	Supply chain	Woman
21	Tertiary private hospital	Woman

Delphi Consensus Process

A January 2024 workshop engaged 12 decision-makers (7 also interviewed previously), to refine and prioritize interventions identified during interviews. The iterative Delphi method facilitated consensus-building on key strategies and barriers to achieving net-zero healthcare. Sessions included an overview of the interview findings, discussion on stakeholders and prioritization of actions. Three voting rounds ranked interventions by impact and feasibility. Discussions addressed implementation practicality, concluding with a strategic synthesis of findings for future actions. Workshop transcripts were analysed using NVivo.

Recruitment & Informed Consent

Participants were recruited via direct outreach and snowballing, with no financial incentives provided, though workshop subsistence costs were covered. Informed consent was obtained in writing and verbally, with confidentiality upheld through anonymized data collection and storage. An information sheet (Appendix VII) detailed study objectives and potential benefits, and participants had opportunities to ask questions throughout.

7.4.3. Results

Interviews

While there was a consensus on the necessity and potential benefits of this transformation, discussions revealed a complex landscape of opportunities and barriers across five emerging themes: infrastructure; competing priorities; finances; awareness, knowledge and engagement; and strategy, coordination and leadership. Stakeholders further emphasized the importance of building a healthcare system that is resilient to Kenya's unique climate vulnerabilities.

> *'We are making sure that we are minimising our carbon footprint from the beginning and doing it in a way that is protective of our planet rather than following the historical approach to maximize everything and then think 'how do we reverse the damage'.' – Health Worker*

Strategy, Coordination and Leadership

The Ministry of Health's ongoing efforts to finalize a climate change strategy work plan illuminates the challenge of formulating a clear and actionable blueprint towards health system mitigation and adaptation (Participant 15). Indeed, even when strategies have been formulated, administrative complexities and implementation delays occurred, such as county project timelines not being honoured (Participant 18).

The gap between strategic formulation and implementation suggests inherent challenges in coordination and leadership (Participant 18). The multifaceted nature of GHG mitigation interventions implies the need to engage several sectors. Pivotal entities to facilitate this, such as the Ministry of Health and the Ministry of Environment, face resource constraints. These constraints, both in terms of finance and human resources, significantly impair the translation of policies into tangible actions (Participant 16). The current policy architecture does not prioritize reducing GHG emissions unless aligned with cost savings or other near-term benefits, and there are evident discrepancies between legislative frameworks and the lived experiences on the ground (Participant 03 & Participant 10). Specifically, there are no frameworks that can be implemented by counties towards these efforts resulting in limited translation into county legislation (Participant 05).

From an operational lens, the lack of baseline measurements, such as vulnerability and adaptation assessments or carbon benchmarking, raises questions about the strategic alignment and real-world feasibility of current measures. The private sector, with potential for innovation, finds its contributions impeded by systemic issues such as corruption (Participant 01).

Unique to its health system is the devolution of powers to the county level, allowing counties to tailor policies to their specific contexts. This decentralized system presents both challenges and opportunities. If a particular policy becomes successful in one county, others might emulate it, promoting broader policy adoption (Participant 11). Moreover, an opportunity exists to create regional blocks with several counties to stimulate exchange of learned lessons and access to funding (Participant 05).

National prioritization of climate change by the current leadership, as well as global partnerships, like the Alliance for Transformative Action on Climate and Health (ATACH), spotlight Kenya's commitment and offer platforms for advocacy and collaboration. Such global endorsements and initiatives could serve as catalysts for driving domestic agendas (Participant 13). The country's flexibility and receptiveness to bilateral donors and international funding partners also hold promise, as collaborative discussions could yield support (Participant 18). Additionally, the current global emphasis on climate change can be leveraged, especially considering the increasing donor inclination towards climate and health work (Participant 12).

> *'Now is the time to take advantage because everyone now knows about climate change because of all the attention it has gotten politically. Even 2-3 years ago that landscape was different. Now is the time to have this conversation, because of the buzz around it.'*
> *– Health Worker*

Finances

Finances consistently emerged as both barriers and enablers in achieving a net-zero healthcare system in Kenya by 2030. Participants underscored the substantial financial challenges associated with implementing mitigation measures. Stakeholders from diverse backgrounds, including development agencies, faith-based health services, and national government representatives, echoed concerns over financial constraints. The threefold greater cost of sevoflurane, an anaesthetic gas commonly used in surgery, in place of nitrous oxide was highlighted as a significant challenge, despite its lower global warming potential. Furthermore, transitioning to solar energy, despite its long-term benefits, necessitates substantial initial capital investments in panels, batteries, and distribution systems which participants identified as burdensome given the prevailing limited health system funding. Several interviewees indicated challenges with the financing and allocation of funds for waste management, while others highlighted the limited funding specifically dedicated to climate and health.

Some stakeholders pinpointed potential financial enablers. For instance, they viewed increasing cost of grid electricity as a push factor driving interest in solar energy. Others alluded to the promising return on investment of solar initiatives, suggesting payback periods as short as 18-20 months (Participant 03). The potential of carbon trading emerged as an intriguing concept, with some stakeholders arguing for the commercialization of carbon credits as a pathway to drive decarbonisation targets. Solar energy was repeatedly highlighted as both an ecologically sound and financially viable solution, given Kenya's heavy reliance on renewable energy sources. Several interviewees emphasized the potential cost-saving benefits of solar energy in the long term, provided initial capital investments can be managed – explored in the government's Energy System and Transition Plan.

'The universal language the world understands is the language of commerce.' – Supply Chain Expert

Competing priorities

Insights from a Development agency stakeholder emphasized that Kenya grapples with competing health priorities (Participant 06). Adding layers to this argument, a participant providing health services discussed inherent systemic constraints in Kenya; from struggling referral systems, lack of ambulances to lack of access to healthcare for pastoralist communities, highlighting that often, the provision of necessities supersedes broader sustainability goals (Participant 09).

A narrative from a private hospital respondent identified a disparity in acceptance rates, with administrative staff showing more willingness to adopt sustainable practices, while health workers in clinical settings, such as operating theatres, were less inclined (Participant 21). This was further echoed by insights from the health workforce commenting on work in regions facing scarcity, where the immediate concern revolves around providing basic levels of care rather than sustainability (Participant 11). Healthcare delivery, access, and affordability often take precedence over other priorities (Participant 04).

External influences, particularly from the private sector, often conflict with sustainability efforts, evidenced by the tendency to promote single-use equipment over reusable alternatives because of patient perception of safety (Participant 11). The national government faces challenges including slow acceptance from healthcare managers and industry players (Participant 15).

This web of competing priorities was summarized by a member of the health workforce, underscoring the immediate challenges of hospitals grappling with medicinal shortages and the overarching government focus on opinion polls, often overshadowing the long-term repercussions of climate change. The urgency of the issue, they noted, struggles to resonate at the grassroots level where the effects of climate change are not immediately palpable. Thus, bringing climate change to the forefront of the healthcare agenda necessitates not only systemic change but also heightened advocacy and awareness campaigns (Participant 12).

'If you market love to people that are heartbroken you will never get them to understand it. If you talk about carbon for people that need oxygen, they will not get it.' – Supply Chain Expert

'There is a lot of growth in our health system and a lot of investment coming up, but we have a long way to go.' – Faith Based Health Services Provider

Infrastructure

An interviewee from the faith-based health services (Participant 09) highlighted challenges in accommodating healthcare facilities that are part of larger, multi-use structures, such as clinics situated in high-rise buildings, because of dependency on other users in the building. An academic (Participant 02) noted that one of Kenya's leading hospitals has outdated infrastructure, affecting waste management and diversion from landfills. A development agency stakeholder (Participant 06) pointed to market challenges, such as the unavailability of more sustainable technologies in Kenya. Limited availability and poor-quality medicines can lead to ineffective treatments, increasing emissions through additional interventions (Participant 09 & Participant 21).

These challenges are compounded by the need for facilities that can withstand Kenya's climate pressures, such as frequent heavy rainfall. For example, an academic (Participant 02) noted the importance of integrating green spaces within hospital designs, not only for patient well-being but as a form of adaptation to enhance local climate resilience. These adaptive measures align closely with the need for sustainable infrastructure development that Participant 09 and Participant 21 discussed, particularly in terms of energy and water efficiency.

Conversely, the increased accessibility and availability of photovoltaic equipment, particularly from countries like China, supports a growing momentum in sustainable energy solutions and health delivery. As new healthcare facilities emerge, they present unique opportunities. Such facilities can leverage innovative designs, materials, and technologies to enhance energy efficiency and long-term planning. This includes considering architectural elements, including passive ventilation, cool roofs and rammed earth construction, utilising less power-consuming machinery, and focusing on energy-saving practices.

Awareness, Knowledge and Engagement

A development agency representative (Participant 06) highlighted that many within the healthcare system do not yet understand the urgent need to reduce GHG emissions. This sentiment is echoed by representatives from faith-based health services (Participant 09) and supply chain (Participant 19), who pointed out the lack of knowledge and sensitization required for unified action. Participants from building design (Participant 03), health workforce (Participant 10), and academia (Participant 02) emphasized that the complexity of information related to GHG emissions and mitigation strategies needs simplification to be more comprehensible to a wider audience.

The lack of tailored roadmaps for Kenyan hospitals is another barrier. Representatives from tertiary private hospitals (Participant 21) mention that existing guidelines, often developed with Western hospitals in mind, might not be directly applicable in Kenya. Furthermore, the current curricula in medical and nursing schools do not adequately cover climate change and its relation to health, leading to a gap in education. An academic (Participant 01) emphasized the challenge of CEOs with clinical backgrounds lacking managerial insight and the necessity to sensitize the board management.

Stakeholder engagement also emerges as a concern, with representatives from the health workforce (Participant 11) highlighting that Kenya's commitments have not been adequately communicated or implemented at subnational levels. Similarly, siloed operations among partners (Participant 07) and a lack of intersectoral communication between climate change and public health professionals (Participant 01) were identified as barriers. Finally, engagement with community has been identified to be lacking – with an underrepresentation of traditional knowledge in research (Participant 08).

A representative from building design (Participant 03) emphasized the advantage of Kenya's educated and professional workforce as an opportunity, suggesting that, given proper resources and direction, they are poised to drive the transition. The current leadership's commitment to the climate and health agenda, as described by a national government representative (Participant 15), also presents an opportunity for accelerated progress. Moreover, the possibility of international collaboration and partnerships is a promising avenue, offering both resources and expertise.

> *'Yes, Kenya needs to have a strategic change when it comes to allocation of resources in the health sector and there is a need for [health workers] to realize that the climate change crisis is a health crisis.' – National Government Representative*

Workshop

A thematic analysis conducted on the interviews identified 14 key process components towards a net-zero healthcare system in Kenya (Table 18, Appendix B). These components, ranging from leadership and political will to financing and stakeholder engagement, were collectively validated by the workshop participants.

Emphasising a whole-of-society approach, the workshop participants underscored the necessity of engaging a diverse array of stakeholders to ensure the successful transformation of Kenya's healthcare system. Figure 5 illustrates identified stakeholders, categorized by their impact, power, and relevance to each of the 14 process components. The workshop discussions revealed that stakeholders with high-power and high influence required close management to harness their potential effectively, whereas those with high power but low influence needed strategies tailored to maintain their support and involvement.

A perceived underrepresentation of large sources of emissions in implemented actions, such as the supply chain, was identified in the workshop. Building on this, the workshop participants ranked actions necessary for achieving net-zero emissions in the healthcare system through a Delphi process. When deciding on priority based on impact, participants initially focused on developing comprehensive national healthcare policies supported by existing evidence. As the workshop progressed, generating actionable, localized data to inform policies and actions emerged as the top priority in the eventual consensus reached after three rounds of voting, because of larger potential for impact. The discussions further highlighted the importance of leveraging local resources and technologies to build resilient healthcare infrastructures that not only withstand climate-related challenges but also contribute to reducing emissions. The workshop addressed the transformative potential of integrating renewable energy solutions, such as solarization of health facilities, to ensure reliable energy supply and reduce dependency on unsustainable power sources.

In terms of feasibility, early discussions favoured the implementation of clean energy solutions in healthcare facilities, reflecting the sector's readiness and the supportive policy environment for renewable energy initiatives. However, eventual consensus after two rounds of voting favoured simpler and immediately impactful actions, such as establishing hospital vegetable gardens and internal guidelines for departmental behaviour change. These actions were seen as quicker to implement and requiring fewer resources, making them practical choices given the current barriers. By the conclusion of the workshop, there was a consensus that while long-term, strategic policy development is crucial, the integration of directly actionable items that yield tangible results is equally vital. This balanced approach ensures immediate, practical benefits while laying the groundwork for sustained systemic change. Table 19 showcases the ranking results of each round of voting, both for ranking based on impact (three rounds) and ranking based on feasibility (two rounds).

Table 18 Process components identified through interviews and validated by workshop towards a net-zero healthcare system in Kenya.

Component	Description
1. Leadership & Political Will	Effective leadership must transcend organizational boundaries, promoting net-zero healthcare that overcomes system fragmentation and aligns with national climate goals.
2. Goal Setting & Action	Setting clear, actionable goals is vital, reflecting a commitment that aligns with Kenya's structured policy environment for effective implementation.
3. Financing	Addressing financial barriers through innovative funding solutions and government incentives for renewables, ensuring sustainable investments.
4. Awareness and Sensitization	Enhancing understanding through targeted awareness campaigns and education, crucial for engaging all healthcare stakeholders in the climate agenda.
5. Baseline Data	Collecting and utilising baseline data to inform and tailor interventions, essential for accurate monitoring and effective mitigation and adaptation strategies.
6. Research & Innovation	Encouraging robust research initiatives and innovative solutions that can be practically applied to mitigate climate impacts within healthcare settings.
7. Strategic Planning	Developing comprehensive strategic, ensuring plans are actionable and aligned with broader health goals.
8. Legislation, Policies, and Guidelines	Establishing supportive legislative and policy frameworks ensure compliance across the healthcare system.
9. Education and Capacity Building	Building capacity through education and training, integrating climate change into healthcare curricula to foster a knowledgeable workforce ready to implement sustainability initiatives.
10. Engagement	Promoting broad-based engagement strategies that include all levels of government and the community, essential for the widespread adoption of measures.
11. Implementation	Ensuring that policies and guidelines are translated into actions that result in tangible, measurable outcomes.
12. Behavioural Change	Supporting behavioural change initiatives that address cultural norms and practices.
13. Monitoring and Follow-up	Implementing rigorous monitoring and follow-up mechanisms to ensure ongoing compliance and adaptation of strategies to emerging challenges.
14. Reporting, Transparency, and Recognition	Maintaining high standards of transparency in reporting and recognising efforts to meet sustainability benchmarks, essential for accountability and continuous improvement.

Table 19 Outcomes of Delphi Ranking Exercise

Actions (alphabetical)	Impact Priority Ranking out of 12 (average score)			Feasibility Ranking out of 12 (average score)	
	Round 1	*Round 2*	*Round 3*	*Round 1*	*Round 2*
A. Clean energy implementation for facilities.	6 (7)	2 (7.89)	2 (9.38)	1 (10.13)	6 (7)
B. Developing national sustainable healthcare policies based on existing evidence.	1 (8.88)	3 (7.78)	3 (8.88)	9 (5.63)	8 (5.71)
C. Developing requirements for green building.	8 (5.75)	10 (5.44)	11 (4.5)	6 (6.38)	7 (6.43)
D. Establishing monitoring and follow-up committees.	10 (5.38)	11 (5)	7 (5.5)	5 (6.75)	2 (9.14)
E. Generate evidence that influences policy decisions and action.	2 (8.63)	1 (9.33)	1 (10.88)	3 (8)	4 (7.86)
F. Hospital vegetable gardens for organic foods.	12 (2.25)	12 (2.89)	12 (2)	4 (7.63)	1 (9.57)
G. Incentivization of healthcare facilities that adopt GHG mitigation strategies through lower taxes.	3 (8)	4 (7.56)	4 (8.25)	11 (4.13)	12 (2.14)
H. Internal guideline for department/unit behaviour change.	10 (5.38)	7 (6.22)	7 (5.5)	2 (8.13)	3 (9)
I. Limit use of one time use equipment in surgical practice.	9 (5.5)	9 (5.78)	6 (5.88)	7 (6.25)	9 (4.86)
J. Reuse and recycling of medical waste.	4 (7.13)	6 (6.33)	10 (4.88)	10 (5.5)	9 (4.86)
K. Sustainable healthcare education for practicing health workers	6 (7)	7 (6.22)	5 (7)	8 (6)	5 (7.29)
L. Sustainable healthcare education in the medical curriculum.	4 (7.13)	4 (7.56)	9 (5.38)	12 (3.5)	11 (4.14)

Participants scored various healthcare sustainability actions based on priority and feasibility. Each option was ranked by participants, with points awarded in descending order (the top-ranked option received the most points). The sum of these points for each option was then divided by the number of participants to calculate the average ranked score for each round.

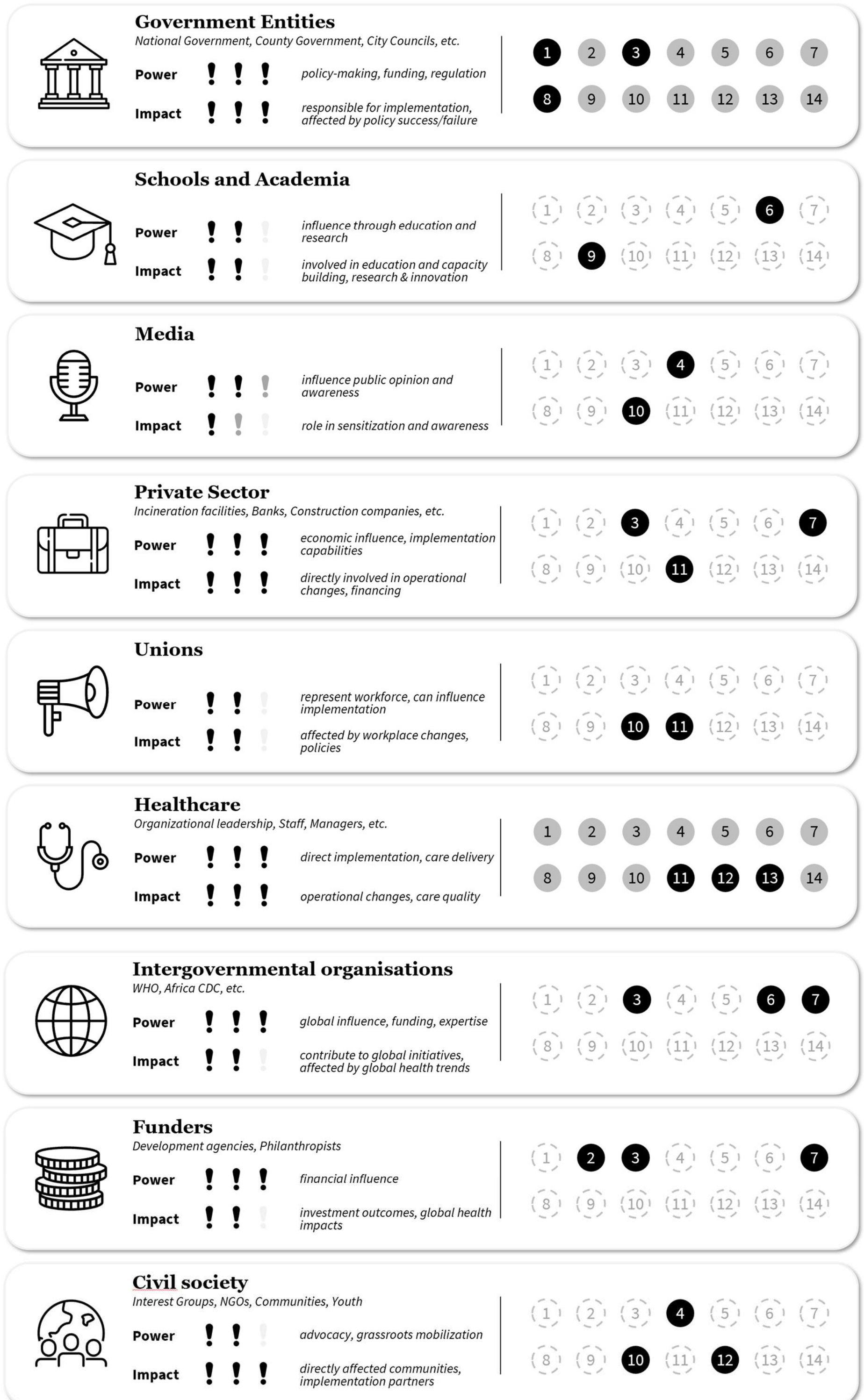

Figure 5 Overview of stakeholders relevant to the transformation of Kenya's healthcare system to net-zero.

For each group of stakeholders their power and impact are illustrated with exclamation marks, ranging from 1 (low power/impact) to 3 (high power/impact). Their relevance to several process components is illustrated, with grey indicating intermediate relevance and black indicating high relevance. Process components are: 1. Leadership & Political Will, 2. Goal setting & action, 3. Financing, 4. Awareness and sensitization, 5. Baseline data, 6. Research & Innovation, 7. Strategic planning, 8. Legislation, policies and guidelines, 9. Education and capacity building, 10. Engagement, 11. Implementation, 12. Behavioural change, 13. Monitoring and follow-up, 14. Reporting, transparency and recognition.

7.4.4. Discussion

This study marks an effort towards understanding and delineating the pathway for Kenya to establish a net-zero healthcare system by 2030. To our knowledge, this is the first comprehensive qualitative exploration focusing on this transformative goal in Kenya. Our results indicate a shared optimism among stakeholders about the potential for transformation, albeit tempered by the recognition that significant barriers must be addressed.

A central challenge identified is the tension between immediate healthcare needs and long-term sustainability goals. In Kenya, priorities such as basic service provision and addressing shortages of medicines, especially during climate emergencies, often overshadow sustainability initiatives. Systemic issues, including strained referral systems and a shortage of health workers, further compound this challenge, with immediate concerns about access to care and workforce capacity taking precedence over long-term climate goals (165–167). Additionally, external pressures, such as the preference for single-use equipment in the private sector due to perceived safety by patients, conflict with efforts to reduce waste (168). Limited availability of sustainable technologies and poor-quality medicines can further increase emissions through ineffective treatments and additional interventions (169,170). Financial barriers, such as the high cost of sevoflurane and the upfront investments required for solar energy, exacerbate the challenge, particularly given the limited funding dedicated to climate and health (171–173). However, rising electricity costs and increased availability of solar technologies are driving interest in solar energy, with returns on investment potentially seen within 18-20 months (174–176). Engaging stakeholders to explore these financial implications and co-benefits, including their connectedness with adaptation, could provide necessary insights for policymakers. For example, in Guinea, the Ministry of Health and Public Hygiene, in collaboration with the Ministry of the Environment and Rural Development, has undertaken a comprehensive emissions evaluation covering major public and private healthcare facilities to identify potential for carbon footprint reductions, cost savings, and improved operational efficiency – with cost savings likely being a major driver of change. In turn, this initiative is intended to support fund mobilization and engage experts towards implementation of interventions (53).

Effective governance is pivotal in driving the transition to a net-zero healthcare system. Results indicate the critical need of the national government to harmonize efforts with county-level administrations, linking national policies to actionable county-level strategies. Kenya's decentralized health system presents both opportunities and challenges. The devolution of powers allows counties to tailor policies to their specific contexts, potentially accelerating localized success. However, the lack of baseline measurements and standardized frameworks poses significant barriers, as operational gaps in carbon benchmarking and vulnerability assessments undermine strategic alignment and real-world feasibility (177–179). Additionally, relevant ministries and healthcare institutions face resource constraints—both financial and human—which further impair the translation of policies into tangible actions (180,181). Delays in county-level project timelines and administrative complexities have hindered the effective execution of climate strategies (165,182), while discrepancies between legislative frameworks and ground realities remain evident (183). Furthermore, systemic corruption impedes private-sector innovation in advancing GHG mitigation efforts (184,185). Inspiration can be drawn from structures in other countries, as this dynamic is similar to South Africa, where the Presidential Climate Commission was established to coordinate between national, provincial, and local governments to integrate climate policies into various sectors, including health, through five-year integrated development plans (186,187). In Togo, the Ministry of Health and Public Hygiene oversees the climate and health agenda, with a scientific committee in charge of involving regional and district healthcare directors to integrate sustainability practices (53). Additionally, Kenya's involvement in global partnerships, such as the ATACH, offers platforms for collaboration, which could drive domestic agendas and mobilize international funding support (188). Coordinating national policies based on locally relevant evidence through the Climate Change and Health Strategic Working Group can play a significant role in establishing a robust framework for implementing sustainable healthcare practices.

The contrast between feasibility and impact, as showcased by the workshop outcomes, highlight difficulties for policymakers to make informed choices that optimize impact without exceeding current capabilities. A notable shift in rankings between the first and second part of the workshop reflected that, as discussions progressed, participants discussed the practical barriers more deeply such as financial and operational constraints. Three interventions stand out for their high rankings across both impact and feasibility in the final rounds of voting in the workshop. Generating evidence that influences policy decisions and action, and developing policies based on existing evidence, emerged as two of these three. By analysing ongoing initiatives through robust data collection, targeted, evidence-based interventions can be identified, implemented more widely, and incorporated into national policies. Clean energy implementation for facilities also ranked highly, with a strong potential for substantial benefits despite moderate implementation challenges. In regions with high solar and wind potential, these systems have demonstrated significant greenhouse gas reductions, cost savings, and improved health outcomes. For instance, in a rural health facility in the Philippines, a solar photovoltaic system is modelled to enable continuous healthcare delivery even during climate-related disruptions, highlighting dual benefits for mitigation and adaptation (45).

The limitations of this study include that it may not fully represent all views within Kenya's diverse healthcare landscape. Furthermore, the findings are constrained by the temporal scope of the study and might not reflect continuous changes in policy or practice. Complementing qualitative insights with quantitative studies could offer a more detailed assessment of emissions reductions and intervention effectiveness. The Aga Khan Development Network, through the ENBEL project in partnership with Kenya's Ministry of Health, has contributed to this process by training Kenya's County Public Health Officers in the use of their Carbon Management Tool in June 2023 (189,190). It is also important to consider the political economy of translating workshop and interview insights into practice. While stakeholders in engagement settings, such as workshops, may express ambitious goals for GHG reduction, the realities of policy implementation could lag. Political, financial, and institutional barriers can significantly slow or alter the trajectory of these ambitions, and this should be considered when interpreting the study's findings (189,190). It is also important to consider the political economy of translating workshop and interview insights into practice. While stakeholders in engagement settings, such as workshops, may express ambitious goals for GHG reduction, the realities of policy implementation could lag. Political, financial, and institutional barriers can significantly slow or alter the trajectory of these ambitions, and this should be considered when interpreting the study's findings.

7.4.5. Conclusion

The pathway to a net-zero healthcare system in Kenya is contingent upon a strategic synthesis of policy, practice, and partnership. Each step forward must carefully consider the interplay of immediate feasibility and long-term impact, harnessing both governmental support and international best practices to build a resilient and sustainable healthcare infrastructure. (189,190).

The integration of climate action with health system planning presents an opportunity to enhance public health outcomes while contributing to national climate goals. The continued exploration, evaluation and reporting of these themes and navigation of their related complexities, both within and outside of Kenya, are essential for refining strategies and achieving the ambitious targets set forth by Kenya.

7.4.6. Acknowledgements

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7.5 Discussion and Implications

This qualitative study underscores the complex and multi-layered nature of implementing GHG mitigation interventions within healthcare systems in LMICs, particularly Kenya. The barriers identified by stakeholders - ranging from infrastructural limitations to financial constraints - are not unique to Kenya. They mirror challenges faced by many LMICs where healthcare systems already grapple with resource shortages, inefficiencies, and the demands of expanding access to care. In this way, the chapter reinforces a key theme of the thesis: the transformation to sustainable healthcare systems in LMICs must be context-sensitive and tailored to local realities. Generalized global approaches will not suffice without considering specific national and regional challenges.

One significant implication of this research is the recognition of the delicate balance between immediate healthcare needs and long-term sustainability goals. In Kenya, stakeholders repeatedly emphasized the tension between addressing acute healthcare issues - such as improving access to care, securing medical supplies, and providing basic services - and the broader, future-oriented goal of achieving net-zero emissions. This tension is likely to be echoed in other LMICs. Therefore, the research suggests that climate policy, particularly as it pertains to healthcare, must be framed not only in terms of future benefits but also as a strategy that can deliver priority benefits in the near term, such as cost savings, improved health outcomes, and greater system resilience. These more immediate gains can help build momentum and stakeholder support, aligning mitigation efforts with existing healthcare priorities. However, achieving a sustainable healthcare system will require financial and technical support from global partners. HICs, which have historically contributed more to climate change, have a critical role to play in supporting LMICs through climate finance, capacity-building initiatives, and knowledge-sharing platforms.

The analysis employed an exploratory, inductive approach using thematic analysis, with themes emerging from the data rather than being pre-imposed, reflecting elements of grounded theory principles. The findings were synthesised narratively to capture stakeholder insights into barriers and enablers of GHG mitigation in Kenya's healthcare sector. The study's findings on stakeholder engagement highlight the importance of leadership and political will at both the national and county levels. Kenya's decentralized governance structure presents both opportunities and challenges for implementing GHG mitigation interventions. The study suggests that aligning national climate commitments with local governance mechanisms is critical to achieving success. This reflects a broader thesis implication: in contexts where healthcare systems are decentralized, effective coordination between national policies and local implementation is crucial for system-wide change.

Another key theme emerging from the paper is the need for capacity building and education within the healthcare system. The lack of awareness and technical knowledge on GHG mitigation among health workers and administrators was a recurring barrier identified by stakeholders. This aligns with the thesis's emphasis on strengthening institutional capacities in LMICs to support sustainable transformations. Education and training, particularly around climate-health intersections, must be prioritized as a foundational element of healthcare system sustainability.

Finally, this chapter illustrates the potential synergies between GHG mitigation and climate change adaptation in Kenya's healthcare system. Several of the interventions highlighted - such as clean energy implementation - provide dual benefits by both reducing emissions and enhancing the healthcare system's resilience to climate-related disruptions. This reflects a central argument of the thesis: that integrating mitigation and adaptation strategies in healthcare systems is not only possible but necessary for LMICs, which are often disproportionately affected by climate change. Kenya's experience can offer valuable lessons for other LMICs, demonstrating how healthcare systems can navigate the challenges of reducing emissions while simultaneously preparing for the impacts of climate change.

Kenya's experience illustrates that achieving a net-zero healthcare system will require a combination of strong political will, stakeholder collaboration, capacity building, and carefully crafted policies that align immediate healthcare priorities with long-term climate goals. As other LMICs embark on similar pathways, the lessons from Kenya's journey will serve as a crucial point of reference in shaping global approaches to sustainable healthcare systems.

Chapter 8: Health workers in Kenya's Net-Zero Healthcare Transformation

8.1 Introduction

Chapter 8 focuses on the crucial role health workers play in Kenya's journey toward achieving a net-zero, resilient healthcare system by 2030, aligning with national commitments under the UNFCCC COP26 Health Programme. The transformation to a sustainable healthcare system is a complex and multifaceted process, requiring collaboration across stakeholders, and Chapter 7 confirmed that health workers are at the forefront of this effort. This chapter introduces the mixed-methods study that investigates how Kenyan health workers perceive their roles in this transformation and the barriers and opportunities they face in contributing to climate change mitigation and adaptation within their healthcare settings.

Kenya, as a lower-middle-income country, faces unique challenges that stem from both the disproportionate impacts of climate change and the need for its healthcare system to continue and improve the delivery of care in increasingly strained conditions. This is a dual challenge: while health workers are tasked with reducing emissions within their operations, they must also adapt to the climate-related disruptions that exacerbate health vulnerabilities.

This study adds a new dimension to the ongoing discussions by exploring the specific perspectives and experiences of health workers in Kenya - those who directly implement and interact with mitigation and adaptation efforts on the ground. Their insights, gathered through an online questionnaire and a subsequent focus group discussion, offer critical understanding of how health workers can be better equipped and supported to lead the transformation toward a sustainable healthcare system. Moreover, the study highlights the knowledge gaps and systemic challenges that hinder effective climate action within the sector.

8.2 Aims and Objectives

The overarching aim of this study is to explore the role of education for the healthcare workforce in Kenya to enhance their understanding of climate change's health impacts and empower them to implement effective interventions in their practice. The study seeks to identify the critical knowledge gaps and educational needs of health workers and to propose actionable strategies for integrating climate change education into the healthcare system, tied to the following objectives:

1. To identify the specific climate change knowledge required by various types of health workers in Kenya to effectively build sustainable and resilient healthcare systems.

2. To determine the essential educational components needed to enhance health workers' capabilities in climate change mitigation and adaptation.
3. To explore ways in which existing policies and frameworks can be leveraged to support the integration of climate change education into healthcare professional development.

By addressing these objectives, the study aims to inform policies and educational strategies that support health workers as key drivers in Kenya's transformation to a net-zero healthcare system.

8.3 Research Paper Cover Sheet

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SECTION C – Prepared for publication, but not yet published

Where is the work intended to be published?	The Oxford Open Climate Change
Please list the paper's authors in the intended authorship order:	Iris Martine Blom, Melvine Anyango Otieno, Marie-Claire Wangari, Agan Leonard, Winslet Mwende, Naomi Wanjiku Gitau, Iain Cross, Anita Berlin, Andy Haines, Sarah Whitmee
Stage of publication	**In press**

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	IMB conceptualized the study, designed the methods with SW, AH, AB, IC and MO. Investigation was performed by all authors. IMB analysed and curated the data, reviewed by SW and AH. IMB wrote the original draft, and all authors reviewed and edited. Supervision was provided by SW and AH.

SECTION E

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Date	10/12/2024

Supervisor Signature	SWhitmee
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8.4 The Role of Health Workers in Kenya's Net-Zero Transition: A Mixed-Methods Study on Healthcare System Climate Change Mitigation and Adaptation[3]

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[3] Please note that this manuscript has been peer reviewed and accepted for publication since first thesis submission. Minor comments were received and the manuscript, as accepted for publication, can be found in Appendix XI.

Abstract

Climate change presents a critical challenge to healthcare systems, particularly in low- and middle-income countries like Kenya. Health workers are key to leading the transition toward a sustainable, climate-resilient healthcare system. This mixed-methods study explores the perceptions, knowledge, and roles of Kenyan health workers in mitigation and adaptation in healthcare. An online questionnaire, completed by 118 health workers, explored their understanding of climate change's impacts on health, the healthcare system's role in emissions reduction and adaptation, and current practices. A subsequent focus group discussion delved deeper into the identified themes, with a particular focus on education of health workers to support climate action.

The findings reveal that while health workers are aware of the health risks posed by climate change, financial limitations and insufficient training present significant barriers to the implementation of sustainable practices. The focus group emphasized the need for practical, context-specific education to equip health workers with actionable knowledge and skills, alongside fostering emotional resilience and ethical leadership. Key recommendations include co-creating educational programs with communities and health workers, integrating climate-health modules into curricula, and leveraging innovative approaches such as peer-led workshops and social media campaigns. These insights underscore the transformative potential of education in empowering health workers to lead Kenya's transition to a sustainable, climate-resilient healthcare system.

Lay Summary

Climate change is a big challenge for healthcare systems, especially in countries like Kenya. Health workers are key to making healthcare more sustainable and better prepared for climate-related issues. This study asked Kenyan health workers about their views on health system responses to climate change.

We found that most Kenyan health workers know about the health risks of climate change, but they need more training and support to act. In a group discussion, participants said education should focus on practical skills, like handling new disease patterns and managing climate-related emergencies. They also shared creative ideas, like using social media and peer-led workshops to spread knowledge.

Participants emphasized the importance of working closely with local communities and making sure national policies fit local needs. They also highlighted the need for mental health support and leadership training to help health workers manage challenges. By providing better education and materials, Kenya can strengthen its healthcare system and prepare for a healthier, more sustainable future.

8.4.1. Introduction

Climate change presents an unprecedented challenge to global healthcare systems. It is increasingly recognized as the largest health threat of the 21st century, exacerbating existing health issues and introducing new risks (191). Healthcare systems, responsible for about 5% of global greenhouse gas (GHG) emissions, are both a contributor to the crisis and heavily affected by its consequences (17). Most of these emissions come from healthcare systems in high income countries and, going forward, low-emitting countries will have important policy choices about GHG emitting sectors including healthcare (191). As healthcare systems aim to manage the adverse impacts of climate change, they must simultaneously adapt to the change that cannot be prevented and mitigate their environmental footprint.

Low- and middle-income countries (LMICs), including Kenya, are disproportionately vulnerable to the health impacts of climate change. Kenya is facing both direct health effects—such as increased frequency of heatwaves and changing patterns of infectious diseases—and indirect effects, including reduced access to essential services and infrastructure (55). In response, Kenya has committed to transitioning its healthcare system toward a resilient system with net-zero emissions by 2030, as part of the World Health Organization's (WHO) United Nations Framework Convention on Climate Change 26th Conference of Parties (UNFCCC COP26) Health Programme in 2021 (25). Following Kenya's National Climate Change Action Plan (NCCAP) which recognized the importance of integration of climate change into all sectors including health, Kenya identified key strategic actions including developing education programs to empower communities, enhancing disaster preparedness, and strengthening resilience against climate-induced health challenges, and integrating climate change into cross-sector curricula at all levels including for the health workforce (49).

Kenya's health workers are recognized by decision-makers as central stakeholders in the country's transition to a climate resilient, net-zero healthcare system (192,193). Their role extends beyond patient care to actively influencing the planning, implementation, and evaluation of climate adaptation and mitigation strategies. Interviews conducted in Kenya in 2023 with key stakeholders in the healthcare system transformation affirm that health workers are pivotal in guiding sustainable practices at every level of healthcare delivery, ensuring that interventions are feasible, impactful, and aligned with national climate objectives (193). Beyond implementation, the active engagement of these health workers is crucial for the design of solutions, the development of national sustainable healthcare policies, and the generation of localized data to inform climate actions. This mirrors findings from other contexts, such as in England's "Greener NHS" programme, where health workers have been instrumental in leading low-carbon initiatives, and in Australia, where health workers underlined their role in implementation towards sustainable, climate-resilient healthcare (194,195). Health workers' capacity to drive change and willingness to engage are indispensable for achieving Kenya's ambitious climate targets within its healthcare system.

In this manuscript, we describe health workers' perceptions of their roles and contributions to Kenya's net-zero, resilient and sustainable healthcare transition. Through a mixed-method approach - including a questionnaire and a focus group discussion with health workers - we explore integrating climate change mitigation and adaptation into routine healthcare delivery. By focusing on the perceptions of health workers, we provide a first step towards understanding how they can best be supported to drive the necessary transformation toward a resilient, sustainable healthcare system.

8.4.2. Methods

This study employed a mixed-methods approach to investigate the roles and perceptions of health workers in Kenya's transition to a net-zero healthcare system. The study was conducted in two phases: (1) a structured questionnaire aimed at capturing baseline knowledge, attitudes, and practices of health workers regarding climate change mitigation and adaptation, and (2) a focus group discussion, informed by the outcomes of the questionnaire, further explored barriers, opportunities, and actionable strategies for health workers to contribute to sustainable healthcare practices.

Study Setting and Participants

The online study targeted health workers and university students in Kenya, including medical doctors, nurses, pharmacists, community health workers, dentists, and those training in these professions. Participants were recruited through outreach to professional and student health associations, representing the diverse healthcare workforce across the country. These associations were identified using the authors' prior knowledge, professional networks, and publicly available information, ensuring representation from a range of healthcare institutions, including public hospitals, private facilities, and community health centres.

For the questionnaire, convenience sampling was employed based on participants' availability and willingness to participate. The questionnaire was disseminated through existing association communication channels and public social media platforms. As a result of this sampling method, response rates could not be calculated. Convenience sampling was used in this study to efficiently explore this area for the first time, addressing challenges such as transnational communication and recruitment constraints.

For the focus group, purposive sampling was used to select representatives from twelve professional healthcare associations and their student or young professional networks. Each association was invited to nominate one representative to convey their collective perspectives, and a total of seven representatives were ultimately nominated and participated in the discussion, representing community health workers, dentists, pharmacists, nurses, medical doctors, family physicians, and pharmacy and medical students. Focus groups were chosen as the primary method for this phase due to their ability to facilitate group interaction, generate rich and diverse insights, support exploratory research by enabling participants to build upon each other's ideas, and provide a deeper understanding of collective perspectives and dynamics, ensuring representation from key stakeholders and offering a comprehensive initial exploration of educational and policy needs (196).

Phase 1: Questionnaire

A structured questionnaire was distributed online to health workers across Kenya to assess knowledge, perceptions, and current engagement in climate change-related mitigation and adaptation practices. The questionnaire (Appendix IX) included both closed and open-ended questions designed to assess various aspects of healthcare professionals' perceptions and practices related to climate change. The questionnaire was developed based on a review of relevant literature and drafted collaboratively by the research team. It was refined through feedback from a pilot group of 10 Kenyan healthcare professionals, ensuring clarity, cultural relevance, and alignment with the study's objectives. Questions addressed the following topics: participants' awareness of climate change and its health impacts; their understanding of healthcare's contribution to greenhouse gas emissions; existing transformation efforts within healthcare settings; barriers and opportunities to implementing climate change mitigation and adaptation strategies; and participants' willingness to engage in healthcare system transformation.

Phase 2: Focus Group Discussion

The focus group discussion, conducted after the questionnaire, was designed to delve deeper into the themes that emerged from this initial exploration. The questionnaire provided a broad overview of health workers' knowledge, perceptions, and practices related to climate change, highlighting education as a critical gap. Building on these findings, the focus group further explored education by concentrating the current understanding and perception of climate change within respective healthcare professional groups, the role of health workers in climate mitigation and adaptation efforts (including an exploration of power dynamics in driving change and implementing educational initiatives), an exploration of knowledge and training needs regarding sustainable and resilient healthcare (with attention to local knowledge systems and contextualised educational approaches), and barriers and opportunities for implementing climate change education within healthcare (Appendix II).

To ensure a culturally sensitive and inclusive discussion, two facilitators were present. One (IMB) led the discussion, while the second (MO) observed cultural nuances, monitored participant engagement, and provided input or clarifications to maintain sensitivity. The second facilitator also provided feedback to refine the analysis, supporting a safe and inclusive environment for all participants. The focus group was conducted via Zoom due to geographical constraints, lasting approximately two and a half hours. All discussions were audio-recorded with participants' consent and transcribed verbatim for analysis.

Data Analysis

Data from the questionnaire were analysed using descriptive statistics to summarize respondents' knowledge, attitudes, and practices concerning climate change mitigation and adaptation. Categorical variables were summarized as frequencies and percentages, while continuous variables were presented as means and standard deviations. Responses to open-ended questions were thematically coded to identify recurring themes related to barriers and opportunities for action.

Transcripts from the focus group discussion were analysed using thematic analysis. Initial coding was performed using NVivo software to identify major themes, followed by a second round of analysis to refine and categorize these themes. Key findings were triangulated with the results from the questionnaire to provide a comprehensive understanding of the health workers' perceptions and roles in the net-zero healthcare transition.

Ethical Considerations

The proposal for this research was approved by the Research Ethics Committee of the London School of Hygiene & Tropical Medicine (Ref. 28210) and the Kenya Medical Research Institute (KEMRI, Ref. 4662), and licensed by the National Commission for Science, Technology and Innovation (NACOSTI, Ref. 519115 and extension Ref. 285069). Written informed consent was obtained through the questionnaire form and ahead of the focus group from all participants prior to their participation in the study. Confidentiality was maintained throughout the research process. All participants were informed how to leave the study if they wished, which they could do at any time. Verbal consent was obtained at the beginning and end of the focus group to proceed with the focus group and analysis, respectively. Focus group participants were reminded of confidentiality at the beginning and the end of the focus group.

8.4.3. Results

A total of 118 health workers participated in the questionnaire phase, conducted between June and December 2023. The focus group discussion followed in November 2024, with 7 participants representing a total of 29,800 health workers and students, selected from various Kenyan professional healthcare associations, including their student and young professional networks.

Results Phase I: Questionnaire

Demographics

Of the 118 participants in the questionnaire, 67 (56.8%) were practising health professionals, including junior doctors, general practitioners, and specialists, while 51 (43.2%) were students, primarily in medical, nursing, and pharmacy fields. Medical doctors made up 24 participants (20.3%), with nurses and nursing students accounting for 8 participants (6.8%). Other professions included pharmacists, community health workers, microbiologists, and public health officers. Participants worked and studied in 20 counties, with the largest groups in Uasin Gishu (29.7%, n = 35), Nairobi (19.5%, n = 23), Kisumu (9.3%, n = 11), and Kiambu (5.9%, n = 7) (see Figure 6). Most respondents (40.7%, n = 48) were active in public healthcare, while 16.1% (n = 19) were in private facilities, 11.0% (n = 13) in NGO-based providers, and 4.2% (n = 5) in faith-based institutions. 47.5% (n = 56) of participants were women and 52.5% (n = 62) were men. Ages ranged from 19 to 57 years, with a mean age of 27.2 years. The majority of participants (75%, n = 88) were aged 20–30.

Compared to available data on the Kenyan healthcare workforce, which is predominantly young and includes approximately 58% women and 42% men, the sample is reasonably representative in terms of gender but skews toward younger participants due to the inclusion of students. Geographically, the participation aligns with known trends of higher workforce concentrations in urban areas, though some underrepresentation of rural counties is noted. (197)

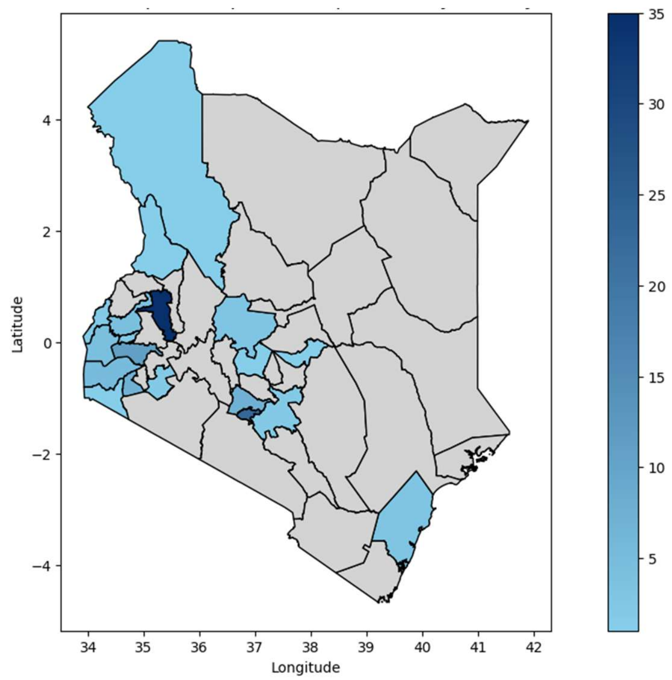

Figure 6 Heat map of Kenya presenting counties in which questionnaire participants work primarily.

Knowledge & Experience

Respondents rated their knowledge of climate change and health at a mean of 6.84 (SD: 2.24) on a scale of 1 to 10, indicating a perception of moderate knowledge. Most participants viewed climate change as a major threat to health, with 60% strongly agreeing and 30% agreeing. Similarly, 80% of respondents strongly agreed (45%, n=53) or agreed (35%, n=41) to having witnessed the effects of climate change in their practice. Greenhouse gas emissions (55%, n=65 strongly agreeing, 30%, n=35 agreeing) and air pollution (65%, n=77 strongly agreeing and 25%, n=30 agreeing) were recognized as a significant health threats.

Perceptions of the Healthcare System's Role in Emission Reduction and Climate Change Mitigation

Opinions on the healthcare system's current efforts in reducing GHG emissions were mixed, with 40% (n=47) agreeing or strongly agreeing this was taken into consideration, while 35% (n=41) disagreed or strongly disagreed. However, 90% (n=106) agreed that reducing GHG emissions should be integrated into healthcare practices.

Regarding Kenya's goal of a net-zero healthcare system by 2030, 45% (n=53) agreed it as achievable, while 25% (n=30) disagreed. There was strong support for the role of health workers, with 90% (n=106) agreeing that they should lead advocacy and implementation efforts to reduce emissions.

Environmental concern was high, with 95% (n=112) of respondents agreeing the current state is alarming, and just as many expressing an interest in learning how to reduce GHG emissions in healthcare.

Responsibility was seen as shared, with 95% (n=112) agreeing that the government and the private sector should take responsibility, and 90% (n=106) supporting roles for community leaders and individuals.

Sources of Healthcare Emissions and Current Interventions in Emission Reduction

The majority of respondents (84%, n=99) identified the production, transport, and disposal of goods and services—such as pharmaceuticals, medical devices, and hospital equipment (emission scope 3 emissions)—as the largest contributor to emissions in Kenya's healthcare system. Additionally, 10% pointed to indirect emissions from purchased energy sources, such as electricity, steam, cooling, and heating (scope 2), while 4% highlighted emissions directly from healthcare facilities and vehicles (scope 1).

Regarding actions taken to reduce greenhouse gas emissions, 87 respondents (74%) reported that they have not yet implemented any interventions. However, some respondents have engaged in efforts like waste management, recycling, energy efficiency measures (e.g., solar power), and sustainable transportation. Education and advocacy were also frequently mentioned as key opportunity areas of focus for reducing emissions. A large proportion of respondents (95%, n=112) expressed interest in implementing future interventions, such as tree planting, better waste management, and using alternative energy sources.

Proposed Solutions

Respondents identified several key interventions to reduce greenhouse gas emissions in Kenya's healthcare system. The most frequently mentioned intervention was the adoption of renewable energy sources (e.g., solar and wind) for healthcare facilities to decrease reliance on fossil fuels. In addition, supply chain management strategies, such as proper disposal of medical waste, increased recycling, and minimising single-use products, were widely supported. Respondents also advocated for telemedicine as a means to reduce patient travel and associated transportation emissions. Other recurring suggestions included sustainable transportation initiatives, such as adopting electric vehicles and encouraging carpooling or public transport, and education and awareness programs aimed at health workers and the general public to promote sustainable practices. Finally, respondents emphasized the importance of green procurement, focusing on the purchase of eco-friendly, recyclable, and energy-efficient products.

Participants highlighted the critical need for integrating climate change adaptation into Kenya's healthcare system, with a strong focus on emergency preparedness and resilient infrastructure. This includes retrofitting facilities to withstand extreme weather events and ensuring reliable energy systems powered by renewable energy sources such as solar panels. In addition, respondents emphasized the importance of telemedicine to reduce travel and maintain continuity of care during climate disruptions, which also aligns with the broader strategy to reduce emissions. Building sustainable supply chains was also viewed as a key opportunity to reduce emissions and adapt, through promoting the use of locally sourced materials.

Opportunities & Barriers

Several opportunities for successfully implementing these measures were identified. Policy and regulatory frameworks were considered essential to encourage healthcare facilities to prioritize sustainability. Many respondents saw public-private partnerships as a key opportunity for mobilising funding and resources to support emission reduction initiatives. Technological innovation, such as energy-efficient medical devices and advanced waste disposal systems, was viewed as another critical factor in driving progress. Additionally, community engagement—including tree-planting campaigns and public awareness programs—was frequently mentioned as a way to promote sustainability at the local level.

The most significant barrier identified by respondents was financial constraints, particularly the lack of funding for the adoption of green technologies and waste management infrastructure. Lack of awareness and education among health workers and the public was also seen as a major obstacle. Other barriers included resistance to change within healthcare institutions and infrastructure limitations, with some facilities lacking the capacity to implement renewable energy or waste management systems.

To overcome these barriers, respondents recommended increased funding and financial incentives, such as government grants or international donor support, to facilitate the transition to greener technologies. Education and training programs were seen as crucial to raising awareness and addressing resistance to change. Respondents also called for stronger policy enforcement to compel healthcare facilities to adopt emission reduction measures. Finally, they highlighted the importance of collaboration and partnerships between government, healthcare institutions, and environmental organizations to support the implementation of sustainable practices.

Finally, when asked whether Kenya needs to change its approach to zero emissions of the healthcare system if it is going to be successful, respondents overwhelmingly called for stronger policies and better enforcement. Key suggestions included prioritising renewable energy adoption, improving waste management practices, and increasing government investment in climate-resilient infrastructure. Education and capacity-building initiatives for health workers and public awareness campaigns were seen as critical to driving change. Additionally, multisectoral collaboration, public-private partnerships, and international cooperation were identified as essential for securing the necessary funding and technological innovation to achieve zero emissions in the healthcare system.

Results Phase II: Focus Group on Education

The findings from Phase I highlighted that while health workers are seen by key stakeholders and decisionmakers as key drivers in promoting sustainability and resilience of the healthcare system, many still lack the necessary education and training to effectively fulfil this role. A focus group was conducted to explore how education might equip health workers with the knowledge and skills needed to lead in implementing emission reduction strategies and climate adaptation within the healthcare system.

A total of seven representatives from professional and student organizations participated, including four women and three men. Collectively, they represented over 29,800 health workers and university students, including community health workers, dentists, pharmacists, nurses, medical doctors, family physicians, and pharmacy and medical students. Participants brought a wide range of perspectives, spanning clinical, educational, and advocacy roles within the healthcare system. The second facilitator noted that participants engaged openly and confidently, with no evident cultural or contextual barriers influencing the discussion.

The discussion began by validating the outcomes of the questionnaire, confirming that while awareness about climate change among health workers is generally high, there is a significant gap in actionable knowledge and practical skills. One participant reflected this sentiment by referencing a similar internal survey:

> *"The majority know that climate change is there and impacting the work, but there is very little knowledge about what has been done or what can be done." (Participant 5, Representing Medical Practitioners, Pharmacists, and Dentists)*

This lack of practical knowledge is further compounded by the increasing burden on health workers due to emerging disease patterns linked to climate change. One participant shared a vivid account of the challenges in a rural clinic, where a lack of preparedness for flooding led to delayed patient care, significant supply chain disruptions, and outbreaks of waterborne diseases. Another participant highlighted the strain on the health workers:

> *"There is an increased workload due to these new patterns and new diseases." (Participant 5, Representing Medical Practitioners, Pharmacists, and Dentists)*

Participants emphasized the dual role of health workers as both caregivers and advocates for climate and health. Beyond clinical responsibilities, they are deeply embedded in their communities, where they serve as trusted sources of knowledge and agents of change. One participant illustrated this by stating,

> *"Health workers are also health advocates for the communities in which they live. So, educating one single health worker from a community is an immense opportunity to addressing some of the issues that we have talked about." (Participant 5, Representing Medical Practitioners, Pharmacists, and Dentists)*

However, a disconnect between national policies and local realities was consistently noted. Participants felt that while national policies like the National Climate Change Action Plan outline ambitious goals, their relevance and applicability to local contexts remain unclear. The group strongly recommended bridging this gap by tailoring policy implementation to reflect the lived realities of health workers and the communities they serve, and ensuring funding is allocated to national plans. One participant remarked, *"Family physicians transcend between the facility and the community, but how national policies and information is distilled for action or awareness downstream to us remains vague." (Participant 3, representing Family Physicians)*

The focus group also identified several key gaps in education. These included education on climate change and health overall, training on disaster response, managing shifts in disease burden, and integrating sustainability into healthcare practices. Participants stressed the importance of a generic teaching framework during university and for working professionals that allows for contextualization to local realities, ensuring the training is adaptable and relevant. They emphasized the need for practical, actionable education that equips health workers with the skills to address these challenges effectively, while also fostering their ability to disseminate critical health information to communities, including in local languages. In addition to practical education, participants highlighted the need for professional development that fosters emotional resilience and equips health workers to navigate the ethical challenges of addressing climate change. Reflective practice and advocacy emerged as essential competencies, enabling health workers to lead in their communities while maintaining their well-being amidst crises.

Young professionals and students emerged as a critical group, with participants highlighting their heightened awareness of climate-health issues and their potential as change agents. One participant noted,

"The younger generation is more knowledgeable about climate and health, which is a privilege we older colleagues do not have." (Participant 2, Representing Young Doctors)

This was accompanied by recognition of their challenges, particularly limited access to decision-making processes and resources. Participants stressed the importance of empowering these groups through targeted education, mentorship, and leadership opportunities to enable them to contribute effectively to sustainability efforts. As one participant emphasized,

"We need to ensure that young professionals and students have the tools and platforms to translate their enthusiasm into actionable change." (Participant 1, Representing Medical Students)

Finally, the group proposed a range of recommendations for improving climate-health education. They underscored the importance of co-creation and decolonization in designing educational programs, guided by the principle of "*nothing for us without us*", which prioritizes community involvement, partnership, and building local assets. Participants highlighted the value of involving diverse stakeholders, including environmentalists, universities, trade unions, tertiary colleges, religious institutions, civil society organizations, county assemblies, county departments of environment and climate change, the Ministry of Health, and international bodies such as the United Nations, in addition to engaging communities at local levels to ensure alignment with both (inter)national policies and grassroots needs. Creative approaches to education were also suggested, such as leveraging social media, facilitating knowledge exchange through peer-led workshops, and embedding climate-health modules within existing curricula. The participants stressed that such strategies must remain community-focused, inclusive, and empowering, ensuring health workers can actively engage with and address the needs of the populations they serve. One participant reinforced the value of research in advancing actionable insights for climate-health education, noting:

> *"Research such as this is needed." (Participant 5, Representing Medical Practitioners, Pharmacists, and Dentists)*

8.4.4. Discussion

Climate change poses significant challenges to healthcare systems worldwide, particularly in low- and middle-income countries like Kenya, where health workers are grappling with the dual responsibility of mitigating emissions while adapting to climate impacts (19). This study offers a unique perspective on the perceptions, knowledge, and roles of Kenyan health workers as the country transitions toward a net-zero, climate-resilient healthcare system. In alignment with global goals such as the Paris Agreement and Kenya's commitments under the World Health Organization's Health Programme at COP26, this research highlights both the opportunities and barriers that health workers encounter as key stakeholders in these efforts (72,160).

The questionnaire responses of Kenyan health workers reveal a generally high level of concern about climate change, with 90% of respondents acknowledging the importance of integrating GHG emissions reduction into healthcare practices. This strong consensus reflects the global recognition that healthcare systems must play a central role in combating climate change, not only because of their direct emissions but also due to the public health threats posed by climate-related disruptions (105). While a global survey across 12 countries suggests that many health professionals, particularly in high-income countries, similarly express high levels of concern about climate change, a substantial proportion report that lack of knowledge and systemic barriers constrain their ability to engage in climate-health advocacy (198). This highlights the importance of not only raising awareness but also equipping healthcare workers with the necessary skills and support structures to act - an area where Kenyan respondents demonstrated a particularly strong willingness. Similarly, the identification of supply chain emissions as the largest contributor to healthcare's carbon footprint aligns with global estimates that have demonstrated the outsized impact of procurement and product usage in hospitals (17).

A noteworthy finding is the widespread support for renewable energy adoption as a key solution to reduce emissions, a sentiment echoed in other LMICs, where renewable energy presents a cost-effective and sustainable alternative to traditional energy sources in healthcare (45). The emphasis on telemedicine as a means of reducing travel-related emissions is also consistent with global trends whereby it has gained significant traction during the COVID-19 pandemic and has been advocated as a sustainable model for future healthcare delivery (199).

The barriers identified in this study, particularly financial constraints and the lack of education, align with findings from similar contexts. The perception of a lack of enforcement of policy frameworks is another recurrent theme that has been widely documented in both global and national studies. Health workers in Kenya highlighted the need for stronger governmental leadership and more effective policy implementation, echoing calls for healthcare policies that are better integrated with national climate strategies (200). Furthermore, the call for multisectoral collaboration and international cooperation aligns with recommendations from the World Health Organization and its Alliance for Transformative Action on Climate and Health (ATACH), which underscores the importance of cross-sector partnerships in achieving climate-resilient health systems (73).

An assessment in 2022 showed that South African health workers, despite positive attitudes towards environmental sustainability, lacked the necessary knowledge and training to implement effective practices (201). Like our findings, this emphasizes the critical need for targeted education and capacity-building to empower health workers to lead sustainability efforts. Without such educational initiatives, progress towards sustainable healthcare will remain limited, underscoring the urgency of integrating climate education into healthcare training.

Through the questionnaire, education emerged as a cornerstone in achieving sustainable, resilient healthcare. The focus group then further validated global assertions that healthcare education must transition from traditional disease-focused approaches to include sustainability as a core component (71,202). In Kenya, the focus group participants emphasized a disconnect between national policy ambitions and local realities, underscoring the need for education that bridges this gap. This aligns with the literature advocating for systems thinking and context-specific approaches to training, ensuring that policies are actionable and resonate with the lived realities of health workers (71).

Building on this, integrating sustainable healthcare education in Kenya requires a transformative approach that prioritizes contextual relevance and societal impact. This need for transformation is highlighted in the focus group findings, which identified critical gaps in practical knowledge and skills, particularly in translating policy into actionable local strategies. Transformative learning, as adapted by Redvers from Freire's pedagogy, goes beyond traditional methods by embedding principles of societal change, advocacy, and justice. This approach aligns with the gaps identified by our participants, particularly in addressing the disconnection between policy and practice. Transformative education necessitates interdisciplinary, place-based, and action-oriented learning that integrates personal and collective experiences, empirical observation, and an ethico-political understanding of both local and global relevance (70,203).

Participants in the focus group reinforced the principle of "nothing for us without us," advocating for educational co-creation with communities and stakeholders towards decolonization of health education. This aligns well with global transformative education frameworks emphasising the inclusion of Indigenous and local knowledge systems as critical to planetary health solutions (70,71). Incorporating local languages and community-driven approaches improves inclusivity and empowers health workers to act as advocates and educators within their own contexts.

Rooted in praxis, transformative education bridges knowledge and action, fostering critical thinking and relational care. This includes co-creating curricula with communities, emphasising place-based and experiential learning, and incorporating diverse knowledge systems, such as Indigenous perspectives. The principles of compassion, knowledge, and reflection central to this educational model enable health workers to navigate and address the profound challenges posed by climate change, positioning them as advocates and agents of social and environmental justice. Additionally, embedding sustainability into healthcare education must consider the interconnectedness of ecological, social, and health systems. Practical implementation requires curricular integration of sustainability concepts and the cultivation of values that inspire future healthcare professionals to lead meaningful systemic change. (70,71)

From a practical standpoint, the focus group proposed both formalized and informal strategies for integrating climate-health education into existing systems. Formalized approaches included embedding sustainability modules within existing health curricula, ensuring alignment with national climate policies, and developing structured, recognized educational programs as part of healthcare worker development initiatives. Informal strategies focused on utilising social media to disseminate knowledge and increase accessibility, as well as fostering experiential learning and knowledge exchange through self-organized, peer-led workshops. These approaches collectively echo the emphasis in sustainable healthcare education literature on embedding sustainability across curricula and leveraging digital tools for widespread impact (71,202).

Finally, as health workers navigate the challenging realities of climate change, emotional resilience and ethical leadership were recognized as integral to education. The literature underscores the role of reflective practice and advocacy as essential competencies for health workers, particularly in LMICs, where resource constraints often magnify challenges (71). Young professionals and students, with their heightened awareness of climate-health issues and openness to innovation, were identified as pivotal change agents. However, systemic barriers, such as limited access to leadership roles, hinder their ability to drive meaningful change. By prioritising capacity-building through education, healthcare systems can not only empower individuals but also enhance their overall resilience and ability to address climate-related challenges effectively.

Strengths & Limitations

This study offers valuable insights into the perceptions and roles of Kenyan health workers in climate mitigation and adaptation, contributing to a growing body of research on sustainable, resilient healthcare. A key strength lies in its mixed-methods approach, which allowed for an exploration of both broad trends through the questionnaire and deeper contextual insights via the focus group. The recruitment of participants through professional and student healthcare associations ensured diverse representation across a range of professions, healthcare settings, and regions. Additionally, participant checking of questionnaire findings in the focus group strengthened the credibility and validity of the results.

However, several limitations must be acknowledged. Convenience sampling was used for the questionnaire, relying on participants' availability and willingness to engage. While this method is well-suited for exploratory studies like this, it may have introduced selection bias, potentially overrepresenting individuals with a pre-existing interest in climate change. Consequently, the findings may not fully reflect the views of the broader Kenyan health workforce. The reliance on online recruitment and data collection may have further excluded participants from underserved or remote areas with limited internet access, affecting the representativeness of the sample. Moreover, the questionnaire relied on self-reported knowledge of climate and health issues rather than explicitly testing this knowledge. This may have resulted in participants overestimating or underestimating their actual level of knowledge, adding potential bias to the findings.

The focus group employed purposive sampling to gather diverse perspectives from key healthcare stakeholders. While this approach enabled rich qualitative insights, the small sample size and reliance on association representatives may not fully capture the experiences of health workers in all contexts. Additionally, the virtual format of the focus group, while pragmatic given geographic constraints, may have limited opportunities for informal interaction or non-verbal communication, which are often more readily observed in in-person discussions.

It is also important to acknowledge the positionality of the research team. While MO, a Kenyan researcher, played a central role in contextualising the study and ensuring cultural relevance, the lead researcher from the global north (IMB) may still represent perceived power imbalances in conducting research in a middle-income country. Efforts were made to mitigate this by incorporating input from Kenyan collaborators throughout the study design, data collection, and interpretation.

Despite these limitations, this study provides foundational insights into the educational and policy needs of Kenyan health workers in the context of climate change. Future research should aim to address these limitations by employing broader recruitment strategies, combining virtual and in-person methodologies, and expanding participant representation to capture a wider range of perspectives.

8.4.5. Conclusion

This study highlights the pivotal role of health workers in Kenya’s transition to a net-zero, climate-resilient healthcare system. Education emerges as a cornerstone in bridging the gap between policy ambitions and actionable practices, addressing critical barriers such as limited knowledge and the disconnect between national strategies and local realities. By equipping health workers with practical skills, reflective capacities, and systemic understanding, transformative education provides a pathway to empower them as leaders in sustainable healthcare.

Currently, the WHO's ATACH presents an opportunity to incorporate an educational focus within its framework. Integrating transformative education into ATACH's goals can address the complex interconnections between health, climate, and equity, equipping health workers with the necessary tools to advocate for and implement meaningful change. Transformative education has the potential to catalyse systemic change, fostering a health workforce that is not only prepared to meet current challenges but also to lead the way in creating equitable, sustainable solutions for future generations.

By investing in education that prioritizes contextual relevance, societal impact, and collaboration, Kenya can ensure that its healthcare system evolves into a model of climate resilience and sustainability, with health workers at the forefront of this critical transformation.

8.4.6 Acknowledgements

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8.5 Discussion and Implications

The outcomes of this study reveal a pressing need for tailored educational programs to build the capacity of health workers in climate change mitigation and adaptation. One of the major barriers identified is the lack of targeted knowledge among health workers, despite widespread recognition of climate change as a significant health threat. This aligns with the findings in other chapters of the thesis, which highlight gaps in both data and evidence as fundamental challenges to achieving net-zero healthcare. By addressing these gaps through targeted education, health workers can be better positioned to contribute to the climate action goals outlined in Kenya's national health strategies, particularly within the context of the COP26 Health Programme commitments. The focus group findings extend this discussion by emphasising the importance of co-creating educational programs with health workers, communities, and policymakers. This approach ensures that education is not only targeted but also contextually relevant and aligned with local needs and realities. Participants underscored the need for integrating reflective practices and fostering ethical leadership as part of the curriculum, bridging the gap between knowledge acquisition and practical application in diverse healthcare settings.

Moreover, the study's focus on educational needs adds a crucial dimension to the broader thesis. Previous chapters have explored the structural and systemic barriers to reducing healthcare-related emissions, such as infrastructure challenges, financial constraints, and policy gaps. This chapter emphasizes that without equipping health workers with the knowledge and skills to implement sustainable practices, these structural barriers will persist. The findings suggest that educational programs must not only focus on technical knowledge but also on building a broader understanding of the healthcare system's role in climate action, including emissions reduction, sustainable supply chains, and resilient infrastructure. The focus group outcomes further elucidate that overcoming structural barriers requires a dual focus on systemic enablers and individual empowerment. Participants highlighted the role of emotional resilience and ethical leadership in enabling health workers to navigate the complex challenges of implementing sustainable practices within constrained systems. These insights reinforce that education must go beyond technical training to include competencies for advocacy, resilience, and systems thinking.

The identification of specific educational components necessary for enhancing health workers' capabilities provides actionable insights for developing training programs. These components align with the thesis' broader themes of identifying and scaling effective interventions in the healthcare system. By bridging the knowledge gap, health workers can contribute more effectively to implementing the practical mitigation strategies discussed in earlier chapters, such as renewable energy adoption, sustainable procurement, and waste management. Insights from the focus group also identified creative educational tools, such as peer-led workshops and the integration of sustainability modules into existing training curricula, as effective methods for disseminating knowledge. These practical approaches align with earlier chapters' emphasis on scalable interventions, providing actionable pathways for embedding climate change education in Kenya's healthcare system.

Furthermore, the study's findings regarding the need for policy integration to support the continuous professional development of health workers have significant implications for the thesis. The policy recommendations identified here extend the work done in Chapter 7, which highlighted the importance of national climate-health policies. This chapter reinforces the idea that national and institutional policies must include education as a key strategy for advancing climate action within healthcare systems. The focus group revealed that policy integration must also address the disconnect between national climate strategies and their practical application at the local level. Participants pointed to the need for clear, actionable guidelines within policies to ensure that health workers can align their practice with national goals. This adds depth to the policy implications discussed in Chapter 7, suggesting that policies must actively bridge the gap between high-level commitments and on-the-ground realities.

In terms of broader implications, the study highlights the potential for health workers to become advocates for systemic change. By engaging health workers not only as practitioners but also as advocates for sustainable healthcare, Kenya can leverage their unique position within the health system to promote policies that align with both national and international climate goals. This approach is consistent with global efforts, such as the WHO's ATACH, which emphasizes the role of health workers in driving climate action (73). Focus group participants emphasized that health workers' unique role as trusted figures within communities positions them not only as implementers of climate strategies but also as change agents for promoting sustainability. This dual role supports the thesis's broader argument about leveraging health workers' influence to advance systemic change. Moreover, participants' discussions underscored the need for platforms that amplify health workers' voices in policymaking, ensuring that their practical insights inform national and global strategies.

Finally, this chapter's focus on educational strategies connects directly with the thesis's central argument that Kenya's healthcare system needs a multi-faceted, integrated approach to achieving net-zero emissions. Education and capacity-building are not standalone solutions but are integral to the broader strategy of enabling healthcare systems to adapt to and mitigate the impacts of climate change. By positioning health workers as key agents of change, this chapter provides a vital link between the systemic, operational, and behavioural changes required to transform Kenya's healthcare system. The focus group outcomes highlight that educational strategies must explicitly address multi-level engagement, connecting individual health workers with community, institutional, and policy-level actions. By adopting a holistic approach that integrates these dimensions, the education of health workers can become a cornerstone of the systemic transformation required to achieve Kenya's net-zero goals.

In conclusion, the findings of this study reinforce that the role of health workers is indispensable in the transformation to a resilient and sustainable healthcare system, and equipping them with the necessary knowledge, skills, and policy support is essential for driving meaningful change. The educational strategies outlined in this chapter, coupled with the structural and policy interventions discussed in previous chapters, form a comprehensive direction for advancing sustainable healthcare in Kenya.

Chapter 9: Discussion

9.1 Overview of Findings

This thesis explores the critical intersection of climate change and healthcare systems, specifically focusing on the mitigation of GHG emissions and adaptation strategies within LMICs, with Kenya serving as a focal case study. The findings collectively underscore the complex, multi-layered challenges and opportunities presented by the global imperative for sustainable and climate-resilient healthcare systems.

Globally, healthcare systems are both significant contributors to and vulnerable to the impacts of climate change. Healthcare systems account for about 5% of global GHG emissions (191). While LMICs contribute a relatively small percentage of these emissions, their engagement in mitigation can be an opportunity contributing to achieving UHC. For example, adopting renewable energy sources such as solar not only supports environmental sustainability but also directly addresses the financial and infrastructural barriers to UHC by reducing operational costs and improving the reliability of electricity supply in health facilities, particularly in underserved areas. Participation in climate action may attract funding opportunities from sources like the Green Climate Fund, Regional Development Banks, and the World Bank, providing critical resources to expand access to essential health services. Furthermore, showcasing leadership in sustainability can enhance the credibility and morale of health systems, fostering trust and engagement among both health workers and the communities they serve.

The findings emphasize the urgency of integrating both climate mitigation and adaptation into healthcare planning, not merely as isolated strategies but as synergistic actions that reinforce the resilience and sustainability of health systems. However, a crucial outcome emerging from the analysis is the disparity between high-level commitments - such as those articulated in the COP26 Health Programme - and the on-the-ground realities of implementation (Chapter 5). While several countries have pledged to achieve net-zero healthcare systems, the progress is hampered by fragmented data, insufficient accountability mechanisms, and the absence of standardized indicators for tracking emissions reduction. This critical gap in indicators and accountability structures risks undermining sustained momentum toward net-zero healthcare goals.

In the context of Kenya, the findings bring to the fore the potential for LMICs to lead in climate-resilient, sustainable healthcare transformations through which healthcare systems are strengthened and their coverage expanded, provided that interventions are designed with local context and capacity in mind. The systematic review of GHG mitigation interventions reveals that energy efficiency and renewable energy integration are not only feasible but offer significant emissions reductions in healthcare settings (Chapter 6). These findings emphasize that aligning healthcare access priorities with mitigation strategies can yield immediate benefits, such as improved energy reliability and enhanced resilience, where sustainability can be an integral part of healthcare improvements rather than a competing priority. However, the review also exposes a critical gap in evidence concerning broader healthcare supply chain emissions - an area that demands further attention if Kenya is to fully realize its net-zero ambitions. The need for scalable, context-specific interventions becomes evident, especially in regions like Kenya, where infrastructure and energy access vary widely between urban and rural settings.

A central finding of the thesis is the recognition that healthcare system transformations must align with both immediate healthcare needs and long-term climate goals. This is particularly salient in Kenya, where UHC remains a priority, and yet the sector is increasingly recognized as a critical actor in national climate strategies. The qualitative research on stakeholder perspectives underscores the inherent tension between these dual imperatives (Chapter 7). Stakeholders expressed concerns about the financial and infrastructural constraints that hinder rapid mitigation but simultaneously underlined the opportunity for co-benefits of climate mitigation, such as cost savings through energy efficiency and improved healthcare system resilience. Yet, an unexpected finding from the Delphi process was that participants were consistently convinced of the need and feasibility of mitigation, challenging assumptions often made by high-income countries and funders about LMIC priorities. This strong belief represents an opportunity to accelerate momentum, provided strategic and operational gaps are addressed. The findings also reveal a cautious optimism among specific Kenyan stakeholders regarding the feasibility of the 2030 net-zero target, alongside demonstrable political will and strong public awareness of climate change impacts. This high momentum positions Kenya more favourably to advance sustainable healthcare transformation, providing a critical leverage point for accelerating international support and action.

The role of health workers emerges as a pivotal factor in bridging this gap between policy ambition and practical implementation. The findings highlight that while there is a widespread recognition among Kenyan health workers of the health threats posed by climate change, there remains a significant deficit in the technical knowledge required to implement effective mitigation and adaptation strategies (Chapter 8). Despite broad awareness among health workers about the health impacts of climate change, the thesis highlights the complete absence of formal education on sustainable healthcare, representing a critical missed opportunity for systemic capacity-building. The identification of this substantial educational gap is an original contribution of this research, clearly highlighting targeted education and curriculum development as immediate and actionable next steps for Kenya. Educational and capacity-building interventions identified are therefore crucial not only for enabling health workers to act on climate but also for embedding sustainable practices within the day-to-day operations of healthcare facilities. Moreover, health workers, given their role at the intersection of patient care and system management, are uniquely positioned to advocate for systemic change, further emphasising the need for targeted education.

Another key contribution of this thesis is the demonstration of how climate mitigation and adaptation in healthcare systems must be integrated into broader national and international policy frameworks (Chapter 7 & 8). The research suggests that Kenya, by centring healthcare within its NAPs and other climate strategies, can set a precedent for other LMICs in linking health system resilience with national climate action. Although integration of adaptation and mitigation is generally accepted as necessary, the specific identification of critical gaps in indicators and accountability mechanisms is a novel finding of this thesis. These gaps were strikingly evident in Kenya's context, and this research has provided actionable insights into developing standardised indicators and robust accountability frameworks, essential for meaningful progress. The thesis also underscores that the success of these integration efforts hinges on the alignment between national policy ambitions and localized, context-driven implementation.

Finally, this thesis argues for the need to address governance and financial models in driving the transformation to sustainable healthcare. As shown in Kenya's case, achieving net-zero healthcare will require stronger cross-sector collaboration, clearer governance structures, and a mobilization of international financial support (Chapter 7). The lessons learned from global and national analyses converge on the importance of accountability mechanisms that can track and incentivize progress towards sustainability (Chapter 5). In this respect, the thesis offers both a diagnostic framework for understanding the challenges that LMICs face and a roadmap for addressing these barriers through tailored, evidence-based interventions.

In addition, the findings suggest that long-term sustainability requires healthcare systems to not only respond to the immediate impacts of climate change but also to anticipate future risks (Chapter 7). This forward-looking approach to climate action in healthcare systems, particularly in LMICs, emphasizes that adaptation strategies must be built into national and local healthcare planning frameworks. This proactive stance is necessary to ensure that systems are resilient not only to current challenges but to the evolving nature of climate risks.

Together, the findings contribute to a growing body of knowledge on how countries, including specifically Kenya, can balance the imperative of reducing their healthcare systems' emissions with the pressing need to enhance system resilience and meet immediate healthcare demands. The thesis demonstrates that this balance could be not only possible but is in fact essential. Lessons learned from Kenya's journey can serve as inspiration for others aiming to achieve sustainable, climate-resilient healthcare systems.

9.2 Conceptual Framework: Mitigation and Adaptation Interactions

This thesis employs a conceptual framework that emphasizes the critical interplay between mitigation and adaptation strategies within healthcare systems, particularly in the context of LMICs. From the outset, the framework sought to capture how healthcare systems, as both contributors to and victims of climate change, must adopt integrated approaches that simultaneously reduce GHG emissions (mitigation) and enhance resilience to climate impacts (adaptation). As explored throughout the thesis, these dual imperatives are not isolated but deeply interconnected, particularly in resource-constrained settings like Kenya.

The findings of this research reinforce and expand on the original conceptual framework, highlighting several key insights about the synergies and tensions between mitigation and adaptation. The systematic review of GHG mitigation interventions (Chapter 6) reveals that some interventions designed to reduce emissions in healthcare systems, such as renewable energy integration, may also provide substantial adaptation benefits. For instance, energy interventions that increase the use of solar or hybrid energy systems not only reduce reliance on fossil fuels but also enhance energy security in rural and underserved areas. This dual function of certain mitigation strategies - lowering emissions while simultaneously building resilience - is central to the conceptual framework, emphasising that well-designed interventions can offer co-benefits across both domains.

However, the interactions between mitigation and adaptation are not always straightforward, and the thesis identifies areas where trade-offs must be carefully managed. In Kenya, for example, the infrastructure required to implement advanced mitigation strategies, such as emissions monitoring and renewable energy transitions, may be financially and logistically challenging, particularly in rural areas where healthcare access remains a priority (Chapter 7). The qualitative findings highlight that stakeholders could be caught between the immediate need to improve healthcare service delivery and the longer-term goal of reducing the system's environmental footprint. This tension underscores the importance of aligning mitigation and adaptation strategies in ways that consider the local context, priorities and resource limitations, a critical insight for LMICs as governments develop national healthcare policies that aim to meet both climate and health goals.

Moreover, the thesis emphasizes the importance of integrating mitigation and adaptation within national climate action frameworks, as illustrated by Kenya's commitment to creating a net-zero, climate-resilient healthcare system by 2030. The conceptual framework is validated by Kenya's approach, which reflects an understanding that climate-related vulnerabilities in the healthcare system should be comprehensively addressed. Mitigation strategies - particularly those that lower healthcare's contribution to national GHG emissions - must be pursued alongside efforts to strengthen the healthcare system's capacity to withstand climate-related shocks, such as extreme weather events, changing disease patterns, and resource scarcity. Importantly, climate justice considerations mean that (historical) high emitters should take the lead in mitigation efforts because they are responsible for by far the largest share of emissions. The findings from the Delphi process and focus group reinforce that human agency, in the form of stakeholder conviction and health worker awareness, is a critical driver of system transformation. These results show that social and educational factors, such as belief in mitigation feasibility and the presence of formal sustainability education, are essential for successful healthcare climate action.

The research also reveals that effective integration of mitigation and adaptation requires strong governance and policy frameworks that incentivize the alignment of these strategies at both national and local levels. In Kenya, the opportunity to embed healthcare within broader NAPs is critical, as it allows for a more coherent approach to building resilience while lowering emissions. The thesis points to the need for cross-sectoral collaboration, where healthcare systems are not only seen as service providers but as active participants in national climate policy (Chapter 5). This collaboration ensures that mitigation and adaptation are not treated as parallel tracks but as interdependent components of a sustainable, climate-resilient healthcare system.

In conclusion, the original conceptual framework, which emphasises the integration of mitigation and adaptation strategies within healthcare systems, is reinforced by the findings of this thesis. The research demonstrates that these interactions must be carefully managed to harness the synergies while minimising trade-offs, especially in LMICs like Kenya, where the healthcare system faces significant resource and infrastructure constraints. The framework also highlights that future efforts must prioritise the alignment of mitigation and adaptation within national and local climate strategies, ensuring that healthcare systems can simultaneously reduce their environmental impact and build resilience against the growing threats posed by climate change.

9.3 Policy Implications and Future Directions

The findings from this thesis provide a strong foundation for advancing healthcare system sustainability and resilience policies. The integration of climate mitigation and adaptation strategies within healthcare systems, as demonstrated throughout this work, necessitates well-crafted policies that are both locally relevant and globally informed (Chapter 7 & 8). This section discusses the key policy implications arising from the research and outlines future directions for further investigation, particularly in areas where evidence gaps persist.

9.3.1. Policy Implications

The research underscores the need for a multi-faceted policy approach that integrates healthcare into broader national and international climate agendas (Chapter 5). For Kenya, a central recommendation is to further embed healthcare-specific strategies within national climate policies, particularly the NAP and Kenya's National Climate Change Action Plan. The thesis also identifies a notable level of political will and cautious optimism among diverse stakeholders regarding Kenya's net-zero healthcare target. These findings suggest that national ambition can be matched with policy action, provided that this momentum is supported by clear institutional mandates and targeted capacity-building, robust cross-sector coordination, and operational planning that bridges long-term strategies with short-term actionable interventions. By positioning healthcare as a critical component of national climate resilience efforts, the Kenyan government can better access international financing mechanisms, such as the Green Climate Fund and the Adaptation Fund, to support the mitigation of healthcare systems.

A significant policy recommendation relates to the development and implementation of accountability mechanisms (Chapter 5). The findings highlight that while many countries, including Kenya, have pledged to achieve net-zero healthcare systems, progress has been impeded by fragmented data, insufficient monitoring, and a lack of standardized indicators. This issue was particularly evident in the Kenyan context, where the absence of locally relevant indicators and weak accountability structures emerged as key barriers. Policymakers must prioritize the establishment of robust data collection systems and performance metrics to track healthcare-related emissions, particularly in areas like healthcare supply chains, which remain poorly monitored. Establishing clear accountability frameworks within international climate agreements will help ensure that countries can meet their climate commitments and sustainably track progress towards resilience and net-zero goals.

Another critical area of focus is the financing of healthcare transformation. As noted in the Kenya case study, financial constraints are a major barrier to the implementation of climate mitigation strategies within healthcare systems (Chapter 6 & 7). The research points to the need for stronger cross-sectoral collaboration and the development of innovative financing models. For instance, public-private partnerships can play a pivotal role in scaling renewable energy solutions, such as hybrid solar energy systems, that both reduce emissions and enhance energy security in healthcare facilities. International donors, HICs and the climate finance mechanisms they support should also prioritise healthcare in their funding strategies, ensuring that LMICs receive adequate financial and technical support for mitigation and adaptation in healthcare. Targeted investment in context-specific interventions, such as renewable energy integration in rural facilities, climate-smart procurement, and low-carbon infrastructure, can generate immediate co-benefits for healthcare delivery and emissions reductions. Although this thesis focused primarily on internal drivers, barriers, and opportunities within Kenya, it is recognized that the success of LMICs in achieving sustainable and resilient healthcare systems could critically benefit from broader international support. High-income countries, given their historical responsibility for climate change, play a vital role in enabling

LMIC progress through climate finance, capacity-building initiatives, and equitable knowledge-sharing platforms. The pathways identified in this thesis, from infrastructure improvements to workforce education, would be accelerated and strengthened through such support, underscoring the global interconnectedness of healthcare climate action. However, since the interviews, further aid cuts and geopolitical instability, including recent funding withdrawals from key agencies, underscore that support trajectories are dynamic and potentially unreliable. This raises concerns around over-reliance on external support. Therefore, the thesis recognises the justice-based rationale for HIC contribution but cautions against positioning it as the sole engine for change. This further illustrates the need for longitudinal studies to understand how policy and stakeholder sentiment evolve over time in response to shifts in global financing landscapes.

The findings further emphasize the importance of capacity-building policies (Chapter 8), particularly in addressing the complete absence of structured education on sustainable healthcare in Kenya. The role of health workers in driving systemic change is a key outcome of this research. The current gap underscores the urgent need to institutionalise sustainability education as a formal policy priority, integrated into curricula, professional training, and national health workforce development plans. This should include not only technical training on resilience, emissions reduction and sustainability practices but also broader education on the role of health workers and emotional resilience. By empowering health workers as advocates and implementers of climate action through embedding sustainability explicitly within curricula, professional training and peer-led learning, Kenya can accelerate the transformation to a sustainable healthcare system.

9.3.2. Future Directions for Research

Several research gaps were identified throughout this thesis, which offer important avenues for future investigation. One of the most critical gaps relates to the broader healthcare supply chain and its contribution to GHG emissions (Chapter 6). While energy efficiency and renewable energy interventions have received some attention, there remains a paucity of evidence on how supply chain management can be optimized to reduce emissions in healthcare systems, particularly in LMICs. Future research should focus on quantifying supply chain emissions in healthcare settings and exploring scalable interventions, such as sustainable procurement practices and circular economy models, that can reduce the environmental footprint of healthcare delivery, as well as explore the role and relevance of stakeholders globally.

Another key area for future research is the long-term effectiveness of GHG mitigation interventions in healthcare systems (Chapter 6). The systematic review conducted as part of this thesis revealed a dearth of longitudinal studies that track the sustainability outcomes of interventions over time. Rigorous research that evaluates the durability, scalability, and cost-effectiveness of interventions, particularly in resource-constrained settings, is needed to inform evidence-based policy development. Additionally, research should explore the health, social and economic co-benefits of healthcare transformation, such as job creation in renewable energy sectors and improvements in public health outcomes.

The research also highlights the need for greater exploration of the synergies and trade-offs between mitigation and adaptation strategies (Chapter 5-8). While the conceptual framework developed in this thesis provides a strong foundation, future studies should investigate how specific mitigation interventions can enhance healthcare system resilience to climate impacts, particularly in rural and underserved areas. For example, research on how renewable energy solutions can improve healthcare delivery during climate-related disruptions, such as floods or droughts, will be critical for informing integrated climate and health policies in at-risk settings. Additionally, there is potential to investigate the economic, health, and other benefits of social prescribing, such as increasing contact with nature, for example in urban settings in LMICs. Emerging evidence from the NHS suggests that social prescribing not only improves individual health outcomes but also alleviates pressure on healthcare services, presenting an opportunity for LMICs to achieve co-benefits in health and climate resilience (204).

On education, further research should detail the implementation and impact of education on sustainable healthcare (Chapter 8). This includes assessing the impact of educational frameworks such as transformative learning and evaluating their role in bridging knowledge gaps and fostering sustainable, climate-resilient healthcare practices. Identifying the most effective methods for integrating climate education into professional development programs and curricula will be key to enabling sustainable healthcare transformations.

Additional attention must also be given to pharmaceutical products, medicines, and medical devices, which constitute a substantial share of healthcare-related emissions, particularly under Scope 3 emissions. Recent estimates suggest that in high-income countries, medicines alone contribute around 20% of healthcare emissions, while when combined with medical devices, they account for approximately 50% to 60% of total healthcare emissions (29,205,206). Although the Kenyan healthcare system relies heavily on imports for essential drugs and medical equipment, there is currently little research quantifying the associated carbon footprint or assessing sustainable alternatives. This gap is significant, as pharmaceutical supply chains are not only emissions-intensive but also pose opportunities for climate action through sustainable procurement policies, promotion of essential medicines lists aligned with low-carbon principles, and support for local, low-emission production where feasible. Future research should systematically assess pharmaceutical and device-related emissions in Kenyan and LMIC healthcare systems and explore interventions that could simultaneously strengthen healthcare delivery and reduce carbon footprints.

Integrating this often-overlooked dimension will be critical for truly achieving net-zero and resilient healthcare systems.

Lastly, future research should further examine the political and institutional dimensions of healthcare mitigation and adaptation (Chapter 7). The findings suggest that effective policy implementation hinges on strong governance structures and political will. Comparative research on how different countries are navigating the political and institutional challenges of transforming to net-zero healthcare systems could provide valuable insights into best practices and barriers to success.

9.4 Limitations

This thesis, while providing valuable insights into the intersections between climate change and healthcare systems, acknowledges several limitations that shape the interpretation of its findings. A major challenge was the availability and quality of data, particularly regarding healthcare-related GHG emissions and vulnerabilities. While this thesis serves as foundational work, further research is needed to address these data gaps and develop standardised, robust datasets that enable accurate tracking of healthcare emissions.

The systematic review of GHG mitigation interventions, (Chapter 6) while informative, was constrained by the limited number of studies available, particularly those addressing long-term outcomes. This limits the conclusions that can be drawn about the effectiveness of certain mitigation strategies in LMICs. Additionally, this thesis does not comprehensively address the significant carbon footprint associated with pharmaceuticals and medical devices, which represents a critical research gap for future work. Nevertheless, this thesis lays the groundwork for future research to expand the evidence base, providing a starting point for more rigorous studies that can offer greater clarity on how these interventions work in diverse contexts, particularly through longitudinal and comparative designs that assess long-term effectiveness and contextual variability.

Similarly, the qualitative findings drawn from stakeholder perspectives in Kenya (Chapter 7 and 8) offer rich, context-specific insights, but their applicability to other LMICs could be limited. Kenya's unique healthcare and political landscape may not mirror those of other countries, which presents an opportunity for future studies to replicate this approach in different settings. This would allow for broader generalization of the insights gained, enriching the global discourse on sustainable healthcare transformations in LMICs. In particular, while the thesis found strong stakeholder conviction about climate mitigation and high levels of optimism, further research is needed to assess whether these attitudes are shared across other LMICs, and how such perceptions influence system-level change.

Although the potential health outcomes of mitigation and adaptation strategies are acknowledged, they are not explored in detail in this thesis. Future studies should further investigate the co-benefits of climate action in healthcare, particularly how reducing emissions can directly improve public health outcomes, e.g. from reduced air pollution, improved diets and increased physical activity. This is crucial to understanding the full scope of benefits that mitigation can offer and the relevance to different contexts including LMICs where priorities rightly are healthcare resilience, quality and coverage.

The conceptual framework proposed in this thesis (Chapter 2), which integrates mitigation and adaptation strategies, serves as a useful model but is inherently limited by the complexity of these interactions in real-world settings. While the framework captures key dynamics, further refinement is needed as it is applied in diverse healthcare contexts. This thesis provides the groundwork for such refinements, offering a foundation for future work to build upon.

Finally, the relatively short temporal scope of the research limits its ability to assess the long-term impacts of the proposed strategies. Future longitudinal studies are necessary to track the progress of healthcare systems over time, especially as they work towards net-zero goals.

Despite these limitations, this thesis makes significant strides in mapping the complex landscape of climate change and healthcare. By laying the groundwork for future research, it offers a diagnostic framework for understanding the challenges faced by LMICs and a roadmap for addressing these barriers through tailored, evidence-based interventions.

Chapter 10: Conclusions

This thesis brings forward a new understanding of the intricate challenges and opportunities that healthcare systems face in the global response to climate change. It goes beyond recognising healthcare as both a contributor to and a victim of climate change, offering a comprehensive approach to the dual imperatives of mitigation and adaptation in LMICs with a specific focus on Kenya.

This research offers an original contribution by documenting a high level of political will, societal awareness, and cautious optimism among select Kenyan stakeholders toward the 2030 net-zero target. These findings challenge the prevailing assumption that mitigation is a lower priority in LMICs and suggest that global actors may underestimate the readiness and ambition within such contexts. The Delphi process, in particular, revealed a consistent conviction among a broad range of stakeholders regarding the necessity and feasibility of climate mitigation in Kenya's health sector, suggesting strong national momentum that can be leveraged if systemic gaps are addressed. This research was conducted at a time of high momentum for climate action in Kenya. However, with increasing uncertainty in international aid and global climate finance, further research should track how attitudes and feasibility perceptions evolve. The dynamic nature of climate governance requires ongoing monitoring to ensure that optimism is not misplaced and that policy pathways remain adaptive to changing external support conditions.

The findings also expose critical system gaps. Notably, while there is broad awareness of the health impacts of climate change, there is currently no structured education on sustainable healthcare embedded in Kenya's health workforce training. This absence presents a missed opportunity to translate ambition into action and underscores the need to treat education not merely as an enabler, but as a central pillar of healthcare system transformation. In parallel, the lack of standardised indicators and accountability mechanisms undermines the ability to track and evaluate progress towards net-zero goals. These omissions must be addressed if Kenya is to sustain momentum and avoid the risk of performative or unmeasurable climate action. While rooted in Kenya's context, the identified enablers, such as political momentum, health worker conviction, and targeted educational strategies, may hold relevance for other LMICs pursuing healthcare system transformation.

The thesis underlines that mitigation and adaptation should be pursued as interdependent strategies within healthcare systems. This dual approach, highlighted in the conceptual framework, shows that well-designed interventions, such as renewable energy integration and effective healthcare delivery, can improve coverage, reducing inequities in access while offering significant emissions reductions. The case of Kenya exemplifies how LMICs can lead this transformation with ambition, provided interventions are locally tailored, respond to priorities and are supported by strong policy frameworks. Through its contributions, this thesis has expanded the boundaries of existing research, showing that the current global efforts, such as those under the COP26 Health Programme, while necessary, are insufficient without localized implementation plans that address specific infrastructural, financial, and governance challenges. The research highlights that the transformative potential of healthcare systems lies in the synergy between health outcomes and mitigation and adaptation strategies. It offers an updated lens: that these approaches should not only be seen as mutually reinforcing but as jointly essential to leapfrog the carbon-intensive development paths of HICs.

Moreover, the thesis moves the conversation forward by reasserting the importance of health workers as agents of change within these systems. By positioning health workers as not just implementers but potential advocates for sustainability, this research makes a strong argument for the central role of education and capacity building in achieving climate goals. This focus on the human element of healthcare, coupled with the need for systemic reforms, introduces a holistic vision for sustainable healthcare transformations - one that is not solely dependent on infrastructure and policies but also on the empowerment of those at the frontline of care.

The contribution of this thesis extends into the policy realm. While global frameworks provide a necessary scaffold, this research underscores that healthcare systems in LMICs require tailored policies that reflect their specific opportunities and barriers. Kenya's case shows that high-level ambition can coexist with gaps in implementation, and that bridging this divide depends on strategic coordination, financing, and improved monitoring. The call for stronger cross-sector collaboration, as demonstrated in Kenya's experience, introduces a new policy direction - one that advocates for an integrated approach to climate action where healthcare is central in national climate strategies and financing mechanisms.

Building on the findings, several strategic priorities emerge to support Kenya's transition toward a net-zero, climate-resilient healthcare system. Translating high-level ambition into impact will require the development of robust, context-sensitive indicators and accountability mechanisms to track both emissions and system resilience over time. National momentum should be leveraged through clear governance structures, cross-sectoral coordination, and operational planning that bridges long-term strategies with short-term implementation. Targeted investment in locally appropriate interventions, such as clean energy integration in rural facilities, climate-smart procurement systems, and low-carbon infrastructure, can generate immediate benefits for both health service delivery and mitigation goals. As the system evolves, participatory approaches that enable health workers and facility managers to shape and lead sustainability initiatives will be essential to ground climate commitments in day-to-day practice. Finally, addressing the complete absence of formal education on sustainable healthcare is critical. Embedding sustainability within health professional training and continuous development, alongside peer-led learning and systems thinking, will be foundational to enabling the health workforce to act as agents of change within a resilient, low-carbon healthcare system.

These recommendations also carry implications for global funders and international policymakers. The conviction for mitigation found among these Kenyan stakeholders challenges dominant assumptions that LMICs are solely adaptation-focused, highlighting the urgency of flexible, responsive funding that can support integrated climate-health strategies. Investments should prioritise foundational enablers, such as education systems, data infrastructure, and accountability frameworks, which are often underfunded yet vital to unlock sustainable transformation. To genuinely support LMIC leadership in this space, funders must move beyond replicating high-carbon models from high-income settings and instead back context-appropriate, low-emission health infrastructure designed for leapfrogging. This approach would not only unlock environmental and health co-benefits but position countries like Kenya at the forefront of global health system transformation. Rather than depending solely on volatile external finance, LMICs may also benefit from diversified strategies that include regional cooperation, South-South knowledge exchange, and integrated fiscal planning.

Looking forward, this thesis sets the stage for future research by identifying key gaps in the current knowledge base, particularly regarding healthcare supply chain emissions, the long-term effectiveness of adaptation and mitigation interventions and their interactions with healthcare system strengthening. These gaps offer a roadmap for the next generation of research, which must focus on developing comprehensive data sets and long-term studies that track both the environmental and health impacts of climate interventions in healthcare and translate those into education frameworks and useable tools, including for practitioners.

Ultimately, this thesis provides a grounded, evidence-informed understanding of both the barriers and opportunities facing Kenya as it advances toward a net-zero, climate-resilient healthcare system. By integrating mitigation and adaptation strategies with an emphasis on the role of health workers and context-specific solutions, this research offers a pathway for sustainable healthcare transformations that are globally insightful yet locally actionable. It demonstrates that the transformation to sustainable healthcare systems is not solely a technical challenge but a socio-political one which requires aligning policy, capacity-building, and community-level engagement to ensure resilience and sustainability in the face of climate change.

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Appendices

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Appendix I: The COP26 health commitments: A springboard towards environmentally sustainable and climate-resilient healthcare systems?

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Highlights

- Climate change necessitates urgent adaptation and mitigation, including in health systems.
- The World Health Organization co-launched the COP26 Health Programme as a platform for national commitments.
- Over 50 countries committed to environmentally sustainable and/or climate-resilient health systems.
- National health policies should reflect a contextual balance between mitigation and adaptation.
- These policies must recognise mitigation and adaptation interlinkages, combine bottom-up and top-down approaches and be based on evidence.

Manuscript

The 26th Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change took place in Glasgow, United Kingdom, in November 2021. It was the first COP since governments were due to have submitted updated nationally determined contributions (NDCs), setting out commitments to meet the Paris Agreement[1]. According to the 2021 UN Emissions Gap Report, even if all unconditional 2030 climate pledges are fully implemented, the world is on course for a 2.7C temperature rise by the end of the century, with catastrophic implications for human health[2]. In fact, at present levels of warming (1.1C), climate change is already exerting devastating health impacts around the world[3].

While mitigation - the action of reducing further harmful emissions - is more urgent than ever, national representatives at COP26 commented on how this was not balanced with attention, technical resources, and financing for adaptation, particularly for low- and middle-income countries (LMICs) to enable them to protect their populations from the growing health impacts of climate change. Indeed, limited financial resources present a major challenge in low-resource settings, especially for adaptation. Governments of high-income countries (HICs) have still not delivered on their commitment of 100bn USD annually by 2020 to support LMICs to implement climate change mitigation and adaptation measures across all sectors[4,5]. However, even this level of funding would fall far short of the trillions needed (1.6–3.8 trillion USD annually for mitigation to limit warming to 1.5C and 280–500 trillion USD annually for adaptation by 2050 in developing countries alone)[4,6].

COP26 further highlighted the dangerous progression of climate change due to insufficient ambition. The state of health systems, which are comprise of the people, institutions, and actions required to deliver health services to improve the health outcomes of a target population, will play a central role in determining whether appropriate care can be delivered in the face of climate risks[7]. Yet, it is estimated that health systems worldwide emit 4.9% of greenhouse gas (GHG) emissions – paradoxically also contributing to the climate-health emergency itself[8]. Furthermore, those in lower resource settings with less access to high-quality healthcare are expected to endure the worst effects[3,9,10]. Therefore, given that health systems are already facing the impacts of climate change, it is imperative that adaptation is prioritized in both planning and budgeting where needed.

Ahead of COP26, the Global Climate and Health Alliance (GCHA) launched the Healthy NDC Scorecard, which provides an overview of the extent to which health considerations are included in national climate commitments. The Scorecard indicates that the reflection of health considerations in national climate commitments is strongest in countries most vulnerable to climate impacts[11]. Still, a more in-depth focus on health system mitigation and adaptation is needed. The World Health Organization (WHO), Healthcare Without Harm, the UK COP Presidency and the UNFCCC Climate Champions launched a country commitments platform as part of their COP26 Health Programme as a solid first step towards such an outcome. Overall, a total of 51 countries made commitments, of which 50 committed to a climate-resilient health system, 46 to a sustainable, low carbon health system, and 14 to a net-zero health system. According to the Programme's guiding stipulations, actions to deliver commitments on resilience included conducting vulnerability and adaptation assessments, developing national adaptation plans (NAPs), and using these as a basis to apply for funding for implementation. Meanwhile, countries committing to more environmentally sustainable health systems were encouraged to carry out a baseline assessment of GHG emissions and to develop a plan of action with an accompanying timeline. Finally, the net-zero commitment for the health system included setting a target date ideally in advance of 2050 [12].

In order to provide a global perspective on the COP26 Health Programme, we conducted a document review of the most recent NDCs and adaptation communications submitted before the close of COP26 on the 12th of November 2021 by countries that made commitments as part of the COP26 Health Programme. Table 1 reflects our analyses, recording text identified as related to these commitments. While a myriad of other policies exist at both national and international levels in which health system mitigation and adaptation actions might be detailed, NDCs and adaptation communications provide an overall snapshot of a country's national priorities related to delivering on the Paris Agreement at the time the relevant document was submitted. At the global level, we found that out of the countries that committed to the respective commitments, most countries (76%, 38 out of 50, see Table 1) have some language on health systems resilience in their NDC, which can serve as a basis for more detailed plans if not already existing outside of these documents. However, comparatively few countries (24%, 11 out of 46, see Table 1) currently have language in these documents relating to health system mitigation, potentially indicating that detailed policies are less likely to already be in place. While many countries include a brief mention of resilient or sustainable health systems, most do not include a detailed plan. Amongst the countries which do integrate notable detail are Lao People's Democratic Republic, Chile, and Colombia[1]. In addition, Fiji refers to a fully developed national mitigation and adaptation plan in the context of health, contained in a separate document[13]. The authors also note that no NDC or adaptation communication explicitly referred to the interaction between adaptation and mitigation measures, either through synergies, co-benefits, conflicts or trade-offs. While Togo does mention the creation of solar water heaters in 122 health centres as an adaptation mechanism - which presumably also contributes to mitigation - it is not clear whether the mitigation benefits of this action were also recognized.

Table 1. Overview of the countries that made commitments as part of the COP26 Health Programme and any identified text related to these commitments in NDCs and adaptation communications (ADCOM). The cells are empty where no relevant text was identified [1,12]. NAP - National Adaptation Plan.

Country	**CPO26 Health Commitments**				**Publication date (day/mo/yr)**	**Analysis**	
	Climate resilient health systems	Sustainable low carbon health systems	Net zero commitment	Net zero target	For NCDs unless otherwise stated	Details relevant to commitments (adaptation)	Details relevant to commitments (mitigation)
Argentina	X	X			30/12/2020	A national health adaptation plan and specifically early warning systems are mentioned.	
Bahamas	X				31/10/2016	Includes a list of adaptation measures being planned or undertaken for the health sector, including awareness-raising and emergency management	
Bahrain	X				18/10/2021		
Bangladesh	X	X			26/12/2020		
Belgium	X	X	X	2050	ADCOM (EU) 07/11/2021	ADCOM (EU): At the EU level, the European Commission has launched the Climate and Health Observatory for related risk assessment, monitoring, communication, and prevention.	
Belize	X	X			01/09/2021	Actions listed to build adaptive capacity in the healthcare sector include a Climate Change Vulnerability and Capacity Assessment, management of disease vectors, early warning systems, investment in infrastructure, and public education awareness programme	
Bhutan	X	X			24/06/2021	The NAP process will feature in-depth sectoral assessments for sectors including health, and the NAP itself will include priority needs of the health sector	
Canada	X	X			12/07/2021		
Cape Verde	X	X			15/02/2021		The need to transition to renewable energy sources in hospitals and for sustainability of healthcare facilities is mentioned.

Central African Republic	X	X			11/10/2016	The importance of health sector adaptation is mentioned several times. Specific public health interventions include climate-related disease surveillance.	
Chile		X			09/04/2020	A focus on resilience of health systems is mentioned, and a health adaptation plan will be developed. A plan is mentioned to implement disaster risk management across the health sector.	
Colombia	X	X			10/12/2020	The planning of an early warning system, vector-borne disease analysis, and health systems vulnerability analysis is mentioned. A health adaptation plan will be developed, including implementation in the health sector. There is a general mention of building health resilience through prevention and health promotion. The need of building health resilience in the public health sector is mentioned.	
Costa Rica	X	X			29/12/2020	Increasing knowledge, monitoring and responses within the health sector are planned. Integrating adaptation within the health sector planning is identified.	
Dominican Republic	X	X			29/12/2020	The need for adaptation in the health sector is mentioned.	
Egypt	X				29/06/2017	Interventions in the health sector include identification of health risks, raising community awareness, increasing the ability of the health sector in dealing with climate change, and supporting Ministry of Health efforts to improve the social and economic status	
Ethiopia	X	X			23/07/2021	Ethiopia has an H NAP. In addition, specific measures mentioned include surveillance and improvement in general and emergency services and reducing malaria and cholera	Improving access to safe energy sources such as solar and improving management of waste
Fiji	X	X	X	2045	31/12/2020	Specific 'Guidelines for climate-resilient and environmentally sustainable healthcare facilities in Fiji' are mentioned. The guidelines include specific planning for climate resilience and environmental sustainability objectives and indicators of the health system in Fiji.	
Germany	X	X			ADCOM (EU) 07/11/2021	ADCOM (EU): At the EU level, the European Commission has launched the Climate and Health Observatory for related risk assessment, monitoring, communication and prevention.	
Ghana	X	X			04/11/2021; ADCOM 04/11/2021	Adaptation to climate-induced health risks, disease surveillance is mentioned. ADCOM: The NAP Framework is said to prioritise health as a climate-sensitive sector, and a climate change unit has been established in the health ministry. A national vulnerability assessment also included health. According to the adaptation communication, climate and health is also key component of the NDC. The Government has a national health adaptation strategy approved by a relevant government body and is currently implementing projects or	There is a specific mention that the adaptation actions will be fuelled by renewable energy.

						programmes on health sector adaptation to climate change	
Indonesia	X	X	X		22/07/2021	Improved provision of basic health services and health sector adaptation included in National Medium-Term Development Planning. Specific interventions include addressing drivers of vulnerability to climate change impacts, enhanced stakeholder participation, enhanced community capacity in reducing health impacts, and community awareness-raising.	
Ireland	X	X			18/12/2020; ADCOM (EU) 07/11/2021	ADCOM (EU): AT the EU level, the European Commission has launched the Climate and Health Observatory for related risk assessment, monitoring, communication and prevention.	
Jamaica	X	X			01/07/2020		
Jordan	X	X	X		12/10/2021	Health included in adaptation plan, also has a National Climate Change and Health Adaptation Strategy and Action Plan with actions spanning those relating to improved understanding of risk and improved adaptive capacity.	
Kenya	X	X	X	2030	28/12/2020	An adaptation program including disaster risk reduction through early warning systems, prevention and response to droughts and flood risk management is mentioned. A vulnerability assessment is planned.	
Lao PDR	X	X			11/05/2021	The need for climate resilience in public health is mentioned, including the infrastructure and climate change-related impacts. Mentions a 'Strategy on Climate Change and Health Adaptation 2018 – 2025′ and 'action plan 2018 – 2020′. The strategy includes a detailed plan under ten components, including objectives and indicators.	The Ministry of Public Health is specifically mentioned, including a plan to ensure mainstreaming of climate change into their activities, including conducting studies research and promoting the use of environmentally friendly technologies that mitigate greenhouse gas emission and/or increase resilience to climate change.
Madagascar	X	X			21/09/2016	Multi-hazard warning systems	
Malawi	X	X	X		30/07/2021	Health is mentioned as a priority sector for NAPs, and preventive, treatment and disease surveillance measures are mentioned for malaria, diarrhoea and malnutrition	
Maldives	X	X			28/12/2020	There is a detailed focus on risk reduction and management.	
Morocco	X	X	X		22/06/2021	An assessment of health-related vulnerabilities has been carried out, with attention to emerging diseases and the increasing burden of existing ones. An updated national strategy for health sector adaptation was underway when the NDC was published, while another was already implemented. Plans are included to improve the knowledge and capacity of health professionals.	
Mozambique	X	X			04/06/2018		

Nepal	X	X			08/12/2020		There is a specific mention of moving from burning healthcare waste to other forms of waste disposal.
Netherlands	X	X			ADCOM (NL) 30/09/2021; ADCOM (EU) 07/11/2021	ADCOM (NL): The National Adaptation Strategy includes a comprehensive approach to adaptation that integrates climate-resilient policies across all sectors, including health ADCOM (EU): At the EU level, the European Commission has launched the Climate and Health Observatory for related risk assessment, monitoring, communication and prevention.	The goal of the Green Deal on Sustainable Health is to work towards climate-neutral healthcare. This means net-zero emissions and the circular use of resources, such as more sustainable use of water supplies.
Nigeria	X	X	X		30/07/2021; ADCOM 21/10/2021	Mentions building capacity to integrate climate issues into the health sector and health agencies, and training women community nurses to address climate change related diseases ADCOM: The health sector is given prominence in Nigeria's adaptation planning, with measures including strengthening disease prevention and treatment for those diseases expected to increase as a result of climate change, establishing early warning and health surveillance programs, and strengthening the adaptation strategy for the health sector.	
Norway	X	X			07/02/2020		
Oman	X	X			29/07/2021	Health is mentioned in the context of GCF funding, most likely linked to adaptation. Opportunities for improved climate resilience have also been identified for public health, and barriers to achieving resilience are mentioned.	
Pakistan	X	X			21/10/2021	Health is one of the sectors prioritized for inclusion in the climate change adaptation agenda, including research, disease surveillance, multisectoral collaboration, and emergency planning.	
Panama	X	X			28/12/2020	In its NDC, Panama commits to expand the planning instruments to reduce the vulnerability of the population through the development of its Climate Change Plan for the Health Sector, focusing on strengthening systems of epidemiological surveillance with environmental risks and climate risks	Emissions reductions in the health sector are also briefly mentioned in relation to public, private and civil society entities.
Peru	X	X	X	2050	18/12/2020	Health is mentioned as a priority area in adaptation.	
Rwanda	X				ADCOM: 29/10/2021	A standalone health adaptation plan is mentioned. ADCOM: Rwanda has assessed the vulnerability of the health sector to climate change, including risk of waterborne and vector-borne diseases, flood/landslide mortality and damage to land, infrastructure and household assets and displacement	
Sao Tome and Principe	X	X	X		30/07/2021		
Sierra Leone	X	X	X		31/07/2021	The National Framework for Climate Services (NFCS) will benefit a wide	Waste management from

						range of sectors and climate intervention areas, including health. Some priorities include improving health delivery services, improving supply of safe drinking water and sanitation, increasing funding to the health sector, development of an early warning systems, strengthening meteorological and hydrological institutions, providing coastal infrastructure, improving sanitation, amongst other actions.	the health sector is considered alongside other sources of waste.
Spain	X	X	X	2050	ADCOM: (ESP) 28/10/2021; ADCOM (EU) 07/11/2021	ADCOM (ESP): Public health is identified as a key issue for adaptation, and specific measures are in place for heat. In addition, under the national adaptation plan, a catalogue of experiences and good practices in public administrations and companies in relation to health adaptation measures. ADCOM (EU): At the EU level, the European Commission has launched the Climate and Health Observatory for related risk assessment, monitoring, communication and prevention.	
Sri Lanka	X	X			24/09/2021	Health is mentioned in the list of sectors for which adaptation and resilience is being prioritised, and interagency coordination for early warning on climate and weather-related disasters and health emergencies is mentioned in the context of access to water. Health sector adaptation measures cover policy level initiatives to mainstream targeted climate resilience actions, improved capacity to manage climate influenced health and disease conditions, addressing air pollution related health impacts and reduce morbidity and mortality from climate induced disasters.	It is mentioned that as part of the COVID-19 recovery, the health system will be enhanced, digitalized and waste management will become more sustainable.
Tanzania	X	X			30/07/2021	Adaptation measures in the health sector include promoting climate-resilient public health system and infrastructure, surveillance and early warning systems, and vulnerability and risk assessments.	
Togo	X	X			12/10/2021	Adaptation is considered within the health sector at the national level, and particular emphasis is placed on improving resilience and responses to infectious disease. A vulnerability and adaptation assessment for the health sector has been completed.	Solar electrification of 314 health centres and equipment of 122 health centres in solar water heaters, mentioned as part of adaptation yet also contributes to mitigation.
Tunisia	X				10/10/2021	The NDC mentions the need to control the health risks linked to climate change and integrate their management supported through a more resilient health system with adequate human resources and integrated attention to gender, as well as strengthening the role of health in leadership and collaboration cross-sector approach to climate change and promote applied research. In addition, the NDC mentions specific interventions such as surveillance and early warning systems and evaluating the effectiveness of health	

						interventions and systems in different climatic conditions.	
Uganda	X	X			12/10/2021		
United Arab Emirates	X	X			29/12/2020	A health climate risk assessment is mentioned. Specifically, adaptation to heat is mentioned. A policy and action plan on health and climate change is planned, including a specific mention to train health personnel to deal with risks posed by climate change.	
United Kingdom	X	X	X	2040	ADCOM 19/10/2021	ADCOM: The second UK Climate Change Risk Assessment (CCRA) and the Third Strategy for the Adaptation Reporting Power include health considerations / the health sector. Health adaptation and resilience measures are listed for England, Wales, and Scotland. As part of the NAP, Public Health England (PHE) will widen the scope of existing plans by developing new adverse weather and health plans, which will cover heatwave, cold weather, flooding, and other weather-related hazards. The UK seeks to improve the resilience of its health system through the systematic assessment of its vulnerability to climate change, addressing these vulnerabilities through actions in the NAP. Since April 2017, the National Health Service (NHS) has been working to understand and address overheating risk in mandatory Green Plans. Vector Surveillance efforts are also underway.	
United States of America	X	X			22/04/2021		
Yemen	X	X	X		No NDC		

The way forward

The COP26 Health Commitments proved to be a valuable mechanism for demonstrating the willingness of health systems to do their share in responding to the climate crisis through both mitigation and adaptation. However, while commitment is a requisite first step for action, implementation cannot be guaranteed. Especially for mitigation actions, which are not widely reflected in the analysed documents, these commitments may, in some cases, be the first announcement of such intention[14]. Furthermore, the commitments will only be realised if accompanied by country-specific policy development and implementation. At present, there is no established accountability mechanism to monitor the delivery of these commitments, nor of financing to support such implementation, with the latter identified as the leading national barrier to the implementation of national climate and health plans and strategies[14]. To transition from commitment to action, countries should integrate health system adaptation, mitigation, and resilience considerations into national and sub-national policies and develop detailed and adequately resourced implementation plans at the local level.

At present, adequately targeted investment is lacking. Existing multilateral funding is skewed towards mitigation rather than addressing the acute and growing threats already facing LMICs, with just 25% of international climate financing allocated to adaptation in 2019[15]. Furthermore, an assessment of major international climate financing flows revealed that, as of 2018, only 0.5% of multilateral funds were explicitly allocated to health projects[16]. To date, no health-specific projects are included in the list of funded initiatives on the Green Climate Fund website[17]. Financial resources and technical assistance need to be provided for an adequate health system response.

Article 9 of the Paris Agreement calls for balance in the allocation of resources to adaptation and mitigation actions according to national context, needs and development[18]. The concept of "balance" between mitigation and adaptation in climate policymaking referred to earlier in this commentary should also be carefully considered in the context of the COP26 Health Programme commitments. The commitments and their implementation should protect vulnerable communities from climate risks and address social justice by increasing the adaptive capacity across communities, including vulnerable groups. Furthermore, environmentally sustainable and climate-resilient healthcare systems could be protective against climate change, contribute to the equitable quality of care across the populations they serve, and create ripple effects across the sectors with which they interact, for example through their supply chains. To achieve this, further understanding is needed of whether specific mitigation or adaptation actions create synergies, co-benefits, conflicts, or trade-offs with each other. Then, contextualized risk assessments should inform this approach and identify priorities within adaptation and mitigation. The health policy and systems research community has extensive and appropriate expertise to build a health systems' mitigation and adaptation evidence base which requires adequate funding and engagement of cross-disciplinary researchers[19,20].

Finally, there is a need to combine the 'top-down' approach of the COP26 Health Programme with a 'bottom up' approach to the design, implementation and evaluation of policies. As part of the public policy and health policy discourse, the terms 'bottom-up' versus 'top-down' approaches to implementation are well known. Top-down approaches provide valuable international momentum and stem from globally relevant discourse. In contrast, bottom-up approaches crucially take the local, community-level needs up to decision-makers[21]. Bridging global movements and local perspectives is not only necessary for successful implementation but will in turn influence future global directions.

The COP26 Health Programme has created important momentum and has the potential to catalyse much-needed change. Following this, COP27 in Sharm El Sheikh will provide a unique opportunity to solidify and expand the commitments and put climate impacts and adaptation finance central to the global climate debate. It will also provide an opportunity for a broad review of progress towards the COP26 Health Programme commitments, but more defined accountability mechanisms must be established to ensure a transition from rhetoric to reality. Real progress will depend on year-round work: by governments to develop policies with the participation of all key stakeholders, by researchers to identify mitigation and adaptation solutions and disseminate findings, and by the health community at large to continue to amplify the links between health and climate change.

Contributor's statement

The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. IMB initiated the study. All authors contributed to the design, writing, reviewing, and editing of the study.

Declaration of interests

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Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Amanda Quintana – None.

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The Lancet Planetary Health

Appendix II: Measuring environmentally sustainable healthcare: a scoping review

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Summary

Work to reduce environmental pollution from the health system is hampered by an absence of consensus on the definition of environmentally sustainable healthcare and the relevant measurement needed. This scoping review aims to encourage standardisation across sustainability efforts by examining how environmentally sustainable healthcare is defined and measured in current literature. We conducted a scoping review to identify candidate publications that included either a definition or description of environmentally sustainable healthcare or a measurement of the impact of healthcare on the environment. 328 publications were included in the final analysis. 52 publications included definitions or descriptions of environmentally sustainable healthcare. Results of the study highlight the heterogeneity in the current definition, measurement, and measurement calculation methods of environmentally sustainable healthcare in published literature. Work is needed to create more harmonised definitions and measurement to support progress and reduce environmental pollution from healthcare.

Introduction

Health-care systems globally have a substantial role in generating greenhouse gases and other pollutants that have direct and indirect impacts on human and planetary health.[1–4] Recognising this role, many health-care systems have committed to reducing pollution and are taking steps towards environmental sustainability. As of June, 2024, 84 countries across all income levels have pledged to develop health systems that are resilient to climate change and have low carbon footprints.[5] In March, 2023, over 100 health organisations in the USA endorsed a climate pledge aiming to achieve net-zero emissions by 2050.[6] Similar initiatives and pledges are also being signed across Europe.[7,8]

Although these pledges mark important strides in addressing pollution related to healthcare, efforts in this area remain fragmented and are not guided by standardised definitions and measurements. For example, measurements of greenhouse gas emissions in healthcare can be estimated using a wide range of techniques and approaches that might not be comparable with one another.[9,10] Practice Greenhealth, a fee-based hospital membership organisation dedicated to health-care sustainability advocacy, publishes the only annual benchmarking report for US hospital members, on a range of environmental sustainability measures.[11] However, the report is limited to paying members who choose to voluntarily submit data. Without rigorous, standardised tools, decision makers might find themselves uncertain about which interventions to pursue or might be missing evidence regarding the effectiveness of implemented changes.

Various nascent national and international reporting schemes for sustainability in healthcare exist, but none has yet produced standardised, understandable, actionable, and comparable metrics.[12,13] To guide and facilitate progress on this topic, a clear operational definition of environmentally sustainable healthcare is needed, as well as robust, comparable, and timely measurements, to support the most effective policies, measure progress, and benchmark success.[14–16]

This scoping review aims to contribute to the development of standard definitions and measurement of environmentally sustainable healthcare by addressing the following questions: how is environmentally sustainable healthcare defined in the existing literature? Which environmental impacts of healthcare are measured and at what levels of analysis? Which measures are used? What are the underlying data sources? Which measurement techniques are applied?

Methods

Search strategy and selection criteria

The following electronic databases were searched on Feb 23, 2023: PubMed, Embase, Web of Science Core Collection, and Google Scholar. Articles were identified by the presence of specific search terms in either the titles or abstracts. Search terms used were “healthcare system”, “health system”, “healthcare”, “healthcare”, “health sector”, “environmental footprint”, “environmental sustainab*”, “environmental impact”, “climate change”, “carbon footprint”, “carbon emission”, “greenhouse gas”, “energy us*”. Articles were limited to those published between January, 2010, and Feb 23, 2023, and written in English.

The search strategy was devised for use in MEDLINE (accessed via PubMed) and adapted for other databases. The search in Google Scholar was restricted to the first 20 hits per search to limit irrelevant results.

Inclusion criteria were that publications had to include either a definition or description of environmentally sustainable healthcare, a measurement of the impact of healthcare on the environment, or both. Exclusion criteria included a focus on the health impacts of the environment, the adaptation of healthcare in response to climate change, or environment and health educational efforts.

All study types were eligible for inclusion, including research articles, reviews, editorials, and opinion pieces. Results from grey literature were also eligible for inclusion if they met the aforementioned criteria, were retrieved from our search strategy, and were accessible (i.e., able to be viewed without payment or other barriers to access).

Methods of screening and selection criteria

To select publications for inclusion in this scoping review, the PRISMA Extension For Scoping Reviews was followed.[17] The procedure is depicted in the PRISMA flow diagram (figure 1).

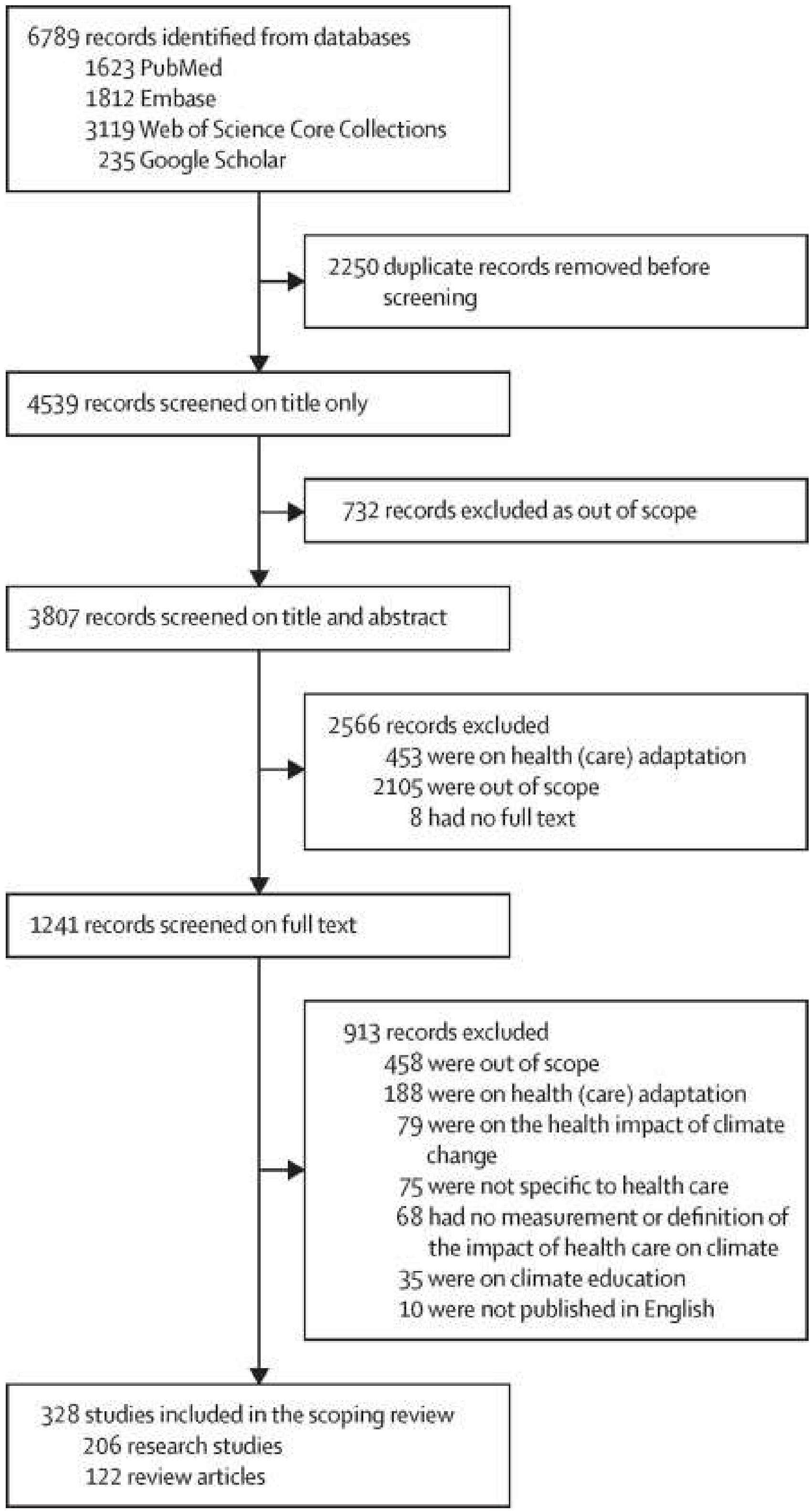

Figure 1 Scoping review PRISMA flowchart

In the first step, search result titles were screened by one researcher (MP, AD, DK, GM, or IB) for inclusion. To avoid removing relevant articles, investigators sought to remove only articles clearly out of scope during this initial review. Next, a screening of titles and abstracts was conducted by two reviewers (two of MP, AD, DK, GM, and IB) independently. Finally, after title and abstract screening, the full texts of the resultant studies were assessed for inclusion by two reviewers independently (two of MP, AD, DK, GM, and IB). Any discrepancies between reviewers during either the title and abstract or the full text screening were discussed among reviewers and resolved by a third reviewer if necessary (MP, AD, DK, GM, or IB).

Data extraction

The following information was extracted for all studies: author, title, year of publication, journal, presentation of original research (yes or no), the definition or description of environmentally sustainable healthcare, and the medical specialty or the type of care on which the research focused. Data on the medical specialty and care context were further grouped into four categories: perioperative care and surgical care, procedural care, specialty-based care, and care provided in other settings. The definitions or descriptions of environmentally sustainable healthcare were evaluated for thematic and keyword focus and the source of the definition (e.g., WHO) or description was recorded.

For articles presenting original research, the following data were extracted: sustainability measures reported, the health system level to which measures apply (e.g., greenhouse gas estimates of a hospital's activity are categorised as hospital level), the impact category to which measures belonged (e.g., greenhouse gases or solid waste), the measured data sources, and the measure calculation methods. Many studies included multiple measures and multiple corresponding impact categories. Possible values for selected variables can be seen in the panel. Table 1 provides an example data extraction. Additional information, definitions, and examples of extracted data, including the generation of impact categories, medical specialty classifications, and other variables, are available in the appendix (pp 1–7). Tables including all articles and extracted data are available in the appendix (pp 8–49).

	Title	**Year**	**Journal**	**Review or research**	**Definition of environmentally sustainable healthcare**	**Medical specialty**	**Level**	**Impact categories**	**Measures**
Imran Abdullah et al	Energy performance contracting initiative in Malaysian public hospitals	2020	International Journal of Integrated Engineering	Research	NA	NA	Hospital	Greenhouse gases and energy use	Greenhouse gas was measured in tonnes CO_2e/year using administrative data and conversion calculation methods; data on greenhouse gases were also sourced by direct observation, interviews, and conversion

									database; energy use was measured in kWh/year and kWh/m^2 per year using administrative data

Table 1

Example data extraction of a research article

See appendix (pp 8–42) for full list of measures reported. NA=not applicable.

Panel

Selected data extraction categories and response options

System level

- Global
- National
- Regional or local
- Specific programme
- Hospital
- Other facility types
- Procedural
- Service or department
- Product or device

Impact categories

- Air pollution
- Energy use
- Greenhouse gases
- Recycling
- Resources consumed
- Solid waste
- Travel
- Varied environmental impacts*
- Water use

Data source†

- Conversion database
- Demographic data
- Input–output database
- Maps
- National and subnational databases
- Public spending data
- Published literature
- Administrative data
- Patient records
- Direct observation
- Expert knowledge
- Interviews
- Assumptions
- Survey
- Manufacturer data
- Lifecycle inventory database

Methods‡

- NA
- Simple calculations
- Multistep calculations
- Conversion calculations
- Lifecycle assessment calculations (process based)
- Lifecycle assessment calculations (input–output based)
- Lifecycle assessment calculations (hybrid)
- Mapping
- Modelling

Definitions and examples for data categories and response options can be found in appendix pp 1–7. NA=not applicable.

Each measure reported by a publication was assigned to an impact category. Impact categories were determined during data extraction (i.e., as individual measures were extracted, they were classified into novel or existing impact categories). If more than one measure was assigned to the same impact category for a single publication, only one impact category was generated for counting purposes. For example, an article reporting two measures of carbon dioxide equivalent emissions, and one measure of waste produced by a hospital would generate one occurrence of the greenhouse gases impact category with two associated measures and one occurrence of the solid waste impact category with a single associated measure. Only the measures reported in the study were included in the measures category. Data used as an input to reported measures were assigned to the data sources category (rather than the impact category) even if these inputs might be considered measures of environmental impact themselves.

For each impact category identified, corresponding data sources and methods were determined based on data reported in the publication.

As the goal of data extraction was to identify definitions and measures of environmental sustainability, rather than assess the quality of the measurement results themselves, we did not assess article quality.

Results

A total of 328 publications were included in our analysis. Of these, 206 presented original research, whereas 122 were opinion or review articles. Four articles from the grey literature were retained. One publication from National Health Service England and one publication from the Dutch National Institute for Public Health and the Environment were included in the original research category;[7,18] one publication from WHO and one publication from the Commonwealth Fund were included in the review article category.[19,20]

152 publications focused on a specific medical specialty or specific care context (104 research articles and 48 review articles). The most common category was specialty care (n=101), among which nephrology (n=21), anaesthesiology (n=14), and dentistry (n=12) were the most reported specialties. 39 articles reported on perioperative care, with those focused on surgery being the most common (n=10). 12 articles focused on other care contexts and three on procedural care.

Definitions of environmentally sustainable healthcare

52 publications included definitions or descriptions of environmentally sustainable healthcare. A full list is available in the appendix (pp 50–56). Of these publications, 17 referenced existing definitions either explicitly or implicitly, including 14 that referred to a definition from Our Common Future (often referred to as the Brundtland report).[21] Five studies cited definitions or reports from WHO.[22–26]

Two publications included original definitions or descriptions. McGain and colleagues defined environmentally sustainable healthcare as care that “encompasses emissions to air, water, and soil, enables holistic environmentally preferable choices, and addresses efficient use of natural resources towards a circular economy”,[27] whereas Kaplan and Forst described it as encompassing “leaner energy, less waste, safer chemicals, smarter purchasing, healthier food, and engaged leadership”.[28]

The most common themes identified in these definitions and descriptions included: the environment (n=26); health (including public, environmental, planetary, clinical, and social health; n=22); economics and cost (including health-care spending, environmental economics, and circular economy; n=16); carbon emissions (n=14); impact on future generations (n=14); resources (including use and preservation of natural resources, resource consumption, and goods and services; n=12); and wellbeing (n=11).

Impact categories

Across all 206 original research articles, nine impact categories were identified. The category with the most occurrences was greenhouse gases (157 occurrences), followed by solid waste (56), energy use (47), varied environmental impacts including those not already included in other categories (36), water use (30), air pollution (28), travel (27), resources consumed (four), and recycling (three; figure 2). More information on these categories is available in the appendix (pp 5,8–42).

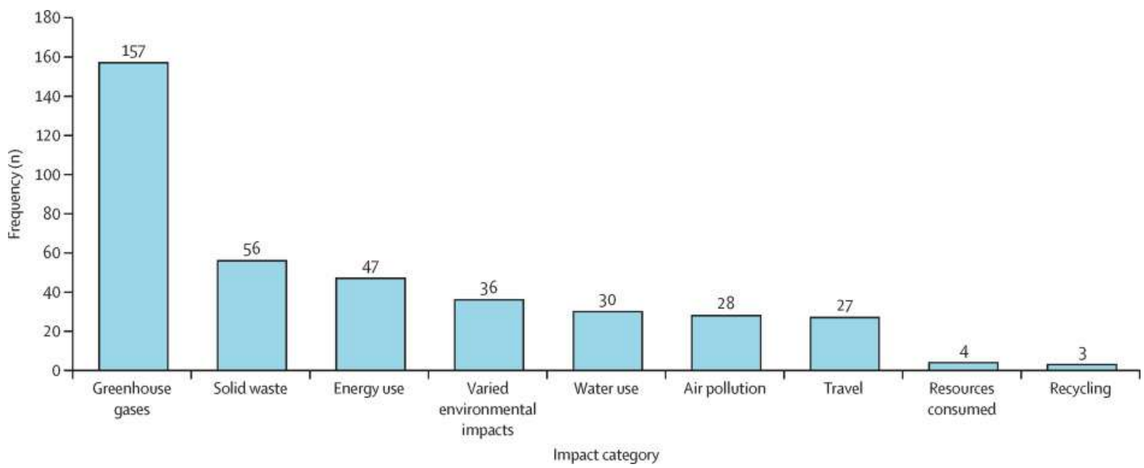

Figure 2 Frequency of impact categories among research articles

Impact categories by system level

The frequency of impact categories varied substantially between health system levels. 83 impact categories were identified at the product or device level, whereas nine were identified at the global level (figure 3). Greenhouse gases were investigated across all system levels and this impact category was the most common in nine of ten system levels. The solid waste impact category was identified at all system levels, except for the specific-programme level, and was the second most frequently identified category in five of ten system levels.

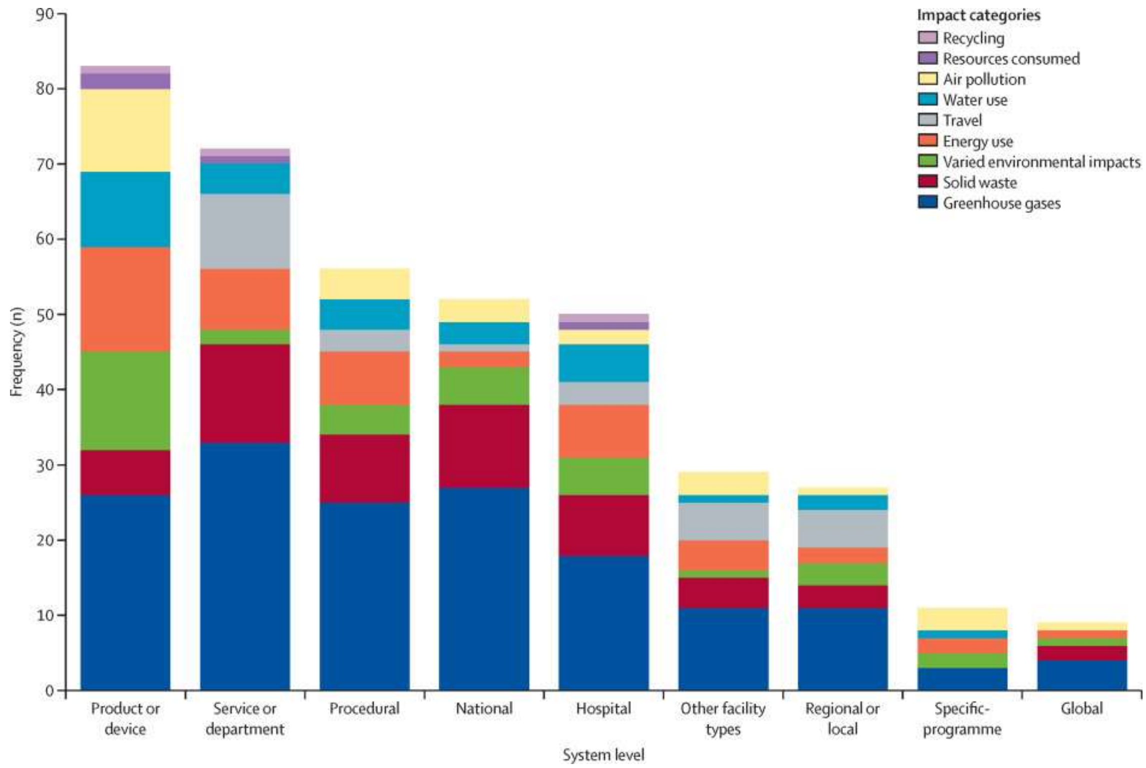

Figure 3 Frequency of impact categories by system level

Measures reported

Frequently reported measures were identified in three of the impact categories (table 2). Carbon dioxide equivalent was the most commonly reported greenhouse gas measure, representing 90% of all greenhouse gas measures. Weight of waste was the most common solid waste measure (89% of all waste measures), and kWh was the most commonly reported energy measure (80% of all energy measures). The most frequently reported air pollution measure was weight of trichlorofluoromethane, representing 27% of all air pollution measures. No measure in the varied environmental impact category represented more than 10% of the total measures reported in this category.

	Total number of measures reported	**Most common measures (% of total reported)**	**Other measure examples**
Greenhouse gases	269	Weight (e.g., g, kg, tonnes) of CO_2 equivalent (90%)	Volume of specific anaesthetic gases
Waste	97	Weight (e.g., g, kg, tonnes) of type of waste (89%)	Percentage of materials disposed of (as opposed to recycled, reprocessed, or reused)
Air pollution	74	Weight (e.g., g, kg, tonnes) of trichlorofluoromethane equivalent (27%)	Smoke density

Energy use	70	Amount of energy (kWh, megajoules; 80%)	Litres of oil

Table 2

Common and divergent measures for common impact categories

In addition to measures reporting outcomes, four articles also reported structural or process-type measures associated with environmental outcomes that were not included in our impact categories.[29–32]

Measure denominators

Among the most frequently reported measures, time was the most common denominator (e.g., year, day, observation period) across all impact categories when reported at the hospital, other facility, specific services, and system levels. For measures reported at the procedure level, the procedure was the most commonly reported denominator (e.g., the water use in nephrology could be expressed as gallons of water or haemodialysis treatment [procedure] as opposed to water use of the nephrology unit).

Data sources and calculation methods

The nine impact categories were identified a total of 392 times among research articles. Of these, 179 (46%) occurrences used the same combination of data sources and calculation methods as at least one other occurrence in the same impact category. The remaining 213 (54%) occurrences used data source and calculation method combinations unique to their study. The frequency of calculation methods and data sources by impact category are presented in table 3.

	Frequency of calculation method	**Number of unique data source combinations by calculation method**	**Common data sources by calculation method**
Greenhouse gases (n=157)			
Conversion calculations	72	41	Conversion database, administrative data, direct observation, published literature
Process-based LCA	45	27	LCI database, direct observation, manufacturer data, administrative data
Input–output-based LCA or hybrid LCA	21	18	National and subnational databases, input–output database
Solid waste (n=56)			
Simple or no calculations	40	19	Direct observation, administrative data
Modelling	7	5	Published literature

Energy use (n=47)			
Simple or no calculations	22	13	Administrative data, direct observation
Process-based LCA	19	14	Manufacturer data, direct observation, LCI database
Varied environmental impacts (n=36)			
Process-based LCA	27	20	Manufacturer data, direct observation, LCI database, administrative data
Water use (n=30)			
Process-based LCA	16	12	Direct observation, manufacturer data, LCI database
Simple or no calculations	10	7	Direct observation, administrative data
Air pollution (n=28)			
Process-based LCA	21	15	Direct observation, manufacturer data, LCI database, administrative data
Travel (n=26)			
Simple or no calculations	17	19	Survey data, patient records, maps
Mapping	6	3	Maps

Table 3

Calculation methods and data sources for common impact categories

Impact categories are presented with total frequency. See appendix (pp 8–42) for a full list of calculation methods and data sources reported. LCA=lifecycle assessment. LCI=lifecycle inventory.

Of the 157 occurrences of the greenhouse gas category, the most common calculation method was conversion calculation, with 72 (46%) studies using this technique. 45 (29%) occurrences used process-based lifecycle assessment (LCA) calculations and 21 (13%) used input–output-based LCAs or a hybrid LCA that used both process-based and input–output-based approaches.

Simple or no calculations were the most common calculation method among the 56 occurrences of solid waste, the 40 occurrences of energy use, and the 26 occurrences of travel impact categories. Process-based LCA calculations were the most common calculation methods for the varied environmental impacts, water use, and air pollution categories.

Across all impact categories, process-based LCAs were used 132 times. 62 (47%) uses were for measures corresponding to the product or device level. 22 (17%) of these uses corresponded to the procedural level, 15 (11%) to the hospital level, nine (7%) to the service or department level, nine (7%) to the specific-programme level, six (5%) national level, five (4%) to the regional or local level, and four (3%) to the other facility type level. System levels corresponding to measurements generated using input–output-based LCAs included the national level (nine occurrences), the global and regional levels (three occurrences each), and the procedural and service or department levels (one occurrence each). Measures using hybrid LCA procedures corresponded to the national level on nine occurrences, the service or department level on three occurrences, and the procedure level on one occurrence.

Discussion

Our scoping review highlighted the heterogeneity in the definition and measurements of environmentally sustainable healthcare in published literature. This absence of standardisation is an important impediment to creating a common approach necessary to guide progress through shared goals, methods, and learning.

Definitions of environmentally sustainable healthcare

Under 20% of all included publications provided a definition or description of environmentally sustainable healthcare. Of these, under half of the publications referenced existing definitions, with many citing general definitions of environmental sustainability, such as one from Our Common Future that defines sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs".[21] Other definitions focused on specific environmental impacts of the health sector, such as the production of greenhouse gases. This diversity of definitions is not unique to healthcare and can lead to a corresponding diversity of management approaches.[33]

General definitions of sustainability, including those from organisations, such as WHO, might not have the specificity necessary for non-experts in the health field to operationalise them through measurement, interventions, and goals. One description of environmentally sustainable healthcare that corresponds directly to operational goals came from the Dutch Green Deal Sustainable Care initiative to improve the sustainability of the health-care sector; the initiative focused on reduced carbon emissions, stimulation of circular practices, creation of a health-enhancing environment, and reduced medicine residues in surface water and groundwater.[18] Wider adoption of a definition clearly aligned with specific goals and the actions necessary to improve sustainability might be useful to guide work in this area.

Along with more precise and more easily operationalizable elements that refer to specific types of environmental impacts, a useful definition of environmentally sustainable healthcare might also include the concept of health. Over 40% of all definitions and discussions in the reviewed manuscripts referred to health. The incorporation of this idea into a common definition, and with links to specific environmental impacts, could provide additional justification for environmental work in the health sector.

Accounting for existing health system priorities is an important aspect of promoting environmental sustainability goals.[34] *The* Lancet *Commission on Sustainable Healthcare* provides a definition of sustainable health-care systems that focuses on optimising care for patients while maintaining other system goals, including sustainability.[35] A general definition might also make conceptual links to the more traditional concept of (economic) sustainability to leverage existing efforts in this area, such as reduction of low-value care that can have both financial and environmental benefits.

Reported measures and impact categories

Our scoping review showed frequent reporting of greenhouse gas measures. This focus on greenhouse gases is also reflected in common environmental goals in the health sector and elsewhere that focus on net zero carbon emissions or other carbon emission reduction goals.[5–7] In contrast, reported definitions of environmental sustainability generally focused on a wide range of elements and only one in four definitions specifically mentioned greenhouse gases. The focus of measures and goals on carbon emissions might lead some systems to overlook other important aspects of environmental sustainability, such as resource use, which can have additional environmental impacts in addition to carbon emissions, and other types of pollution, including air, water, or others. Organisations working on health-care sustainability have used a wide range of measurement categories, including leadership, waste, chemicals, food, the operating room, transportation, purchasing, energy, water, buildings, and climate.[7,12,36] Considering a wider range of environmental impacts might help health systems to better manage their total environmental footprint.

The frequencies of impact categories were heterogeneous across system levels, with the highest frequency of impact categories identified at the product or device, service or department, and procedure levels. The increased frequencies at these levels might reflect data availability or the interests and perspectives of the researchers conducting the study.

Heterogeneity of impact categories across study levels is not necessarily a weakness, so long as measurement can appropriately inform policy action. If water reduction strategies, for example, are most effective at the hospital level, then focusing on water measurement at this level is appropriate. Some goals might require multiple levels of action and thus multiple levels of measurements would be needed. An analysis of the levels and targets of currently used and proposed environmental policy action might be useful in shaping future measurement goals. Different policies might also require different types and quantities of data, necessitating different methods. Decarbonisation strategies on a system-wide level might require a single system-wide carbon emission study using an input–output-based LCA, whereas decisions on a product level might need very precise comparative data across a wide variety of products, using process-based LCA studies.

Reported measures showed relative homogeneity within the greenhouse gas, waste, and energy use categories, indicating some consensus around measurement and reporting in these categories. However, most of these measures were not normalised, preventing comparison across contexts or studies. Comparability might benefit from identifying standard denominators by level, with a focus on patient-oriented or service-output metrics. At the hospital level, for example, results might be normalised by hospital beds, patient-days, adjusted patient-days, or, if necessary, square feet, or some financial measure, depending on measurement type. Additional work is needed to expand previous efforts to identify and build consensus on normalisation techniques.[12]

Comparability of measures was hindered in some cases by the heterogeneity of data sources and calculation approaches. Of the 157 studies reporting greenhouse gases, there were 102 (65%) unique combinations of calculation methods and data sources. Although heterogeneity is expected and even necessary across contexts, measurement levels, and policy objectives, strong heterogeneity, even among similar impact categories at the same level, hindered comparability. Along with a consensus about which measures are relevant to report, work is also needed to standardise calculation methods and data sources.

A very small number of studies reported structural or process measures, such as the presence of environmental sustainability-related protocols. These types of measures are generally easier to collect and compare across settings and can be useful in supporting implementation science research. However, the links between structural measures and desired outcomes are often indirect. Additional development and validation of these measures, linking them to important outcomes, might facilitate reporting in some cases.

Measurement methods

Across all impact categories, LCA was the most used method. LCA studies provide a holistic environmental assessment of a process, product, or service, including impacts from across the lifecycle, and produce environmental impact measures that are not regularly reported outside of studies of this type, such as the amount of 1,4-dichlorobenzene equivalent (ecotoxicity) or particulate matter produced. Although this approach is useful for assessing total environmental impacts, LCA techniques require a high level of specific expertise and can be time-consuming to conduct. A simplified, standardised LCA option might be one way of making this technique more accessible.[37]

Although our analysis did not focus on this topic, many articles used a variety of scopes and boundaries when calculating measures that negatively impact cross-study comparability. Outputs from studies using LCA techniques are not directly comparable with results from studies using other methods with reduced scope (e.g., studies not including the upstream or downstream impacts of a process). Incompatibility of scopes might also apply to comparisons between studies using LCA techniques. Additional work on healthcare specific guidelines for LCA to enable adequate cross-study comparisons is currently under development.[38]

Limitations

Our study includes several limitations. Our data search was limited to online databases and English language articles, which might have resulted in fewer articles from non-English speaking countries. We also did not conduct a specific search of grey literature, although these publications were eligible for inclusion if they were retrieved in our searches.

Data extracted from articles included in our study did not always fit neatly with the available values for variables, such as calculation technique or data sources. Different possible response options might have modified results although most studies did fit well with existing options.

Moving forward

Advancing and harmonising environmental sustainability definitions and measurements in the health-care sector will require substantial effort. This work might benefit from adopting approaches used for the evaluation and reporting of health quality metrics, including established measurement criteria.[14,16,34,39,40] This approach includes consensus building techniques, such as expert panels along with empirical analyses that could be supported by groups, such as the Agency for Healthcare Research and Quality, the Care Quality Commission in England, or the Organization for Economic Cooperation and Development. Initial work on this topic at organisations, such as the National Academy of Medicine, The Joint Commission, and The *Lancet* Commission on Sustainable Healthcare, should continue, as these bodies can have important roles in building consensus, aligning goals and standards, and providing technical expertise. External pressure applied from reporting bodies both inside and outside healthcare might also help to spur progress in this area and recent efforts from the corporate and financial sector might generate progress in the health-care system.[15,41,42]

Environmental sustainability in the health-care sector is a multifaceted issue and will need expertise across a wide range of areas, including those that are not frequently considered to be part of healthcare, such as sustainability science, building design, waste services, transportation, and others. Incorporating these voices into measurement development will be crucial to create appropriate, actionable, and understandable metrics for stakeholders.

Work on measurement should also include consideration of the setting and relevant actions for improvement. Decarbonisation goals on a health system level might need very different types of measures to waste segregation improvement goals in a local clinic.

Conclusion

Environmental sustainability in the health-care sector is a growing topic with important human and planetary health consequences. Although interest is growing, there remains substantial work to define and measure goals and track progress.

Overcoming the current heterogeneity in measuring and defining environmental sustainability in healthcare necessitates collaborative efforts. By fostering partnerships among stakeholders, including researchers, policy makers, health-care providers, and environmental experts, and using rigorous, standardised approaches, we can address methodological inconsistencies and develop common frameworks. Through collaborative action, we can advance the field, driving progress towards more accurate, comprehensive, and actionable measures of environmental sustainability and help the health-care field to achieve its important sustainability goals.

Contributors

MP, AD, and DK conceived the project and the methodology. MP, AD, IB, GM, and DK conducted the literature review, data extraction, and data analysis. A-CD and JS contributed to data extraction and categorisation methodology. MP led the writing of the scoping review. All authors provided critical feedback and helped shape the analysis and manuscript.

Declaration of interests

MP received payment for lectures at École des Hautes Études en Santé Publique, Public Health School, Rennes, France. IB received consulting fees and travel support from London School of Hygiene & Tropical Medicine; payment for a lecture from The Medical Society Consortium on Climate and Health; and travel support from the conference organisers of the Climate & Health 2023 Conference on Oct 21–22, 2023, at the Zucker School of Medicine, NY, USA. WA received an honorarium for lectures from Harvard Medical School and travel support from Massachusetts General Hospital. JDS received royalties or licences from Up to Date; consulting fees from the Institute for Healthcare Research; payment for lectures from several medical societies and academic institutions; and travel support from the World Innovation Summit for Health, American Thoracic Society, National Academy of Medicine, Johns Hopkins University, and the Health Summit at Sundance. JS received consulting fees from Gerson Lehman group, AlphaSights, CapVision, and Teleflex; payment for lectures from AstraZeneca, University of New Mexico, Columbia University, University of Colorado, Harvard University, Institute for Healthcare Improvement, and University of California at Los Angeles; and travel support from Vizient, AstraZeneca, University of Colorado, and Institute for Healthcare Improvement. All other authors declare no competing interests.

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Supplementary Material (1)

PDF (1.91 MB)

Supplementary appendix

Footnotes

*Environmental impacts not already included in other categories, such as nitrogen equivalent emissions; further examples are available in appendix p 5.

†Source of data used to calculate measures.

‡The calculation methods used to transform raw data from the data source into reported measures.

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Appendix III: Climate-Sensitive Health Outcomes in Kenya: A Scoping Review of Environmental Exposures and Health Outcomes Research, 2000 – 2023

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This article is a preprint and has not been peer-reviewed [it has been submitted for publication]. It reports new medical research that has yet to be evaluated and so should *not* be used to guide clinical practice.

History

April 26, 2024.

[6] Evidence of retention of copyright.

Abstract

Climate change threatens health and social development gains in Kenya, necessitating health policy planning for risk reduction and mitigation. To understand the baseline state of knowledge of environmental determinants of health in Kenya relevant to climate change, a comprehensive scoping review was undertaken. Compliant with a pre-registered protocol, nine bibliographic databases and grey literature sources were searched for articles published from 2000-2023. Two-stage screening was conducted on 17,394 articles; 635 full-texts were screened in duplicate. A final 353 articles underwent data extraction for topic categorisation, bibliometric analysis, and narrative summary. This was comprised of 344 (97%) journal articles, 59% of which were published after 2014 (n=207). Main study designs included observational (n=211) and modelling studies (n=64). Health topics centred on vector-borne diseases (41%, n=147), primarily vector abundance (n=102) and malaria (n=60), while injury or death (n=10), mental health conditions (n=7) and heat exposure (n=7) studies were less frequent. Environmental health research in Kenya is largely conducted in the Lake Victoria Basin, Rift Valley and Coastal regions, with fewer studies from the northern arid and semi-arid regions. Findings of this review suggest a growing and diverse field of predominantly observational research with an increasing focus on social determinants and policy-relevant themes, however research on vector-borne disease dwarfs other health outcomes and sparsely populated but climatically fragile regions are less represented in published literature. Addressing existing gaps in baseline evidence underpinning associations between the environment and health outcomes will benefit climate change attribution research and support future development of evidence-informed climate change and health policy in Kenya.

Introduction

The recent convergence of increasing extreme weather events and rising awareness of attributable anthropogenic contributions to climate change has sharpened global attention to the impact of environment on human health, wellbeing and livelihoods. This is particularly evident in sub-Saharan Africa (SSA) which experiences adverse effects of climate change, despite nominal contributions to global greenhouse gas emissions [1]. Kenya is highly susceptible to climate change due to its varied topography, diverse climatic zones, and reliance on natural resources and is the largest economy in East Africa with a growing population of 2.3% projected to nearly double by the turn of the century [2].

Currently, Kenya stands at an inflection point toward rapid industrialisation and sustainable growth, with the potential to provide a blueprint for climate-resilient economic development in the region. Kenya was the first country in Africa to enact legislation exclusively on climate change via the 2016 Climate Change Act [3], which sets out pathways towards sustainable development through the National Climate Change Action Plan. This plan in turn advises on mechanisms of integrating sectoral climate change mitigation and adaptation actions at national and sub-national levels [4]. In 2023, Kenya convened the inaugural Africa Climate Summit in conjunction with the Africa Union Commission and launched the Nairobi declaration on green development [5] which linked health alongside economic development in support of the United Nations 2030 Sustainable Development Goals [6].

Various environmental exposures (EE) including weather, hydrometeorological hazards and air pollution pose risks to social development gains due to their influence on human health [7]. However, many of these causal relationships have not been clearly defined in Kenya, potentially limiting opportunities for detection and attribution research over longer timeframes that would permit the evaluation of health impacts of climate change, with implications for the development of evidence-informed climate change and health policy. To better understand the state of environmental health research, a comprehensive synthesis of published output on the influence of EE on health outcomes (HO) in Kenya was undertaken with the following objectives: (a) to undertake a scoping review of literature on relationships between EE and HO; (b) to map the links between these exposures and climate-sensitive HO and health equity through bibliometric analysis, topic mapping and narrative synthesis; and (c) to identify knowledge gaps and future research needs to strengthen the evidence base underpinning climate change and health (CCH) attribution for policy development. This article presents initial bibliometric analysis and narrative summary findings from the broader scoping review work on environmental health research in Kenya.

Materials and Methods

Protocol and registration

Reporting of this review was guided by the PRISMA extension for scoping reviews [**8**], as well as an established team of article reviewers, a library information professional, and subject matter experts in medicine, veterinary medicine, nutrition, demography, water, sanitation and health, and child health and development. A scoping review was deemed most suitable given the complexities and wide breadth of the subject matter and lack of similar reviews [**9**]. The protocol for this review was registered on Open Science Framework on April 14, 2023 [**10**].

Eligibility criteria

We aimed to identify a wide range of original literature describing the relationships between EE and HO, excluding intervention studies. The range of exposures included weather variables such as temperature and precipitation, hydrometeorological hazards including droughts and flooding, and climate variability phenomena such as El Niño – Southern Oscillation, with a full list found in **Table S1**. In recognition of the moderating effects of land-use change, terrestrial, aquatic and air pollution on health, these environmental drivers were also incorporated. Eligible health outcomes encompassed direct and indirectly impacted outcomes for example, heat stroke and vector-borne diseases (VBD), respectively.

We included any original research published in English between January 1, 2000, and February 20, 2023. This timeframe reflects the growing interest and discourse on health implications of climate change as well as improvements in environmental attribution methods in public health sciences [**11**]. As our review focused on Kenya, we included studies on any demographic populations including transborder pastoralist communities, as well as global studies, if data from Kenya was disaggregated and extractable. Eligible studies were required to include some measure of a HO produced by either qualitative or quantitative analysis.

Information source

The search strategy was informed by the Population-Exposure-Comparator-Outcome (PECO) model: [**12**]

P: population of Kenya

E: environmental exposures, including weather, hydrometeorological hazards and air quality variables

C: no effect of environmental exposures on health conditions (as available, studies will not be excluded for lack of comparison groups)

O: disease burdens or measures of association or effect of environmental exposures on health outcomes and included synonyms for health outcomes guided by categories listed in the World Health Organisation report, Quality Criteria for Health National Adaptation Planning [**13**]. The full methods, search terms and database search results were conducted by a Library information professional and are hosted in an open access digital repository maintained by the London School of Hygiene & Tropical Medicine [**14**]. Nine bibliographic databases were searched in February 2023: Medline, Embase, Global Health, Food Science and Technology Abstract and Econlit via OvidSP, GreenFile and Africa-Wide Information via EBSCOhost, Clarivate Analytics Web of Science core content and Scopus. Grey literature sources included Google Scholar and websites of 10 organizations known to be working on environment or CCH research in Kenya.

Selection process

All citations were deduplicated and transferred into the reference manager software EPPI-Reviewer Web 4.14.2.0 [**15**] for two-stage screening. Title and abstract screening were conducted by a single trained reviewer against *a priori* inclusion criteria. All reviewers were trained on an initial sample of 800 abstracts in duplicate to ensure consistency. Following primary screening, full-text articles were reviewed in duplicate for eligibility. At both stages of screening, reasons for exclusion were noted.

Data extraction

Data extraction was undertaken by two independent reviewers and confirmation of final extracted data arbitrated by a third reviewer. All articles were categorized by main HO (**Table 1**) and EE (Table S1). Main categories were further divided into subcategories that were refined using an iterative approach during data extraction. Data on publication year; author institutional affiliation; study type; article type; funder(s); location(s); and analysis method(s) were recorded. To investigate authorship and geographical extent of collaborations, the institutional affiliation(s) of authors were categorized into regional or international groups; funders were likewise allocated into one of six funding models. Analytical methods for each article were assessed by main study design and analysis methods employed. Covariate results were extracted and described in brief narrative summaries.

Topic Category	Topic Subcategories	
Injury or Death	Direct injury Direct death	Burden estimate
Heat Exposure & Skin Conditions	Heat stress Skin conditions	
Cardiovascular, Circulatory & Respiratory Disorders	Heart disease & circulatory disorders Lung & airway conditions	Respiratory infections
Waterborne Diseases & Water Access Disorders	Cholera Diarrheal diseases Leptospirosis Cryptosporidiosis Schistosomiasis	Giardia Dehydration & kidney disorders Water insecurity Harmful algal blooms

Vector-borne Diseases	Vector or parasite abundance or prevalence Malaria Dengue Trypanosomiasis Lymphatic filariasis Leishmaniasis	Tick-borne diseases Soil-transmitted helminths Yellow Fever Chikungunya West Nile Virus
Zoonoses	Animal reservoir abundance or zoonotic disease prevalence Anthrax Coxiella burnetti	Bartonellosis Rift Valley fever Brucellosis
Malnutrition & Foodborne Diseases	Stunting Wasting Malnutrition	Food insecurity Escherichia coli & Salmonella
Mental Health Conditions	Eco-anxiety & depression Stress & resilience	Cognitive capacity
Adverse Birth or Pregnancy Outcomes	Neonatal or infant outcomes Maternal health outcomes	
Health Equity Research	Toxic level: air pollutants Toxic level: water & terrestrial pollutants Toxic level: other pollutants Neoplasia Pre-existing conditions Displacement & migration Occupational hazards	Health vulnerability Awareness & Perceptions Conflict Gender-based violence Access to health facilities Health inequities

Table 1. Health outcome topic categories and their corresponding subcategories

Evidence synthesis

We used bibliometric analysis and narrative summaries to synthesise the evidence. To explore characteristics of environment and health research in Kenya, we mapped locations of empirical research on HO to Kenya's main climatological zones [16], used keywords for conceptual mapping using VOSviewer software [17] and developed a Sankey diagram to illustrate environmental drivers of HO using R software [18, 19].

Protocol amendments

We applied two protocol amendments to our review. We expanded our eligibility criteria to include a category of research articles that measured pollutant toxicity since they provided data on an exposure risk, even if they did not measure impact on an explicit HO.

The second protocol amendment was made to the HO categories informed by the Quality Criteria for Health National Adaptation Plans [13]. We added the category "Adverse Pregnancy or Birth Conditions" to better reflect gender disparities in HO and expanded equity related subthemes under a category titled "Health Equity".

Results

The bibliographic database search identified 29,443 records, of which 12,132 were duplicates removed prior to screening (Fig 1). The grey literature search identified 77 pieces of grey literature and 6 records from cited references, resulting in 17,394 unique references that underwent title and abstract screening. Of these, 635 underwent full text screening and 353 met inclusion criteria for the final article set (Table S2). A total of 26 full text reports, including 13 conference abstracts, could not be retrieved.

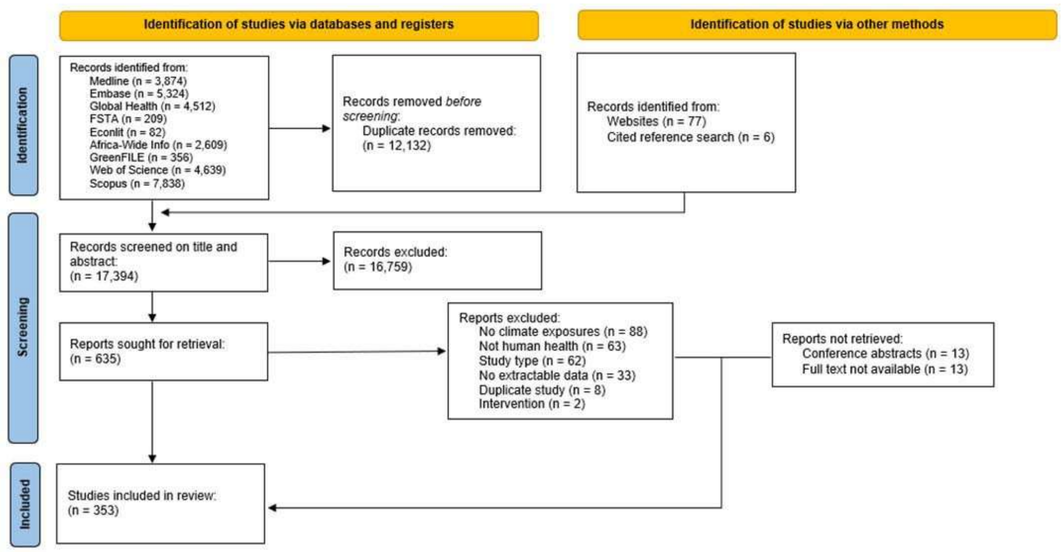

Fig 1. PRISMA flow diagram of evidence selection [20].

Article characteristics

The characteristics of the final set of articles are described in **Table 2**. The study set is primarily comprised of journal articles (97%, n=344). Research on environmental determinants of health in Kenya increased in frequency per 5-year period from 2000 to 2019 with a small decline between 2020–2023, likely due to the shorter search period of 3 years and 2 months. Analysis of author's institutional affiliations found that 52% (n=186) of articles were authored by international collaborations, while fewer than 20% (n=67) were exclusively from Kenyan institutions. Likewise, the majority of funding came from international public and private research funders, with just over 10% (n=46) of funders cited as public (n=28), university (n=10), or private funders (n=8) from Kenya. 58 studies did not cite a funding source.

Characteristic	Included literature (n)

Year Published	353
2000 - 2004	25
2005 - 2009	43
2010 - 2014	78
2015 - 2019	118
2020 - 2023	89
Institutional Collaborations	353
Kenyan	67
African Region	26
International	186
International without African collaborations	74
Study Type	353
Observational	211
Modelling Study	64
Mixed methods	24
Trials*	24
Qualitative	27
Meta-analysis	3
Geographic Scale	353
National	53
Regional	194
City/community	91
Not specified/relevant	13

*Includes both randomised and non-randomised trials

Table 2. Single selectable bibliometric characteristics of included literature

Most study designs (60%, n=211) were observational in nature while modelling, qualitative, and randomized and non-randomized trials constituted 18% (n=64), 7.6% (n=27), and 6.7% (n=24), respectively. Methods of analysis reflected the main study designs, where 21% (n = 144/689, **Table 3**) used regression analysis, 8% (n=54/689) advanced modelling methods including mechanistic modelling, spatial modelling, machine learning and multicriteria decision making, 6.5% (n = 45/689) qualitative methods such as interviews and focus groups and 2.1% (n = 15/689) applied health risk exposure assessment calculations.

Characteristic	Included literature (n)
Health Outcome Categories	421

Vector-borne Diseases	147
Health Equity Research	129
Waterborne Diseases & Water Access Disorders	29
Cardiovascular, Circulatory & Respiratory Disorders	28
Malnutrition & Foodborne Diseases	24
Zoonoses	23
Adverse Birth or Pregnancy Outcomes	16
Injury or Death	11
Mental Health Conditions	7
Heat Exposure	7
Methods of Analysis	689
Descriptive statistics	236
Parametric and non-parametric statistical tests	156
Regression analysis	144
Advanced modelling methods	54
Qualitative methods	45
Time-series analysis	36
Health risk assessment	15
Meta-analysis	3
Funder(s)	411
International funder(s)	251
No funding cited	58
International university funding	56
Kenya Government	28
University funding	10
Private/local funder	8

Table 3. Multi-selectable bibliometric characteristics of included literature

Table 2 summarises publication year, institutional collaboration, study type, and geographic scale. Articles were allocated once within each category.

Table 3 summarises health outcome categories, methods of analysis and funder type. Articles could be allocated more than once within each category.

Keyword trends

To identify trends in research interest, bibliometric keyword co-occurrence analysis was used to map the temporal relationship between terms in publication titles and abstracts [17]. A total of 11,070 terms were identified and for optimization purposes, a threshold of inclusion of a minimum of 8 occurrences was established and a relevance score of 60% was used, resulting in 142 keywords. The period of time over which the greatest shift in keyword trends occurred is shown in **Fig 2**. Connection lines indicate networks and circle sizes correspond to occurrence. Cluster density visualization highlights closeness between terms over time, illustrated as two clusters of keywords: cluster 1 (left, n = 68) VBD and climate exposures and cluster 2 (right, n = 74) social science and policy-oriented keywords.

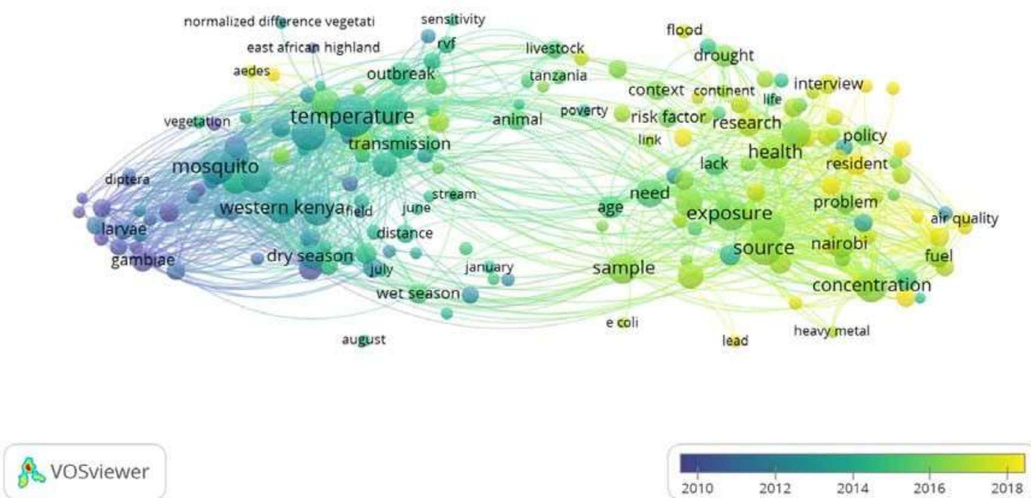

Fig 2. Time-scaled bibliometric keyword analysis.

A network map based on co-occurrence of keywords in titles & abstracts of included articles.

Environmental drivers of health outcomes in Kenya

Occurrences of environmental covariates of HO are shown in **Fig 3**, extracted from 353 articles. Rainfall represented the most frequent exposure studied (n=218) and was specifically investigated as a driver of VBD in 115 occurrences within the article set. Other exposures linked to VBD included temperature (n=118), habitat change (n=61) and seasonality (n=60) – the latter of which was the third-most studied exposure (n=142) after temperature (n=168). Climate change was a non-specific exposure term used in studies that evaluated awareness of participants to climate change impacts on health (n=10). Less studied EE by frequency included wildfires (n=1), plastic pollution (n=1) and water level change (n=3).

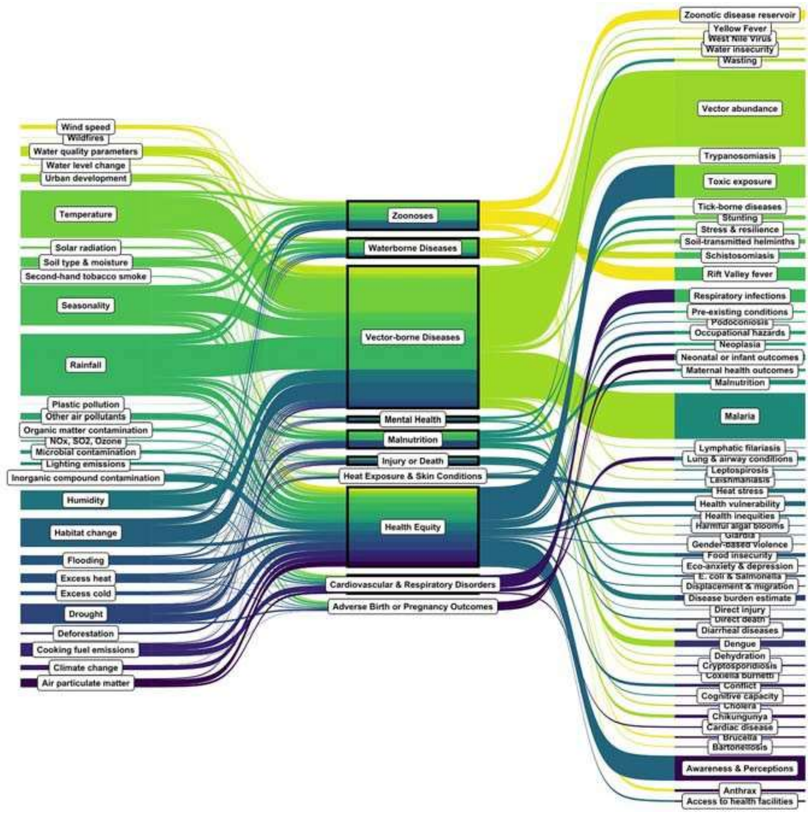

Fig 3. Sankey diagram of pathways between environmental exposures and health outcomes

Some category and subcategory names have been abbreviated for illustrative purposes, see **table 1** for full categorization.

The most frequently studied HO was VBD (n=502), followed by research relevant to health equity (n=281). The health equity category encompassed research describing toxic levels of air, terrestrial and water pollutants (n=117) (see **Table 1** for full listing). Health outcomes including heat stress (n=15), maternal health outcomes (n=9), access to health facilities (n=6), eco-anxiety and depression (n=4) were infrequent in the article set. A full listing of all studies categorised by main HO is provided in Table S2.

Research locations in Kenya

Health outcome topic mapping from 287 articles with sub-location data (**Fig 4**) highlights the geographical distribution of empirical research based on climatological zones in Kenya [**16**]. The highest density of research occurs in Kenya's humid southwest region, including the Lake Victoria Basin, Rift Valley region and Nairobi, where 75% of VBD (153/205) and 80% of health equity research (105/132) was conducted. In contrast, HO studied in the northern arid and semi-arid lands (ASALs) of Kenya more frequently focused on malnutrition and zoonoses, of which less literature was identified overall (**Table 3**). Empirical research was least frequently conducted in the Northwestern Region, where it was also the least diverse of all regions, encompassing only half of all possible outcome categories.

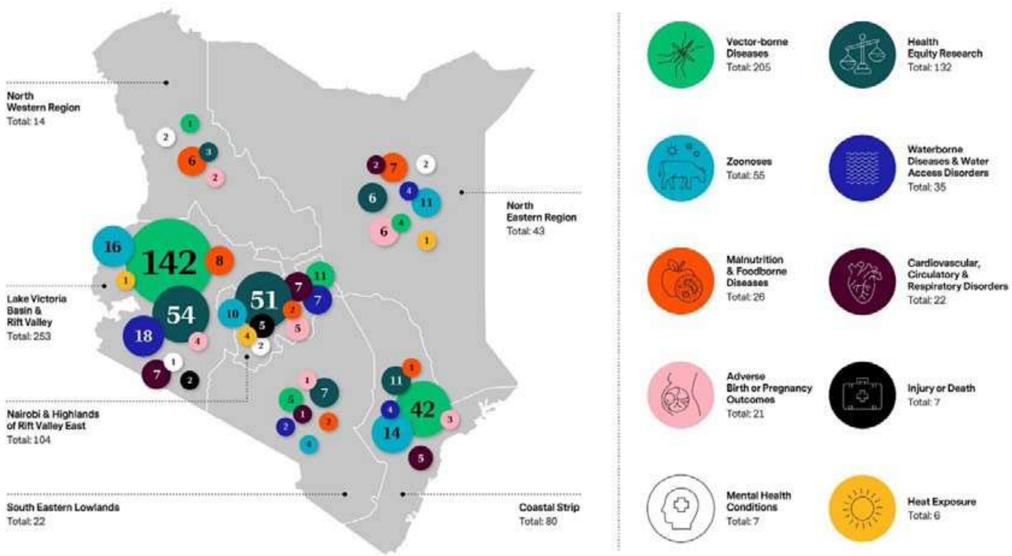

Fig 4. Health outcomes studied in empirical environmental research conducted in Kenya by climatological zone.

This figure shows health outcome results extracted from studies that cited a location for data collection (n=287).

Health outcome summaries

Vector-borne diseases

VBDs were the most studied HO in this review, evaluated in 147 studies, 69% of which focused on vector abundance (n=102). These studies included assessments of malaria, dengue, yellow fever, West Nile Virus and other VBD, and explored a variety of burden indicators, such as disease risk, incidence, and vector population dynamics influenced by EE. Malaria was the most studied disease, based on both clinical case reports (n=60) and vector abundance studies (n=66), with most research conducted in southwestern Kenya (Table S2). There was comparatively less literature available on non-malarial diseases such as dengue (n=7); soil-transmitted helminths (n=4); West Nile Virus (n=2) and a single result each for trypanosomiasis, lymphatic filariasis, leishmaniasis, tick-borne diseases and yellow fever.

Health equity research

The largest subtopic of this category assessed respondent's awareness and perceptions of CCH (n=51), followed by exposure to air and water pollution, with 36 and 22 articles respectively. Demographic and social determinants were frequent elements to these studies, especially air pollutant exposure studies in informal settlements [**21**, **22**] and studies on gender vulnerabilities of indoor air pollution [**23**–**25**].

Gendered access or lack thereof was identified in educational attainment and accessibility to health facilities [26, 27]. Two studies explored gender roles and violence in view of climate change, identifying a potential exacerbation of inequalities and harmful practices like female genital mutilation and intimate partner violence [27, 28]. Water-scarcity driven conflicts in pastoralist communities were also explored in three studies [29–31].

Waterborne diseases & water access disorders

Twenty-nine studies investigated waterborne disease and water access disorders in Kenya. Warming temperatures both increased and decreased Schistosomiasis transmission depending on the region, while precipitation had delayed influence on snail vector density [32–34]. Increased rainfall during the rainy season impacted cholera risk [35], and seasonality significantly influenced snail abundance and cryptosporidium prevalence [36–38]. Three studies on diarrheal disease risk assessed in the under-five population reported that dry season trends drive rotavirus infections [39–41].

Cardiovascular, circulatory & respiratory disorders

A number of studies on cardiovascular, circulatory and respiratory disorders assessed the relationship with household air pollutants (HAPs) (n=14), finding that exposure, especially over extended periods of time in women and children is linked to adverse outcomes [23, 42]. Exposure to HAPs such as particulate matter ($PM_{2.5}$) and carbon monoxide (CO) have been linked to reduced cardiac function [43] and volatile organic compounds from wood smoke are associated with increased self-reported respiratory, eye irritation and headache symptoms [44]. In households that used firewood or unprocessed biomass, children and infants under the age of five had a greater relative risk of developing acute respiratory infections (ARI) compared to those using kerosene fuels; long-term exposure to $PM_{2.5}$ also increased these conditions and symptoms [42, 45, 46].

Malnutrition & foodborne diseases

Approximately 5% of studies included in this review evaluated the impact of climate variables on nutritional deficiencies (n=24), frequently measured in relation to drought or changes in precipitation or through proxy measures such as Normalized Difference Vegetation Index. In northern Kenyan counties, temperature is positively associated with malnutrition [47] and the impact of drought is inversely correlated with validated growth measures such as middle-upper-arm-circumference, height-for-age and weight-for-age Z-scores in children [48, 49].

Zoonoses

Two studies assessed how EE impact wildlife host density and immunocompetence of rodents in relation to zoonotic disease [50], as well as interactions between precipitation and land-use change on infected rodent host density [51]. Climate risk factors for Rift Valley Fever (RVF), a zoonotic virus that causes disease in livestock and haemorrhagic fever in humans, was evaluated in fifteen studies through empirical and modelling methods applied to livestock, humans and mosquito vectors. Rainfall abnormalities, vegetation change and measures of humidity were shown to determine the abundance and suitability of potential habitats for RVF vectors [52–54], and also impact vector and host susceptibility [55].

Adverse birth or pregnancy outcomes

Environmental exposures that impact the health of mothers and infants were investigated in 16 studies. Seven articles evaluated precipitation, seasonality and drought and the associated effect on anthropometric measurements of nutritional status [49, 56]. Disease prevalence in children under five years of age, assessed in six studies, was characterized by seasonal patterns of occurrence; investigated diseases included rotavirus, *Escherichia coli,* shigellosis, cryptosporidiosis and other enteropathogens [37, 39–41]. Two additional studies looked at infant ARI, including human metapneumovirus [57] and Respiratory Syncytial Virus incidence [58].

Injury or death

Ten studies were categorized as evaluating death or injury due to trauma linked to environmental exposures as well as studies that measured disease burden, using standard mortality and morbidity metrics. The relationship between temperature and premature mortality was assessed using years of life lost [59, 60] and through burden estimates of morbidity [61–63] and disability-adjusted life-years (DALYs) [64]. DALYs were also used in four studies to estimate the overall burden of HAPs on health [64–67].

Mental health conditions

Mental health conditions were infrequently studied (n = 7) in the article set. These studies evaluated the impacts of extreme weather events and climate shocks on economic status, mental wellbeing, and psychological distress [68–71].

Heat exposure & skin conditions

Four studies investigated the impacts of temperature extremes on mortality measures and found significant positive associations between exposure to low temperature and mortality in Nairobi populations [59, 60, 72, 73]. An additional two studies reported on vulnerability indices [74], hydration in agro pastoralists [75] and a single study described Podoconiosis distribution and risk prediction in relation to different scenarios of environmental suitability [76].

Discussion

Our review compiled literature on EE and health impacts in Kenya, and in doing so, identified broad trends and emerging gaps in evidence. With meteorological projections indicating warmer temperatures, changing rainfall patterns and increasing flood and drought events [77, 78], the findings of this review are relevant to researchers and policymakers aiming to establish the risks to population health attributable to Kenya's changing climate.

Research trends

We found a diverse range of research on environmentally mediated HO. Nonetheless, the highest proportion of literature focused on VBD, particularly studies that evaluated clinical malaria as well as malaria vector abundance. There is an identified inequality in global funding trends for research on the 23 WHO-defined neglected tropical diseases (NTDs), as emphasized by funding from United States of $100 million on these diseases versus $1.5 billion for human immunodeficiency virus, malaria and tuberculosis combined in 2016 alone [79–81]. While this funding has substantially advanced understanding and supported successful control measures of these high burden diseases, many environmentally mediated NTDs in Kenya remain understudied [82]. In addition, a comparatively low amount of literature used a One Health approach to evaluate interconnected relationships between human, animal and environmental health pathways. This may be due to a lack of data, difficulties in establishing ecological dependencies, and challenges in the use of integrative and multisectoral approaches to support sustainable control efforts [83].

Most literature in this review was published by collaborations of international authors and supported by international funders, raising questions about inequities in global health research and funding structures in Kenya particularly given the prominence of Kenyan actors in CCH research in Africa [84]. More equitable funding and support for Kenyan-produced research outputs could drive contextually relevant research agendas and better amplify local voices [84, 85].

Shifting narratives

Our evaluation of key themes in environment and health research in Kenya suggests a broadening of interest over the last decade towards social science, health equity and policy research from more conventional environmental health topics such as VBD. This shift reflects a larger pattern of change towards improvements in attribution methods alongside cross-disciplinary approaches, including those in social sciences, occurring in public health research [86–88]. Subjects relevant to health equity were identified in several articles focused on vulnerable populations including pollution exposure studies of residents of informal settlements, water scarcity conflicts in pastoralist communities, and extreme weather effects on intimate partner violence, cognitive development and education access for young girls. Some studies measured associations between EE and HO, such as air pollution exposure on cardiovascular or respiratory outcomes, but a proportion measured toxic exposure risks only. A shift was also seen towards studies which explored contextual experience of CCH pathways, assessed through qualitative techniques. Perceptions of how climate change impacts health provide insights to the need for improved public health promotion in

Kenya and underscore calls for targeted capacity building as well as climate change training for health workers and the wider public health sector [89].

Research gaps

Mental health conditions were less frequently studied in our article set. A recent scoping review found that despite rapid growth, the global output of climate change and mental health research is comparatively lower than other health conditions and limited in scope [90]. Similarly, heat exposure was understudied, despite climate model projections that indicate parts of Kenya, alongside other SSA countries, will experience the greatest increase in frequency of heat stress days globally [74].

Recent research from West Africa has confirmed a link between heat impacts and adverse birth outcomes related to foetal strain [91], however most research on this topic is based on data from high-income countries, possibly due to scarcity of temperature ground monitoring and health data [92]. Given the high fertility rate in Kenya and relatively high rate of neonatal mortality [93, 94], the low volume of gender-oriented articles points to an important research gap. Accordingly, we found need to amend health outcome categories that were based on a WHO framework on climate-sensitive health risks to specifically include adverse birth and pregnancy outcomes [95], given recognized inequities in climate impacts on women's health [96].

There was a gap in research on malnutrition and foodborne disease, a principal risk factor of deaths and disabilities in Kenya, despite evidence that climate change has contributed to the ongoing Horn of Africa drought causing 20,000 excess child deaths in 2022 [97–99]. In infants and children, malnutrition can have long-lasting health impacts which is relevant to Kenya's young population [48]. In the northern ASALs of Kenya where pastoralist communities reside, there is a need for greater exploration of the impacts of worsening drought patterns on these groups [100]. These EE can cause secondary effects in communities in the form of tribal conflict over water and livestock resources or gendered violence [27, 31]. Ongoing conflict and insecurity in northern areas may exacerbate geographic disparities seen in research output, resulting in a much higher density of publications in the southwestern region, home to nearly 90% of the population in an area less than 20% of Kenyan land mass [2, 101]

Limitations

As environmental health research is a rapidly growing area of study, our search terminology attempted to encompass a wide variety of exposures and outcomes in line with WHO defined pathways. We aimed to minimise missing articles by using broad terminology in our search and screening criteria, incorporating a grey literature search, and using recognized frameworks for health categorization. In addition, this scoping review did not set out to conduct a risk of bias assessment and thus cannot draw conclusions on quality of evidence; however future reviews would benefit from assessment to provide confidence in results.

Conclusions

This review provides a baseline analysis of the scale and scope of evidence describing environmental impacts on health in Kenya. Its diversity illustrates the wide range of health pathways that have been studied in Kenya and identifies trends in institutional collaborations, funding patterns, and research priorities. Greater attention is needed on vulnerable groups, geographical disparities in research and complex relationships between environmental determinants and less frequently studied HO to ensure equity of the growing research. Targeted capacity building, funding reform and enhanced support for local and regional institutional networks are necessary steps to build the evidence base and safeguard population health in the face of Kenya's changing climate.

CRediT authorship contribution statement

Jessica Gerard: Formal Analysis, Investigation, Visualization, Data Curation, Writing – original draft, Writing – Review & Editing. **Titus Kibaara**: Investigation, Data Curation, Writing – original draft, Writing – Review & Editing. **Iris Blom:** Conceptualization, Methodology, Investigation, Data Curation, Writing – Review and Editing. **Jane Falconer:** Methodology, Investigation, Data Curation, Writing – Review & Editing. **Shamsudeen Mohammed:** Methodology, Investigation, Data Curation, Writing – Review & Editing. **Zaharat Kadri-Alabi**: Investigation, Data Curation, Writing – Review & Editing. **Roz Taylor:** Investigation, Data Curation, Writing – Review & Editing. **Leila Abdullahi:** Conceptualization, Methodology, Writing – Review & Editing. **Robert C Hughes:** Conceptualization, Investigation, Writing – Reviewing & Editing. **Bernard Onyango**: Conceptualization, Investigation, Writing – Reviewing & Editing. **Ariel Brunn**: Conceptualization, Formal Analysis, Investigation, Visualization, Writing – original draft, Writing – Review & Editing, Supervision.

Declaration of competing Interest

IMB declares having received three partial grants for her studies. A Prince Bernhard Culture Fund grant number 40037327 was awarded on 15 September 2021; Stichting VSBFonds grant number VSB.21/00168 was awarded on 17 May 2021; dr. Hendrik Mullerfonds without grant number was awarded on 9 December 2021. RCH reports receiving grant funding for research on climate change and health from the Wellcome Trust, The Bernard van Leer Foundation, and Fondation Botnar, and has worked as an employee or consultant for the Children's Investment Fund Foundation, The Clean Air Fund and The Abu Dhabi Early Childhood Development Authority. Additional authors declare they have no actual or potential competing interests that could influence the work herein reported.

Data Availability

The full methods, search terms and database search results are hosted in an open access digital repository maintained by the London School of Hygiene & Tropical Medicine. Citation: Falconer, J and Brunn, A

(2024). Search strategies for "Scoping study of Economic and Data System Considerations for Climate Change and Pandemic Preparedness in Africa". [Data Collection]. London School of Hygiene & Tropical Medicine, London, United Kingdom. https://doi.org/10.17037/DATA.00003769.

Supporting Information

S1 Table. Environmental exposure topic categories and their corresponding subcategories

S2 Table. Narrative summaries table Included study set with summaries of results and information pertinent to this research.

Acknowledgements

This work was supported by the Childrens' Investment Fund Foundation [grant number 2008-05023]. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of this manuscript. The opinions expressed here belong to the authors, and do not necessarily reflect those of the funder.

Appendix IV Ethics Approvals

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LONDON SCHOOL of HYGIENE &TROPICAL MEDICINE

Observational / Interventions Research Ethics Committee

Dr Iris Martine Blom
LSHTM

13 January 2023

Dear Dr Iris Martine Blom

Study Title: PhD: Greenhouse gas mitigation of health care systems in LMICs and its interactions with adaptation in the context of climate change - Case Study Kenya

LSHTM Ethics Ref: 28210

Thank you for responding to the Observational Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Conditions of the favourable opinion

Approval is dependent on local ethical approval having been received, where relevant.

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document Type	File Name	Date	Version
Other	Research_Ethics_online_training_certificate	09/10/2021	October 2021
Protocol / Proposal	Interview Topic Guide	23/11/2022	1
Protocol / Proposal	Delphi Method Workshop Topic Guide	23/11/2022	1
Protocol / Proposal	Questionnaire Topic Guide	23/11/2022	1
Investigator CV	Resume Iris Martine Blom 2022	23/11/2022	1
Protocol / Proposal	Study Protocol	23/11/2022	1
Information Sheet	[Interview] Information Sheet and Consent Form	23/11/2022	1
Information Sheet	[Workshop] Information Sheet and Consent Form	23/11/2022	1
Information Sheet	[eConsent Questionnaire] Information Sheet and Consent Form	23/11/2022	1
Advertisements	[Interview] Recruitment Email	23/11/2022	1
Advertisements	[Workshop] Recruitment Email	23/11/2022	1
Advertisements	[Questionnaire] Recruitment Email	23/11/2022	1
Advertisements	[Questionnaire] Poster	25/11/2022	1
Protocol / Proposal	Study Protocol	01/01/2023	2
Information Sheet	[Interview] Information Sheet and Consent Form	02/01/2023	2
Information Sheet	[Workshop] Information Sheet and Consent Form	02/01/2023	2
Information Sheet	[eConsent Questionnaire] Information Sheet and Consent Form	02/01/2023	2
Advertisements	[Interview] Recruitment Email	02/01/2023	2
Advertisements	[Workshop] Recruitment Email	02/01/2023	2
Covering Letter	Cover Letter Request for Clarifications	02/01/2023	1

Page 1 of 2

After ethical review

The Chief Investigator (CI) or delegate is responsible for informing the ethics committee of any subsequent changes to the application. These must be submitted to the Committee for review using an Amendment form. Amendments must not be initiated before receipt of written favourable opinion from the committee.

The CI or delegate is also required to notify the ethics committee of any protocol violations and/or Suspected Unexpected Serious Adverse Reactions (SUSARs) which occur during the project by submitting a Serious Adverse Event form.

An annual report should be submitted to the committee using an Annual Report form on the anniversary of the approval of the study during the lifetime of the study.

At the end of the study, the CI or delegate must notify the committee using an End of Study form.

All aforementioned forms are available on the ethics online applications website and can only be submitted to the committee via the website at: http://leo.lshtm.ac.uk

Additional information is available at: www.lshtm.ac.uk/ethics

Yours sincerely,

[redacted]

Professor David Leon and Professor Clare Gilbert
Co-Chairs

ethics@lshtm.ac.uk
http://www.lshtm.ac.uk/ethics/

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KEMRI/RD/22 **March 20, 2023**

TO: **DR. IRIS MARTINE BLOM,**
PHD CANDIDATE POPULATION HEALTH,
LONDON SCHOOL OF HYGIENE & TROPICAL MEDICINE,
PRINCIPAL INVESTIGATOR.

THROUGH: **MS. MELVINE OTIENO,**
KENYA IN-COUNTRY STUDY COORDINATOR

Dear Sir,

RE: **NON-KEMRI 4662 *(RESUBMISSION OF INITIAL):* GREENHOUSE GAS MITIGATION OF HEALTH CARE SYSTEMS IN LMICS AND ITS INTERACTIONS WITH ADAPTATION IN THE CONTEXT OF CLIMATE CHANGE: CASE STUDY: ANALYSING THE UNFCCC COP26 HEALTH CARE NET-ZERO COMMITMENT OF KENYA**

Reference is made to your letter dated March 06, 2023. The KEMRI Scientific and Ethics Review Unit (SERU) acknowledges receipt of the revised study documents on March 06, 2023;

1. The protocol, including consent and tools.
2. Response cover letter and comments.
3. Questionnaire topic guide.

This is to inform you that the Committee notes that the issues raised during 332nd Committee C meeting of the KEMRI Scientific Ethics Review Unit (SERU) held on **February 23, 2023** have been adequately addressed.

Consequently, the study is **granted approval** for implementation effective this day, **March 20, 2023** for a period of **one (1) year**. Please note that authorization to conduct this study will automatically expire on **March 19, 2024.** If you plan to continue with data collection or analysis beyond this date, please submit an application for continuation approval to SERU by **February 05, 2024.**

Please note that only approved documents including (informed consents, study instruments, Material Transfer Agreement) will be used. You are required to submit any proposed changes to this study to SERU for review and the changes should not be initiated until written approval from SERU is received. Any unanticipated problems resulting from the implementation of this study should be brought to the attention of SERU and you should advise SERU when the study is completed or discontinued.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours faithfully,

[redacted]

ENOCK KEBENEI,
THE ACTING HEAD,
KEMRI SCIENTIFIC AND ETHICS REVIEW UNIT

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KEMRI/RD/22 **March 26, 2024**

TO: **DR. IRIS MARTINE BLOM,**
PHD CANDIDATE POPULATION HEALTH,
LONDON SCHOOL OF HYGIENE & TROPICAL MEDICINE,
PRINCIPAL INVESTIGATOR.

THROUGH: **MS. MELVINE OTIENO,**
KENYA IN-COUNTRY STUDY COORDINATOR

Dear Sir,

RE: **NON-KEMRI 4662 *(REQUEST FOR ANNUAL RENEWAL WITH DEVIATION):* GREENHOUSE GAS MITIGATION OF HEALTH CARE SYSTEMS IN LMICS AND ITS INTERACTIONS WITH ADAPTATION IN THE CONTEXT OF CLIMATE CHANGE: CASE STUDY: ANALYSING THE UNFCCC COP26 HEALTH CARE NET-ZERO COMMITMENT OF KENYA**

Thank you for the continuing review report for the period **March 20, 2023** to **March 08, 2024**

The Expedited Review Team noted that a protocol deviation form has been submitted as the request for annual renewal was done after the expiration date of the last approval. Measures taken to address deviation are adequate.

This is to inform you that the Expedited Review Team of the KEMRI Scientific and Ethics Review Unit (SERU) was of the informed opinion that the progress made during the reported period is satisfactory. The study has therefore been granted **approval** for continuation.

This approval is valid from **March 26, 2024** through to **March 25, 2025**. Please note that authorization to conduct this study will automatically expire on **March 25, 2025.** If you plan to continue with data collection or analysis beyond this date, please submit an application for continuing approval to the **SERU** by **February 11, 2025.**

You are required to submit any amendments to this protocol and other information pertinent to human participation in this study to the SERU for review prior to initiation.

Yours faithfully,

[redacted]

ENOCK KEBENEI,
THE ACTING HEAD,
KEMRI SCIENTIFIC AND ETHICS REVIEW UNIT

In Search of Better Health

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 519115

Date of Issue: 29/April/2023

RESEARCH LICENSE

This is to Certify that Dr.. Iris Martine Martine Blom of London School of Hygiene , has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nairobi on the topic: Greenhouse gas mitigation of health care systems in LMICs and its interactions with adaptation in the context of climate change: Case Study: Analysing the UNFCCC COP26 Health Care Net-Zero Commitment of Kenya for the period ending : 29/April/2024.

License No: NACOSTI/P/23/24919

[redacted]

519115

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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See overleaf for conditions

THE SCIENCE, TECHNOLOGY AND INNOVATION ACT, 2013 (Rev. 2014)
Legal Notice No. 108: The Science, Technology and Innovation (Research Licensing) Regulations, 2014

The National Commission for Science, Technology and Innovation, hereafter referred to as the Commission, was the established under the Science, Technology and Innovation Act 2013 (Revised 2014) herein after referred to as the Act. The objective of the Commission shall be to regulate and assure quality in the science, technology and innovation sector and advise the Government in matters related thereto.

CONDITIONS OF THE RESEARCH LICENSE

1. The License is granted subject to provisions of the Constitution of Kenya, the Science, Technology and Innovation Act, and other relevant laws, policies and regulations. Accordingly, the licensee shall adhere to such procedures, standards, code of ethics and guidelines as may be prescribed by regulations made under the Act, or prescribed by provisions of International treaties of which Kenya is a signatory to
2. The research and its related activities as well as outcomes shall be beneficial to the country and shall not in any way;
    i. Endanger national security
    ii. Adversely affect the lives of Kenyans
    iii. Be in contravention of Kenya's international obligations including Biological Weapons Convention (BWC), Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), Chemical, Biological, Radiological and Nuclear (CBRN).
    iv. Result in exploitation of intellectual property rights of communities in Kenya
    v. Adversely affect the environment
    vi. Adversely affect the rights of communities
    vii. Endanger public safety and national cohesion
    viii. Plagiarize someone else's work
3. The License is valid for the proposed research, location and specified period.
4. The license any rights thereunder are non-transferable
5. The Commission reserves the right to cancel the research at any time during the research period if in the opinion of the Commission the research is not implemented in conformity with the provisions of the Act or any other written law.
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15. Relevant Institutional Scientific and Ethical Review Committee shall monitor and evaluate the research periodically, and make a report of its findings to the Commission for necessary action.

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REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **285069**

Date of Issue: **14/May/2024**

RESEARCH LICENSE

This is to Certify that Dr.. Iris Martine Martine Blom of London School of Hygiene and Tropical Medicine, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nairobi on the topic: GREENHOUSE GAS MITIGATION OF HEALTH CARE SYSTEMS IN LMICS AND ITS INTERACTIONS WITH ADAPTATION IN THE CONTEXT OF CLIMATE CHANGE: CASE STUDY: ANALYSING THE UNFCCC COP26 HEALTH CARE NETZERO COMMITMENT OF KENYA for the period ending : 14/May/2025.

License No: **NACOSTI/P/24/35070**

285069

Applicant Identification Number

[redacted]

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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Appendix V Appendix of ‘Evaluating progress and accountability for achieving COP26 Health Programme international ambitions for sustainable, low-carbon, resilient health-care systems’

Iris Martine Blom, Fawzia N Rasheed, Hardeep Singh, Matthew J Eckelman, Meghnath Dhimal, Martin Hensher, Renzo R Guinto, Alice McGushin, Xuejuan Ning, Poornima Prabhakaran, Marina Romanello, Dana van Alphen, Nick Watts, Jessica C Yu, Carol Zavaleta-Cortijo, Andrea J MacNeill*, Jodi D Sherman*

Table of Contents

Detailed Overview of COP26 Commitments and Country-level Data across all Identified Indicators

Themes	Commitments				Resilient Healthcare Systems		
Country	WHO COP26 Heath Programme Country Commitments				V&A Assessments (2024)	National Adaptation Plans (2020)	Health National Adaptation Plans (2024)
	Climate resilient health systems	Sustainable low carbon health systems	Net zero commitment	Net zero target	V&A Assessment completed/ updated since 2020 (Self-reported)	Health identified as vulnerable sector?	HNAP completed/updated since 2020 (self reported)
Argentina	yes	yes	no				Yes
Australia	yes	yes	yes	2050			
Austria	yes	yes	yes	2040			
Bahamas	yes	no	no		Yes		
Bahrain	yes	no	no				
Bangladesh	yes	yes	no		Yes		
Belgium	yes	yes	yes	2050	Yes		
Belize	yes	yes	no				
Bhutan	yes	yes	no				Yes
Botswana	yes	yes	no				
Brazil	yes	yes	no			Yes	
Brunei Darussal	yes	yes	no				
Burkina Faso	yes	yes	yes	2040		Yes	
Canada	yes	yes	no		Yes		Yes
Cape Verde	yes	yes	no				Yes
Central African R	yes	yes	no				
Chile	no	yes	no			Yes	
Colombia	yes	yes	no			Yes	
Congo	yes	yes	yes	2035			
Costa Rica	yes	yes	no				
Democratic Rep	yes	yes	yes				
Dominican Repu	yes	yes	no				
Ecuador	yes	yes	no		Yes		Yes
Egypt	yes	no	no				
Ethiopia	yes	yes	no			Yes	Yes
Fiji	yes	yes	yes	2045	Yes	Yes	Yes
France	yes	yes	yes	2050			Yes
Gabon	yes	no	no				
Georgia	yes	yes	yes	2050			
Germany	yes	yes	yes	2045	Yes		
Ghana	yes	yes	no				
Guinea (Republi	yes	yes	yes				
Indonesia	yes	yes	yes	2030	Yes		
Ireland	yes	yes	yes	2050			
Islamic Republic	yes	yes	no		Yes		
Israel	yes	yes	no				
Ivory Coast	yes	yes	yes	2040			Yes
Jamaica	yes	yes	no				
Japan	yes	yes	no				
Jordan	yes	yes	yes	2050			
Kenya	yes	yes	yes	2030		Yes	
Kuwait	yes	no	yes	2060			
Lao PDR	yes	yes	yes	2050	Yes		Yes
Lebanon	yes	yes	no				
Liberia	yes	yes	yes	2030	Yes		Yes
Madagascar	yes	yes	no				
Malawi	yes	yes	yes	2030			
Maldives	yes	yes	no				
Mauritania	yes	yes	no		Yes		
Morocco	yes	yes	yes	2050			
Mozambique	yes	yes	no		Yes		
Nepal	yes	yes	no		Yes		Yes
Netherlands	yes	yes	yes	2050			
New Zealand	yes	yes	no				
Niger	yes	yes	no				
Nigeria	yes	yes	yes	2035			
Norway	yes	yes	yes	2045	Yes		
Occupied Territo	yes	yes	no			Yes	
Oman	yes	yes	yes	2060			
Pakistan	yes	yes	no				
Panama	yes	yes	no		Yes		
Peru	yes	yes	yes	2050			Yes
Philippines	yes	yes	no				
Poland	yes	yes	no				
Rwanda	yes	no	yes	2050			
Sao Tome and P	yes	yes	yes	2050			
Seychelles	yes	yes	no		Yes		
Sierra Leone	yes	yes	yes	2035	Yes		
Somalia	yes	yes	yes	2050			
Spain	yes	yes	yes	2050			Yes
Sri Lanka	yes	yes	no			Yes	Yes
Tanzania	yes	yes	no	2030			
Timor-Leste	yes	yes	yes				Yes
Togo	yes	yes	no			Yes	Yes
Tunisia	yes	no	no				
Türkiye	yes	yes	no		Yes		Yes
Uganda	yes	yes	no		Yes		
United Arab Emi	yes	yes	yes	2050	Yes		Yes
United Kingdom	yes	yes	yes	2040	Yes		Yes
United States of	yes	yes	yes	2050	Yes		Yes
Viet Nam	yes	yes	yes	2050	Yes		
Yemen	yes	yes	yes	2050			
Zambia	yes	yes	yes	2030	Yes		
Total	82	76	38		25	10	21

Existence of a health surveillance system (2021)

Airborne and respiratory illnesses	Heat-related illness	Impacts on healthcare facilities	Injury and mortality from extreme weather events	Malnutrition and food-borne diseases	Mental and psychosocial health	Noncommunicable diseases
Yes	Yes		Yes			Yes
Yes		Yes	Yes	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes				Yes	Yes	Yes
Yes			Yes	Yes	Yes	Yes
Yes		Yes	Yes	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes			Yes	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes	Yes			Yes	Yes	Yes
Yes		Yes	Yes	Yes		Yes
Yes	Yes		Yes	Yes	Yes	Yes
Yes			Yes	Yes		
Yes	Yes		Yes	Yes	Yes	Yes
Yes					Yes	Yes
Yes				Yes		Yes
Yes	Yes		Yes	Yes	Yes	Yes
Yes		Yes	Yes	Yes	Yes	Yes
Yes				Yes		Yes
Yes				Yes		Yes
Yes			Yes	Yes		Yes
Yes			Yes	Yes	Yes	Yes
Yes				Yes		Yes
Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes	Yes		Yes	Yes	Yes	Yes
				Yes		Yes
Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes		Yes	Yes	Yes	Yes	Yes
Yes				Yes		Yes
Yes				Yes		
Yes		Yes	Yes	Yes		Yes
				Yes		Yes
				Yes	Yes	Yes
Yes	Yes		Yes	Yes		Yes
Yes		Yes		Yes		Yes
Yes				Yes	Yes	Yes
34	13	13	23	35	22	35

			Existence of a health surveillance system which includes meteorological information (2021)						
Vector-borne diseases	Waterborne diseases and other water-related health outcomes	Zoonoses	Airborne and respiratory illnesses	Heat-related illness	Impacts on healthcare facilities	Injury and mortality from extreme weather events	Malnutrition and food-borne diseases	Mental and psychosocial health	Noncommunicable diseases
Yes	Yes	Yes	Yes	Yes		Yes			
Yes	Yes	Yes							
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes	Yes	Yes							
Yes	Yes	Yes	Yes						
Yes	Yes	Yes	Yes			Yes			
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
Yes	Yes	Yes				Yes			
Yes	Yes				Yes				
Yes	Yes								
Yes	Yes	Yes			Yes			Yes	
Yes	Yes			Yes					
Yes	Yes		Yes			Yes	Yes	Yes	
Yes	Yes	Yes		Yes		Yes			Yes
Yes	Yes	Yes							
Yes	Yes	Yes							
Yes	Yes	Yes	Yes	Yes		Yes			Yes
Yes	Yes								
Yes	Yes	Yes							
Yes	Yes	Yes							
Yes	Yes	Yes							
Yes	Yes	Yes	Yes			Yes			
Yes	Yes								
Yes	Yes	Yes							
Yes	Yes	Yes	Yes						
Yes	Yes	Yes							
Yes	Yes	Yes							
Yes	Yes	Yes							
Yes	Yes	Yes		Yes					
Yes	Yes	Yes							
Yes	Yes	Yes	Yes			Yes			
Yes	Yes		Yes						
Yes	Yes	Yes					Yes		
Yes	Yes	Yes				Yes			
Yes	Yes	Yes							
Yes	Yes	Yes							
Yes	Yes		Yes	Yes		Yes			Yes
Yes	Yes								
Yes	Yes	Yes							
39	39	30	12	8	4	12	4	3	5

			Low-Emission or Net-Zero Healthcare Systems			
			GHG emissions assessed (2024)	Action plan developed (2024)	Estimated Healthcare GHG Footprint (2020)	
Vector-borne diseases	Waterborne diseases and other water- related health outcomes	Zoonoses	GHG emissions assessed for health system since 2020 (self-reported)	Low-carbon, sustainable healthcare system action plan for health system developed since 2020 (self-reported)	Total GHG (Mt CO2-e)	Total GHG (kg CO2-e/cap)
Yes					7.8	173
					28.9	1125
					3.9	442
					0.2	371
	Yes	Yes			0.6	374
					2.6	16
					10.2	888
					0	56
Yes	Yes	Yes			0	41
					0.5	197
					27.2	127
Yes	Yes	Yes			0.1	201
					0.6	30
					20.5	540
Yes					0.1	96
					0.1	23
					4.9	256
					4.9	96
					0.3	44
					1	191
					1.1	12
Yes	Yes	Yes			0.8	71
					1.7	96
					6.2	58
Yes					1.8	16
					0.1	58
			Yes	Yes	21.7	322
					0.3	125
					0.6	158
			Yes		57.5	691
					1.5	46
Yes			Yes		0.3	26
					39.3	145
					1.1	226
					19.1	219
Yes					16.7	1910
Yes					1.1	42
					0.2	65
					127	1016
					1.2	114
					2.4	45
					2.6	585
					0.2	21
					2.1	380
					0.2	31
Yes			Yes		0.3	10
Yes					0.3	18
					0.1	255
				Yes	0.1	32
				Yes	2.6	72
Yes					0.6	19
			Yes		0.5	18
			Yes	Yes	10.3	590
			Yes	Yes	6.6	1298
					0.5	19
					7.9	38
			Yes		1.5	277
Yes					1.5	322
					3.1	14
					1	243
					2.6	78
					5.7	51
Yes					10.7	281
					0.4	31
		Yes			0	58
Yes					0	396
Yes		Yes			0.2	24
					14.7	310
Yes					1	47
					1.3	21
					0	37
Yes					0.2	29
					1	85
					18.8	223
					0.8	18
					7.5	810
			Yes	Yes	39.7	593
					474.1	1411
					5	51
					0.6	29
18	4	6	9	6	1042.44	

	Financial Resources towards Resilient and Low Emission Healthcare Systems						
Air pollution (2020)	Income status	Global Health Expenditure Database (2020)					Universal Health Coverage (2021)
Disability-Adjusted-Life-Years (DALYs) from PM2.5 and Ozone air pollution associated with health-care delivery and supply chains rounded to two significant figures.	World Bank Classification	Current Health Expenditure per Capita US$	Current Health Expenditure in million US$	Domestic General Government Health Expenditure %	Domestic Private Health Expenditure %	External Health Expenditure %	UHC Service Coverage Index (SDG 3.8.1)
16000	Upper-middle incom	895	40311	64	36	0	79
36000	High income	5959	152962	74	26	0	87
3800	High income	5567	49552	77	23	0	85
300	High income	1825	742	61	39	0	77
610	High income	1105	1633	63	37	0	76
4000	Lower-middle incom	51	8482	18	77	5	52
17000	High income	5104	58811	78	22	0	86
44	Upper-middle incom	280	110	71	27	3	68
49	Lower-middle incom	134	103	78	17	5	60
840	Upper-middle incom	359	914	73	21	6	55
46000	Upper-middle incom	705	150302	44	55	0	80
140	High income	650	287	94	6	0	78
1100	Low income	54	1166	43	38	18	40
17000	High income	5668	214766	74	26	0	91
93	Lower-middle incom	176	9927	62	25	13	71
200	Low income	40	214	14	51	36	32
9900	High income	1281	24717	56	44	0	82
9800	Upper-middle incom	462	23542	71	29		80
420	Lower-middle incom	81	461	43	46	11	41
2000	Upper-middle incom	953	4883	72	28	0	81
1800	Low income	21	1973	16	46	37	42
1600	Upper-middle incom	354	3895	66	34	1	77
3400	Upper-middle incom	472	8300	61	39	0	77
6800	Lower-middle incom	151	16217	32	67	1	70
3000	Low income	29	3363	28	37	34	35
81	Upper-middle incom	232	214	65	29	6	58
29000	High income	4755	320137	77	23		85
480	Upper-middle incom	228	523	56	34	11	49
1600	Upper-middle incom	355	1336	44	55	1	68
71000	High income	5936	493699	79	21		88
2500	Lower-middle incom	87	2814	53	38	9	48
560	Lower-middle incom	47	5916527	24	53	23	40
42000	Upper-middle incom	133	36227	55	44	1	55
1600	High income	6098	30274	78	22		83
21000	Lower-middle incom	573	2102208768	54	46	0	74
46000	High income	3637	31851	68	31	1	85
1900	Lower-middle incom	85	1314451	37	50	14	43
370	Upper-middle incom	324	915	68	30	2	74
140000	High income	4436	59325656	100	15	0	83
1400	Lower-middle incom	285	3110	39	56	5	65
3900	Lower-middle incom	87	4506	49	33	17	53
2800	High income	1542	6725	89	11	0	78
240	Lower-middle incom	68	4521592	43	42	15	52
2400	Lower-middle incom	522	2958	44	45	10	73
260	Low income	101	515	5	81	14	45
460	Low income	17	486	19	36	46	35
580	Low income	43	824	22	22	55	48
200	Upper-middle incom	826	425	80	18	2	61
240	Lower-middle incom	63	285	44	49	7	40
2900	Lower-middle incom	193	7085	42	56	2	69
970	Low income	34	1072	32	16	52	44
810	Lower-middle incom	58	1711	30	59	11	54
15000	High income	5846	89098	69	31	0	85
10000	High income	4223	21374	78	22		85
770	Low income	35	848	37	47	16	35
13000	Lower-middle incom	70	14533	15	75	10	38
4600	High income	7704	41354	86	14	0	87
	Upper-middle income						
1600	High income	855	3886	89	11	0	70
3400	Lower-middle incom	38	8674	35	58	6	45
2100	High income	1358	5832	54	45	0	78
5200	Upper-middle incom	388	12938	69	31	0	71
8700	Lower-middle incom	166	18674	45	54	1	58
22000	High income	1026	38944	72	28	0	82
690	Low income	58	761	40	24	36	49
21	Lower-middle incom	159	35	41	14	46	59
69	High income	782	82	78	22	0	75
320	Low income	46	379	15	53	32	41
	Low income						27
20000	High income	2899	137218	73	27		85
1500	Lower-middle incom	158	3429	49	49	2	67
2200	Lower-middle incom	39	5564527	43	24	33	43
74	Lower-middle incom	121	157	55	7	38	52
410	Low income	54	457	15	70	15	44
1100	Lower-middle incom	247	2999	61	38	0	67
29000	Upper-middle incom	395	33254	79	21		76
1400	Low income	37	1638	22	38	40	49
8300	High income	2192	20356	61	39	0	82
46000	High income	4927	257564	53	16	0	88
470000	High income	11758	3950149	57	43	0	86
7600	Lower-middle incom	154	14907	42	57	1	68
	Low income						42
920	Lower-middle incom	60	1144	57	10	33	56

Inclusion of Healthcare Systems in Governance and NDCs

2023 and 2021 Healthy NDC Scorecard						Climate Change and Health Agreements Ministry of Health (self-reported				
Integrated governance	Health impacts	Health sector action	Health co-benefits	Economics and finance	Monitoring and implementation	Environment	Transportation	Agriculture	Education	Energy
1	2	3	3	0	0					
0	0	0	0	0	0					
						Yes				
0	0	0	0	0	0	Yes		Yes	Yes	Yes
	2		2	1						
						Yes				
0	0	0	1	0	0	Yes				
1	0	3	3	1	1					
	1		3	1						
						Yes	Yes	Yes	Yes	Yes
0	2	3	2	1	3					
	1		3	1						
	3		3	1						
0	3	3	3	2	3					
0	2	2	3	0	1	Yes	Yes	Yes		
						Yes	Yes	Yes		Yes
	2		2	0						
0	2	2	2	0	0					
	3		0	0						
						Yes	Yes	Yes	Yes	Yes
0	1	2	3	1	2					
						Yes				
2	1	1	0	0	0					
						Yes		Yes		Yes
2	3	3	3	1	3					
0	0	0	0	0	0					
1	2	3	2	1	0					
	3		0	0		Yes				Yes
2	2	1	0	0	0					
	3		2	0						
						Yes				
	3		2	1						
0	3	3	2	1	0					
	3		2	1						
1	3	3	1	1	0					
	0		1	0						
						Yes	Yes	Yes		
0	0	0	0	0	0					
0	2	1	1	1	0					
	2		3	1						
	0		0	0						
1	2	3	3	2	3	Yes	Yes		Yes	
						Yes	Yes	Yes	Yes	Yes
	1		0	0						
						Yes				Yes
						Yes				Yes
						Yes	Yes	Yes	Yes	Yes
	3		1	1		Yes				
						Yes				
0	2	3	3	2	0					
2	2	3	3	1	0					
0	0	0	0	0	0					
1	1	3	3	0	3					
0	2	3	3	0	2					
0	1	0	3	0	0					
	1		3	1						
	3		1	1						
						Yes		Yes	Yes	Yes
						21	8	10	7	11

, 2021)				Policies and engagement (self-reported, 2021)		
National meteorological and hydrological services	Social services	Urban development and housing	Water, sanitation & hygiene (WASH)	Designation of a focal point responsible for health and climate change within the Ministry of Health	Existence of a multi-stakeholder mechanism on health and climate change	National health and climate change plan or strategy developed
				Yes	Yes	
				Yes	Yes	
Yes		Yes	Yes	Yes	Yes	
				Yes		
Yes			Yes	Yes		Yes
Yes				Yes		Yes
				Yes	Yes	
				Yes	Yes	
Yes		Yes	Yes	Yes	Yes	Yes
				Yes	Yes	
				Yes		
				Yes	Yes	
			Yes	Yes		Yes
Yes			Yes	Yes	Yes	Yes
Yes		Yes	Yes	Yes	Yes	Yes
				Yes		Yes
				Yes		
				Yes	Yes	
Yes			Yes	Yes	Yes	Yes
				Yes	Yes	Yes
			Yes	Yes		
				Yes		Yes
Yes			Yes	Yes	Yes	Yes
				Yes		Yes
				Yes	Yes	Yes
Yes				Yes	Yes	
Yes				Yes	Yes	Yes
Yes		Yes		Yes	Yes	Yes
			Yes	Yes	Yes	Yes
			Yes	Yes	Yes	
Yes		Yes	Yes	Yes	Yes	Yes
				Yes	Yes	
			Yes	Yes	Yes	
			Yes			Yes
Yes	Yes	Yes	Yes	Yes		Yes
				Yes		Yes
				Yes		Yes
			Yes	Yes	Yes	Yes
Yes			Yes	Yes		Yes
				Yes		Yes
Yes				Yes		
	Yes	Yes	Yes	Yes	Yes	
				Yes		Yes
15	2	7	18	42	25	25

Indicator	Readily quantifiable	Existing public means or data		
	Yes or No	Yes or No	Details	Publicly available data
Component 1: Climate-transformative leadership and governance				
1.1.1 Climate change and health focal points designated within the Ministry of Health with specific programme of action and budget allocated	Yes	No	No public data available to the authors' knowledge.	
1.1.2 Health sector commitment to achieve climate resilience in the health system	Yes	Yes	ATACH.	See page 2-9 for an overview of country specific data.
1.1.3 Health sector commitment to transition the health system (including health care facilities and supply chains) to low carbon or net-zero emissions	Yes	Yes	ATACH.	See page 2-9 for an overview of country specific data.
1.1.4 Climate change and health focal points or units, working in collaboration with relevant climate- sensitive health programmes (e.g. vector-borne diseases, nutrition, infectious diseases, disaster risk reduction) to build climate resilient and low carbon programmes	Yes	No	No public data available to the authors; knowledge.	
1.1.5 Gender-sensitive approach adopted in the regulations and strategies on climate change and health	No			
1.1.6 Meaningful participation of the health sector in main climate change processes at national, regional, and global levels with UNFCCC global negotiations, National Adaptation Plan, National Communications (NCs), Nationally Determined Contributions (NDCs), and long-term low-emission development strategies (LT-LEDS) promoted	No			
Objective 2: Policy development				
1.2.1 National strategy on health and climate change (covering both resilience and low carbon sustainability approaches) developed	Yes	Yes	Published national strategies.	The authors are aware of one national strategy, namely the [Australian National Health and Climate Strategy](). See page 2-9 for an overview of country specific data.
1.2.2 Health component of National Adaptation Plan (HNAP) developed and integrated as a chapter in the overall NAP	Yes	Yes	WHO Review National Adaptation Plans in 2020.	
1.2.3 Health is integrated into the Nationally Determined Contributions (NDCs)	Yes	Yes	Global Climate and Health Alliance NDC Scorecard 2021 and 2023.	See page 2-9 for an overview of country specific data.
1.2.4 Mechanism to estimate GHG emissions in the health system established	Yes	No	No public data available to the authors' knowledge of nationally established mechanisms, however GHG emission assessments do exist by the Lancet Countdown.	
1.2.5 A roadmap or action plan for building climate resilience in health systems developed in collaboration with health-determining sectors and community actors to support HNAP implementation	Yes	No	No published national roadmaps identified.	
1.2.6 A roadmap or transition plan for reducing GHG emissions in the health system developed in collaboration with health-determining sectors, including decarbonization targets	Yes	Yes	Published national roadmaps.	The authors are aware of one published national roadmap by the English National Health Service.
1.2.7 Coordinated strategies established within the health sector and in health-determining sectors to develop policies for building a climate-resilient and low carbon health system, maximizing health co-benefits	No			
Objective 3: Cross-sectoral collaboration				
1.3.1 Agreements (e.g. Memoranda of Understanding) established between the Ministry of Health and key stakeholders at national level (e.g. meteorological and hydrological services, ministries of environment, food and agriculture, energy, transport, planning), including specific roles and responsibilities in relation to protecting health from climate change and/or reducing the GHG emissions of health sector operations	Yes	No	No public data available to the authors' knowledge.	
1.3.2 Multisectoral governance and coordination (involving people, communities, civil society, private sector, and all other engaged stakeholders) mechanisms established to support climate resilience and decarbonization in the health system	Yes	No	No public data available to the authors' knowledge.	

1.3.3 Main policies and strategies from health-determining sectors reflect climate change and health considerations both in relation to adaptation (e.g. climate-resilient water and sanitation safety plans) and mitigation (e.g. promotion of policies maximizing health co-benefits in the transport sector)	No			
1.3.4 Inter-ministerial group on climate change and health established and promoting health in all adaptation and mitigation policies of key health-determining sectors	Yes	No	No public data available to the authors' knowledge.	
1.3.5 Health impact assessments conducted for new mitigation and adaptation policies and programmes in all health-determining sectors, in accordance with article 4.1.f. of the UNFCCC (minimize adverse effects on public health)	Yes	No	No public data available to the authors' knowledge.	
Component 2: Climate-smart health workforce				
Objective 1: Health workforce capacity				
2.1.1 Percentage of health workers having received training on climate resilience in the past two years	Yes	No	No public data available to the authors' knowledge.	
2.1.2 Percentage of health workers having received training on low carbon sustainability in the past two years	Yes	No	No public data available to the authors' knowledge.	
2.1.3 Health workers in specific programmes have information and training on the interlinkages between specific health outcomes and climate variability and change	No			
2.1.4 Health workforce capacity developed on decarbonization opportunities in health systems and health care facility operations, the supply chain and in-service delivery	No			
2.1.5 Curricula on climate change and health covering both resilience and low carbon sustainability issues developed and imparted in secondary and/or tertiary levels	No			
Objective 2: Organizational capacity development				
2.2.1 Contingency plans for the deployment of sufficient health personnel for acute shocks (e.g. extreme weather events and outbreaks) developed at the relevant level (i.e. national, provincial, local)	Yes	No	"Contingency plans" need to be defined before this can be measured.	
2.2.2 Innovative approaches to reducing GHG emissions at health system or health care facility level (e.g. teams sharing best practices across different domains, and a system of rewards) promoted	No			
2.2.3 Percentage of health workforce participating in decision-making, planning and management of climate change risks	Yes	No	No public data available to the authors' knowledge.	
2.2.4 Number of capacity building initiatives integrating climate change and health at early stages of professional health training	No			
2.2.5 Innovative capacity building plans responding to identified human resources and institutional capacity gaps developed	No			
Objective 3: Information, awareness and communication				
2.3.1 Health professionals, the media and community leaders trained on climate change risk communication, including communication of uncertainty	No			
2.3.2 Stakeholder forum on climate change and health established as a way to engage health determining sectors, the media and community groups	Yes	No	No public data available to the authors' knowledge.	
2.3.3 Internal and external health communication plans with focus on raising awareness of climate change risks and health outcomes and implementing efficient strategies to build climate-resilient health system developed	Yes	No	No public data available to the authors' knowledge.	
2.3.4 Internal and external health communication plans with focus on measuring GHG emissions and implementing strategies to reduce health system emissions developed	Yes	No	No public data available to the authors' knowledge.	
2.3.5 Health workers and communities understand potential future health risks related to climate change and the actions they can take	No			
2.3.6 Awareness among decision-makers, health workers, the media and community leaders on climate change and health raised	No			
2.3.7 Initiatives with focus on climate change risk communication established among different target audiences, developed in the health action plan	No			
Component 3: Assessments of climate and health risks and GHG emissions				

Objective 1: Health risks				
3.1.1 Climate change and health vulnerability and adaptation assessments conducted, providing evidence on current and future health risks from climate variability and change	Yes	No	No public overview at this level of detail available to the authors' knowledge.	
3.1.2 Baseline rates and climate sensitivity of health conditions, allowing the selection of priority risks, and continuous monitoring of changing risk conditions and health outcomes assessed	Yes	No	No public data available to the authors' knowledge.	
3.1.3 Information on health system's capacity (for each of the ten components included in this framework) to address the increased health risks from climate change gathered as part of the V&A assessments	No			
3.1.4 Results of V&A assessments integrated into health system planning and into key climate change processes (e.g. HNAP)	No	No	No public overview available to the authors' knowledge.	
3.1.5 Vulnerable populations and areas prone to high current and future climate-related health risks identified and mapped	Yes			
3.1.6 Health trends in climate-sensitive diseases assessed	No			
Objective 2: GHG emissions				
3.2.1 Assessment of GHG health sector emissions conducted	Yes	Yes	ATACH.	See page 2-9 for an overview of country specific data. The authors are aware of [one public national inventory limited to carbon emissions by the English National Health Service]. The authors are aware of [one public LCA database], which is global and not national.
3.2.2 Publicly report a GHG inventory for a base year of emissions.	Yes	Yes	Public inventory of GHG emissions.	
3.2.3 Information on the environmental impact, including GHG emissions, of products and services used or delivered by the health system	Yes	Yes	Public healthcare products database.	
3.2.4 Information on key GHG emissions in health systems and/or health care facilities available and used to inform interventions aiming to reduce emissions	No			
3.2.5 Low regret interventions for reduction in GHG emissions identified for each of the key GHG emission hotspots (e.g. access to renewable energy, energy efficiency, greener waste management practices, transition to low carbon transport, reducing emissions from anaesthetic gases and inhalers)	No			
3.2.6 Interventions to reduce supply chain emissions identified, including through: more efficient use of resources; low carbon substitutions and product innovation; and requirements for health system suppliers to reduce GHG emissions	No			
3.2.7 Agreements with health system suppliers to reduce GHG emissions in the supply chain established	Yes	No	No public data available to the authors' knowledge.	
3.2.8 Number of health facilities with GHG emissions assessed	Yes	No	No public data available to the authors' knowledge.	
Objective 3: Progress tracking				
3.3.1 Assessments' results used to identify a set of key indicators to be tracked over time both for health systems' climate resilience and reductions in GHG emissions	No			
3.3.2 Establish a dedicated climate change team responsible for coordinating implementation of the climate strategy and monitoring progress across the system	No			
3.3.3 Assessments' results used to prioritize allocation of resources and effective climate change and health interventions both for resilience and low carbon sustainability	No			
3.3.4 Plan defined and mechanism established for iterative assessments of health risks from climate variability and change	No			
Component 4: Integrated risks monitoring, early warning, and GHG emissions tracking				
Objective 1: Integrated disease surveillance and early warning				
4.1.1 An integrated climate and health surveillance system for specific climate sensitive diseases implemented	No			
4.1.2 Early detection tools (e.g. rapid diagnostics, syndromic surveillance) used to identify changing incidence and early action identified and implemented	Yes	No	No public data available to the authors' knowledge.	

4.1.3 Climate-informed health early warning systems that predict the risk of outbreaks of priority infectious diseases (e.g. malaria, dengue, cholera) developed and implemented	Yes	No	No public data available to the authors' knowledge.	
4.1.4 Climate and weather information used to assess risk of outbreaks of climate-sensitive diseases (i.e. integrated health and climate surveillance systems)	Yes	No	No public data available to the authors' knowledge.	
4.1.5 Participation of the Ministry of Health in cross-sectoral groups receiving warnings on extreme- weather events	No			
4.1.6 Geographic and seasonal distribution of health risks and outcomes (e.g. risk mapping) tracked for priority climate-sensitive diseases	Yes	No	No public data available to the authors' knowledge.	
Objective 2: Monitoring and progress tracking				
4.2.1 Monitoring process with a clearly defined mechanism for the tracking system to measure progress in GHG emissions reduction established	No			
4.2.2 Impacts from main climate-related determinants of health (e.g. water availability and quality, air quality, food) monitored by the health sector	No			
4.2.3 Indicators on climate change risks, impacts, vulnerability, capacity of health systems, and emergency preparedness capacity, as well as climate and environmental variables included in relevant monitoring systems at the national level and reported over time	Yes	No	"Indicators" to be defined first before this can be measured.	
4.2.4 Periodic reviews for improvement or deterioration of capacities identified in V&A assessments	Yes	No	"Capacities" to be defined and measured first, before this can be measured.	
Objective 3: Communication				
4.3.1 A communication plan or strategy on climate risks to health (both for acute shocks and stresses) developed and implemented, outlining the scope of information for diverse audiences (e. g. media, public, health personnel and other sectors) and events, including who should communicate, and the means of communications – developed and implemented	Yes	No	No public data available to the authors' knowledge.	
4.3.2 A communication plan or strategy on health system decarbonization – outlining the scope of information for diverse audiences (e.g. media, public, health personnel and other sectors) and events, including who should communicate, and the means of communication – developed and implemented	Yes	No	No public data available to the authors' knowledge.	
4.3.3 Information on the health system's carbon emissions and best reduction practices and opportunities shared with relevant stakeholders and communities	No			
4.3.4 Community engagement and feedback mechanisms established to empower affected populations to respond to warnings, and to guide future development of monitoring and warning systems including with regards to environmental impacts of health care	No			
Component 5: Health and climate research				
Objective 1: Research agenda development and implementation				
5.1.1 National research agenda on climate change and health developed	Yes	Yes	Published national research agendas.	The authors are aware of [one national research agenda](#) spanning climate change and health in full in the Netherlands. The [Dutch national research agenda](#) incorporates health system decarbonization.
5.1.2 National research agenda on climate change and health incorporates health system decarbonization	Yes	Yes	Published national research agendas.	
5.1.3 The health system has a budget dedicated to climate and health research agenda	Yes	No	No public data available to the authors' knowledge.	
5.1.4 Results of a V&A assessment are used to inform a national research agenda on climate change and health	No			
5.1.5 Research agenda incorporating the need to identify technologies for climate resilience with GHG emission reduction potential in priority areas	No			
Objective 2: Research capacity				
5.2.1 Multidisciplinary research partnerships, rosters of national experts, and knowledge management networks established to support research agenda development and implementation	Yes	No	No public data available to the authors' knowledge.	

5.2.2 Incentives for tertiary educational institutions to offer research programmes on climate change and health provided	No			
5.2.3 Data-sharing agreements within and outside the health sector established for supporting research on GHG emissions and low carbon technologies established	No			
5.2.4 Data-sharing agreements within and outside the health sector for supporting research on climate-sensitive disease surveillance and monitoring established	No			
5.2.5 Data-sharing agreements within and outside the health sector for supporting research on climate resilience established	No			
5.2.6 Financial investment mechanisms established to support research programmes and postgraduate research training programmes	No			
Objective 3: Research into policy				
5.3.1 Mechanism for researchers to inform planning, policy, and stakeholder groups established	No			
5.3.2 Mechanisms to support, spread and scale innovation across the health system that supports climate resilience and/or health care decarbonization established	No			
5.3.3 Research findings on climate change and health disseminated and used to develop key health (e.g. health sector strategic plans, strategies of priority vertical programmes) and climate change (e.g. NAP, NDCs, LT-LEDs) plans, policies and strategies	No			
5.3.4 Evidence-based capacity for decision-making within and outside the health sector to contribute to policy outcomes developed	No			
5.3.5 Health services-oriented climate and health research promoted	No			
5.3.6 Research on climate change and health conducted and translated into health policy	No			
5.3.7 Adaptation and mitigation decision-making based on the results of the research agenda implementation	No			
5.3.8 Research on climate change and health responds to needs by policy makers	No			
Component 6: Climate resilient and low carbon infra- structures, technologies, and supply chain				
Objective 1: Adaptation of current infrastructure, technologies, and supply chain				
6.1.1 Climate resilience interventions implemented at health system and/or facility level	No			
6.1.2 Specifications for siting and construction of health facilities iteratively reviewed and revised in line with projected climate risks	Yes	No	"Climate risks" need to be defined before this can be measured.	
6.1.3 Specifications for technologies and selection of products and processes of services, iteratively reviewed and revised in line with projected climate risks	Yes	No	"Climate risks" need to be defined before this can be measured.	
6.1.4 Number of health facilities retrofitted according to climate resilient and low carbon standards	Yes	No	"Climate resilient and low carbon standards" need to be defined before this can be measured.	
6.1.5 Specifications for siting and construction of health facilities, and energy, water, waste management and sanitation provisions iteratively reviewed and revised in line with (i) projected climate risks, and (ii) the latest standards for low or zero carbon and environmentally sustainable buildings	Yes	No	(i) and (ii) need to be defined before this can be measured.	
6.1.6 Training and recommendations for prescription of pharmaceuticals during extreme heat revised	No			
6.1.7 Improvement plan for ensuring health service delivery during extreme weather events and outbreaks of climate-sensitive diseases developed based on results of vulnerability assessments of health care facilities	No			
Objective 2: Promotion of new technologies				
6.2.1 Access to renewable energy in health care facilities promoted as an adaptation and low carbon sustainable measure	No			
6.2.2 Environmentally sustainable technologies suitable for harsh conditions (e.g. green cooling) adopted	No			
6.2.3 New technologies such as e-Health, telemedicine or satellite imagery used to strengthen climate resilience and reduce carbon emissions, while contributing to improving health systems performance and UHC	No			

Objective 3: Environmental sustainability of health operations				
6.3.1 Assessments of health sector impacts on the environment, including GHG emissions, conducted	No			
6.3.2 Decarbonization actions implemented at health system and/or facility level	No			
6.3.3 Interventions implemented to reduce emissions from high carbon medicines at the 'point of use', e.g. reducing emissions from inhalers and anaesthetic gases	No			
6.3.4 Active transport (e.g. cycling and walking) and the use of public transportation for patients, visitors, and health workers promoted	No			
6.3.5 Health sector transportation systems transitioned to low GHG emissions	No			
6.3.6 GHG emissions and environmental sustainability considerations integrated within health sector procurement policies and practices, with suppliers, procurement teams and other stakeholders engaged to support implementation	No			
6.3.7 Purchases from companies with transparent sustainability standards and science-based targets (near- and long-term) for reducing GHG emissions for products and services prioritized	No			
6.3.8 Cross-sectoral collaboration mobilized for improving practices on environment and health protection	No			
6.3.9 Environmentally sustainable, low carbon diets and procurement of locally produced food promoted, and interventions implemented to minimize food waste in health care facilities	No			
6.3.10 Number of health facilities incorporating climate variability and change in decisions related to siting, construction, technologies, procurement, and procedures to ensure provision of basic services (including energy, water and sanitation, waste management)	No			
Component 7: Management of environmental determinants of health				
Objective 1: Monitoring				
7.1.1 Integrated monitoring systems collect data on environmental hazards (e.g. water quality, water availability, air quality)	Yes	No	No public data available to the authors' knowledge.	
7.1.2 Proportion of health facilities with access to energy, safe water, and sanitation services	Yes	No	No public data available to the authors' knowledge at the health facility level.	
7.1.3 Integrated monitoring systems allowing collection and analysis of data on environmental hazards, socioeconomic factors and health outcomes established	No			
Objective 2: Regulatory mechanisms				
7.2.1 Regulations on key environmental determinants of health (air quality, water quality, food quality, waste management) designed to reflect broader ranges of expected climatic conditions and the health sector's own contribution to GHG emissions and environmental impacts	Yes	No	"Environmental determinants" need to be contextually defined first before this can be measured.	
7.2.2 Regulations for clean energy systems promoted as a means to improve local air quality and reduce the number of premature deaths from exposure to air pollution	No			
7.2.3 Risk assessment and management approaches aiming to minimize the health impacts from climate change via water, sanitation and hygiene (WASH) implemented (e.g. climate resilient water and sanitation safety plans)	No			
Objective 3: Coordinated cross-sectoral management				
7.3.1 Environmental health impact assessments for policy and programmes in sectors such as transport, water, food and agriculture, and WASH implemented in coordination with the Ministry of Health	No			
7.3.2 Joint multisectoral risk management approaches to health risks related to climate related emergencies and disasters, water, waste, food, and air pollution implemented	No			
7.3.3 Low carbon sustainability approach integrated in managing the environmental determinants of health	No			
7.3.4 Proportion of population with primary reliance on clean fuels and technologies increased	Yes	Yes	WHO Global Health Observatory: Proportion of population with primary reliance on clean fuels (%)	
Component 8: Climate-informed health programmes				
Objective 1: Health programming				

8.1.1 Information and evidence gathered in components 3–5 (i.e. addressing research, assessments, and integrated surveillance) used to inform action on priority climate-sensitive health programmes	No			
8.1.2 Proportion of health programmes informed by a V&A assessment in integrating climate change and health adaptation and resilience actions within their own programmes	No	No	No public data available to the authors' knowledge.	
8.1.3 Proportion of health programmes integrating climate change mitigation actions	Yes			
8.1.4 Procurement processes and mechanisms of specific health programmes are assessed and improved based on climate resilience and low carbon sustainability considerations	No			
8.1.5 Investment plans to address identified capacity gaps in health programmes to deal with the increased health risks from climate variability and change developed	No			
8.1.6 Information on current and projected climate change risks integrated into strategic health programmes	No	No	No public data available to the authors' knowledge.	
8.1.7 Number of health programmes with standard operating procedures to respond to environmental risks revised for integration of climate information	Yes			
8.1.8 Service delivery informed by a sound understanding of the different exposure pathways from climate related hazards, and targeted to those most at-risk, considering gender differences and diverse vulnerability factors	No			
Objective 2: Delivery of interventions				
8.2.1 Health sector response plan for key climate-sensitive health risks implemented	No			
8.2.2 Public health programmes are targeted to those most at-risk of health impacts from climate change (e.g. maternal, newborn and children, older people, migrants, people with pre-existing conditions)	No			
8.2.3 Number of health sector programme areas implementing GHG emission reduction interventions	No			
8.2.4 Number of short- and long-term climate resilience interventions defined and prioritized on key health programmes	No			
8.2.5 Number of sustainable low carbon interventions defined and prioritized on key health programmes	No			
8.2.6 Risk maps and analysis of seasonal trends in diseases used to target resources and preventive measures for those most at-risk	No			
Component 9: Climate-related emergency preparedness and management				
Objective 1: Policies and protocols				
9.1.1 Policies, protocols, plans, and strategies for Health Emergency and Disaster Risk Management (H-EDRM) reviewed and improved through the integration of climate-sensitive health risks and weather and climate information (e.g. El Niño/La Niña conditions)	No			
9.1.2 Health sector contingency plans for extreme weather events developed and implemented	No			
9.1.3 Gender sensitivity and equity approaches included in H-EDRM, considering vulnerable populations and regions at risk from climate related hazards	No			
9.1.4 Health sector contingency plans for extreme weather events, including risk reduction, preparedness, and response, are aligned with the WHO H-EDRM or a local health emergency and disaster risk management framework	Yes	No	No public data available to the authors' knowledge.	
9.1.5 Protocols for H-EDRM integrate low carbon and environmentally sustainable practices including for logistics, supply change, procurement and storage of medicines and equipment, and transport	Yes	No	No public data available to the authors' knowledge.	
Objective 2: Risk management				
9.2.1 Risk assessments for current and projected future exposure to extreme weather events routinely used to inform health sector strategic development plans	No			
9.2.2 Climate change related emergency and disaster response plans for individual health facilities developed and implemented	No			
9.2.3 Geographical and seasonal distribution of climate health risks and outcomes used to inform emergency and disaster response plans	No			

9.2.4 EWS for extreme weather events and climate-sensitive diseases used to inform roles and responsibilities of different actors for H-EDRM planning	No			
Objective 3: Community empowerment				
9.3.1 Capacity development programmes implemented to support the roles of local communities to identify risks, prevent exposure to hazards, and take action to save lives in extreme weather events	No			
9.3.2 Stakeholder mechanism to support participation, dialogue and information exchange, to empower civil society and community groups as primary actors in emergency preparedness and response established	Yes	No	No public data available to the authors' knowledge.	
9.3.3 Mechanisms in place to ensure information related to health risks from extreme weather events reaches communities in a way that preventive action by them is triggered	No			
Component 10: Sustainable climate and health financing				
Objective 1: Health specific funding and financing mechanisms				
10.1.1 Scale-up public financing to build the foundations of climate resilient and low carbon health system	No			
10.1.2 Domestic or international funding accessed to strengthen climate resilience of health systems	No			
10.1.3 Resources for climate change and health interventions, both for resilience and low carbon sustainability, included in national or subnational health investment plans	Yes	No	No public data available to the authors' knowledge.	
10.1.4 Domestic or international funding to strengthen low carbon sustainability of health systems accessed	No			
10.1.5 Percentage of the national health budget addresses risks posed by climate variability and change including at health care facility level	Yes	No	No public data available to the authors' knowledge.	
10.1.6 Decadal and longer-term forecasts used to inform health investments (e.g. construction of new health care facilities)	No			
10.1.7 Results of V&A assessment and HNAP used to access health funding and financing mechanisms	No			
Objective 2: Climate change funding streams				
10.2.1 Climate change and health projects and programmes submitted to and granted by the main international climate change funding mechanisms (e.g. Green Climate Fund (GCF), the Global Environment Facility (GEF), the Adaptation Fund (AF) and bilateral donors)	Yes	No	None currently to the authors' knowledge.	
10.2.2 Investment cases for climate resilient and low carbon sustainable health systems developed by relevant actors (e.g. multilateral development banks) and used to facilitate access to funding and financing	Yes	No	None currently to the authors' knowledge.	
Objective 3: Funding and financing for health-determining sectors				
10.3.1 Health impacts of climate change monitored in programmes funded through financial mechanisms specific to health-determining sectors	No			
10.3.2 Climate interventions across sectors with a focus on health, including sustainable low carbon health facilities funded	No			
10.3.3 Climate change adaptation and mitigation projects and programmes submitted and granted to key health-determining sectors integrate costed activities related to assessing and monitoring potential positive and negative health impacts	Yes	No	No public data available to the authors' knowledge.	
10.3.4 Screening for climate variability and change, and related health risks included as criteria for selecting investments in key health determining sectors, such as water, sanitation, food and agriculture, energy, transport, and urban planning	Yes	No	None currently to the authors' knowledge.	

Appendix VI PRISMA-P (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols) 2015 checklist: recommended items to address in a systematic review protocol*

Blom, IM (2022). PRISMA-P Checklist for 'A Systematic Review Protocol for Identifying the Effectiveness of Greenhouse Gas Mitigation Interventions for Healthcare Systems in Low- and Middle-Income Countries'. [Data Collection]. London School of Hygiene & Tropical Medicine, London, United Kingdom. *https://doi.org/10.17037/DATA.00002988*.

Concerning: A Systematic Review Protocol for Identifying the Effectiveness of Greenhouse Gas Mitigation Interventions for Healthcare Systems in Low- and Middle-Income Countries

Authors: Blom IM, Asfura JS, Eissa M, Mattijsen JC, Sana H, Haines A and Whitmee S

Section and topic	**Item No**	**Checklist item**	**Where to find section in manuscript**
ADMINISTRATIVE INFORMATION			
Title:			
Identification	1a	Identify the report as a protocol of a systematic review	Noted in the title as well as body of text.
Update	1b	If the protocol is for an update of a previous systematic review, identify as such	NA
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number	NA
Authors:			
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author	Name and affiliation on title page. Email addresses of each author provided as part of protocol submission. Physical address provided on title page.
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review	Contributions confirmed as part of protocol submission and under declarations in the manuscript.
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments	There is a specific section that outlines the approach for documenting protocol amendments which can be found under declarations.
Support:			
Sources	5a	Indicate sources of financial or other support for the review	Indicated under declarations in the manuscript and as part of the submission.
Sponsor	5b	Provide name for the review funder and/or sponsor	Names provided under declarations.

Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol	There was no role and this is confirmed in the manuscript.
INTRODUCTION			
Rationale	6	Describe the rationale for the review in the context of what is already known	This is part of the introduction.
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)	These are part of the introduction.
METHODS			
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review	This is part of the methodology section.
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage	This is part of the methodology section.
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated	This is part of the methodology section.
Study records:			This is part of the methodology section.
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review	This is part of the methodology section.
Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)	This is part of the methodology section.
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators	This is part of the methodology section.
Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications	This is part of the methodology section.
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale	This is part of the methodology section.
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis	This is part of the methodology section.
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesised	This is part of the methodology section.

	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2, Kendall's τ)	
	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression)	
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned	NA
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)	This is part of the methodology section.
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)	This is part of the methodology section.

*** It is strongly recommended that this checklist be read in conjunction with the PRISMA-P Explanation and Elaboration (cite when available) for important clarification on the items. Amendments to a review protocol should be tracked and dated. The copyright for PRISMA-P (including checklist) is held by the PRISMA-P Group and is distributed under a Creative Commons Attribution Licence 4.0.**

From: Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart L, PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ. 2015 Jan 2;349(jan02 1):g7647.

LSHTM Data Compass

Appendix VII Annexes to: A Systematic Review to Identify the Effectiveness of Greenhouse Gas Mitigation Interventions for Healthcare Systems in Low- and Middle-Income Countries

Blom, I (2023). *Annexes to: A Systematic Review to Identify the Effectiveness of Greenhouse Gas Mitigation Interventions for Healthcare Systems in Low- and Middle-Income Countries.* [Data Collection]. London School of Hygiene & Tropical Medicine, London, United Kingdom. https://doi.org/10.17037/DATA.00003678. (122)

VII.i Annex 1 Systematic Review Searches per Electronic Database

Ovid EMBASE, Ovid MEDLINE, Ovid Global Health

Search line	Content of search
1	(netzero or net zero).mp.
2	Carbon Footprint/
3	Greenhouse Effect/
4	exp Climate Change/
5	(carbon or CO_2 or methane or CH4 or nitrous oxide or N2O or hydrofluorocarbon* or HFC* or perfluorocarbon* or PFC* or F-gas or fluorinated gas or sulfur hexafluoride or SF6 or nitrogen trifluoride or NF3 or emission* or greenhouse or GHG or climat* change* or global warming or footprint or eco-friendly or climate friendly or environment* friendly or eco-efficient or environment* responsible or environment* sound or energy-efficient or energy-saving or green initiative* or environmental impact or short-lived climate pollutant or black carbon).mp.
6	(environment* and sustainab*).mp.
7	1 or 2 or 3 or 4 or 5 or 6
8	exp "Delivery of Healthcare"/
9	exp Health Facilities/
10	(health system* or healthcare or healthcare or health sector or health supply chain* or health service* or health cent* or delivery of health or health delivery or health facilit* or hospital or hospitals or clinic or clinics or emergency room* or operat* room* or operat* theat* or patient care or ward* or urgent care or primary care or secondary care or tertiary care or quaternary care or telemedicine or medical cent* or diagnostic care or rehabilitative care or preventative care or palliative care or home care).mp.
11	8 or 9 or 10
12	7 and 11
304	or/13-303 [ALL LOW AND MIDDLE-INCOME COUNTRIES (expert search)]
305	12 and 304
306	limit 305 to yr="1990 - 2023"

Table 1 Systematic Review Search Ovid Databases

Web of Science

Search line	Content of search
1	(((ALL=(netzero OR "net-zero")) OR ALL=((carbon or CO_2 or methane or CH4 or "nitrous oxide" or N2O or hydrofluorocarbon* or HFC* or perfluorocarbon* or PFC* or "F-gas" or "fluorinated gas" or "sulfur hexafluoride" or SF6 or "nitrogen trifluoride" or NF3 or emission* or greenhouse or GHG or "climat* change*" or "global warming" or footprint or "eco-friendly" or "climate friendly" or "environment* friendly" or "eco-efficient" or "environment* responsible" or "environment* sound" or "energy-efficient" or "energy-saving" or "green initiative*" or "environmental impact" or "short-lived climate pollutant" or "black carbon").mp.)) OR ALL=(environment* and sustainab*)) AND ALL=("health system*" or healthcare or "healthcare" or "health sector" or "health supply chain*" or "health service*" or “health cent*” or "delivery of health" or "health delivery" or "health facilit*" or hospital or hospitals or clinic or clinics or "emergency room*" or "operat* room*" or "operat* theat*" or "patient care" or ward* or "urgent care" or "primary care" or "secondary care" or "tertiary care" or "quaternary care" or telemedicine or "medical cent*" or "diagnostic care" or "rehabilitative care" or "preventative care" or "palliative care" or "home care")
2-15	[ALL LOW AND MIDDLE-INCOME COUNTRIES (expert search)]
16	#2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15
17	#16 AND #1

Table 2 Systematic Review Search Web of Science

Africa-Wide Information

Search line	Content of search

1	((((netzero OR "net-zero")) OR ((carbon or CO_2 or methane or CH4 or "nitrous oxide" or N2O or hydrofluorocarbon* or HFC* or perfluorocarbon* or PFC* or "F-gas" or "fluorinated gas" or "sulfur hexafluoride" or SF6 or "nitrogen trifluoride" or NF3 or emission* or greenhouse or GHG or "climat* change*" or "global warming" or footprint or "eco-friendly" or "climate friendly" or "environment* friendly" or "eco-efficient" or "environment* responsible" or "environment* sound" or "energy-efficient" or "energy-saving" or "green initiative*" or "environmental impact" or "short-lived climate pollutant" or "black carbon").mp.)) OR (environment* and sustainab*)) AND ("health system*" or healthcare or "healthcare" or "health sector" or "health supply chain*" or "health service*" or "health cent*" or "delivery of health" or "health delivery" or "health facilit*" or hospital or hospitals or clinic or clinics or "emergency room*" or "operat* room*" or "operat* theat*" or "patient care" or ward* or "urgent care" or "primary care" or "secondary care" or "tertiary care" or "quaternary care" or telemedicine or "medical cent*" or "diagnostic care" or "rehabilitative care" or "preventative care" or "palliative care" or "home care")

Table 3 Systematic Review Search Africa-Wide Information

LILACS

Search line	Content of search
1	(((((netzero OR net-zero)) OR ((carbon or CO_2 or methane or CH4 or nitrous oxide or N2O or hydrofluorocarbon$ or HFC$ or perfluorocarbon$ or PFC$ or F-gas or fluorinated gas or sulfur hexafluoride or SF6 or nitrogen trifluoride or NF3 or emission$ or greenhouse or GHG or climat$ change$ or global warming or footprint or eco-friendly or climate friendly or environment$ friendly or eco-efficient or environment$ responsible or environment$ sound or energy-efficient or energy-saving or green initiative$ or environmental impact or short-lived climate pollutant or black carbon).mp.)) OR (environment$ and sustainab$))) AND ((health system$ or healthcare or healthcare or health sector or health supply chain$ or health service$ or health cent$ or delivery of health or health delivery or health facilit$ or hospital or hospitals or clinic or clinics or emergency room$ or operat$ room$ or operat$ theat$ or patient care or ward$ or urgent care or primary care or secondary care or tertiary care or quaternary care or telemedicine or medical cent$ or diagnostic care or rehabilitative care or preventative care or palliative care or home care))

Table 4 Systematic Review Search LILACS

Global Index Medicus

Search line	Content of search
1	(((((netzero OR net-zero)) OR ((carbon or CO_2 or methane or CH4 or nitrous oxide or N2O or hydrofluorocarbon* or HFC* or perfluorocarbon* or PFC* or F-gas or fluorinated gas or sulfur hexafluoride or SF6 or nitrogen trifluoride or NF3 or emission* or greenhouse or GHG or climat* change* or global warming or footprint or eco-friendly or climate friendly or environment* friendly or eco-efficient or environment* responsible or environment* sound or energy-efficient or energy-saving or green initiative* or environmental impact or short-lived climate pollutant or black carbon).mp.)) OR (environment* and sustainab*))) AND ((health system* or healthcare or healthcare or health sector or health supply chain* or health service* or health cent* or delivery of health or health delivery or health facilit* or hospital or hospitals or clinic or clinics or emergency room* or operat* room* or operat* theat* or patient care or ward* or urgent care or primary care or secondary care or tertiary care or quaternary care or telemedicine or medical cent* or diagnostic care or rehabilitative care or preventative care or palliative care or home care))

Table 5 Systematic Review Search Global Index Medicus

GreenFile

Search line	Content of search
1	(((((netzero OR "net-zero")) OR ((carbon or CO_2 or methane or CH4 or "nitrous oxide" or N2O or hydrofluorocarbon* or HFC* or perfluorocarbon* or PFC* or "F-gas" or "fluorinated gas" or "sulfur hexafluoride" or SF6 or "nitrogen trifluoride" or NF3 or emission* or greenhouse or GHG or "climat* change*" or "global warming" or footprint or "eco-friendly"

	or "climate friendly" or "environment* friendly" or "eco-efficient" or "environment* responsible" or "environment* sound" or "energy-efficient" or "energy-saving" or "green initiative*" or "environmental impact").mp.)) OR (environment* and sustainab*)) AND ("health system*" or healthcare or "healthcare" or "health sector" or "health supply chain*" or "health service*" or "delivery of health" or "health delivery" or "health facilit*" or hospital or hospitals or clinic or clinics or "emergency room*" or "operat* room*" or "operat* theat*" or "patient care" or ward* or "urgent care" or "primary care" or "secondary care" or "tertiary care" or "quaternary care" or telemedicine or "medical cent*" or "diagnostic care" or "rehabilitative care" or "preventative care" or "palliative care" or "home care")) AND (Afghanistan OR Albania OR Algeria OR “American Samoa” OR Angola OR Argentina OR “Argentine Republic” OR Armenia OR Azerbaijan OR Bangladesh OR Belarus OR Byelarus OR Belorussia OR Belize OR Benin OR Bhutan OR Bolivia OR Bosnia OR Botswana OR Brazil OR Bulgaria OR Burma OR “Burkina Faso” OR Burundi OR “Cabo Verde” OR “Cape verde” OR Cambodia OR Cameroon OR “Central African Republic” OR Chad OR China OR Colombia OR Comoros OR Comores OR Comoro OR Congo OR “Costa Rica” OR “Côte d'Ivoire” OR Cuba OR Djibouti OR Dominica OR “Dominican Republic” OR Ecuador OR Egypt OR “El Salvador” OR Eritrea OR Ethiopia OR Fiji OR Gabon OR Gambia OR Gaza OR “Georgia Republic” OR Georgian OR Ghana OR Grenada OR Grenadines OR Guatemala OR Guinea OR “Guinea Bissau” OR Guyana OR Haiti OR Herzegovina OR Hercegovina OR Honduras OR India OR Indonesia OR Iran OR Iraq OR Jamaica OR Jordan OR Kazakhstan OR Kenya OR Kiribati OR Korea OR Kosovo OR Kyrgyz OR Kirghizia OR Kirghiz OR Kirgizstan OR Kyrgyzstan OR “Lao PDR” OR Laos OR Lebanon OR Lesotho OR Liberia OR Libya OR Macedonia OR Madagascar OR Malawi OR Malay OR Malaya OR Malaysia OR Maldives OR Mali OR “Marshall Islands” OR Mauritania OR Mauritius OR Mexico OR Micronesia OR Moldova OR Mongolia OR Montenegro OR Morocco OR Mozambique OR Myanmar OR Namibia OR Nauru OR Nepal OR Nicaragua OR Niger OR Nigeria OR Pakistan OR Palau OR Panama OR “Papua New Guinea” OR Paraguay OR Peru OR Philippines OR Phillippines OR Philipines OR Phillipines OR Principe OR Romania OR Rwanda OR Ruanda OR Samoa OR “Sao Tome” OR Senegal OR Serbia OR “Sierra Leone” OR “Solomon Islands” OR Somalia OR “South Africa” OR “South Sudan” OR “Sri Lanka” OR “St Lucia” OR “St Vincent” OR Sudan OR Surinam OR Suriname OR Swaziland OR Syria OR “Syrian Arab Republic” OR Tajikistan OR Tadzhikistan OR Tadjikistan OR Tadzhik OR Tanzania OR Thailand OR Timor OR Togo OR Tonga OR Tunisia OR Turkey OR Turkmen OR Turkmenistan OR Tuvalu OR Uganda OR Ukraine OR Uzbek OR Uzbekistan OR Vanuatu OR Venezuela OR Vietnam OR “West Bank” OR Yemen OR Zambia OR Zimbabwe OR ((developing or "less* developed" or "under developed" or "underdeveloped" or "middle income" or "low* income") AND (economy or economies)) OR ((developing or "less* developed" or "under developed" or underdeveloped or "middle income" or "low* income" or underserved or "under served" or deprived or poor*) AND (countr* or nation$ or population$ or world)) OR (low* AND (gdp or gnp or "gross domestic" or "gross national")) OR (low AND middle AND countr*) OR (lmic or lmics or "third world" or "lami countr*") OR ("transitional countr*") OR ("global south") OR ("Africa South of the Sahara" or "sub-Saharan Africa" or "subSaharan Africa") OR ("Central Africa" OR "Eastern Africa" OR "Southern Africa" OR "Western Africa"))

Table 6 Systematic Review Search GreenFile

VII.ii Annex 2 Conceptual Framework Detailed Sections

Situation and Context Analysis

Problem Statement

Climate change is expected to cause a major impact on human health due to many direct and indirect health effects (12). However, healthcare systems themselves contribute to 4.4.% of all GHG emissions (23). Healthcare systems need to implement mitigation interventions to ensure an adequate, effective and systematic response to these health effects whilst aiming for synergies or co-benefits with adaptation. Mitigation interventions should span all three scopes of emissions, including healthcare operations, energy and supply chains. There is a paucity of evidence guiding these interventions, particularly in LMICs.

At the UNFCCC COP26, countries committed to environmentally sustainable healthcare systems – of which the majority were LMICs (25). This provides an opportunity for these LMICs to transform their healthcare systems through GHG mitigation, with potential co-benefits for adaptation and health, while inspiring individuals, other sectors and efforts in HICs.

Context

To assess and influence the probability of success or failure of interventions towards GHG mitigation in healthcare systems, the implementation process needs to be taken into account. This includes the financial constraints, including costs and cost-savings. It also consists of the availability and accessibility of low-emission alternatives for healthcare providers and patients and other potential barriers.

Impact

The impact is the sustained and long-term change envisioned (207). Three levels of impact are identified. Firstly, the direct impact of GHG mitigation of healthcare systems in LMICs. By considering adaptation through identifying synergies and co-benefits, a knock-on impact would be a reduction of climate risk for health. Finally, and indirectly, these interventions could impact the awareness of and inspire climate action by individuals (patients), the community, other sectors and HICs.

Outcomes & Mechanisms

The outcomes are shorter-term changes that contribute to the eventual impact (207). These outcomes include different mitigation interventions across the three scopes of emissions. An overview of these scopes and their subdomains where interventions can be implemented are as follows and adapted from Rasheed et al.'s infographic (31):

1. A reduction of GHG emissions of healthcare operations (Scope 1):
    a. Stimulate low carbon prescriptions

    b. Increase efficiency and minimise patient travel, e.g. through strategic planning and multidisciplinary consults
    c. Transition to a healthcare system of community-based health promotion and disease prevention with a prominent role of primary healthcare
    d. Shift towards higher usage of eHealth, including teleconsults
    e. Stimulate the use of low-carbon transport alternatives for operations, including low emission ambulances

2. A reduction of GHG emissions of healthcare energy (Scope 2):
    a. Transition to clean energy through renewable energy sources and low carbon grids
    b. Use of battery power to expand the renewable energy supply
    c. Utilise energy efficiently, e.g. LED lighting

3. A reduction of GHG emissions of healthcare supply chains (Scope 3):
    a. Reuse of medical devices and supplies
    b. Reduce the acquisition of non-reusables and high-emission alternatives and increase the use of low-emission alternatives
    c. Transition to a predominantly plant-based hospital menu with locally produced foods (particularly for staff and visitors)
    d. Stimulate health workers and patients to minimise transport and, when necessary, use active transport or electric, shared vehicles
    e. Use low-emission alternatives for transportation and distribution
    f. Encourage low-emission travel options for business travels
    g. Procure from net-zero suppliers or suppliers with a strategy to move to net-zero

There is a lack of an overview of evidence about which specific mechanisms will lead to the abovementioned outcomes. Their outputs are specific to the intervention and measured by reducing GHG emissions.

It is vital to consider the interlinkages of all mitigation interventions leading to the above-listed outcomes with adaptation and categorise them under co-benefit, synergy, conflict, or trade-off. Whilst deciding which interventions to implement, preference should be given to those that synergise with adaptation or provide adaptation co-benefits.

Assumptions

Assumptions are an underlying process of the Theory of Change and refer to thinking processes leading to the abovementioned information (207). The following assumptions have been identified:

Delivery assumptions

- Relevant interventions towards GHG mitigation in healthcare systems in LMICs can be identified in the literature;
- There is sufficient interest and dedication of policymakers to implement these interventions;
- Including through supporting organisations, the right skills, abilities and resources are present to implement and measure these interventions.

Impact assumptions

- GHG mitigation in healthcare systems while considering actions relevant for adaptation in the context of climate change is relevant for improved health outcomes;
- Knock-on effects could include a reduction of climate risk for health through adaptation, yet it is vital to evaluate the evidence of these potential effects;
- Indirect effects could include inspiration and motivation to act across different groups, including individuals, communities, other sectors and HICs, yet future research has to confirm whether this is, in fact, a hypothesis that can be verified.

Possible unintended consequences

- An identified risk is that this project can potentially distract people from investing and implementing adaptation actions in contexts where urgency requires adaptation to be a priority due to an urgent need to adapt because of impacts or intervention measures can have a conflict or trade-off with adaptation. Therefore, every step must consider whether recommendations are transferable across contexts and the relation of proposed mitigation interventions with adaptation. Where urgency requires, adaptation should indeed be prioritised.

Theory of change process assumptions

- Robust data on the impact of GHG mitigation interventions and experts have been consulted while designing this Theory of Change;
- The Theory of Change is intended to be a 'living document' and continuously adapt to newly found evidence and insights.

VII.iii Annex 3 Global Warming Potential

Global Warming Potential (GWP) is a metric devised to evaluate and compare the climate-warming effects of different gases. Essentially, it gauges the amount of energy a ton of a particular gas will trap over a set duration, most commonly 100 years, in relation to a ton of carbon dioxide (CO_2). Higher GWP values indicate that the gas has a more pronounced warming effect than CO_2 over the stipulated period. This standardized measure allows for compiling comprehensive greenhouse gas inventories and assessing emission reduction prospects across various sectors and gases. (208)

VII.iv Annex 4 GRADE Certainty Assessment

Certainty assessment							Impact	Certainty
№ of studies	**Study design**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**		
GHG Mitigation of healthcare system energy through hybrid energy systems								
10	observational studies	not serious	not serious	not serious	not serious	none	A variety of hybrid energy systems, including renewable energy sources adjusted to contexts, reported reductions in CO2 emissions ranging from 25% to a theoretical 233%.	⨁⨁◯◯ Low
GHG Mitigation of healthcare system waste through waste management systems with composting or recycling								
4	observational studies	not serious	not serious	not serious	not serious	none	Relative emission reductions are reported ranging between 46.46-114% in systems that include waste segregation, composting, and material recycling while considering efficient low-emission transportation options.	⨁⨁◯◯ Low
GHG Mitigation of healthcare system waste through incineration and autoclave process efficiency								
2	observational studies	not serious	not serious	not serious	serious[a]	none	Relative emission reductions in waste management systems is reported to take place through centralising the autoclave (reduces electricity needed), considering efficient transportation, and ensuring incinerators are up to date with a clear process and well trained operator.	⨁◯◯◯ Very low
GHG Mitigation of healthcare system waste through replacing plastic sharps containers by cardboard sharps containers								
1	observational studies	not serious	not serious	not serious	very serious[a]	none	Using cardboard sharps containers instead of plastic sharps containers led to a reported 61.68% reduction in black carbon emissions.	⨁◯◯◯ Very low
GHG Mitigation of healthcare system waste through microwave sterilization and landfilling								
1	observational studies	not serious	not serious	not serious	not serious	none	Medical waste management of a city through microwave sterilization with landfill medical waste disposal technology reduces relative emissions as compared to rotary kiln incineration (68%), pyrolysis incineration (28%), plasma melting (80%), and steam sterilization with landfill (18%).	⨁⨁◯◯ Low
GHG Mitigation of healthcare heating and cooling through heat exchangers								
1	observational studies	not serious	not serious	not serious	not serious	none	An eight-row heat pipe heat exchangers system added to the air conditioning system in one hospital ward was assessed to reduce CO2 emissions compared to the regular air-conditioning system by 147%, as a result of heat generation.	⨁⨁◯◯ Low
GHG Mitigation of anaesthetic gases through induction dose only sevoflurane								
1	randomised trials	not serious	not serious	not serious	not serious	none	Induction dose only sevoflurane during paediatric ophthalmic examination for children aged 1-5 at one hospital reduces 22% of emissions compared to standard low-flow sevoflurane.	⨁⨁⨁⨁ High
GHG Mitigation of a hospital building through lobby design								
1	observational studies	not serious	not serious	serious[b]	not serious	none	In this cold-climate region, a lobby with two exterior walls, south oriented at the same height as the rest of the hospital relatively emits the least with a relative reduction of 0.014-0.074 kg CO2/m2 depending on the comparison design.	⨁◯◯◯ Very low
GHG Mitigation of operations and logistics of cataract surgery								
1	observational studies	serious[c]	not serious	not serious	not serious	none	Multiuse pharmaceuticals, reusing surgical supplies, a short surgical duration and quick turnaround time resulted in a relative reduction of emissions of 95.38% as compared to the same surgery in the United Kingdom.	⨁◯◯◯ Very low
Climate Adaptation from mitigation interventions								
1	observational studies	not serious	not serious	serious[d]	extremely serious[d]	none	A solar PV panel energy system with and without grid-connection for a rural healthcare facility in the Philippines can contribute to the resilience of a healthcare facility to short-term disasters and events and as longer-term climate changes occur.	⨁◯◯◯ Very low

CI: confidence interval

a. Results (partially) based on visual observation pollution.; b. Outcomes in electricity generated in CO2e using national emission factors.; c. Comparison to the United Kingdom.; d. Adaptation was a consideration in the article and not measured.

VII.v Annex 5 PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Abstract
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Eligibility criteria
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Methods
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Search Strategy
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Selection Process & Data Extraction
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Selection Process & Data Extraction
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Selection Process & Data Extraction
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Selection Process & Data Extraction
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Methods
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Methods
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Methods
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Methods
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Methods
	13d	Describe any methods used to synthesise results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Methods

	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Methods
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Methods
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Methods
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Methods
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Study selection & characteristics
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Study selection & characteristics
Study characteristics	17	Cite each included study and present its characteristics.	Study selection & characteristics
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Critical appraisal and risk of bias
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	GHG Mitigation Interventions and Outcomes, Table 5
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Results
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Table 5
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Results
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Results
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Critical appraisal and risk of bias
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Confidence in cumulative evidence
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion
	23b	Discuss any limitations of the evidence included in the review.	Limitations, gaps & opportunities
	23c	Discuss any limitations of the review processes used.	Limitations, gaps & opportunities
	23d	Discuss implications of the results for practice, policy, and future research.	Limitations, gaps & opportunities
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Methods
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Methods
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Methods
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Declarations: Funding Statement

Competing interests	26	Declare any competing interests of review authors.	Declarations: Declaration of Interests
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Declarations: Data Availability Statement

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

Appendix VIII to: Towards a Net-Zero Healthcare System in Kenya: Stakeholder perspectives on opportunities, challenges and priorities

Iris Martine Blom, Melvine Anyango Otieno, Susannah Mayhew, Neil Spicer, Andy Haines, Sarah Whitmee

Table of Contents

Information Sheet

Participant Information Sheet

Title of Project: *Greenhouse gas mitigation of the Kenyan healthcare system*

Introduction

We would like to invite you to take part in a research study. Joining the study is entirely up to you. Before you decide, you need to understand why the research is being done and what it would involve. One of our team will go through this information sheet with you and answer any questions you may have. Ask questions if anything you read is not clear or you would like more information. Please feel free to talk to others about the study if you wish. Take time to decide whether or not to take part.

What is the purpose of the study?

Climate change is having and is increasingly expected to have direct and indirect effects on health. Healthcare systems should adapt to deal with these effects, whilst mitigating their own greenhouse gas emissions to not further contribute to the health emergency. This poses an opportunity for healthcare systems to advance in an environmentally sustainable manner. A key challenge is to identify pathways towards advancement whilst mitigating emissions in healthcare systems, with a particular evidence gap in Low- and Middle-Income Countries.

The London School of Hygiene and Tropical Medicine (LSHTM) are conducting research on greenhouse gas mitigation of healthcare systems and particularly in Kenya to identify lessons learned, pathways, opportunities, barriers and solutions towards greenhouse gas mitigation of healthcare systems and through that create recommendations for more environmentally sustainable healthcare.

Why have I been asked to take part?

You have been invited because we believe your knowledge, experiences and expertise will contribute to a better understanding of this topic and we would like to build our research and recommendations on your guidance.

Do I have to take part?

No. It is up to you to decide to take part or not. If you don't want to take part, that's ok.

We will discuss the study together and give you a copy of this information sheet. If you agree to take part, we will then ask you to sign a consent form.

What will happen to me if I take part?

If you agree to take part in this study, we will record your consent to participate. We would then like to invite you to take part in an interview to be held in the beginning of 2023. During the interview, we will ask your perspective on the current status of greenhouse gas mitigation of the healthcare system in Kenya, the opportunities and barriers, and potential solutions to these barriers. With your permission, we would like to audio-record the interview to better ensure accuracy and to transcribe and report findings. All that is shared during the interview will be anonymised before sharing it with any external party.

What will I have to do?

Participate in an interview and potentially, and with your permission, be available for brief follow-up questions or clarification by email or video call.

What are the possible risks and disadvantages?

Because this study only involves participating in an interview, we do not anticipate any harm or discomfort for you other than the time it will take you to participate in the interview. There are two potential risks with low likelihood of occurring, which are information risks (e.g., loss of privacy and/or breach of confidentiality), for which a data management plan is in place, ethical approval and data regulation is sought, and all researchers carry legal responsibility to minimie this risk as much as possible, and psychological or emotional risks (e.g., fear, stress, confusion, guilt) which will be minimized by information provision and contact information for any questions.

What are the possible benefits?

We cannot promise the study will help you but the information we get from the study will help our knowledge and understanding of this research area of greenhouse gas mitigation of healthcare systems.

What if something goes wrong?

If you have a concern about any aspect of this study, you should ask to speak to the researchers who will do their best to answer your questions: 00000000000 / 00000000000. *If you remain unhappy and wish to complain formally, you can do this by contacting: Patricia Henley at* 00000000000 *or +44 (0) 20 7927 2626.*

The London School of Hygiene and Tropical Medicine holds insurance policies which apply to this study. If you experience harm or injury as a result of taking part in this study, you may be eligible to claim compensation.

Can I change my mind about taking part?

You can withdraw from the study at any time. If you wish to withdraw, we will securely keep your audio-recorded contribution up to the point of withdrawal. If you withdraw, you can choose to still include your contribution in the anonymised transcript or request that we remove all your comments from the final transcript and written records. If you withdraw, you can choose whether we retain your personal information after withdrawal or remove it from our records.

What will happen to information collected about me?

We will need to use information from you. All information collected about you will be kept private. Only the study staff and authorities who check that the study is being carried out properly will be allowed to look at information about you. Information will include your name, contact details and experience. We will keep all information about you safe and secure.

Data may be sent to other study staff in London, but this will be anonymised. This means that any information about you which is shared beyond the chief investigator and the two supervisors, will have your *name and address removed so that you cannot be recognised, and your data will have a code number instead.*

Your personal details, meaning your name and other identifiable information, will be kept in a different safe place to the other study information and will be destroyed within 10 years of the end of the study.

At the end of the project, the study data will be archived at the data compass at the London School of Hygiene & Tropical Medicine. The data will be made available to other researchers worldwide for research and to improve medical knowledge and patient care. Your personal information will not be included and there is no way that you can be identified.

What are your choices about how your information is used?

You can stop being part of the study at any time, without giving a reason. Participation in the interview means we will record and transcribe your contribution which may be quoted anonymously in research arising from the interview. If you wish to withdraw, we will securely keep your audio-recorded contribution up to the point of withdrawal. If you withdraw, you can choose to still include your contribution in the anonymised transcript or request that we remove all your comments from the final transcript and written records. If you withdraw, you can choose whether we retain your personal information after withdrawal or remove it from our records. If you withdraw, we will not use your quoted remarks in any publications arising from this research.

Where can you find out more about how your information is used?

You can find out more about how we use your information

- *At* https://www.lshtm.ac.uk/files/research-participant-privacy-notice.pdf
- *by asking one of the research team*
- *by sending an email to* DPO@lshtm.ac.uk

What will happen to the results of this study?

The study results will be published in a medical journal so that other researchers and policymakers can learn from them. Your personal information will not be included in the study report and there is no way that you can be identified from it.

Who is organising and funding this study?

London School of Hygiene & Tropical Medicine is the sponsor for the research, and they have full responsibility for the project including the collection, storage and analysis of your data, and will act as the Data Controller for the study. This means that we are responsible for looking after your information and using it properly.

Funding for the study has been provided by the Prince Bernhard Culture Fund, Stichting VSBFonds and the dr. Hendrik Mullerfonds. The funders play no role in study design, conduct, data analysis and interpretation, manuscript writing, and dissemination of results.

Who has reviewed this study?

All research involving human participants is looked at by an independent group of people, called a Research Ethics Committee, to protect your interests. This study has been reviewed and given favourable opinion by

The London School of Hygiene and Tropical Medicine Research Ethics Committee (28210). The Kenya Medical Research Institute approved the study (4662), and the National Commission for Science, Technology and Innovation provided a license (519115).

Further information and contact details.

Thank you for taking time to read this information sheet. If you think you will take part in the study, please read and sign the consent form.

If you would like any further information, please contact Dr Iris Martine Blom who can answer any questions you may have about the study.

Contact details:

Dr Iris Martine Blom

Email: 00000000000

Telephone: 00000000000

If you have any concerns about the study, please contact the head of research governance at LSHTM Patricia Henley at 00000000000 or +00000000000.

Detailed Analysis Interviews

B.1 Net-zero Commitment

Based on the interviews conducted, there is a shared sentiment that Kenya's commitment to achieve a net-zero healthcare system by 2030 is an ambitious goal.

Stakeholders from development agencies, the health workforce, academia, and government representatives provided opinions that oscillated between optimism and scepticism. For instance, a representative from a development agency (Participant 06) believes that the target is achievable if prioritised. Similarly, a view from the health workforce (Participant 11) offers an optimistic lens, suggesting that since Kenya is still in the early stages of building its health systems, it could integrate sustainability practices from the outset. This sentiment is echoed by representatives of intergovernmental organizations (Participant 13 and Participant 14), who highlight the country's high-level political commitments and financial plans that underscore the intent.

'We are making sure that we are minimizing our carbon footprint from the beginning and doing it in a way that is protective of our planet rather than following the historical approach to maximize everything and then think 'how do we reverse the damage'.'

However, a prevailing sentiment shared by many stakeholders, including those from the building design, academia, supply chain, and national government (Participant 03, Participant 04, Participant 07, Participant 15, Participant 16, and Participant 17), suggests significant challenges. The policy environment has not provided adequate incentives for hospitals to adopt green practices. Financial constraints, lack of access to green financing, outdated infrastructure, resistance to change among health workers, and an overall lack of political will are consistently cited as barriers.

'For us to meet that target, a driver needs to be identified, responsibilities made clear and these need to be financed. Without that, there will be a lot of meetings and agreeing, and no matter the approach, implementation won't work.'

In the workshop, the discourse surrounding Kenya's focus on healthcare system mitigation versus adaptation resulted in a strong agreement for prioritizing both. Despite Kenya's relatively low contribution to global emissions, stakeholders articulated robust arguments for a proactive mitigation approach. They again highlighted that, as a growing nation, Kenya has a unique opportunity to integrate sustainable practices into the early stages of healthcare development. This approach not only lays a strong foundation for future health system resilience but also addresses broader societal impacts. Stakeholders pointed out the inherent interconnectedness of climate change with health outcomes, emphasizing that mitigation in healthcare can significantly enhance national preparedness against climate-related health crises ('We need to walk the talk.'). Furthermore, it was mentioned that establishing robust mitigation strategies now can prevent the exacerbation of health inequalities in the future. This conversation underscored the necessity of a dual approach where mitigation complements adaptation, ensuring that the healthcare system not only copes with the current climate impacts but also actively contributes to a sustainable and equitable future.

B.2 Sources of GHG Emissions

Interviewees, such as representatives from a tertiary private hospital (Participant 21) and the health workforce (Participant 11), agreed that direct emissions (Scope 1) are largely from hospital operations, especially from laundries and operating theatres. Medical equipment and consumables, such as drapes and gowns, add to these emissions. More significantly, a national government representative (Participant 16) emphasized that health products and technologies - drugs, vaccines, ICU equipment, etc. - are substantial contributors. Radiology was identified as a key department of interest, due to its high energy demands.

Anaesthetic gases were highlighted as notable emission sources within Scope 2 (Participant 16). A recurring theme was the emission contributions from energy sources. Several stakeholders, including representatives from faith-based health services (Participant 09), building design (Participant 03), health workforce (Participant 11), NGOs providing health services (Participant 18), and national government (Participant 16, Participant 17), reiterated that unreliable electricity coverage necessitates the frequent use of diesel generators. This dependency on generators, especially diesel-powered ones, is a major contributor to GHG emissions in the healthcare system. Another point of concern was the use of firewood and charcoal for cooking in rural hospitals, leading to deforestation, indoor air pollution and further GHG emissions.

Regarding Scope 3, the pharmaceutical industry emerged as an important topic, with concerns about environmentally unsafe disposal methods (Participant 15). Transport was another recurring topic. Remote locations necessitate regular long-distance travel, often by road or air, thus contributing to the carbon footprint (Participant 11, Participant 16). However, a dominant theme throughout was the substantial emissions originating from the supply chain. Representatives from a development agency (Participant 06), supply chain (Participant 20), and national government (Participant 14) detailed that procurement and supply chain management, especially in transporting and managing drugs and equipment, contribute heavily to GHG emissions including an estimate of 80% for healthcare facilities. This is compounded by the frequent expiration of drugs that are then burned, releasing GHGs.

Finally, waste management was highlighted by multiple stakeholders as a critical emission source. Interviews from representatives across various categories, including academia (Participant 01), NGOs (Participant 18), intergovernmental organizations (Participant 14), and national government (Participant 17), cited concerns over improper waste disposal. Specifically, the burning of medical waste and plastics, and the lack of proper segregation methods, contribute to GHG emissions. Inefficient water usage and plumbing were also mentioned as additional factors.

B.3 GHG Mitigation Interventions

Participants shared a variety of interventions across all three scopes of emissions that have been implemented within Kenya, with limited to no data on the impact of these interventions on GHG emissions (Figure 1b).

Regarding Scope 1, a private hospital (Participant 21) has introduced electronic billing, leading to a reduction in paper use. A Development agency (Participant 07) highlighted the adoption of environmentally friendly practices, such as using degradable cups for water dispensers and promoting the use of personal water bottles.

Efforts to enhance efficient operations and logistics have been evident. An academic (Participant 01) spoke about a hospital which has championed energy efficiency. Such facilities have implemented basic measures like ensuring lights are off when not in use, reusing materials, and sensitizing staff through posters about sustainable practices. Another Development agency (Participant 07) emphasized this importance of conveying environmental messaging to employees.

Addressing Scope 2, stakeholders discussed the significance of building equipment efficiency and electrification. A Development agency (Participant 06) underscored the potential carbon reduction from their updating old air conditioners, especially in hotter regions like Kisumu and Mombasa. Various stakeholders also underscored efforts of green building design, from employing LED lighting (Participant 21) to harnessing rainwater for utility purposes (Participant 02) and avoiding harmful CFC materials (Participant 04).

In the realm of medical procedures, reduced inhaled anaesthetic emissions are being pursued. Initiatives are in place to shift from sole nitrous oxide to more environmentally friendly alternatives, such as mixtures (Participant 06 & Participant 03). Similarly, there is a move from metered dose inhalers to dried powder inhalers (Participant 06).

Renewable energy investments, primarily in solar energy, were a prominent theme amongst implemented interventions. Stakeholders from various sectors, including Development agencies (Participant 06 & Participant 07), Faith-based health services (Participant 09), Supply chain (Participant 19), and NGOs providing health services (Participant 18), detailed their shifts to solar power for various purposes, from lighting to boiling water. These transitions were lauded not only for their carbon reduction potential, with one healthcare provider stating a reduction of GHG emissions of about 30-40% across multiple facilities, but also for their economic viability given Kenya's abundant sunshine and related return on investment.

Lastly, regarding Scope 3 indirect emissions, stakeholders discussed initiatives limited to water and waste. Emphasizing sustainable waste management, various healthcare facilities are pushing for responsible waste segregation, recycling of linens and electronic waste, and organic composting (Participant 06, Participant 09, Participant 21 & Participant 03). There is also a focus on water conservation and reutilization, with some facilities setting up biomass boilers as an alternative to diesel (Participant 03).

The workshop illuminated the multifaceted nature of the interventions and underscored the importance of viewing these efforts through a holistic lens. Participants expressed a nuanced understanding of the energy sector's influence on healthcare emissions and highlighted the critical need for integrating energy solutions such as biomass with caution, considering its broader impacts on public health and safety. Discussions also revealed a keen interest in expanding the scope of interventions beyond traditional boundaries, suggesting innovative approaches like integrating waste management with energy production to enhance efficiency and sustainability. The dialogue also stressed the necessity of aligning interventions with national energy policies and health system strategies, ensuring that efforts are synergistic and contribute to both environmental sustainability and health system resilience.

B.4 Stakeholders

Participants underlined the necessity of a whole-of-society approach for a successful transformation. Specific stakeholders identified as crucial to this approach are presented in Figure 2, including their relative impact and power and relevance to each of the 14 process components. The workshop discussions further emphasized connecting stakeholder mapping and engagement strategies. Based on provided insights, stakeholders were categorized using a power-influence grid. It was concluded that high-power, high-influence stakeholders require close management, whereas stakeholders with high power but low interest need to be kept satisfied to ensure their support.

Discussions also highlighted the need for a detailed communication plan to entrench the climate-health agenda up to the Ministry levels, including Environment and Energy, which often overshadow the Ministry of Health's roles. The workshop stressed the critical role of civil society, including Indigenous communities and youth, who are directly affected by climate change and must be engaged more substantially in leadership and decision-making processes. The inclusion of these groups in awareness, sensitization, and behavioural change initiatives was deemed essential for grassroots impact.

Media was recognized as a pivotal stakeholder for raising awareness and ensuring social accountability. Leveraging local media for behaviour change communication and holding governments accountable was seen as crucial for sustaining engagement and ensuring policy implementation reflects community needs and contributions.

Overall, the workshop's feedback integrates into the broader findings by underscoring the dynamic interplay between various stakeholders and the need for a stratified approach to stakeholder engagement, ensuring that all voices, especially those at the grassroots level, are heard and incorporated into strategic planning and implementation.

B.5 Health effects & Adaptation

Participant 20 accentuates the need for understanding 'adaptation' and realigning the health system's contributions to emissions with Kenya's climate vulnerabilities. Further, an academic viewpoint (Participant 01) highlights the subtle yet impactful roles of hospital infrastructure, like greenspaces, in fostering patient well-being. Such measures, though seemingly simple, can have profound positive implications on health outcomes. Connected to that, participant 02 states the imperative of creating resilient hospitals that leverage climate events, such as heavy rainfall, to their advantage while ensuring uninterrupted operation. Tangible solutions, such as water and energy efficiency practices, emerge as pivotal. Participant 13 notes the disproportionate impacts of emissions on regions like Africa and stresses the imperative of a resilient health system that can respond to evolving climate-induced challenges. This is supported by Participant 17, where the need for comprehensive adaptation strategies in health is evident, with an emphasis on climate-smart facilities and a knowledgeable health workforce.

'We cannot talk about mitigation, without talking about adaptation. '

B.6 Process Components

1) Leadership & Political Will

Participants from development agencies, private hospitals, and intergovernmental organizations emphasize the criticality of leadership from the top, be it the CEO, director, or other executive roles. The sentiment is that such leadership positions possess the ability to set the agenda and drive tangible change within organizations.

Parallelly, participants from academia, health workforce, and national government representatives pinpoint the need for political will, especially at national and subnational levels. This aspiration stems from experiences where recent policy shifts, such as lifting bans on tree-cutting, appear against sustainability objectives. Academicians share that the healthcare system's fragmentation compounds the challenge, necessitating a coordinated leadership strategy to prioritize and implement green solutions. Furthermore, government representatives state that the interplay between climate change and health is nascent in policy discourses. The necessity for strategic changes in resource allocation and the creation of an integrated approach, with clear leadership both at the micro (organizational) and macro (national) levels, is underlined.

2) Goal setting & action

Participants highlighted that the very act of committing to sustainability objectives is indicative of interest and intent. Such commitments, even if preliminary, signify the willingness to chart a course towards achieving these ambitious goals. This sentiment is also echoed by an intergovernmental organization, which emphasizes Kenya's advantageous position stemming from its policy environment. The nation already possesses a structured policy framework that outlines its sustainability aspirations and commits it to specific targets, which facilitates current implementation of interventions.

3) Financing

A sentiment conveyed by multiple stakeholders, from development agencies (Participant 06) to national government representatives (Participant 16 & Participant 17), is the need for adequate investment, both in terms of budget allocation and actual expenditure. Stakeholders from faith-based health services and academia echo concerns regarding the current reliance on traditional energy sources and highlight the potential and need of government incentives for renewable energy initiatives, specifically solar energy (Participant 2 & 13).

Issues around accessibility and awareness of available funds persist, as emphasised by interviewees from the supply chain and tertiary private hospitals (Participant 19 & Participant 21). The national government should facilitate funding processes and lead by example in investment and resource allocation. Further, there are potentials with the Global Climate Fund and other international funding opportunities, but with a caveat on the pace of mobilisation and concerns about current inadequate fund absorption capacity at the country level (Participant 11 & Participant 13). The role of the private sector is underscored, emphasising a sense of responsibility, particularly from industries seen as significant polluters (Participant 18). Meanwhile, international frameworks and mechanisms such as NDCs should provide clarity on how national funds are earmarked for climate initiatives, yet ambiguities persist regarding the vast majority of support mechanisms and their implications for health Participant 14).

4) Awareness and sensitisation

The participant from the Development Agency (Participant 06), Supply Chain (Participant 19), and Private Hospital settings (Participant 21), highlight the imperative to engage and sensitise. The discourse revolves around the creation and dissemination of targeted awareness campaigns, sensitising the population on the multifaceted nature of climate change, from droughts and famines to carbon emissions and environmental conservation.

A broader vision emerges from the Health Workforce (Participant 11), emphasising the necessity to transcend traditional solutions like tree planting and explore holistic lifestyle changes. Meanwhile, they spotlight the strategic importance of capacity building and knowledge dissemination at the grassroots level to cultivate both willingness and action. The crucial role of simplifying climate change messaging for effective communication to both politicians and the public is articulated by National Government Representatives (Participant 16 & Participant 17). These discussions accentuate the essentiality of adopting a bottom-up approach, prioritizing community involvement and understanding for successful policy implementation, and fostering collaborations between different parts of society.

From the perspective of a development agency (Participant 06), the challenge is not just about availing funds but ensuring the presence of dedicated personnel capable of overseeing the application of these funds. The agency underscores the need for "getting responsible staff" to manage the transition. The emphasis was further elaborated by having these trained professionals active and responsible throughout the week, regardless of the size of the healthcare facility - be it a larger or a smaller establishment.

5) Baseline data

There is a need for the implementation of interventions and the concurrent collection of baseline data (Participant 06). Such data-driven approaches are not isolated; the private hospital (Participant 21) accentuated its journey of monitoring essential metrics like energy, water, waste, fuel, and food wastage. This data-centric methodology enabled them to set actionable targets. However, as the Faith-based health services representative indicates (Participant 09), the situation remains complex. It is crucial to recognize the unique circumstances that present themselves and tailor the strategies to these realities. The call for a more structured approach is further amplified by the supply chain representative in (Participant 20). They stress the importance of having a vulnerability and adaptation assessment, an essential part under the COP26 commitment, to inform the mitigation and adaptation strategy for the healthcare system.

6) Research & Innovation

In addition to the need to perform baseline measurements related to mitigation and adaptation, stakeholders highlighted the necessity of gauging awareness levels, especially among health workers and decision-makers (Participant 06, Participant 09 & Participant 11). Further, to ascertain the viability of the healthcare system transformation, conducting cost-benefit analyses, financial assessments, and studying potential resource allocations is suggested (Participant 09, Participant 21 and Participant 07). Studying the implications of innovative medical solutions was further suggested (Participant 03). Additionally, the translation of research into tangible actions and policies was underscored, emphasising not just the need for research but its practical application in policymaking and community engagement (Participant 11 & Participant 17). Finally, measuring progress via comparative studies, both locally and internationally, is seen as instrumental in creating persuasive narratives to advocate for the net-zero healthcare transformation, potentially informing frameworks at global platforms such as the WHO (Participant 09). Along the same lines, here exists an untapped potential to learn from countries that have integrated mitigation and adaptation strategies into their health system. Embracing these global practices can offer Kenya valuable insights and hasten its journey towards a sustainable healthcare future (Participant 16).

7) Strategic planning

Development agencies (Participant 06 & 15) underscore the importance of incorporating strategic guidelines and planning for mitigation and adaptation strategies. Similarly, a private hospital (Participant 21) incorporated a five-tier strategy. One of these tiers focused on sustainable growth, with an emphasis on going green. It signifies a growing awareness and commitment at the micro-level towards GHG mitigation in healthcare.

A national government representative (Participant 16) provides a broader perspective on the issue. Emphasizing the need for self-reliance, they contend that while external funding is beneficial, the true crux lies in sound financial planning and allocation directly related to strategic planning. Instruments that enable healthcare institutions to face committees, effect budgets, and secure allocations are paramount. This representative also draws upon personal experience, emphasising the need for evidence-based budgeting informed by strategy.

8) Legislation, policies and guidelines

A need is identified of legislation around the supply chain, specifically focusing on a mechanism wherein suppliers take back redundant or disposable (Participant 06). A faith-based health services representative (Participant 09) further highlights the pressing need for comprehensive policy changes and infrastructure development to handle health facility waste, given the prevalent use of non-renewable energy sources like firewood and diesel.

A representative of the supply chain (Participant 19) asserted the pivotal role of policy frameworks, especially in fostering collaborations with the private sector. Insights from a private hospital (Participant 21) and the health workforce (Participant 11) further underscore the significance of breaking down policies into actionable and comprehensible guidelines for daily practice, thereby enabling the translation of overarching aims into tangible results.

The intergovernmental representative (Participant 14) accentuates the existence of a robust legal framework in Kenya, particularly highlighting the Climate Change Act and the Constitution 2010, both of which emphasize the citizens' right to a clean and healthy environment. This emphasis on the legalities of environmental policies is further explored by the perspective from academia (Participant 09) who suggests the mandatory use of renewable energy sources, such as solar energy, in healthcare institutions.

9) Education and capacity building

The role of government in its potential in utilizing the education system to educate on GHG mitigation is evident from a building design expert (Participant 03). Additionally, voices from the health workforce articulate the need for specialized training for health workers, emphasising the value of the mobilization of existing medical associations for discussions and training dissemination (Participant 10). There is a need for curriculum integration that ingrains sustainability, life cycle thinking, and proactive training for the entire hospital staff (Participant 01). National government representatives also reiterate the essence of aligning healthcare training across various sectors (Participant 15 & Participant 16).

From the non-governmental sector, the foundational role of capacity building is emphasized as a precursor to any successful implementation (Participant 18). The discussion also highlights the need for improved knowledge management systems, given the limited research available. Lastly, the health workforce indicates the necessity of reframing climate change as a direct health issue, noting its consequential impact on healthcare finances and service delivery. Leveraging media for public education and emphasizing climate change as a healthcare concern appears to be pivotal, showcasing the multifaceted nature of the transition towards a net-zero healthcare system (Participant 12).

10) Engagement

Drawing from insights provided by a representative from building design, achieving net-zero in healthcare hinges on interdisciplinary collaborations. As healthcare entails multiple departments from health workers to waste managers, their alignment is important towards transformation (Participant 03). A representative of the health workforce underscores the untapped potential of grassroots engagement, particularly through community health workers and volunteers (Participant 20).

A pivotal challenge identified across interviews concerns the effective mobilisation and engagement of Kenya's 47 counties. The regional and policy layers provide the structure through which global commitments can be trickled down and effectively implemented. Their centrality in healthcare provision makes their alignment and prioritisation of the net-zero transition vital (Participant 10 and Participant 16). Further, the need to break out of siloed operations and embrace more encompassing, integrated strategies is a recurring theme, stressing the need for engagement from private sectors, faith-based communities, and other stakeholders (Participant 20 & Participant 17). Strategic collaborations can leverage strengths, resources, and knowledge to bridge existing gaps (Participant 09 & Participant 07). Significantly, this transition towards a net-zero healthcare system is not an isolated endeavour but is intricately woven with other broader global, national, and local commitments and realities.

11) Implementation

One prominent challenge is the gap between policy formation and its tangible implementation. As highlighted by the representative from the faith-based health services, the presence of policy and guidelines is just a starting point. Actualizing these into tangible outcomes demands significant transformations, which may involve comprehensive shifts in infrastructure, resource allocation, and stakeholder collaboration (Participant 09).

Furthermore, a national government representative suggested a comprehensive approach to encourage sustainable practices across different sectors of the economy. For instance, promoting alternative modes of transport, such as cycling, necessitates not only the provision of appropriate infrastructure but also considerations of safety and security, especially for vulnerable groups like women. Public awareness, sensitization, and offering the public complete information to make informed decisions also emerged as paramount (Participant 16).

12) Behavioural change

Investments in infrastructural or procedural changes will be rendered ineffective if they are not complemented by collective behavioural adjustments, emphasising the human-centric nature of such transformations (Participant 06). Building on this, a stakeholder from the supply chain provides a historical context by drawing parallels with the behavioural transformations required during HIV campaigns. The decade-long journey of destigmatizing HIV and encouraging treatment adoption underscores the intricacies involved in shifting public perceptions and practices. Beyond healthcare procedures, this transformation journey also challenges deep-seated cultures such as overstocking and wastage prevalent in the system, often justified by donor-funding mindsets. Given the vast number of public health facilities in Kenya, this behavioural change, reminiscent of a cultural overhaul, is not only imperative but also complex, demanding multi-faceted strategies and prolonged commitment (Participant 20).

13) Monitoring and follow-up

The need for relevant key performance indicators (KPIs) that genuinely reflect the transformational efforts being made was stated (Participant 06). This sentiment is further elaborated upon with internal monitoring mechanisms, such as the deployment of steering committees spanning various critical departments like transport, procurement, and waste management. These committees not only foster continuous dialogues on goals and challenges but also inculcate a sense of clinical priority, ensuring constant monitoring and regular follow-up. A private hospital accentuated their evolving journey of recognizing and then acting upon indicators like energy, waste, and water. This led to target-setting, with the establishment of monitoring mechanisms embedded directly into the balance scorecards of individuals, thereby ingraining responsibility and accountability (Participant 21).

There is an evident demand for the government's intervention, which could materialize in the form of registration frameworks and policies, as echoed by a faith-based health service provider (Participant 09). This perspective aligns with the insights from an NGO offering health services, which emphasizes the potential role of the Ministry of Health in assessments (Participant 18). An intergovernmental representative offers innovative suggestions like color-coded compliance systems, which might streamline the monitoring process (Participant 14). Moreover, a national government representative elaborates on a broader, strategic framework involving the National Assembly, emphasizing the significance of policy formulation and fund allocation (Participant 16). This macro view is complemented by a micro perspective that stresses the importance of follow-up post-training sessions, to gauge the effectiveness of capacity-building measures (Participant 17).

14) Reporting, transparency and recognition

A representative from a development agency emphasized the necessity of transparency in reporting mechanisms, relating it to the importance of accurate representation of data to stakeholders (Participant 06). The intent is not just monitoring but also ensuring that efforts towards transformation are correctly documented and acknowledged. The representative from a tertiary private hospital brings forth an aspiration of adhering to internationally recognized standards (Participant 21). Such recognitions not only validate the efforts of the healthcare systems but also provide them with a global benchmark against which progress can be gauged.

Appendix IX Supplementary Information to The Role of Health Workers in Kenya's Net-Zero Transition: A Mixed-Methods Study on Healthcare System Climate Change Mitigation and Adaptation

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Appendix 1 Full Questionnaire

Participant Information Sheet

Title of Project: Greenhouse gas mitigation of the Kenyan healthcare system

Introduction

We would like to invite you to take part in a research study. Joining the study is entirely up to you. Before you decide, you need to understand why the research is being done and what it would involve. Ask questions if anything you read is not clear or you would like more information. Please feel free to talk to others about the study if you wish. Take time to decide whether or not to take part.

What is the purpose of the study?

Climate change is having and is increasingly expected to have direct and indirect effects on health. Healthcare systems should adapt to deal with these effects, whilst mitigating their own greenhouse gas emissions to not further contribute to the health emergency. This poses an opportunity for healthcare systems to advance in an environmentally sustainable manner. A key challenge is to identify pathways towards advancement whilst mitigating emissions in healthcare systems, with a particular evidence gap in Low- and Middle-Income Countries.

The London School of Hygiene and Tropical Medicine (LSHTM) are conducting research on greenhouse gas mitigation of healthcare systems and particularly in Kenya to identify lessons learned, pathways, opportunities, barriers and solutions towards greenhouse gas mitigation of healthcare systems and through that create recommendations for more environmentally sustainable healthcare.

Why have I been asked to take part?

You have been invited because we believe your knowledge, experiences and expertise will contribute to a better understanding of this topic and we would like to build our research and recommendations on your guidance.

Do I have to take part?

No. It is up to you to decide to take part or not. If you don't want to take part, that's ok.

What will I have to do?

Participate in a questionnaire which will take approximately 10 minutes to fill out.

What are the possible risks and disadvantages?

Because this study only involves participating in a questionnaire we do not anticipate any harm or discomfort for you other than the time it will take you to participate in the questionnaire. There are two potential risks with a low likelihood of occurring, which are information risks (e.g., loss of privacy and/or breach of confidentiality), for which a data management plan is in place, ethical approval and data regulation is sought, and all researchers carry legal responsibility to minimize this risk as much as possible, and psychological or emotional risks (e.g., fear, stress, confusion, guilt) which will be minimized by information provision and contact information for any questions.

What are the possible benefits?

We cannot promise the study will help you but the information we get from the study will help our knowledge and understanding of this research area of greenhouse gas mitigation of healthcare systems.

What if something goes wrong?

If you have a concern about any aspect of this study, you should ask to speak to the researchers who will do their best to answer your questions: 00000000000 / 0000000000. If you remain unhappy and wish to complain formally, you can do this by contacting: 00000000000 at 00000000 or 0000000000.

The London School of Hygiene and Tropical Medicine holds insurance policies which apply to this study. If you experience harm or injury as a result of taking part in this study, you may be eligible to claim compensation.

Can I change my mind about taking part?

You can withdraw from the study at any time. If you wish to withdraw, we will securely keep your recorded contribution up to the point of withdrawal. If you withdraw, you can choose to still include your contribution in the anonymised transcript or request that we remove all your comments from the final transcript and written records. If you withdraw, you can choose whether we retain your personal information after withdrawal or remove it from our records.

What will happen to information collected about me?

We will need to use information from you. All information collected about you will be kept private. Only the study staff and authorities who check that the study is being carried out properly will be allowed to look at information about you. Information will include your name, gender, age, contact details and position. We will keep all information about you safe and secure.

Data may be sent to other study staff in London, but this will be anonymised. This means that any information about you which is shared beyond the chief investigator and the two supervisors, will have your name and address removed so that you cannot be recognised and your data will have a code number instead.

Your personal details, meaning your name and other identifiable information, will be kept in a different safe place to the other study information and will be destroyed within 10 years of the end of the study.

At the end of the project, the study data will be archived at the data compass at the London School of Hygiene & Tropical Medicine. The data will be made available to other researchers worldwide for research and to improve medical knowledge and patient care. Your personal information will not be included and there is no way that you can be identified.

What will happen to the results of this study?

The study results will be published in a medical journal so that other researchers and policymakers can learn from them. Your personal information will not be included in the study report and there is no way that you can be identified from it.

Who is organising and funding this study?

London School of Hygiene & Tropical Medicine is the sponsor for the research and they have full responsibility for the project including the collection, storage and analysis of your data, and will act as the Data Controller for the study. This means that we are responsible for looking after your information and using it properly.

Funding for the study has been provided by the Prince Bernhard Culture Fund, Stichting VSBFonds and the dr. Hendrik Mullerfonds. The funders play no role in study design, conduct, data analysis and interpretation, manuscript writing, and dissemination of results.

Who has reviewed this study?

All research involving human participants is looked at by an independent group of people, called a Research Ethics Committee, to protect your interests. This study has been reviewed and given favourable opinion by The London School of Hygiene and Tropical Medicine Research Ethics Committee (28210). The Kenya Medical Research Institute approved the study (4662), and the National Commission for Science, Technology and Innovation provided a license (519115).

Further information and contact details

Thank you for taking time to read this information sheet. If you think you will take part in the study please read and sign the consent form on the next page of the form.

If you would like any further information, please contact Dr Iris Martine Blom who can answer any questions you may have about the study.

Contact details:

Dr Iris Martine Blom

Email: 0000000000000000

Telephone: 000000000000

If you have any concerns about the study please contact the head of research governance at LSHTM 000000000000 at 0000000000 or 000000000.

Consent Form

Please write your full name below* [* indicates mandatory question]

Your answer

*

- I have read the written information OR

- I have had the information explained to me by study personnel in a language that I understand,

and I*

Confirm

- confirm that my choice to participate is entirely voluntarily,
- confirm that I have had the opportunity to ask questions about this study and I am happy with the answers that have been provided,
- understand that I allow access to the information about me by the persons described in the information sheet,
- agree to be quoted anonymously in the study findings,
- agree for anonymised data from my questionnaire to be stored at the London School of Hygiene & Tropical Medicine until all study outputs are completed, and shared with other researchers on request in future
- had enough time to think about whether I want to take part in this study,
- agree to take part in this study.
- confirm that my choice to participate is entirely voluntarily,
- confirm that I have had the opportunity to ask questions about this study and I am happy with the answers that have been provided,
- understand that I allow access to the information about me by the persons described in the information sheet,
- agree to be quoted anonymously in the study findings,
- agree for anonymised data from my questionnaire to be stored at the London School of Hygiene & Tropical Medicine until all study outputs are completed, and shared with other researchers on request in future
- had enough time to think about whether I want to take part in this study,
- agree to take part in this study.

Background Information

Are you a health professional or student?*

- Health professional
- Student

Do you work or study in Kenya?*

- Yes

What is your primary health profession or study? *

- Medical doctor: Specialist
- Family doctor
- Medical doctor: junior doctor
- Medical doctor: resident
- General practitioner
- Medical student
- Nurse
- Nurse practitioner
- Nursing student
- Physiotherapist
- Physiotherapy student
- Nutritionist
- Nutrition student
- Midwife
- Midwifery student
- Dentist
- Dentistry student
- Dietitian
- Dietitian student
- Community healthcare worker
- Pharmacist
- Pharmacy student
- Other:

What is your specialisation?*

- Choose

What County do you primarily work in now? *

- Choose

What type of healthcare provider do you work for?*

- Public healthcare provider (e.g. national, county, sub-county hospitals)
- Private healthcare provider (e.g. AAR, Aga Khan, MP Shah)
- Faith-based healthcare provider (e.g. Kijabe, Tenwek, Matter)
- NGO-based healthcare provider (e.g. Amref Clinics)
- Other:

What is your sex?*

- Male
- Female

What is your age?*

- Choose

Would you like to receive a summary of the outcomes of this study?*

- Yes
- No

What is your email address? If you answered yes to the previous question, please note down your email address here which will be used to share the summary of the outcomes of the study with you.

Your answer

Climate change & health

On a scale from 1 to 10, how would you rate your knowledge of climate change and health?*

Very limited knowledge (1) - Very extensive knowledge (10)

Please rate how much you agree with the following statements:*

Strongly Disagree – Disagree - Somewhat Disagree - Neither Agree nor Disagree - Somewhat Agree – Agree - Strongly Agree

- Climate change is a major threat to health.
- I witness the effects of climate change on health in my practice.
- Greenhouse gas emissions are a major threat to health.
- Air pollution is a major threat to health.
- Climate change is a major threat to health.
- I witness the effects of climate change on health in my practice.
- Greenhouse gas emissions are a major threat to health.
- Air pollution is a major threat to health.

Practice

Please rate how much you agree with the following statements:*

Strongly Disagree – Disagree - Somewhat Disagree - Neither Agree nor Disagree - Somewhat Agree – Agree - Strongly Agree

- The healthcare system is currently taking reducing greenhouse gas emissions into consideration in healthcare practices.
- Kenya can achieve its commitment to a net-zero healthcare system by 2030 (this means that the net amount of greenhouse gas emissions added to the atmosphere by the healthcare system is zero).
- Reducing greenhouse gas emissions should be incorporated into healthcare practices.
- Health workers should take a leading role in advocating for reducing greenhouse gas emissions in the healthcare system.
- Health workers should take a leading role in implementing the reduction of greenhouse gas emissions in the healthcare system.
- The current state of our environment (including the rate of climate change) is concerning.
- I am interested in learning how to reduce greenhouse gas emissions in my healthcare practice.
- The government has to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- The private sector (producers, pharmaceutical companies, etc.) has to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- Health workers have to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- Leadership in communities (counsellors, chiefs etc.) has to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- Individuals have to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- The healthcare system is currently taking reducing greenhouse gas emissions into consideration in healthcare practices.
- Kenya can achieve its commitment to a net-zero healthcare system by 2030 (this means that the net amount of greenhouse gas emissions added to the atmosphere by the healthcare system is zero).
- Reducing greenhouse gas emissions should be incorporated into healthcare practices.

- Health workers should take a leading role in advocating for reducing greenhouse gas emissions in the healthcare system.
- Health workers should take a leading role in implementing the reduction of greenhouse gas emissions in the healthcare system.
- The current state of our environment (including the rate of climate change) is concerning.
- I am interested in learning how to reduce greenhouse gas emissions in my healthcare practice.
- The government has to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- The private sector (producers, pharmaceutical companies, etc.) has to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- Health workers have to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- Leadership in communities (counsellors, chiefs etc.) has to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.
- Individuals have to take responsibility in terms of reducing greenhouse gas emissions in the healthcare system.

Measures

In your opinion, which part of the healthcare system causes the highest emissions in Kenya?*

- Emissions emanating directly from healthcare facilities and healthcare owned vehicles.
- Indirect emissions from purchased energy sources such as electricity, steam, cooling, and heating.
- The production, transport, and disposal of goods and services, such as pharmaceuticals and other chemicals, food and agricultural products, medical devices, hospital equipment, and instruments.

Have you already implemented interventions to reduce greenhouse gas emissions in your health practice? If so, which ones?*

If so, please use the 'other' box to type yes and explain how.

- No
- Other:

Are you planning to implement interventions to reduce greenhouse gas emissions in your health practice? If so, which ones?*

If so, please use the 'other' box to type yes and explain how.

- No
- Other:

Are you interested to implement interventions to reduce greenhouse gas emissions in your health practice?*

- Yes
- No

What are your ideas for interventions that should be implemented to reduce greenhouse gas emissions in the healthcare system in Kenya?*

Opportunities & Barriers

Are there key opportunities to implement successful measures to reduce greenhouse gas emissions in the healthcare system? If so, what are they?*

Your answer

How can these opportunities be used to the best advantage?*

Your answer

Are there key barriers to implementing successful measures to reduce greenhouse gas emissions in the healthcare system? What are they?*

Your answer

How can these barriers be overcome?*

Your answer

How are or should these measures be funded?*

Your answer

Adapting to the impact of climate change

To deal with the impacts of climate change, the healthcare system needs to transform and adapt to these impacts. How can this adaptation be considered when reducing greenhouse gas emissions in the healthcare system?*

Your answer

Is adapting the healthcare system currently being considered and if so, how?*

If so, please use the 'other' box to type yes and explain how.

- No
- Other:

General

Does Kenya need to change its approach to zero emissions of the healthcare system if it is going to be successful? If so, what does it need to do? *

If so, please use the 'other' box to type yes and explain how.

- No
- Other

Appendix 2 Focus Group Topic Guide

Session Duration: 2.5 hours

1. Welcome and Introduction (15 minutes)

- Welcome participants and outline the session objectives.
- Present questionnaire outcomes (5 minutes): Provide a brief overview of key findings, focusing on identified knowledge gaps, barriers, and opportunities for action.
- Share the NCCAP document (briefly explain its significance).
- Review focus group structure, emphasizing confidentiality and the value of their contributions.
- Facilitate introductions: Ask each participant to state their role and their organization.

2. Framing the Discussion: Setting the Context (20 minutes)

- Prompt 1: Are you familiar with these relevant policies and commitments at the national level and their relevance to healthcare?
    - Follow-up: Do you feel ownership of these goals in your role? Why or why not?
- Prompt 2: Climate-related health challenges are becoming more pressing globally and locally. What specific challenges have you faced in this area within your work?

3. Exploring Knowledge, Skills, and Behaviours (30 minutes)

- Prompt 3: What specific knowledge or skills do you feel are most urgently needed for health workers to address climate-related health challenges?
    - Follow-up on Practicality: And are there specific resources or tools that would help? you apply these skills?

    - Ask about examples: “Can you share situations where specific knowledge or skills were missing or made a difference?”

4. Framework Exploration and Educational Needs (25 minutes)

- Prompt 7: Education can help learners understand the interconnectedness between different levels:
    - Micro (individual): How personal action influences wider systems.
    - Meso (community): How communities act collectively and engage with individuals and institutions.
    - Macro (institutional): How institutions drive broader system-wide change.
    - Meta (universal): How global values and systems shape education for sustainability.
    - Discussion: In your experience, how can education for health workers foster understanding and action across these interconnected levels?

5. Practical Solutions and Next Steps (30 minutes)

- Prompt 8: If education or training were developed for health workers:
    - What should it focus on?
    - What should it look like?
    - Historically, healthcare education frameworks might be influenced by Western approaches. How can education for health workers better integrate local knowledge systems and community-specific practices?

- Prompt 9: Based on today’s discussion, what are the most practical steps we can take to improve climate-health education for health workers in Kenya? What actions can be taken at individual, organizational, and policy levels?

6. Power Dynamics and Engagement (20 minutes)

- Prompt 5: When it comes to implementing education or training on climate and health, what role do different stakeholders play (e.g., senior management, younger professionals, policymakers)?

- Prompt 6: Younger professionals and students often report being more engaged in issues around climate and health but having limited decision-making power. Does this play a role in efforts to integrate climate and health into health education and practice?

7. Wrap-up and Reflection (10 minutes)

- Summarize key themes and insights shared during the discussion.
- Open the floor for any final reflections or additional thoughts participants would like to share.
- Explain next steps: How the insights will inform further analysis, recommendations, or actions.
- Sharing contact details in case of any questions, comments or additions.

Appendix X Establishing carbon management systems to reduce emissions in healthcare

Fawzia N. Rasheed[1], Muhammad Imran[2], Pacifique Mukamusangwa[3], Muhammad Najam[2], Muhammad Imad-ud-din[2], Iris M. Blom[4], Brama Kone[5], Mazen Malkawi[6], Saleh Rababa[6], Mona Khaleghy Rad[7], Rahim Taghizadeh Asl[7], Mohamed Eissa[8], Gijs Walraven[1]. (53)

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[8] World Health Organization (WHO) Egypt Country Office, Cairo, Egypt

Abstract

In response to findings that healthcare significantly contributes to global greenhouse gas emissions (GHGe), there is increased attention on ways to decarbonise health service delivery. Any effort to effectively reduce carbon emissions must begin with identifying and quantifying their sources. It is only once the contributing factors of carbon emissions are understood, that corrective actions can be identified and planned. However, despite many governments declaring commitments to net zero healthcare targets between 2030 and 2060, it is at the very first step of evaluating emissions that most are stuck. Up until recently, assessing carbon emissions has been a technically complex undertaking, requiring time and expensive sustainability expertise. To overcome these hurdles, the Aga Khan Development Network (AKDN) built an all-in-one, simple-to-use tool designed for use by non-specialist general healthcare staff. The resulting tool has been extensively field tested and used. Through direct engagements and via a collaboration with the World Health Organization (WHO), representatives of Ministries of Health and Environment around the world have received orientation training in how to get started. Developments since, and recommendations to accelerate progress, are covered in this paper.

Introduction

If left unaddressed, the impacts of climate change threaten to undermine gains made in public health over the last 50 years(1,2). Paradoxically, health systems not only have to cope with the health consequences of climate change(3,4), but are also contributing to the crisis, emitting 4-5% of GHGe(5). As such, there is a tactical as well as an ethical imperative for the health sector to reduce its carbon emissions. Furthermore, efforts to reduce carbon emissions in healthcare contribute to increased staff morale and patient trust(6) and often reduce costs(2,3) and thereby contribute to the sustainability of healthcare itself. In other words, decarbonising healthcare has a multitude of co-benefits that combine to make it a priority investment opportunity.

The first step to getting started, upon which all progress is contingent, is to evaluate carbon emissions. This far, 76 Ministries of Health have committed to reducing carbon emissions, of which, 27 have committed to achieving net zero operations by specific dates ranging between as early as 2030 up until 2060(7). That said, the majority of these countries have not started benchmarking emissions from their health sector(8,9).

In theory, calculating carbon emissions would ideally be handled by existing staff embedded within institutions for the following reasons: i) externally sourced expertise is expensive and in short supply; ii) consultant groups use a variety of methodologies, which can add to difficulties with tracking progress over time and making comparisons between institutions; a multiplicity of methods can also confound transparency and undermine trust and confidence in results; iii) actions to reduce carbon emissions require staff awareness, commitment and engagement. As such, embedding data collection within operations through staff can be expected to result in greater understanding and engagement than if this function were outsourced. However, until recently, assessing carbon emissions has not been straightforward. This paper covers progress with developing a tool simple enough for non-specialists to use and reviews some examples of attempts to introduce systems to evaluate and manage carbon emissions within institutions. The experience of the Aga Khan Health Services (AKHS) is shared, alongside progress made by some Ministries of Health.

Methodology

The Development of the AKDN carbon management tool

AKHS began efforts to reduce its carbon footprint in 2019. The agency initially tried carbon calculation tools which were available online, but staff found difficulties with working with these. Multiple tools were required to estimate carbon emissions for different areas. Each tool had different instructions and the results generated required a separate consolidation step to form a comprehensive picture. Based on this experience, a decision was taken to create a single calculating instrument – henceforth referred to as 'the Tool' – and to make it simple to use by regular health facility staff with minimal training.

The Tool was co-developed with eventual users and went through several iterations and field-testing. The process of pilot testing and refining the Tool took over seven months and included 400 health facilities and hospitals in eight countries: Afghanistan, India, Kenya, Kyrgyzstan, Pakistan, Syria, Tajikistan and Tanzania.

Excel was chosen because of widespread familiarity with its use, and because the files are light-weight and can be shared by email. Excel also allowed for working offline which overcame problems for facilities that had irregular internet access. The best available science and internationally recognised standards for carbon conversion factors were used(10–12). To cater for all countries, country-specific carbon intensities for grid electricity were included(13,14) with an option to further customise this data using sub-national data where available. As those new to the field had difficulties understanding the Greenhouse Gas Protocol nomenclature(15) that allocates emissions data into scopes (scope 1 emissions arise from sources that are owned or directly controlled by the entity and largely reflect operational activity; scope 2 emissions are those that the entity is indirectly responsible for and largely stem from its use of energy from the electricity grid; and scope 3 emissions are those that are not produced by the entity itself and are not the result of activities from owned or controlled assets, but arise from those that it is indirectly responsible for up and down its value chain and reside mostly in the supply chain), the Tool was designed to automatically generate results by these categories.

The Tool was designed to work with data that is routinely available in organisations for electricity, fuel, water, refrigerants, inhalers, waste and anaesthetic gases as well as contractor logistics. Sources for these data included bills, meter readings, log books as well as waste and travel records. For the supply chain, which represents the majority of (indirect scope 3) healthcare emissions (the National Health Service, UK (NHS, UK)) reports over 60%; whereas this proportion for AKHS operations ranges from 70-90%), a novel evaluation methodology was developed to form estimates based on financial data – specifically the amounts spent on different categories of items and publicly available information on suppliers' financial reports. This methodology is published elsewhere(16).

The Tool allows for starting with whatever data is available and working towards more complete and accurate data with time. For instance, in the absence of facility-based data, the Tool can generate a 'high level' but rough estimate of carbon emissions using the financial data of operations (otherwise referred to as a 'top down' approach). The Tool is otherwise geared to work with 'bottom up', facility-based data as this helps users identify the sources of carbon emissions by facility without which developing remedial actions and tracking progress is not possible(7,17).

Refinements to the Tool over the development period included self-explanatory instructions within the Tool itself; the addition of factors common to Low-and Middle-Income Countries (LMICs) such as diesel (commonly used for generators) and wood and coal (as sources of fuel for heating); and making data entry as 'fool-proof' as possible, such that obvious errors would prompt a colour alert. Functions were also added to help users save time, such as drop-down lists and the ability to enter the names of facilities just once after which the names would automatically feature on all other sheets. A detailed account of the features is published elsewhere(18).

Following extensive field testing within AKHS, the tool was reviewed by WHO(19) and shared with countries through Ministries of Health and Environment and made publicly available together with a step-by-step guide for users (French and English versions) and, more recently, orientation videos as well through the Alliance for Transformative Action on Climate and Health (ATACH) website(20).

Training on the use of the Tool

Training was provided initially within AKHS and then outside AKHS to WHO, Ministries of Health and other agencies. Both experiences are detailed below.

AKHS

Training for AKHS staff was provided by the developers of the Tool through virtual calls and typically took an hour and a half, with addressing some follow-up questions as staff started inputting data. In instances of staff changes, those that had been trained were able to train their replacements without additional help.

WHO, Ministries of Health and other agencies

Representatives of WHO, Ministries of Health and Environment and other agencies were trained by AKHS upon direct request and through events coordinated by WHO at country or regional levels. The WHO

Regional Office for Africa (AFRO), WHO Regional Office for Eastern Mediterranean (EMRO) and WHO Regional Office for South-East Asia (SEARO) were involved. These and other events also included donors, local NGOs, private individuals, consultants and academia. Training events (in English and French) ranged from a couple of hours to half- or full-day events, depending on the interest expressed and time availability of participants. In some instances, repeat events were scheduled to allow for practice exercises and instruction on interpreting and designing interventions around results, and making projections on the impact of interventions on carbon and costs. Following the first training event, which was conducted in-person, the training method was adapted to enable all subsequent training to be conducted remotely.

Results

Participants involved in training are captured in Figure 1.

Fig 1: Training participants by sector and country

Sector	N*	Countries / Agencies
Ministries of Health	142	Bahrain, Bangladesh, Bhutan, Botswana, Burkina Faso, Cameroon, Central African Republic, Cape Verde, Congo, Ivory Coast, Egypt, Guinea, Indonesia, Iran, Jordan, Kenya, Kuwait, Madagascar, Malawi, Maldives, Morocco, Nepal, Nigeria, Oman, Qatar, Rwanda, Saudi Arabia, Sierra Leone, South Africa, Sri Lanka, Sudan, Syria, Tanzania, Thailand, Timor, Trinidad and Tobago, Togo, Tunisia, Uganda, United Arab Emirates, Yemen
Ministries of Environment	42	Bahrain, Cape Verde, Indonesia, Iran, Iraq, Jordan, Oman, Pakistan, Palestine, Qatar, Saudi Arabia, Thailand, Timor
WHO	85	Bangladesh, Bahrain, Bhutan, Burma, Cape Verde, Central African Republic, Congo, Ivory Coast, Egypt, Ethiopia, France, Ghana, Guinea, India, Indonesia, Iran, Iraq, Jordan, Kenya, Lebanon, Liberia, Madagascar, Maldives, Mauritania, Morocco, Mozambique, Nepal, Nigeria, Oman, Pakistan, Palestine, Qatar, Rwanda, Sao Tome and Principe, Sierra Leone, South Africa, Switzerland, Togo, United States, Yemen
Academia	98	Bangladesh *(North South University),* Iran *(Universities of Medical Sciences at Ahvaz, Beheshti, Tabriz, Tehran, Zahedan, Zabol),* Ivory Coast *(Centre Suisse de Recherches Scientifique en Côte d'Ivoire (CSRS); Université Cocody; Université de Man- Côte d'Ivoire; Université NANGUI ABROGOUA (UNA); Université Péléforo Gon Coulibaly de Korhogo (UPGC))* , Jordan *(German Jordanian University; Jordan University of Science and Technology),* Kenya *(University of Nairobi),* Lebanon *(University of Balamand),* Morocco *(Hassania High School for Public Works for Engineers (EHTP); Université Mohammed VI des Sciences et de la Santé),* Mozambique *(Universidade Eduardo Mondlane (UEM)),* Qatar *(College of Science and Engineering-Qatar; Qatar Environment and Engineering Research Institute),* Rwanda *(National University of Rwanda School of Public Health),* South Africa *(Witwatersrand Reproductive Health Institute),* South Korea *(Global Green Growth Institute),* United Kingdom *(London School of Hygiene and Tropical Medicine; Nottingham Trent University; Oxford University; University of York),* United States *(University of California; Yale University).*
Donors + Development organisations	5	Agence Française de Développement, German Development Agency GIZ, Qatar Foundation, Swiss Development Agency, The Global Fund to Fight HIV/AIDS, Tuberculosis and Malaria

Private health care / Individual consultants	128	Algeria, Botswana, Cameroon, Canada, Cape Verde, Congo, Ethiopia, France, Ghana, Guinea, India Jordan, Kenya, Liberia, Mauritania, Mozambique, Nigeria, Portugal, Qatar, Rwanda, Sierra Leone, South Africa, Spain, Switzerland, Tanzania, Togo, United Kingdom, United States
NGOs	60	Afghanistan, Bangladesh, Bhutan, Canada, Germany (*WASH Society*), Indonesia (*Eksekutif Yayasan Konservasi Way Seputih*), Jordan (*Jordan Health Aid*), Kenya (*Kenya Medical Research Institute*), Lebanon (*Health & Environment Response Agency (HERA)*), Mozambique, Nepal, Pakistan, Qatar (*World Innovation Summit for Health; Earthna*), Sierra Leone, South Africa (*Climate and Health Alliance*), Switzerland (*Terre des Hommes; International Hospitals Federation*), United Kingdom (*Centre for Sustainable Healthcare, Mannion Daniels, WaterAid*)
Total	**560**	

*N= number of individuals as of April 2024

Experience with establishing carbon management systems

Following training, progress with and experience of establishing carbon management systems varied greatly. Accounts from AKHS and from Ministries of Health are presented below.

AKHS

Evaluating emissions

Within six months of training, by mid-2020, all AKHS country operations had established carbon monitoring systems using existing staff. Staff were drawn from different disciplines which included departments of health and safety, project management, procurement, finance, and facility management. In all cases, staff were tasked with data collection on top of other duties. Following training, staff collected and reported on data quarterly(18) across operations (400 facilities in eight countries) including community-based, primary, secondary health facilities, and tertiary hospitals. Data checks by a specialist over a year confirmed that the Tool was being used consistently and correctly.

Staff were guided to begin data collection from the largest facilities as these would have the highest carbon footprint and to start with whatever data they could get and aim for collecting more with time. These staff were also tasked with supporting staff in smaller facilities to collect their own data.

Feedback indicated no difficulties with locating data for electricity and fuel, but data on refrigerants, anaesthetic gases and inhalers required liaising with other staff and particularly those responsible for procurement. Collecting data for the supply chain was consistently reported to be the hardest as this depended on inputs from persons responsible for finance and procurement. However, once staff identified the sources of data, they reported subsequent data collection to be straightforward.

Reducing emissions

Initial data showed that globally around 80% of AKHS' overall (scopes 1, 2 and 3) carbon footprint came from its supply chain(18), with the remaining 20% from grid electricity, generators, anaesthetic gases, refrigerators, travel and waste. To develop remedial actions, AKHS started developing net zero action plans for the larger operations that represented the greatest part of its footprint. While these plans were being designed, staff were directed to start implementing no-cost changes and to focus on the following areas and actions:

- *The supply chain:* Rationalise purchases and avoid disposable products wherever possible in favour of instruments that could be reused / sterilised. Use the guidelines developed by the NHS, UK(21), to promote purchasing from suppliers that report their carbon emissions and net zero targets and those that avoided or would take back plastics in packaging and plastic containers.
- *Anaesthetic gases:* Rationalise the use of anaesthetic gases over other (no gas) options, choose the least carbon-intensive option, and aim for conserving gases during procedures(22),
- *Inhalers:* Use dry powder equivalents instead of propellant-based inhalers wherever clinically possible(23);
- *Waste:* i) Increase recycling (paper, cardboard, glass and tin); ii) divert food waste to animal feed and for composting; iii) minimise incineration through improved waste segregation and monitoring(24); iv) promote the use of reusable or biodegradable food containers and utensils.
- *Transport:* Conduct an audit to identify options for minimising travel including: use of digital meetings, rationalising the use of (fuel - efficient) vehicles and numbers of trips and using economy instead of business class options.
- *Food:* Promote healthy, low-carbon food options(25), and phase out junk food and soft drinks.

As part of the net zero action plans, inventories of lights, air conditioners and refrigerators were made and compared to the most energy-efficient models on the local market. Savings of carbon emissions as well as costs for energy (diesel and electricity) were calculated for better options. Following this exercise, the energy needs and potential for solar installations were evaluated. This sequencing ensured that the size of solar installations was not over estimated.

AKHS estimated costs for energy-efficient equipment and solar installations that would reduce its carbon footprint for its scope 1 and 2 emissions by 60%. After calculating the savings in energy costs, it was clear that the investment would pay for itself in under six years (at 2022's energy prices). Given the attractive business case, finances were secured(26).

WHO staff and Ministries of Health

Establishing carbon monitoring

Following initial training, while there may be additional experience that the authors are unaware of, instances of the public health sector using the Tool have been reported from Bangladesh, Ivory Coast, Egypt, Guinea, Kenya, Pakistan, South Africa, Thailand, Togo, and Zambia through WHO personnel and via a questionnaire applied to those who participated in training. Additional countries that have reported plans to begin the process soon included Madagascar, Sierra Leone, Liberia and Qatar, United Arab Emirates, Morocco, Jordan, Kuwait, Bahrain, Botswana, Burkina Faso, South Africa, Cabo Verde, Congo, Malawi, Nigeria, Rwanda and Uganda.

In most instances, carbon emissions evaluation did not start directly after training. Many countries did not have a body in place ready or with powers to delegate staff for this work. Some of the people trained had no defined ongoing responsibilities. Decisions on whether all facilities or a sub-sample would be included, often took place after training. Some countries reported delays resulting from unsuccessful efforts to seek funds which they required before starting.

Of the countries that reported progress, all began with a training of trainers' program and committees to oversee the process. As advised, all began with a pilot effort before embarking on a full roll out program. Such countries have included public institutions, consultants and academia in lead and support roles and have received technical support from WHO.

To illustrate different approaches the following examples are provided:

Iran

Iran's efforts on climate within the Ministry of Health and Medical Education are reported to the Presidency through the Department of the Environment, which, in turn, is the national agency responsible for climate change actions. The country is working to a five-year national strategy developed with support from partners including WHO country and WHO / EMRO Climate Change Health and Environment office, academic institutes, and universities of medical sciences. Following an initial training in November 2022 of 24 participants, the tool and training materials were translated into Farsi to increase accessibility. A range of health facilities in the public and private sectors were involved in initial data collection. The results have prompted a decision for all medical universities to work with at least one government hospital to establish goals for decarbonisation. Stemming from results this far, remedial activities have prioritised electricity, natural gas use, waste management and anaesthetic gases.

Guinea

In Guinea, the climate and health related efforts of the Ministry of Health and Public Hygiene (MSHP) are reported to the Presidency through the Ministry of the Environment and Rural Development (MEDD). Efforts within the MSHP are overseen through a governance structure involving regional inspectors and hospital directors, coordinated by the National Directorate of Public Hygiene (DNHP) within the MSHP. An MSHP technical working group is being developed with representation from all departments. Technical partners include WHO representatives within the country and from AFRO as well as persons in MEDD who have been trained on the use of the AKDN tool. Following training in June 2022, selected hospital directors identified focal points for their hospitals resulting in a further 64 personnel trained. Data were collected from May to October 2022 in major public and private facilities. Emissions from 51 healthcare facilities were evaluated comprising 67% of University Teaching Hospitals, 88% of Regional Hospitals, 100% Prefectural Hospitals, 78% Communal Medical Centres, 64% of Private Polyclinics / Clinics (PCP), and 67% of Corporate Hospitals. The results were reviewed by experts in MEDD and the MHPH with a WHO consultant and covered all scopes (1, 2 & 3) including the supply chain. Despite some limitations during data collection, requiring working with estimates and data gaps in some areas, this exercise revealed the broad picture of carbon emissions from the healthcare system of Guinea.

Emissions hotspots were identified from the supply chain which represented the largest component, followed by refrigerant, transport, building energy, grid electricity and waste. Preliminary findings were shared through ATACH with stakeholders and a national report has since been prepared. Based on the findings, recommendations in support of the national sustainability plan are under review and in alignment with the CoP26 commitments. Next steps will involve fund mobilisation and engaging experts to develop a comprehensive decarbonisation plan in 2024.

Togo

In Togo, the climate and health agenda is overseen by the Ministry of Health and Public Hygiene (MSHP), with the General Secretary as the coordinator of the Task Force. A scientific committee has also been formulated involving healthcare directors at regional and district level as well as health training officers to spearhead efforts on this agenda. The GIZ as well as WHO have been providing technical support at all levels. In August 2023, the task force and the GIZ team received an initial training by AKDN on the use of its tool.

Subsequently, data collection began with 20 health facilities. Facilities included university hospitals, regional and district hospitals and social medical centres. Data from the supply chain was not included. In instances where records had not been kept, data was estimated and systems for data retention introduced for the future. Based on the analysis of results, areas prioritised for action included electricity, waste, and transport, which represented most emissions. Several areas have been identified to address in the future, including increased capacity and attention to record keeping and collection for all data areas including the supply chain, raising awareness in healthcare staff that healthcare contributes to carbon emissions and of the importance of reforms, and support to develop action plans and guide interventions.

Egypt

In Egypt, efforts on climate change and health are coordinated by the Ministry of Health and Population, specifically through its Environmental Monitoring unit, which in turn, contributes to the national adaptation plan coordinated by the Ministry of Environment. A carbon footprint assessment was initially conducted for selected healthcare facilities in Sharm El-Sheikh using the AKDN carbon management Tool for all three scopes, and then expanded to additional healthcare facilities across governorates: Cairo, Sharkia, Damietta, Qena, Luxor. These initiatives were coordinated by the ministry, with support from the WHO country and WHO / EMRO Climate Change Health and Environment office WHO / EMRO, UNDP, UNICEF, and other relevant national stakeholders.

The results, including observations of shortfalls of administrative staff and especially data / collection and statisticians, are being fed into the national net zero action and adaptation plans.

Morocco

Morocco's climate change initiatives within the Ministry of Health are coordinated with the Ministry of Energy Transition and Sustainable Development, which is the primary national agency responsible for climate change actions. Supported by WHO and the World Bank, the Ministry of Health and Social Protection launched a national assessment of health care facilities' vulnerabilities to climate change; climate resilience; environmental sustainability; and the carbon footprint within a representative sub-sample for the country.

This initiative was carried out by a group of national experts from the Ministry of Health, academia, and other stakeholders as part of the country's commitment towards a climate resilient and net zero health system. The carbon footprint assessment was carried out for 19 hospitals within nine regions. Initial results shows that approximately 77% of the emissions fell into scope 3. These results will be used to inform health national adaptation planning and the Ministry's strategic plans.

Discussion

The development and field-testing of the free AKDN tool and training represents a significant step in the decarbonisation of healthcare. Unlike many tools, which require specialised knowledge and are fragmented in their approach, this tool simplifies the evaluation and management process, making it accessible to non-specialists. This innovation not only fills a crucial gap in the toolkit available for healthcare decarbonisation but also democratises the process, enabling broader participation and faster progress towards net zero goals. While many staff members of Ministries of Health have been trained, few have made a start. Those that have, have successfully been able to use these materials to evaluate carbon emissions, identify areas for action and gaps in staff needs. Progress is, however, needed on a far wider and quicker footing if health systems are to be fit to meet impending challenges and sustain operations.

The diversity of healthcare systems globally requires flexible approaches for carbon management. Experience within AKHS and with countries that have begun this journey indicate that progress significantly depends on what should be obvious: political commitment, good planning and dedicated and capable human resources. Given that the decarbonisation agenda fortuitously comes with immediate and ongoing financial savings(26–28) the hopes are that as the 'business case' becomes better understood, this ought to add to the momentum for investments in this agenda. As such, concerted efforts should be put behind the message that the sooner and greater the volumes of carbon emissions reduced, the greater the cumulative impact on carbon reductions and the more money saved.

While there can be no single approach for national engagement to get to speed with the urgency needed, the response to Covid-19 could provide cues. The national governance and coordination bodies constituted for Covid-19 responses could be reviewed for their suitability for the climate emergency. Coping with the effects of climate change will require high-level decision-making power to coordinate across sectors and redistribute funds and human resources. As such, the higher the office responsible, the better the chances of reforms.

This work requires intellectual leadership to stay abreast of developments, including new technology, and to customise solutions to local contexts. While WHO and development partners have been supporting start up technical help, it makes sense for countries to identify and invest in local entities that can support ongoing needs and build capacity over time. Some countries have moved this route by involving national academic institutions.

The private sector can also be expected to be instrumental. As likely 'first movers', private health service providers will likely identify solutions relevant to the national effort. Engagement with manufacturers and suppliers of medical products and technology will also likely help with generating alternative and lower-carbon products and technologies and securing access over the long-term.

Regardless of agencies involved, to begin the process of establishing a national data collection system, it makes sense to start with the largest of hospitals. Larger facilities will account for the majority of the health sector's carbon footprints and are also more likely to have staff capable for training that can support the orientation of staff in smaller facilities. Larger facilities also host health specialists who can form the basis of national peer support networks to collaborate on innovations in their areas of work. Data from a 'typical' range of health facilities – large to small – can also be used as a quick-start estimate for the national health sector footprint and resource needs.

Inter-country mechanisms to accelerate progress will be needed. This far, ATACH(29) has been set up with the involvement of over 80 countries and hosted by WHO. Building on such platforms, our work suggests that shared learning and collaborative initiatives can significantly enhance the effectiveness of individual efforts, driving faster progress towards shared goals. Collaborations will be needed to go beyond information sharing to consolidate positions and bargaining power to advocate for reforms in realms of policy, regulation and to stimulate innovations in products and technology.

The experiences and insights shared within this paper indicate a clear way forward, reinforcing the urgency and – importantly – the feasibility of beginning decarbonisation efforts now. By embracing the innovative approaches and collaborative strategies discussed, countries can make significant strides toward sustainable healthcare, thereby playing a crucial role in the broader efforts to mitigate and adapt to climate change and its health impacts.

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Appendix XI Manuscript (in press): The Role of Health Workers in Kenya's Net-Zero Transition: A Mixed-Methods Study on Healthcare System Climate Change Mitigation and Adaptation

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Abstract

Climate change presents a critical challenge to healthcare systems, particularly in low- and middle-income countries like Kenya. Health workers are key to leading the transition toward a sustainable, climate-resilient healthcare system. This mixed-methods study explores the perceptions, knowledge, and roles of Kenyan health workers in mitigation and adaptation in healthcare. An online questionnaire, completed by 118 health workers, explored their understanding of climate change's impacts on health, the healthcare system's role in emissions reduction and adaptation, and current practices. A subsequent focus group discussion delved deeper into the identified themes, with a particular focus on education of health workers to support climate action.

The findings reveal that while health workers are aware of the health risks posed by climate change, financial limitations and insufficient training present significant barriers to the implementation of sustainable practices. The focus group emphasized the need for practical, context-specific education to equip health workers with actionable knowledge and skills, alongside fostering emotional resilience and ethical leadership. Key recommendations include co-creating educational programs with communities and health workers, integrating climate-health modules into curricula, and leveraging innovative approaches such as peer-led workshops and social media campaigns. These insights underscore the transformative potential of education in empowering health workers to lead Kenya's transition to a sustainable, climate-resilient healthcare system.

Lay Summary

Climate change is a big challenge for healthcare systems, especially in countries like Kenya. Health workers are key to making healthcare more sustainable and better prepared for climate-related issues. This study asked Kenyan health workers about their views on health system responses to climate change.

We found that most Kenyan health workers know about the health risks of climate change, but they need more training and support to act. In a group discussion, participants said education should focus on practical skills, like handling new disease patterns and managing climate-related emergencies. They also shared creative ideas, like using social media and peer-led workshops to spread knowledge.

Participants emphasized the importance of working closely with local communities and making sure national policies fit local needs. They also highlighted the need for mental health support and leadership training to help health workers manage challenges. By providing better education and materials, Kenya can strengthen its healthcare system and prepare for a healthier, more sustainable future.

Introduction

Climate change presents an unprecedented challenge to global healthcare systems. It is increasingly recognized as the largest health threat of the 21st century, exacerbating existing health issues and introducing new risks [1]. Healthcare systems, responsible for about 5% of global greenhouse gas (GHG) emissions, are both a contributor to the crisis and heavily affected by its consequences [2]. Most of these emissions come from healthcare systems in high income countries and, going forward, low-emitting countries will have important policy choices about GHG emitting sectors including healthcare [1]. As healthcare systems aim to manage the adverse impacts of climate change, they must simultaneously adapt to the change that cannot be prevented and mitigate their environmental footprint.

Low- and middle-income countries (LMICs), including Kenya, are disproportionately vulnerable to the health impacts of climate change. Kenya is facing both direct health effects—such as increased frequency of heatwaves and changing patterns of infectious diseases—and indirect effects, including reduced access to essential services and infrastructure [3]. In response, Kenya has committed to transitioning its healthcare system toward a resilient system with net-zero emissions by 2030, as part of the World Health Organization's (WHO) United Nations Framework Convention on Climate Change 26th Conference of Parties (UNFCCC COP26) Health Programme in 2021 [4]. Following Kenya's National Climate Change Action Plan (NCCAP) which recognized the importance of integration of climate change into all sectors including health, Kenya identified key strategic actions including developing education programs to empower communities, enhancing disaster preparedness, and strengthening resilience against climate-induced health challenges, and integrating climate change into cross-sector curricula at all levels including for the health workforce [5].

Kenya's health professionals are recognized by decision-makers as central stakeholders in the country's transition to a climate resilient, net-zero healthcare system [6,7]. Their role extends beyond patient care to actively influencing the planning, implementation, and evaluation of climate adaptation and mitigation strategies. Interviews conducted in Kenya in 2023 with key stakeholders in the healthcare system transformation affirm that health workers are pivotal in guiding sustainable practices at every level of healthcare delivery, ensuring that interventions are feasible, impactful, and aligned with national climate objectives [7]. Beyond implementation, the active engagement of these health workers is crucial for the design of solutions, the development of national sustainable healthcare policies, and the generation of localized data to inform climate actions. This mirrors findings from other contexts, such as in England's "Greener NHS" programme, where health workers have been instrumental in leading low-carbon initiatives, and in Australia, where health professionals underlined their role in implementation towards sustainable, climate-resilient healthcare [8,9]. Health professionals' capacity to drive change and willingness to engage are indispensable for achieving Kenya's ambitious climate targets within its healthcare system.

In this manuscript, we describe health workers' perceptions of their roles and contributions to Kenya's net-zero, resilient and sustainable healthcare transition. Through a mixed-method approach - including a questionnaire and a focus group discussion with health workers - we explore integrating climate change mitigation and adaptation into routine healthcare delivery. By focusing on the perceptions of health workers, we provide a first step towards understanding how they can best be supported to drive the necessary transformation toward a resilient, sustainable healthcare system.

Methods

This study employed a mixed-methods approach to investigate the roles and perceptions of health workers in Kenya's transition to a net-zero healthcare system. The study was conducted in two phases: (1) a structured questionnaire aimed at capturing baseline knowledge, attitudes, and practices of health workers regarding climate change mitigation and adaptation, and (2) a focus group discussion, informed by the outcomes of the questionnaire, further explored barriers, opportunities, and actionable strategies for health workers to contribute to sustainable healthcare practices.

Study Setting and Participants

The online study targeted health workers and university students in Kenya, including medical doctors, nurses, pharmacists, community health workers, dentists, and those training in these professions. For the purpose of this study, the term 'health workers' is used inclusively to refer to both practicing professionals and students, acknowledging their active roles in healthcare delivery through clinical placements and community engagement. Participants were recruited through outreach to professional and student health associations, representing the diverse healthcare workforce across the country. These associations were identified using the authors' prior knowledge, professional networks, and publicly available information, ensuring representation from a range of healthcare institutions, including public hospitals, private facilities, and community health centres.

For the questionnaire, convenience sampling was employed based on participants' availability and willingness to participate. The questionnaire was disseminated through existing association communication channels and public social media platforms. As a result of this sampling method, response rates could not be calculated. Convenience sampling was used in this study to efficiently explore this area for the first time, addressing challenges such as transnational communication and recruitment constraints.

For the focus group, purposive sampling was used to select representatives from twelve professional healthcare associations and their student or young professional networks. Each association was invited to nominate one representative to convey their collective perspectives, and a total of seven representatives were ultimately nominated and participated in the discussion, representing community health workers, dentists, pharmacists, nurses, medical doctors, family physicians, and pharmacy and medical students. Focus groups were chosen as the primary method for this phase due to their ability to facilitate group interaction, generate rich and diverse insights, support exploratory research by enabling participants to build upon each other's ideas, and provide a deeper understanding of collective perspectives and dynamics, ensuring representation from key stakeholders and offering a comprehensive initial exploration of educational and policy needs [10].

Phase 1: Questionnaire

A structured questionnaire was distributed online to health workers across Kenya to assess knowledge, perceptions, and current engagement in climate change-related mitigation and adaptation practices. The questionnaire (Appendix I) included both closed and open-ended questions designed to assess various aspects of healthcare professionals' perceptions and practices related to climate change. The questionnaire was developed based on a review of relevant literature and drafted collaboratively by the research team. It was refined through feedback from a pilot group of 10 Kenyan healthcare professionals, ensuring clarity, cultural relevance, and alignment with the study's objectives. Questions addressed the following topics: participants' awareness of climate change and its health impacts; their understanding of healthcare's contribution to greenhouse gas emissions; existing transformation efforts within healthcare settings; barriers and opportunities to implementing climate change mitigation and adaptation strategies; and participants' willingness to engage in healthcare system transformation.

Phase 2: Focus Group Discussion

The focus group discussion, conducted after the questionnaire, was designed to delve deeper into the themes that emerged from this initial exploration. The questionnaire provided a broad overview of healthcare workers' knowledge, perceptions, and practices related to climate change, highlighting education as a critical gap. Building on these findings, the focus group further explored education by concentrating the current understanding and perception of climate change within respective healthcare professional groups, the role of health workers in climate mitigation and adaptation efforts (including an exploration of power dynamics in driving change and implementing educational initiatives), an exploration of knowledge and training needs regarding sustainable and resilient healthcare (with attention to local knowledge systems and contextualised educational approaches), and barriers and opportunities for implementing climate change education within healthcare (Appendix II).

To ensure a culturally sensitive and inclusive discussion, two facilitators were present. One (IMB) led the discussion, while the second (MO) observed cultural nuances, monitored participant engagement, and provided input or clarifications to maintain sensitivity. The second facilitator also provided feedback to refine the analysis, supporting a safe and inclusive environment for all participants. The focus group was conducted via Zoom due to geographical constraints, lasting approximately two and a half hours. It was held in English, which was the preferred and professionally appropriate language for all participants, as confirmed during recruitment; no one was excluded on the basis of language. All discussions were audio-recorded with participants' consent and transcribed verbatim for analysis.

Data Analysis

Data from the questionnaire were analysed using descriptive statistics to summarize respondents' knowledge, attitudes, and practices concerning climate change mitigation and adaptation. Categorical variables were summarized as frequencies and percentages, while continuous variables were presented as means and standard deviations. Responses to open-ended questions were thematically coded to identify recurring themes related to barriers and opportunities for action.

Transcripts from the focus group discussion were analysed using thematic analysis. Initial coding was performed using NVivo software to identify major themes, followed by a second round of analysis to refine and categorize these themes. Key findings were triangulated with the results from the questionnaire to provide a comprehensive understanding of the health workers' perceptions and roles in the net-zero healthcare transition.

Ethical Considerations

The proposal for this research was approved by the Research Ethics Committee of the London School of Hygiene & Tropical Medicine (Ref. 28210) and the Kenya Medical Research Institute (KEMRI, Ref. 4662), and licensed by the National Commission for Science, Technology and Innovation (NACOSTI, Ref. 519115 and extension Ref. 285069). Written informed consent was obtained through the questionnaire form and ahead of the focus group from all participants prior to their participation in the study. Confidentiality was maintained throughout the research process. All participants were informed how to leave the study if they wished, which they could do at any time. Verbal consent was obtained at the beginning and end of the focus group to proceed with the focus group and analysis, respectively. Focus group participants were reminded of confidentiality at the beginning and the end of the focus group.

Results

A total of 118 health workers participated in the questionnaire phase, conducted between June and December 2023. The focus group discussion followed in November 2024, with 7 participants representing a total of 29,800 health workers and students, selected from various Kenyan professional healthcare associations, including their student and young professional networks.

Results Phase I: Questionnaire

Demographics

Of the 118 participants in the questionnaire, 67 (56.8%) were practising health professionals, including junior doctors, general practitioners, and specialists, while 51 (43.2%) were students training as health professionals, primarily in medical, nursing, and pharmacy fields. Medical doctors made up 24 participants (20.3%), with nurses and nursing students accounting for 8 participants (6.8%). Other professions included pharmacists, community health workers, microbiologists, and public health officers. Participants worked and studied in 20 counties, with the largest groups in Uasin Gishu (29.7%, n = 35), Nairobi (19.5%, n = 23), Kisumu (9.3%, n = 11), and Kiambu (5.9%, n = 7) (see Figure 1). Most respondents (40.7%, n = 48) were active in public healthcare, while 16.1% (n = 19) were in private facilities, 11.0% (n = 13) in NGO-based providers, and 4.2% (n = 5) in faith-based institutions. 47.5% (n = 56) of participants were women and 52.5% (n = 62) were men. Ages ranged from 19 to 57 years, with a mean age of 27.2 years. The majority of participants (75%, n = 88) were aged 20–30.

Compared to available data on the Kenyan healthcare workforce, which is predominantly young and includes approximately 58% women and 42% men, the sample is reasonably representative in terms of gender but skews toward younger participants due to the inclusion of students. Geographically, the participation aligns with known trends of higher workforce concentrations in urban areas, though some underrepresentation of rural counties is noted. [11]

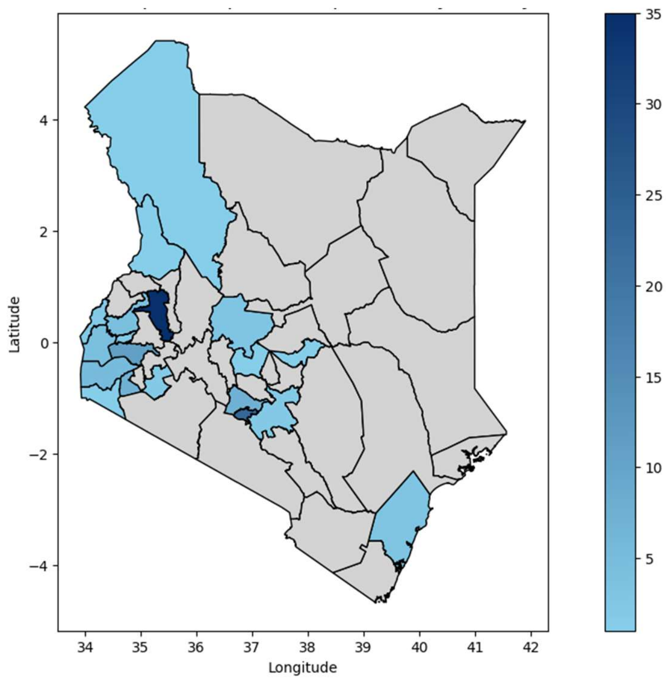

Figure 1 Heat map of Kenya presenting counties in which questionnaire respondents work primarily.

Knowledge & Experience

Respondents rated their knowledge of climate change and health at a mean of 6.84 (SD: 2.24) on a scale of 1 to 10, indicating a perception of moderate knowledge. Most participants viewed climate change as a major threat to health, with 60% strongly agreeing and 30% agreeing. Similarly, 80% of respondents strongly agreed (45%, n=53) or agreed (35%, n=41) to having witnessed the effects of climate change in their practice. Greenhouse gas emissions (55%, n=65 strongly agreeing, 30%, n=35 agreeing) and air pollution (65%, n=77 strongly agreeing and 25%, n=30 agreeing) were recognized as a significant health threats.

Perceptions of the Healthcare System's Role in Emission Reduction and Climate Change Mitigation

Opinions on the healthcare system's current efforts in reducing GHG emissions were mixed, with 40% (n=47) agreeing or strongly agreeing this was taken into consideration, while 35% (n=41) disagreed or strongly disagreed. However, 90% (n=106) agreed that reducing GHG emissions should be integrated into healthcare practices.

Regarding Kenya's goal of a net-zero healthcare system by 2030, 45% (n=53) agreed it as achievable, while 25% (n=30) disagreed. There was strong support for the role of health workers, with 90% (n=106) agreeing that they should lead advocacy and implementation efforts to reduce emissions.

Environmental concern was high, with 95% (n=112) of respondents agreeing the current state is alarming, and just as many expressing an interest in learning how to reduce GHG emissions in healthcare.

Responsibility was seen as shared, with 95% (n=112) agreeing that the government and the private sector should take responsibility, and 90% (n=106) supporting roles for community leaders and individuals.

Sources of Healthcare Emissions and Current Interventions in Emission Reduction

The majority of respondents (84%, n=99) identified the production, transport, and disposal of goods and services—such as pharmaceuticals, medical devices, and hospital equipment (emission scope 3 emissions)—as the largest contributor to emissions in Kenya's healthcare system. Additionally, 10% pointed to indirect emissions from purchased energy sources, such as electricity, steam, cooling, and heating (scope 2), while 4% highlighted emissions directly from healthcare facilities and vehicles (scope 1).

Regarding actions taken to reduce greenhouse gas emissions, 87 respondents (74%) reported that they have not yet implemented any interventions. However, some respondents have engaged in efforts like waste management, recycling, energy efficiency measures (e.g., solar power), and sustainable transportation. Education and advocacy were also frequently mentioned as key opportunity areas of focus for reducing emissions. A large proportion of respondents (95%, n=112) expressed interest in implementing future interventions, such as tree planting, better waste management, and using alternative energy sources.

Proposed Solutions

Respondents identified several key interventions to reduce greenhouse gas emissions in Kenya's healthcare system. The most frequently mentioned intervention was the adoption of renewable energy sources (e.g., solar and wind) for healthcare facilities to decrease reliance on fossil fuels. In addition, supply chain management strategies, such as proper disposal of medical waste, increased recycling, and minimizing single-use products, were widely supported. Respondents also advocated for telemedicine as a means to reduce patient travel and associated transportation emissions. Other recurring suggestions included sustainable transportation initiatives, such as adopting electric vehicles and encouraging carpooling or public transport, and education and awareness programs aimed at health workers and the general public to promote sustainable practices. Finally, respondents emphasized the importance of green procurement, focusing on the purchase of eco-friendly, recyclable, and energy-efficient products.

Participants highlighted the critical need for integrating climate change adaptation into Kenya's healthcare system, with a strong focus on emergency preparedness and resilient infrastructure. This includes retrofitting facilities to withstand extreme weather events and ensuring reliable energy systems powered by renewable energy sources such as solar panels. In addition, respondents emphasized the importance of telemedicine to reduce travel and maintain continuity of care during climate disruptions, which also aligns with the broader strategy to reduce emissions. Building sustainable supply chains was also viewed as a key opportunity to reduce emissions and adapt, through promoting the use of locally sourced materials.

Opportunities & Barriers

Several opportunities for successfully implementing these measures were identified. Policy and regulatory frameworks were considered essential to encourage healthcare facilities to prioritize sustainability. Many respondents saw public-private partnerships as a key opportunity for mobilizing funding and resources to support emission reduction initiatives. Technological innovation, such as energy-efficient medical devices and advanced waste disposal systems, was viewed as another critical factor in driving progress. Additionally, community engagement—including tree-planting campaigns and public awareness programs—was frequently mentioned as a way to promote sustainability at the local level.

The most significant barrier identified by respondents was financial constraints, particularly the lack of funding for the adoption of green technologies and waste management infrastructure. Lack of awareness and education among health workers and the public was also seen as a major obstacle. Other barriers included resistance to change within healthcare institutions and infrastructure limitations, with some facilities lacking the capacity to implement renewable energy or waste management systems.

To overcome these barriers, respondents recommended increased funding and financial incentives, such as government grants or international donor support, to facilitate the transition to greener technologies. Education and training programs were seen as crucial to raising awareness and addressing resistance to change. Respondents also called for stronger policy enforcement to compel healthcare facilities to adopt emission reduction measures. Finally, they highlighted the importance of collaboration and partnerships between government, healthcare institutions, and environmental organizations to support the implementation of sustainable practices.

Finally, when asked whether Kenya needs to change its approach to zero emissions of the healthcare system if it is going to be successful, respondents overwhelmingly called for stronger policies and better enforcement. Key suggestions included prioritizing renewable energy adoption, improving waste management practices, and increasing government investment in climate-resilient infrastructure. Education and capacity-building initiatives for health workers and public awareness campaigns were seen as critical to driving change. Additionally, multisectoral collaboration, public-private partnerships, and international cooperation were identified as essential for securing the necessary funding and technological innovation to achieve zero emissions in the healthcare system.

Results Phase II: Focus Group on Education

The findings from Phase I highlighted that while health workers are seen by key stakeholders and decisionmakers as key drivers in promoting sustainability and resilience of the healthcare system, many still lack the necessary education and training to effectively fulfil this role. A focus group was conducted to explore how education might equip health workers with the knowledge and skills needed to lead in implementing emission reduction strategies and climate adaptation within the healthcare system.

A total of seven representatives from professional and student organizations participated, including four women and three men. Collectively, they represented over 29,800 health workers and university students, including community health workers, dentists, pharmacists, nurses, medical doctors, family physicians, and pharmacy and medical students. Participants brought a wide range of perspectives, spanning clinical, educational, and advocacy roles within the healthcare system. The second facilitator noted that participants engaged openly and confidently, with no evident cultural or contextual barriers influencing the discussion.

The discussion began by validating the outcomes of the questionnaire, confirming that while awareness about climate change among health workers is generally high, there is a significant gap in actionable knowledge and practical skills. One participant reflected this sentiment by referencing a similar internal survey:

> *"The majority know that climate change is there and impacting the work, but there is very little knowledge about what has been done or what can be done." (Participant 5, Representing Medical Practitioners, Pharmacists, and Dentists)*

This lack of practical knowledge is further compounded by the increasing burden on health workers due to emerging disease patterns linked to climate change. One participant shared a vivid account of the challenges in a rural clinic, where a lack of preparedness for flooding led to delayed patient care, significant supply chain disruptions, and outbreaks of waterborne diseases. Another participant highlighted the strain on the health workers:

> *"There is an increased workload due to these new patterns and new diseases." (Participant 5, Representing Medical Practitioners, Pharmacists, and Dentists)*

Participants emphasized the dual role of health workers as both caregivers and advocates for climate and health. Beyond clinical responsibilities, they are deeply embedded in their communities, where they serve as trusted sources of knowledge and agents of change. One participant illustrated this by stating,

> *"Health workers are also health advocates for the communities in which they live. So, educating one single health worker from a community is an immense opportunity to addressing some of the issues that we have talked about." (Participant 5, Representing Medical Practitioners, Pharmacists, and Dentists)*

However, a disconnect between national policies and local realities was consistently noted. Participants felt that while national policies like the National Climate Change Action Plan outline ambitious goals, their relevance and applicability to local contexts remain unclear. The group strongly recommended bridging this gap by tailoring policy implementation to reflect the lived realities of health workers and the communities they serve, and ensuring funding is allocated to national plans. One participant remarked, *"Family physicians transcend between the facility and the community, but how national policies and information is distilled for action or awareness downstream to us remains vague." (Participant 3, representing Family Physicians)*

The focus group also identified several key gaps in education. These included education on climate change and health overall, training on disaster response, managing shifts in disease burden, and integrating sustainability into healthcare practices. Participants stressed the importance of a generic teaching framework during university and for working professionals that allows for contextualization to local realities, ensuring the training is adaptable and relevant. They emphasized the need for practical, actionable education that equips health workers with the skills to address these challenges effectively, while also fostering their ability to disseminate critical health information to communities, including in local languages. In addition to practical education, participants highlighted the need for professional development that fosters emotional resilience and equips health workers to navigate the ethical challenges of addressing climate change. Reflective practice and advocacy emerged as essential competencies, enabling health workers to lead in their communities while maintaining their well-being amidst crises.

Young professionals and students emerged as a critical group, with participants highlighting their heightened awareness of climate-health issues and their potential as change agents. One participant noted,

"The younger generation is more knowledgeable about climate and health, which is a privilege we older colleagues do not have." (Participant 2, Representing Young Doctors)

This was accompanied by recognition of their challenges, particularly limited access to decision-making processes and resources. Participants stressed the importance of empowering these groups through targeted education, mentorship, and leadership opportunities to enable them to contribute effectively to sustainability efforts. As one participant emphasized,

"We need to ensure that young professionals and students have the tools and platforms to translate their enthusiasm into actionable change." (Participant 1, Representing Medical Students)

Finally, the group proposed a range of recommendations for improving climate-health education. They underscored the importance of co-creation and decolonization in designing educational programs, guided by the principle of "*nothing for us without us*", which prioritizes community involvement, partnership, and building local assets. Participants highlighted the value of involving diverse stakeholders, including environmentalists, universities, trade unions, tertiary colleges, religious institutions, civil society organizations, county assemblies, county departments of environment and climate change, the Ministry of Health, and international bodies such as the United Nations, in addition to engaging communities at local levels to ensure alignment with both (inter)national policies and grassroots needs. Creative approaches to education were also suggested, such as leveraging social media, facilitating knowledge exchange through peer-led workshops, and embedding climate-health modules within existing curricula. The participants stressed that such strategies must remain community-focused, inclusive, and empowering, ensuring health workers can actively engage with and address the needs of the populations they serve. One participant reinforced the value of research in advancing actionable insights for climate-health education, noting:

> *"Research such as this is needed." (Participant 5, Representing Medical Practitioners, Pharmacists, and Dentists)*

Discussion

Climate change poses significant challenges to healthcare systems worldwide, particularly in low- and middle-income countries like Kenya, where health workers are grappling with the dual responsibility of mitigating emissions while adapting to climate impacts [12]. This study offers a unique perspective on the perceptions, knowledge, and roles of Kenyan health workers as the country transitions toward a net-zero, climate-resilient healthcare system. In alignment with global goals such as the Paris Agreement and Kenya's commitments under the World Health Organization's Health Programme at COP26, this research highlights both the opportunities and barriers that health workers encounter as key stakeholders in these efforts [13,14].

The questionnaire responses of Kenyan health workers reveal a generally high level of concern about climate change, with 90% of respondents acknowledging the importance of integrating GHG emissions reduction into healthcare practices. This strong consensus reflects the global recognition that healthcare systems must play a central role in combating climate change, not only because of their direct emissions but also due to the public health threats posed by climate-related disruptions [15]. Similarly, the identification of supply chain emissions as the largest contributor to healthcare's carbon footprint aligns with global estimates that have demonstrated the outsized impact of procurement and product usage in hospitals [2].

A noteworthy finding is the widespread support for renewable energy adoption as a key solution to reduce emissions, a sentiment echoed in other LMICs, where renewable energy presents a cost-effective and sustainable alternative to traditional energy sources in healthcare [16]. The emphasis on telemedicine as a means of reducing travel-related emissions is also consistent with global trends whereby it has gained significant traction during the COVID-19 pandemic and has been advocated as a sustainable model for future healthcare delivery [17].

The barriers identified in this study, particularly financial constraints and the limited integration of climate-health topics in existing education systems, align with findings from similar contexts. The perception of a lack of enforcement of policy frameworks is another recurrent theme that has been widely documented in both global and national studies. Health workers in Kenya highlighted the need for stronger governmental leadership and more effective policy implementation, echoing calls for healthcare policies that are better integrated with national climate strategies [18]. While Kenya's contribution to global emissions is minimal, the strong perception among participants that national governments and private sector actors hold primary responsibility for mitigation and adaptation likely reflects their central role in enabling change within the Kenyan healthcare system. This perspective also underscores participants' alignment with national policies such as the National Climate Change Action Plan and Kenya's commitments under the WHO COP26 Health Programme. At the same time, it highlights the need for international support, such as funding, technology transfer, and educational partnerships, to ensure such commitments are realised. Health workers' "dual responsibility" to mitigate and adapt thus reflects not only their willingness to lead change, but also their recognition of systemic dependencies that span national and global levels. Framing climate-health education as an adaptation and mitigation measure provides a compelling entry point for international collaboration, particularly with institutions in high-emitting countries that bear a historic responsibility and are well positioned to support transformative education and capacity-building efforts. Furthermore, the call for multisectoral collaboration and international cooperation aligns with recommendations from the World Health Organization and its Alliance for Transformative Action on Climate and Health (ATACH), which underscores the importance of cross-sector partnerships in achieving climate-resilient health systems [19].

An assessment in 2022 showed that South African health workers, despite positive attitudes towards environmental sustainability, lacked the necessary knowledge and training to implement effective practices [20]. Like our findings, this emphasizes the critical need for targeted education and capacity-building to empower health workers to lead sustainability efforts. Without such educational initiatives, progress towards sustainable healthcare will remain limited, underscoring the urgency of integrating climate education into healthcare training.

Through the questionnaire, education emerged as a cornerstone in achieving sustainable, resilient healthcare. This emphasis on education may be influenced by the high proportion of student participants, whose active engagement in learning may have heightened their awareness of educational gaps. Their dual identity as emerging professionals and current learners brings valuable insight into the urgent need for climate-health training. The focus group then further validated global assertions that healthcare education must transition from traditional disease-focused approaches to include sustainability as a core component [21,22]. In Kenya, the focus group participants emphasized a disconnect between national policy ambitions and local realities, underscoring the need for education that bridges this gap. This aligns with the literature advocating for systems thinking and context-specific approaches to training, ensuring that policies are actionable and resonate with the lived realities of health workers[22].

Building on this, integrating sustainable healthcare education in Kenya requires a transformative approach that prioritizes contextual relevance and societal impact. This need for transformation is highlighted in the focus group findings, which identified critical gaps in practical knowledge and skills, particularly in translating policy into actionable local strategies. Transformative learning, as adapted by Redvers from Freire's pedagogy, goes beyond traditional methods by embedding principles of societal change, advocacy, and justice. This approach aligns with the gaps identified by our participants, particularly in addressing the disconnection between policy and practice. Transformative education necessitates interdisciplinary, place-based, and action-oriented learning that integrates personal and collective experiences, empirical observation, and an ethico-political understanding of both local and global relevance [23,24].

Participants in the focus group reinforced the principle of "nothing for us without us," advocating for educational co-creation with communities and stakeholders towards decolonization of health education. This aligns well with global transformative education frameworks emphasizing the inclusion of Indigenous and local knowledge systems as critical to planetary health solutions [22,23]. Incorporating local languages and community-driven approaches improves inclusivity and empowers health workers to act as advocates and educators within their own contexts.

Rooted in praxis, transformative education bridges knowledge and action, fostering critical thinking and relational care. This includes co-creating curricula with communities, emphasizing place-based and experiential learning, and incorporating diverse knowledge systems, such as Indigenous perspectives. The principles of compassion, knowledge, and reflection central to this educational model enable health workers to navigate and address the profound challenges posed by climate change, positioning them as advocates and agents of social and environmental justice. Additionally, embedding sustainability into healthcare education must consider the interconnectedness of ecological, social, and health systems. Practical implementation requires curricular integration of sustainability concepts and the cultivation of values that inspire future healthcare professionals to lead meaningful systemic change. [22,23]

From a practical standpoint, the focus group proposed both formalized and informal strategies for integrating climate-health education into existing systems. Formalized approaches included embedding sustainability modules within existing health curricula, ensuring alignment with national climate policies, and developing structured, recognized educational programs as part of healthcare worker development initiatives. Informal strategies focused on utilizing social media to disseminate knowledge and increase accessibility, as well as fostering experiential learning and knowledge exchange through self-organized, peer-led workshops. These approaches collectively echo the emphasis in sustainable healthcare education literature on embedding sustainability across curricula and leveraging digital tools for widespread impact [21,22].

Finally, as health workers navigate the challenging realities of climate change, emotional resilience and ethical leadership were recognized as integral to education. The literature underscores the role of reflective practice and advocacy as essential competencies for health workers, particularly in LMICs, where resource constraints often magnify challenges [22]. Young professionals and students, with their heightened awareness of climate-health issues and openness to innovation, were identified as pivotal change agents. However, systemic barriers, such as limited access to leadership roles, hinder their ability to drive meaningful change. By prioritizing capacity-building through education, healthcare systems can not only empower individuals but also enhance their overall resilience and ability to address climate-related challenges effectively.

Strengths & Limitations

This study offers valuable insights into the perceptions and roles of Kenyan health workers in climate mitigation and adaptation, contributing to a growing body of research on sustainable, resilient healthcare. A key strength lies in its mixed-methods approach, which allowed for an exploration of both broad trends through the questionnaire and deeper contextual insights via the focus group. The recruitment of participants through professional and student healthcare associations ensured diverse representation across a range of professions, healthcare settings, and regions. Additionally, participant checking of questionnaire findings in the focus group strengthened the credibility and validity of the results.

However, several limitations must be acknowledged. Convenience sampling was used for the questionnaire, relying on participants' availability and willingness to engage. While this method is well-suited for exploratory studies like this, it may have introduced selection bias, potentially overrepresenting individuals with a pre-existing interest in climate change. Consequently, the findings may not fully reflect the views of the broader Kenyan health workforce. The reliance on online recruitment and data collection may have further excluded participants from underserved or remote areas with limited internet access, affecting the representativeness of the sample. Moreover, the questionnaire relied on self-reported knowledge of climate and health issues rather than explicitly testing this knowledge. This may have resulted in participants overestimating or underestimating their actual level of knowledge, adding potential bias to the findings. Further, the number of participants per professional group was small, limiting the ability to draw profession-specific conclusions. While many participants expressed strong willingness to engage in sustainable practices, the study did not assess whether such willingness would translate into behavioral change in clinical practice. Future research could explore implementation further.

The focus group employed purposive sampling to gather diverse perspectives from key healthcare stakeholders. While this approach enabled rich qualitative insights, the small sample size and reliance on association representatives may not fully capture the experiences of health workers in all contexts. Additionally, the virtual format of the focus group, while pragmatic given geographic constraints, may have limited opportunities for informal interaction or non-verbal communication, which are often more readily observed in in-person discussions.

It is also important to acknowledge the positionality of the research team. While MO, a Kenyan researcher, played a central role in contextualizing the study and ensuring cultural relevance, the lead researcher from the global north (IMB) may still represent perceived power imbalances in conducting research in a middle-income country. Efforts were made to mitigate this by incorporating input from Kenyan collaborators throughout the study design, data collection, and interpretation.

Despite these limitations, this study provides foundational insights into the educational and policy needs of Kenyan health workers in the context of climate change. Future research should aim to address these limitations by employing broader recruitment strategies, combining virtual and in-person methodologies, and expanding participant representation to capture a wider range of perspectives.

Conclusion

This study highlights the pivotal role of health workers in Kenya's transition to a net-zero, climate-resilient healthcare system. Education emerges as a cornerstone in bridging the gap between policy ambitions and actionable practices, addressing critical barriers such as limited knowledge and the disconnect between national strategies and local realities. By equipping health workers with practical skills, reflective capacities, and systemic understanding, transformative education provides a pathway to empower them as leaders in sustainable healthcare.

Currently, the WHO's ATACH presents an opportunity to incorporate an educational focus within its framework. Integrating transformative education into ATACH's goals can address the complex interconnections between health, climate, and equity, equipping health workers with the necessary tools to advocate for and implement meaningful change. Transformative education has the potential to catalyse systemic change, fostering a health workforce that is not only prepared to meet current challenges but also to lead the way in creating equitable, sustainable solutions for future generations.

By investing in education that prioritizes contextual relevance, societal impact, and collaboration, Kenya can ensure that its healthcare system evolves into a model of climate resilience and sustainability, with health workers at the forefront of this critical transformation.

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Declarations

Author Contributions

The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. IMB conceptualized the study, designed the methods with SW, AH, AB, IC and MO. Investigation was performed by all authors. IMB analysed and curated the data, reviewed by SW and AH. IMB wrote the original draft, and all authors reviewed and edited. Supervision was provided by SW and AH.

Declaration of Interests

All authors have completed the ICMJE uniform disclosure form at https://www.icmje.org/disclosure-of-interest/ with completed forms attached.

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The authors declare no other support from any organization for the submitted work; no other financial relationships with any organizations that might have an interest in the submitted work in the previous 36 months, no other relationships or activities that could appear to have influenced the submitted work. All authors have had final responsibility for the decision to submit for publication.

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Data Availability Statement

The data underlying this article will be shared on reasonable request to the corresponding author. The information sheet, informed consent form and focus group topic guide are available in the Supplementary Information.

Ethics Statement

The proposal for this research was approved by the Research Ethics Committee of the London School of Hygiene & Tropical Medicine (Ref. 28210) and the Kenya Medical Research Institute (KEMRI, Ref. 4662), and licensed by the National Commission for Science, Technology and Innovation (NACOSTI, Ref. 519115 and extension Ref. 285069). Written informed consent was obtained through the questionnaire form and ahead of the focus group from all participants prior to their participation in the study. Confidentiality was maintained throughout the research process. All participants were informed how to leave the study if they wished, which they could do at any time. Verbal consent was obtained at the beginning and end of the focus group to proceed with the focus group and analysis, respectively. Focus group participants were reminded of confidentiality at the beginning and the end of the focus group.

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