Strategies for Reduced Healthcare Greenhouse Gas Emissions in Developing Countries: A Systematic Review

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ABSTRACT

Introduction: The healthcare sector contributes 4-5% of all greenhouse gas emissions and must improve environmental efficiency without sacrificing quality or accessibility. Strategies for reducing emissions in hospitals and healthcare facilities need to be effective in developing countries.

Methodology: This systematic review was conducted following PRISMA guidelines to identify strategies for reducing greenhouse gases in healthcare facilities in developing countries. The review included a comprehensive search of six databases for literature published between 2012 and 2024. Screening and selection of studies were based on predefined eligibility criteria, and the risk of bias in included studies was assessed using a modified checklist outlined in the Cochrane Handbook for Systematic Reviews. Analysis was guided by narrative synthesis, and geographical restrictions were placed on developing countries and English-language papers

Results: Out of 5,982 identified papers, 13 studies met the eligibility criteria and were included in this review. Upgrading equipment, using energy monitoring systems, implementing renewable energy sources, proper waste management, digital health, low GWP inhalers and anesthetic gases, and green procurement practices were found to be effective. However, long-term outcomes and consideration of socio-economic and geographical factors are needed to develop context-specific strategies.

Conclusion: A holistic approach including energy efficiency, renewable energy, waste management, digital health technologies, sustainable procurement, and use of medical supplies is essential for reducing greenhouse gas emissions in healthcare facilities. This research can help inform future strategies for effectively lowering emissions in developing countries.

Keywords: Greenhouse gas (GHG) emissions, Hospitals and Healthcare facilities (HHFs), Energy efficiency, Waste management, Digital Health Technologies, Renewable energy.

INTRODUCTION

Background to the Study

Healthcare Green House Gases (GHGs) emissions refer to the healthcare sector's contribution to gases that trap heat in the atmosphere and contribute to the greenhouse effect. According to Rodriguez-Jiménez et al. (2023), universal healthcare systems significantly contribute to the global greenhouse effect, accounting for 4-5% of all emissions. Although the healthcare sector aims to protect and enhance human health, its carbon footprint actively contributes to climate change, posing a significant threat to health and undermining the primary goal of Universal Health Coverage (UHC) (WHO, 2019). The sustainability of healthcare systems has emerged as an important question and concern, as they must function in line with the reduction of improved healthcare outcomes and climate change impact. This balance is particularly important because with the increase in the number of people in the world, along with the increased average lifespan, global healthcare needs continue to rise.

The global healthcare industry is a major contributor to greenhouse gas emissions, with an annual CO2 output at approximately 2 gigatons, which is nearly equivalent to the entire carbon footprint of aviation (WHO, 2022).

The sector must prioritize environmental sustainability without compromising quality and accessibility of services. Collaboration and innovation are key to addressing these challenges and preventing further strain on global healthcare systems, especially in resource-limited countries (Ergo et al.,2019).

The effects of GHG emission outputs vary, with developed countries having superior healthcare facilities compared to developing ones. However, developed countries also have higher absolute emission outputs due to their larger size and nature of operation. For instance, in the United States, healthcare is an industry that emits the ninth most GHGs, accounting for about 8.8% of the total emissions in the nation (Eckelman & Sherman, 2022) while the Australian healthcare systems emit approximately 7% of the country annual GHG emissions (Yung et al., 2020).

Healthcare systems in Africa contribute 10% to the continent's annual greenhouse gas emissions, with top countries like Algeria, South Africa, and Egypt being major contributors (Luz et al., 2023; Nkomo et al., 2022).). These countries struggle to expand their healthcare systems while dealing with the impact of climate change on the health of their populations. Due to lack of resources, they continue to use inefficient and environmentally unfriendly technologies, highlighting the need for strategies tailored to address these challenges.

These challenges highlight the potential risks associated with the impacts of climate change on health care systems, particularly in developing nations, and underscore the significance of integrating health care strategies with climate change and health outcomes. Healthcare systems can and should recognize and seize the opportunity to exert their power in formulating and executing holistic and creative strategies for addressing climate change while at the same time optimizing the population's health status and addressing environmental concerns (Or & Seppänen, 2024). For instance, it is possible to enhance energy efficiency in healthcare facilities and reduce waste using better management practices, as well as adopt renewable energy sources that will help halt global climate emissions (Nižetić et al., 2019). In this sense, the engagement of governments, NGOs, and private sectors is pivotal in expanding these activities and achieving the desired reductions in emissions eventually.

Thus, hospitals and healthcare facilities (HHFs) should acknowledge and thus embrace the application of workable proficiencies and advancement in the fight against climate change at workplaces and homes (Abd Rahman et al., 2021). Promoting the application of efficient strategies in minimizing GHG emissions is beneficial not only to global goals and objectives but also to the healthcare systems globally by increasing their sustainability and efficiency. Combating climate change can be achieved by recognizing practical strategies and innovations within healthcare facilities and leveraging evidence to implement changes that minimize greenhouse gas emissions and promote sustainability. However, due to a lack of substantial evidence-based literature on GHG emissions from healthcare practices in Africa and other developing nations, there is a limitation to a general African continent and other developing nations perspective (Koinig et al., 2019). Without a doubt, more comprehensive GHG emission data and studies should be conducted to estimate and consolidate mitigation strategies to climate change impacts in HHFs.

Problem Statement / Rationale for the Study

Given the increasing awareness of global GHG emissions, it is imperative for the health care sector to take responsibility for environmental pollution. Healthcare in Kenya, for example, has problems like poor energy use, waste management, and fossil energy usage, which have adverse impacts on climate and thus affect health, especially in children, the elderly, and patients with diseases (WHO, 2021). Although the government have developed policies at the strategic level to support sustainability strategies, inconsistencies in coordination, funding, and support have occurred, thus compromising the development of sustainability frameworks for the sector to support environmental preservation when delivering healthcare services (UNEP, 2023). Research is currently calling for more effective and comprehensive interventions that cater to the needs of developing nations, considering each country’s prevailing socio-economic realities and resource endowment challenges (Ansah et al., 2024). This research aims to determine how health care can improve its service delivery while reducing greenhouse gas emissions, thereby developing a conservation-focused health care improvement model that will be crucial for HHFs in developing nations

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Study Aim, Objectives, and Questions

Aim

The systematic review aims to identify and explore effective strategies, innovations and practices in healthcare management that can remarkably reduce GHG emissions in healthcare facilities of developing nations.

Objectives

a) To identify strategies and practices for reduced GHG emissions in healthcare management of developing countries.
b) To evaluate the effectiveness of these strategies and practices in reducing GHG emissions in healthcare facilities in developing nations.

Research questions

a) What are the key strategies and practices currently implemented in healthcare management to reduce GHG emissions in developing countries?
b) How effective are these strategies and practices in minimizing GHG emissions within healthcare facilities in developing nations?

Significance of the Study

a) Focusing on strategies relevant to developing nations addresses a critical knowledge gap in the literature and provides valuable insights for healthcare managers, researchers, and policymakers.
b) Informing policy and practice through findings to healthcare management practices and policymakers of developing nations and to align with national and global climate goals.
c) Promote innovation by exploring successful strategies and innovations. The systematic review can energize the development of innovative, context-specific solutions for reducing GHG emissions.
d) Contributing to global climate action through focusing on strategies that contribute to GHG emissions. The study contributes to universal efforts to alleviate climate change.
e) Improve health outcomes by contemplating strategies that reduce GHG emissions. The study indirectly improves population health and mitigates the health impacts of climate change.
f) Economic benefits through implementing effective strategies to reduce GHG emissions can lead to cost savings for healthcare facilities in resource-constrained settings.
g) The study contributes to and aligns with the achievement of various sustainable development goals, particularly SDG 3 (Good Health and Well-being), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action).

LITERATURE REVIEW

Introduction

Emissions of GHGs are currently a major concern in health facilities worldwide, particularly in developing countries where healthcare systems lack access to electricity (WHO, 2023); heavily rely on fossil energy sources and practice improper healthcare waste management ((Eckelman et al., 2020). This literature review focused on examining previous studies that propose various approaches to reduce GHG emissions in healthcare facilities in developing countries. The review is systematic, starting with the identification and inclusion of relevant studies based on some selection criteria. These studies were then grouped into themes of interest, for example, energy efficiency, use of renewable and clean energy, management and disposal of waste, use of digital health technology and procurement and use of medical supplies. Thus, the review presents a view on contemporary practice and identifies directions for future research and investment toward more sustainability of the health care sector in developing countries.

Thematic Literature Review

The literature review is grouped into themes categorized into five key areas: energy efficiency, renewable and

clean energy, waste management and disposal practices, digital health technologies and procurement and use of medical supplies in healthcare facilities as detailed below.

Energy Efficiency

Energy conservation in hospitals and healthcare facilities (HHFs) can be achieved through various strategies which require monitoring and benchmarking energy consumption to understand the true impact and identify energy conservation opportunities and efficiencies in healthcare facilities (Butler, 2023). Silva et al., (2024), proposes strategies for healthy building designs and retrofitting options, as well as user behavior and renewable energy sources like solar power, as being important in achieving energy conservation. For example, implementing intelligent control algorithms in HVAC systems and cogeneration, investing in energy-efficient, low voltage drives, and high efficiency electric motors can improve functionality and reduce GHG emissions in HHFs equipment and mechanical systems. (Ma et al., 2019; Adnet et al., 2022). Also, LED lighting and motion-sensor systems have been shown to significantly reduce energy consumption (Dion et al.,2023).

Other Sustainable actions applicable in other healthcare areas as pointed out by Roletto et al., (2023) includes turning-off devices during idle periods, favoring the most energy-efficient devices, and educating staff on energy-saving practices, without compromising service quality. These strategies not only contribute to significant energy and cost savings but also maintain the quality of services.

Renewable and Clean Energy

HHFs can harness renewable and clean energy from various sources including geothermal resources, onshore wind farms, solar energy, and biomass. Prajapati (2022) notes that some areas have significant geothermal potential, for direct heat usage and power generation. Also, Amjith (2022) argues that biomass-based hybrid energy systems can provide a cost-effective and environmentally beneficial alternative, particularly for off-grid rural electrification. Also, biomass-derived materials, such as biochar, can be used for renewable energy production, including bioelectricity, biodiesel, and biohydrogen, offering a sustainable approach to create an energy-secure world (Kant, 2021). The use of solar energy in HHFs has been emphasized as a way to achieve reliable and sustainable electricity, especially in LMICs, with successful solarization projects reported in India and sub-Saharan Africa (Sharma et al., 2024). Moreover, by using renewable energy in the form of solar heating, solar cooling, and photovoltaic (e.g., solar electricity) systems can be used to minimize buildings' energy consumption and GHG emissions (Beccali et al.,2016).

Major challenges in implementing renewable and clean energy sources include funding issues, a lack of human resources, limited technical skills, infrastructural deficits, and uncertainty of the renewable energy supply (Sharma et al., 2024). The initial expenditure to implement renewable energy, especially solar panels, is exceedingly high, although it is cost-effective in the long term.

Waste Management and Disposal

HHFs waste management and disposal requires a systematic approach involving separate classification, handling, reduction, and disposal techniques for the waste to be dealt with sustainably (Thakre et al.,2019). The segregation of waste at the point of generation is critical, and factors such as adequate knowledge on healthcare waste management, training on waste management, the presence of guidelines and instructive posters, and availability of color-coded waste bins significantly impact healthcare waste segregation practices (Kwikiriza et al., 2019; Omoleke et al ,2021); Johnson et al.,2013); Ibrahim et al.,2023).

While segregation is the most cost-effective technique for waste minimization, researchers suggest that other tactics such as cutting-edge contemporary incinerators fitted with air pollution controls and shredders exist (Thakre et al.,2019). Through their study, MacNeill et al. (2021) were able to demonstrate how waste disposal that involves autoclaving as well as recycling help lessen noxious gases such as methane and carbon dioxide. They emphasis on the priority to inactivate infectious micro-organisms in clinical solid waste to reduce exposure to infectious waste, decrease labor, lower costs, and yield better compliance with regulatory requirements. Johnson et al., (2013) also advises HHFs to continue ongoing surveillance and training to

maintain good healthcare waste practices.

On the other hand, landfill management strategies such as landfill gas recovery, improved landfill practices, and engineered wastewater management can help reduce greenhouse gas emissions from waste (Bognar et al.,2008). Nordahl et al. (2020) posits that Implementing waste-to-energy systems, such as dry anaerobic digestion to produce renewable natural gas, can divert organic waste from landfills and reduce greenhouse gas emissions

Despite so many studies in these areas, waste management practices in HHFs in developing countries face several challenges. These include a lack of clear regulations and legislation, leading to wide variations in waste generation rates and poor waste segregation, collection, storage, transportation, and disposal practices (Ali et al.,2017). Additionally, there is insufficient knowledge and awareness regarding proper waste management, as well as illegal recycling of unsegregated waste, leading to safety risks. This is aggravated more by on-site treatment of healthcare waste, inadequate attention to healthcare waste management, irregular collection of healthcare waste, and lack of clearly marked containers are also prevalent issues (Tadesse & Dolamo, 2022).

Developing countries may need help implementing these strategies due to high costs and limited technological capacity. However, Sharma et al.'s (2021) paper suggests modifying these strategies to suit developing countries, for example, incineration could be conducted in designated areas away from the hospital to mitigate air pollution. Maximizing the use of available resources by sustaining best practices of healthcare waste management, especially in LMICs is crucial (Johnson et al., 2013)

Digital Health Technologies (DHTs)

DHTs such as telemedicine, artificial Intelligence (AI), and Very Small Aperture Terminals (VSAT) are being used in emerging economies to improve healthcare services by connecting rural centers to urban hospitals, screening for maternal and neonatal health issues, and facilitating data exchange between healthcare facilities and frontline workers (Khan et al.,2022). Telemedicine and EHRs have the potential to reduce GHG emissions in HHFs by eliminating the need for travel and paper-based processes. (Van der Zee et al., 2024; Cummins et al., 2024). Despite this benefit, Turley et al., (2011) noted that the utilization of individual personal computers seemed to increase carbon and energy footprints due to high energy use and generated tonnes of waste, however, the overall net impact of the EHR on ecology is still positive due to reduced use of paper, improve energy conservation. Barriers such as limited internet connectivity, lack of digital skills, prohibitive costs, and infrastructure challenges in developing countries hinder the widespread adoption and effectiveness of these technologies in reducing emissions. (Wu, 2019; Short et al., 2020). Despite their potential, the full benefits of DHTs in reducing GHG emissions are not fully realized due to these barriers.

Procurement and Use of Medical Supplies

Procurement of environmentally friendly equipment, medical supplies and pharmaceuticals is crucial in reduction of GHG emissions in HHFs. This can be achieved by proactively procuring drugs for prescription or dispensing with less environmental burden such as Low GWP Inhalers, selecting specific Low GWP anesthetic gases, minimizing materials used in surgery especially single use items, using eco-friendly transportation, simplifying drug packaging, and promoting the use of environmentally friendly pharmaceuticals by enlisting the preference for low GWP medications (Thiel et al., 2018)

To reduce the environmental emissions of surgeries, health care providers need to implement a combination of approaches, including minimizing materials especially single use supplies, moving away from certain heat-trapping anesthetic gases, maximizing instrument reuse or single-use device reprocessing, and reducing off-hour energy use in the operating room (Thiel et al,2018).

Collectively, these studies indicate that there is a dearth of a systematic strategy in healthcare systems and specific clinical practices to handle and mitigate emissions. Leaving the choice of medical equipment and supplies as the GHG emission source untouched is a major gap for discussion given the centrality of the aspects of sustainable healthcare purchase.

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METHODOLOGY

Study Design

The study incorporated the use of a systematic review methodology to extensively scrutinize and synthesize existing research on strategies for reducing GHGe in healthcare institutions in developing nations. A systematic review was considered the most productive method for this study, for it ensured a rigorous, reproducible, and transparent process of identifying, synthesizing, and evaluating all relevant research on the topic (Higgins et al., 2019).

Article Search Strategy

Article search was conducted using several electronic databases such as PubMed, ProQuest, Google Scholar, Web of Science, AJOL and CINAHL These databases were chosen to capture as many varieties of scholarly articles and research pertinent to the study as is possible as they provided links to peer-reviewed journals and sources that are interdisciplinary and cover a broad range of information for data computation. The utilization of these databases helped to establish that international and local views, particularly from African journals, are taken into consideration in the literature review.

The search strategy integrated the use of a combination of Medical Subject Headings (MeSH) terms and free-text keywords related to greenhouse gas emissions, hospitals or healthcare facilities, and developing nations or LMICs. The search terms were redesigned for each database as destined. A good example of the search strategy for PubMed is as follows,

(("Health Facilities"[Mesh] OR "Delivery of Health Care"[Mesh] OR hospital*[tiab] OR clinic*[tiab] OR "health care"[tiab] OR healthcare[tiab])

AND

("Greenhouse Gases"[Mesh] OR "carbon footprint"[tiab] OR "climate change"[tiab] OR "global warming"[tiab] OR sustainability[tiab] OR "environmental impact"[tiab])

AND

("Developing Countries"[Mesh] OR "low-income country"[tiab] OR "middle-income country*"[tiab] OR "resource-limited setting*"[tiab] OR Africa[tiab] OR Kenya[tiab]))

For widening the search, other sources were used such as reference lists from the identified reviews and the included studies to find out another related research. The grey literature were obtained from the government documents and the WHO reports that may hold some data that are not published in the journals.

Inclusion and Exclusion Criteria

To meet both objectives, the studies were identified and used according to certain inclusion and exclusion criteria. To be included, studies had to investigate, address, or describe strategies, interventions, or innovations intended at the decreasing of the GHG emissions in the HHFs. They studies should have been carried out in, or specifically focused on, the developing nations classified by the World Bank. Types of studies included in the review are the following: qualitative, quantitative, and mixed methods studies, systematic reviews, and meta-analysis. Also, due to a vast number of studies in the field, only the first 12 years of the present century were considered starting with the most recent published in English, or with available English translations.

In contrast, those papers which were limiting their research to developed countries or supply chain studies outside of the healthcare context and editorials or opinion pieces, or papers without full text accessibility were not included in the review.

Article Selection Criteria

The procedure of selecting the articles for this review was carried out in two steps to be as exhaustive as

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possible and as accurate as well. First, assessment of all the articles identified by comparing their titles and abstracts with the inclusion and exclusion criteria set. In the second stage, the 'full-text review,' seeking and evaluation of the full texts of potentially relevant studies. The recording of why any studies have been excluded was done. PRISMA flow diagram was prepared for the whole study selection procedure to give a clear picture of all the steps of inclusion and exclusion.

Data Presentation and Analysis Procedure

A standard data extraction form was developed and piloted on a subset of the included studies to enhance the reliability of the method that was used. Information on every aspect of the study was collected in an orderly manner including article name, authors, year of publication, journal, database, study location, methodology, sample size, and key findings. The extraction involved issues and factors that are related to barriers and enablers to implementation, and context factors that affect implementation. Any inconsistencies that was faced while extracting the data was well documented to help in further analysis.

The quality of the included studies was assessed based on methodological quality with relevant assessment tools that correspond to each study type. For the purpose of this study, the qualitative studies were assessed using the Critical Appraisal Skills Programme (CASP) Qualitative Checklist while the systematic reviews used the AMSTAR-2 Checklist. The quality of each study was comprehensively recorded, and the outcome of these reviews was used in the evaluation and synthesis of findings and strength of evidence.

Due to the expected variability of studies in terms of design and results, only narrative synthesis was used to summarize the results. This synthesis was organized around several key areas: the kinds of approach and actions used, the feasibility of such approach and actions in mitigating emission of GHG, and the influence of contexts on implementational processes as well as feasibility. Furthermore, the barriers and enablers to implementing these practices was looked at, the costs associated with these practices in terms of resource-constrained environments were also answered.

Secondary analysis of subgroup was undertaken to determine if any of the healthcare facility types (general, hospitals, primary care centers, etc.), geographical location, the income level of the country and the type of intervention (energy efficiency and waste management, etc.) will affect the efficacy of the proposed program.

The overall strength of evidence for each key finding was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach. This considered factors such as study design, risk of Bias, consistency of results, directness of evidence, precision, and publication bias.

The following approaches were taken towards the achievement of the research goal to reduce bias in the study: To minimize publication bias, an extensive ConOP strategy was conducted to capture a broad range of studies for the review. The use of duplicate screening and data extraction processes went a long way in reducing selection bias. Further, Cohen's procedure of quality assessment of the selected works was applied to minimize bias that is inevitable in primary research. In the light of this, incorporation of grey literature helped to balance in aspect of publication bias and provide more diverse views.

The findings of this systematic review will be disseminated through several channels: first, by reporting the findings in a learned journal since this will have to conform with academic standards of research and dissemination. Further, details of the study shall be published in various scholarly conferences that are international in scope to get acquainted with more researchers. There will be a policy brief presented for the healthcare managers and policymakers in the developing countries, which will be practical. Finally, the findings will be disseminating the researched data to stakeholders such as the WHO, and Ministries of Health in the developing nations to enhance decision making and practice.

Ethical Considerations

As this study is a systematic review of published literature, formal ethical approval is not required, however, the review adhered to ethical principles in research synthesis, including transparency in reporting, fair representation of findings, and acknowledging limitations.

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FINDINGS

Study Search and Article Selection.

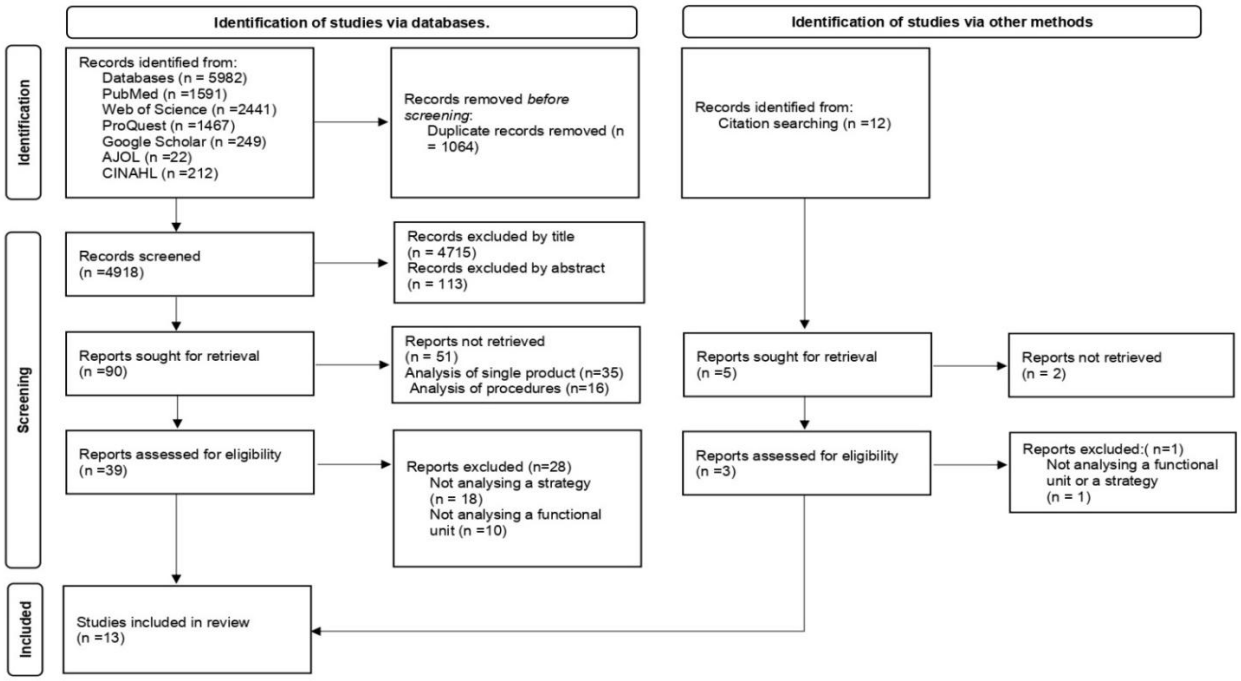
The initial electronic search produced a total of 5,982 articles from several databases regarding the studies on healthcare GHG emission reduction strategies in developing nations. A total of 4,918 articles were considered for the title screening after flushing out 1,064 records of duplicates. In this phase, records were reviewed for their association with themes of interest including energy efficiency, renewable and clean energy implementation, waste management and disposal, digital health technology strategies and Procurement and use of medical supplies for lowering emissions in health care facilities. Out of 203 screened articles, 90 papers were deemed sufficiently related to the titles to be included for further examination. The final step was an abstract review, which thus reduced the number of potential studies to 39. The researcher systematically identified thirteen (13) articles for a full-text review based on our inclusion criteria to provide an extensive coverage of the options available for the reduction of GHGs within the healthcare field for developing countries as summarized in Table 1 below.

Table 1: Study Selection Process.

Stage of Review	Number of Articles	Description
Initial Search	**4368**	Total records retrieved from all databases
Duplicate Removal	**1048**	Number of duplicates articles removed
Title Screening	**3320**	Articles retained after title screening
Abstract Review	**563**	Articles retained after abstract screening
Full -Text Review	**39**	Articles reviewed in details
Additional Studies	**2**	Studies Identified via other methods
Final Selected Studies	**13**	Studies selected for final synthesis

The reasons for excluding the articles after full text study were recorded and presented in the PRISMA 2020 flowchart as shown in Figure 1 below.

Figure 1: Prisma 2020 Flow Diagram for Strategies for Reduced Healthcare Greenhouse Gas Emissions in Developing Countries.



Note. Adapted from BMJ 2021;372: n71

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Results of Selected Studies

Once the studies were selected, the next step involved categorizing them into five key areas: energy efficiency, renewable and clean energy, waste management and disposal practices, digital health technologies and procurement and use of medical supplies in healthcare facilities. This categorization was useful in systematically analyzing the data to identify the various strategies used to minimize the overall discharge of GHG in healthcare services. This way of categorizing the studies provided more of an organized approach to cut across all facets of the studies and examine aspects of GHG reduction comprehensively.

The thirteen (13) studies selected are summarized in the table below:

Table 2: Summary of Selected Studies.

Category	Article Title	Authors/Year of Publication	Database/Journal used	Study Location	Methodology	Sample Size	Key Findings
Energy Efficiency	Improving Energy Efficiency of Thermal Processes in Healthcare Institutions: A Review on the Latest Sustainable Energy Management Strategies	Hohne et al., (2020)	MDPI/Energies	South Africa	Systematic review	Largest energy consumers in South African healthcare institutions (sample Size not Listed)	Energy savings rates of 15%–30% are possible for energy efficiency initiatives, while improvements will decrease energy consumption by 5%–10%.
	Energy Retrofit Strategies for South African health care facilities: A scoping literature review.	Dion et al., (2023)	SCOPUS/ *Cogent Engineering* ,	South Africa	A scoping literature review.	Not indicated	The study offers some insights into specific energy retrofit measures and limitations in healthcare facilities
Renewable Energy	Implementation research on sustainable electrification of rural primary care facilities in Ghana and Uganda	Javadi et al., (2020)	PubMed/ *Health policy and planning* Journal	Uganda and Ghana	Qualitative Study	100 key informants, focus group discussions with over 800 community members	Solar energy installation in health facilities has been associated with increased availability of health services.
	Advancing Solar Energy for Primary Healthcare in Developing Nations: Addressing Current	Sharma et al.,(2024)	PubMed/Cureus..	India and sub-Saharan Africa	Literature Review	Not Indicated	The study discusses the rapid growth of solar capacity and generation and addresses challenges in implementing

	Challenges and Enabling Progress Through UNICEF and Collaborative Partnerships.						solar projects in healthcare facilities.
Waste Management Practices	A Whole Systems Approach to Hospital Waste Management in Rural Uganda	Kwikiriza et al., (2019)	PubMed/ Frontiers in public health Journal	Uganda(Bwindi Community Hospital in South - Western Uganda)	Mixed Method study	15 clinical staff(nurses, midwives, clinical officers, lab staff, and medical doctors) and 6 non-clinical staff (administrators and porters).	Overall, clinical staff had good awareness of waste types and risks, but non-clinical staff had poorer knowledge. This led to incorrect segregation and transportation of waste on site.
	Sustainable waste management of medical waste in African developing countries:	Chisholm et al.,(2021)	PubMed/Sage Journal/ International Solid Wastes and Public Cleansing Association, ISWA,	African Developing Countries	A narrative review.	54 LMIC in Africa	Recommendations for sustainable medical waste management, including the use of eco-friendly technologies for treatment and disposal..
	Medical waste management at the primary healthcare centres in a Northwestern Nigerian State: Findings from a low-resource setting	Omoleke et al (2021)	PubMed/ *Public health in practice*	Northwest Nigeria State(Kebbi State)	Cross Sectional Survey	257 Healthcare Workers	The study found out that 41% of health facilities had trained staff on medical waste management. 48% of HFs treated of medical waste on-site, 77% used Burn-and-bury method and 7% used open burning as the adopted methods of medical waste disposal
	Improving waste segregation while reducing costs in a tertiary-care	Johnson KM, González ML, Dueñas L, et	PubMed/Sage Journal/Environmental and Public	Hospital Bloom, San Salvador, El Salvador (Central	Observational Study	Not Indicated	The study concluded that educating hospital staff in healthcare waste

	hospital in a lower–middle-income country in Central America..	al.(2013)	Health	America)			management can lead to a 44% increase in correct waste segregation and a 48% reduction in biohazardous waste disposals
	Assessing knowledge, attitudes, and practices of healthcare workers regarding medical waste management at a tertiary hospital in Botswana:	Mugabi et al.,(2018) .	PubMed/ Nigerian journal of clinical practice	Botswana	A cross-sectional quantitative study	703 nurses, laboratory technicians, and housekeeping staff	Ongoing training should be provided to HCWs on MWM, with more attention to knowledge of regulatory requirements, and involvement of HCWs in development of MWM policies to enhance compliance
	Healthcare Waste Segregation Practice and Associated Factors among Healthcare Professionals Working in Public and Private Hospitals, Dire Dawa, Eastern Ethiopia.	Ibrahim, M., Kebede, M., & Mengiste, B. (2023).	PubMed/Journal of environmental and public health,	Dire Dawa, Eastern Ethiopia.	cross-sectional study	280 healthcare workers from public and private hospitals.	This study showed that 56.4% of the study participants had good healthcare waste segregation practices and identified factors significantly associated with healthcare waste segregation practices.
Digital Health Technologies	Transport-related emissions and lifetime risk of maternal death in developing nations.	Gani et al., (2024)	PubMed/Health care for women international	Developing Nations	Retrospective study	38 developing Countries	Study finds that there is a statistically significant positive correlation between transport-related carbon emissions and the lifetime risk of maternal death in developing nations.

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	Smart city healthcare delivery innovations: a systematic review of essential technologies and indicators for developing nations.	Mohammadzadeh et al., (2023)	PubMed/BMC Health Serv Res. 2	Developing Nations	A Systematic Review	22 articles	Harnessing the power of data analytics, Internet of Things (IoT) sensors, and mobile applications, smart cities are driving real-time health monitoring, early disease detection, and personalized treatment approaches.
Procurement and use medical Supplies	The Aga Khan Development Network's (AKDN) approach to supply chain carbon foot printing for healthcare providers.	Jerome & Fawzia,(2023)	ScienceDirect/Cleaner Logistics and Supply Chain	LMIC in South and Central Asia and East Africa.	Cross sectional study	11 healthcare operations of AKDN across 8 LMICs.	The majority of an organization's operational footprint comes from four procurement spend categories: medical and surgical supplies, lab consumables, medical equipment, and pharmaceuticals; typically making up 86% of the total emissions for each organization.

For the purpose of quality assessment, a checklist of 24 questions was used and each question was rated on a scale of 1-3; the checklist addressed issues pertaining to study type, methodology, method of data collection and Generalizability or relevance to the question. Each of the 13 selected studies were given an average ranging from 17/24 and above and therefore qualified to be included in this review. These papers were considered methodologically sound, and their topics were close enough to the healthcare sector in developing countries to contribute enough to the review's findings (Table 3).

Table 3:Quality Assessment of Selected Studies

Study ID	**Study Design**	**Methodology (Out of 24)**	**Region**	**Main Focus**
1	Observational Study	18	El Salvador	Waste Management
2	Qualitative Study	19	Uganda	Renewable Energy
4	Cross sectional Study	17	Nigeria	Waste Management

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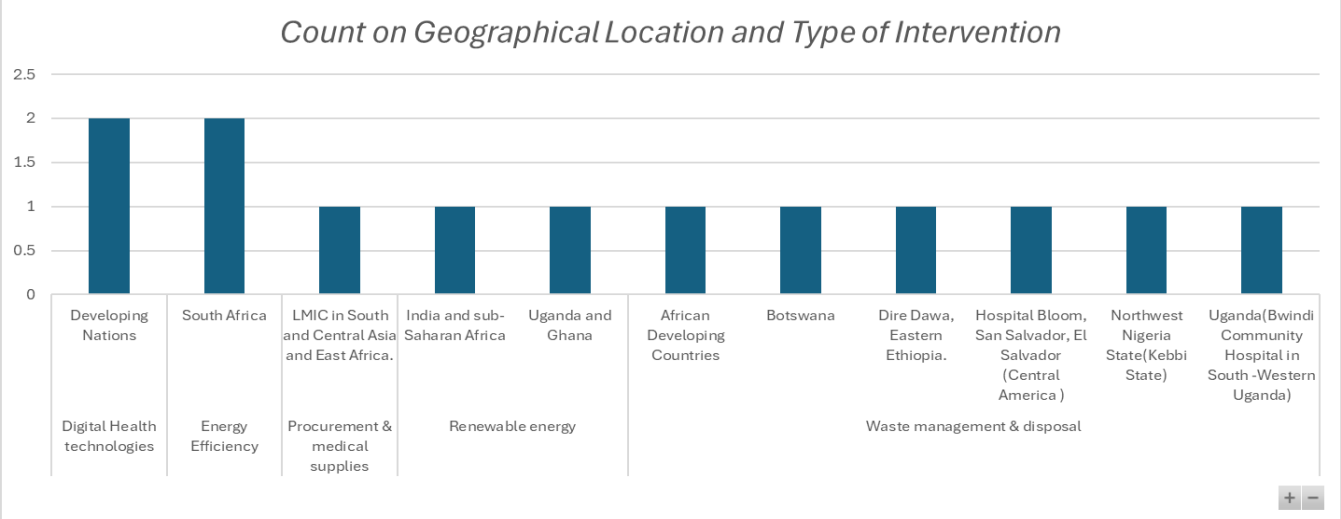
5	Qualitative Study	18	Uganda & Ghana	Renewable Energy
6	Literature Review	18	South Africa	Energy Efficiency
7	Retrospective Study	19	Developing Countries	Digital health Technologies
8	Mixed Method study	17	Uganda	Waste Management
9	Systematic Review	18	South Africa	Energy Efficiency

Subgroup Secondary Analysis

Secondary analysis of subgroup was undertaken to determine if any of the healthcare facility types (general, hospitals, primary care centers, etc.), geographical location, the income level of the country and the type of intervention (energy efficiency and waste management, etc.) will affect the efficacy of the proposed program as shown on table 4 below.

Table 4:Count on Geographical Location and Type of Intervention



DISCUSSIONS

Energy Efficiency

The study by Hohne et al. (2020) found that previous research on healthcare facilities' energy efficiency focused on increasing energy-saving initiatives by 30% without thoroughly evaluating their effectiveness. The study suggests that energy conservation, renewable energy systems, and innovative technology can positively impact energy efficiency. The researchers recommend reducing energy output demands by 30% before implementing renewable energy solutions. They also suggest using energy conservation techniques such as building insulation, daylighting, and occupancy sensors. The study concludes that healthcare institutions in South Africa have high energy consumption, with HVAC and water-heating systems being major contributors. The Performance, Operation, Equipment and Technology (POET) efficiency framework can identify energy-saving opportunities, with potential savings ranging from 15% to 70%. Economic barriers may hinder implementation, but government support is crucial for reaching energy reduction targets. Optimization techniques can provide significant savings at low costs.

Dion et al. (2023) conducted a literature review on energy retrofit strategies in South African public healthcare facilities. They found that despite the deterioration of healthcare buildings, renovation and modernization have been challenging due to complexity and limited insights into energy performance. The study established that existing systems are expensive and energy-intensive, and there is a lack of empirical or theoretical frameworks for energy retrofit planning. The research highlighted a knowledge gap in optimal energy retrofit practices tailored to healthcare system managers and energy utilities. The authors recommend investing more time and

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resources into research and guidelines for systematic planning and implementation of energy retrofitting measures in South African healthcare facilities.

The studies recommended implementing an energy management program, conducting an energy audit, upgrading equipment to energy-efficient options, utilizing lighting technology advancements and implementing strategies to control electricity usage can help HHFs save on energy costs as feasible strategies for reducing GHG emissions in developing countries.

Renewable and Clean Energy

The study by Sharma et al. (2024), discusses the critical role of reliable and sustainable energy, particularly solar power, in achieving health-related SDGs in LMICs. The study emphasizes the importance of uninterrupted electricity for critical medical equipment and services in HHFs in developing nations; highlighting the increasing significance of solar energy globally and its potential to address challenges in the healthcare sector by discussing successful solarization projects in India, sub-Saharan Africa, and other regions while detailing the challenges of implementing solar PV projects in healthcare facilities and the importance of maintenance and proper management.

In other studies, Solar photovoltaic (PV) systems were identified as the main implemented solutions as compared to other sources of renewable and clean energy. The study in Uganda showed that the implementation of solar PV systems can reduce almost 122.742 t of carbon dioxide (Thadani & Go, 2021).

The studies recommended roof solar panels for solar and water heating and biogas treatment for energy generation from organic refuse gas as feasible strategies to be used as renewable and clean energy sources in developing countries.

Waste Management and Disposal Practices

A study in rural Uganda by Kwikiriza et al., (2019), found that clinical staff had good awareness of waste types and risks, while non-clinical staff had limited knowledge. The study also highlighted weak waste segregation and transport practices, emphasizing the need for innovative solutions like onsite-recycling and incineration. Supply chain methodology and systems thinking were deemed crucial for improvement. Other studies in El Salvador (Johnson et al., 2013) and Nigeria (Omoleke et al.,2021), also showed that staff training in waste management led to better segregation and cost savings emphasizing the need for ongoing reinforcement of waste management policies, training, and supplies.

The cross sectional survey by Omoleke et al (2021) found that 48% of HFs treated medical waste on-site, 77% used burn-and-bury method and 7% used open burning as the adopted methods of medical waste disposal highlighting the reliance on outdoor burning as the primary disposal method for hospital waste and the lack of proper waste sorting and segregation. The study revealed a lack of awareness and investment in safe medical waste management by hospital management in resource-poor settings.

Overall, educating hospital staff in waste management can result in better segregation and cost savings, particularly in lower-middle-income countries. Research findings provide policies and solutions for sustainable medical waste management, including the use of eco-friendly technologies and better coordination between healthcare systems and stakeholders. The studies recommend implementation of waste segregation practices to encourage recycling of materials like plastics, paper, and glass and use of technologies like autoclaving or incineration with emission control systems to dispose of medical waste in an eco-friendly manner. It is noted that Improved regulations, training, and awareness are needed to address environmental and health risks in healthcare waste management.

Digital Health Technologies (DHTs)

From the review of the article by Gani et al., (2024) and Mohammadzadeh et al., (2023), the authors recognized DHTs as an innovative solution to decrease GHG emissions, namely by avoiding physical travel both from patients and HCWs by using telemedicine. Also, leveraging on big data analytics, Cloud Computing

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Virtual reality Internet of Things (IoT) sensors on wearable devices and mobile applications for real-time health monitoring, disease early warning, and personalized medication also played a crucial role in minimizing the carbon impact within the sphere of the medical field.

Procurement and Use of Medical Supplies

The study by Jerome and Fawzia, (2023) observed that operations footprint of the HHFs was primarily represented by four spend categories: Medical and Surgical Supplies, Lab Consumables, Chemical & Supplies, Medical, Surgical Lab Equipment, and Pharmaceuticals, which made up an average of 86% of each organization's total footprint. Smaller contributions came from construction, food supplies, imaging supplies, and estates equipment. Medical supplies procurement practices in developing countries can be optimized to reduce GHG emissions in HHFs by Integrating environmental standards into procurement and supplier selections, utilizing available tools and certifications that measure suppliers' operational environmental performance and pressuring suppliers to improve their operations in order to be selected .

Altogether, these works indicate a major failure in developing and implementing a comprehensive business plan at the institutional level to address and control emissions arising from procurement and use of medical supplies. The considerations of medical equipment and supplies in the context of GHG emissions could be seen as one of the global gaps that require further debate, of course, proving the significance of sustainable purchasing in healthcare.

Limitations of the Study and the Reliability of the Results

The findings of this study offer important knowledge on approaches to decrease GHG emissions in HHFs in developing countries; however, some limitations noted can affect the credibility and transferability of the results.

Firstly, the geographical area which is discussed primarily relates to selected regions in Africa and Asia and the size of the sample is limited to some extent by authors and may not reflect the variety of healthcare facilities and systems in all the developing countries. This can cause the selection bias when only positive studies are chosen. Further, the reviewed studies allow for presentation of the short-term intervention outcomes, although the long-term effects of the implemented strategies remain uncertain due to the methodological variability of the 13 selected studies. Few studies provided sufficient descriptive information about the socio-economic and political environment that directs practice in health care sector. The issues of data quality and availability persisted, because data was self-derived and self-reported.

Lastly, healthcare presents a potential for new developments and innovations, as it is dynamic and constantly developing which might make some of the findings of the work less relevant.

Strengths and Weaknesses of the Review

The main strength of this review is that it is a comprehensive review of current literature on the reduction of GHG emissions in healthcare facilities in the developing world. Thus, using strict criteria for searching and selecting the material, the review focused on a sufficient number of works, which means that the conclusions are based on empirical data. Also, the consideration of the range of measures including energy and resource conservation, renewable and cleaner energies, waste minimization and efficient disposal, digital health technologies and procurement and use of medical supplies brings from a better perspective the spectrum of measures that are needed to manage the GHG emissions in the healthcare industry. The quality assessment of selected studies adds to the credibility of the review by only falling into conclusion studies with methodological quality.

The major limitation of the review is that the use of data from some areas can be quite limited because of the differences in cultures, economic potential, and political systems of different states which shape the approaches to the healthcare delivery. Furthermore, the assessment mainly evaluates the short-term consequences of the defined plans, which may not include later effects while not addressing issues of their sustainability. Lastly, the dissimilarity of methodologies and reporting approaches of the included studies may bring some inherent

systematic bias and impact on the validity of the meta-analysis.

Research Gap

Although, the current literature has been seen to be addressing the strategies for reduced GHG emissions in healthcare facilities, there are concerns in assessment of the ultimate impact and durability of such interventions in different environments. The strategies identified are mostly designed to identify short-term effects and observational data but the long-term effects of brought-in measures and practices like energy conserving actions, waste management and disposal systems, digital health technologies or procurement and use of medical supplies are characteristically missing. Moreover, there is a lack of literature focusing on the socio-economic, cultural and political factors that affect the extent to which such strategies are utilized and operationalized within varying healthcare contexts common to developing nations. To a large extent, this gap highlights the need for more research on the contextual enablers and constraints of expanding and sustaining more GHG reductions especially in low-income setting.

CONCLUSION

Reducing GHG emissions is crucial for the healthcare systems of developing countries. Thus, effective strategies such as improving energy efficiency through equipment upgrading (LED Lighting, energy-efficient and low voltage drives and electric motors), the use of energy monitoring systems and renewable energy sources such as solar power and biogas can significantly contribute to reducing GHG emissions. Further, the use of better methods in waste management such as correct segregation and disposal including recycling and advanced medical waste treatment have significant impacts on reducing GHG emissions, while adoption of digital health and especially telemedicine eliminates transportation-related emissions. In some measures also, green development practices for retrofits, such as using locally sourced and renewable materials and promoting natural ventilation, can also help.

Nevertheless, there are still some deficiencies concerning the publication of emissions associated with procurements connected to costs of medical and surgical supplies, lab consumables, chemical & supplies, medical, surgical lab equipment, and pharmaceuticals, medical equipment and materials.

Thus, it is critical to assert that the insights provided in this paper call for the development of a coherent multifaceted approach devoted to the discussed thematic areas. In conclusion monitoring and reporting of emissions, as well as community engagement in eco-friendly activities, capacity building, policy development, and advocacy are important for promoting sustainability in healthcare facilities.

Recommendation and their Implications for Current Practice

The implications of the outcomes arising from this review are profound with respect to healthcare interventions that seek to minimize the discharge of GHG emissions in developing countries. Occupational implementations should therefore focus on energy efficiency enhancements; and renewable and clean energy installation because both interventions have improvements on emissions controls and organizational sustainability. Policy makers need to provide incentives for renewable energy finance and also promote employment generation programs so that people who have to man these technologies can be trained locally. In addition, other management practices that the healthcare organizations should implement is sustainable waste management practices in the area of segregation and source control of separable wastes.

As for the further research, they should investigate the outcomes of GHG reduction strategies and their impact over longer terms and with reference to the wide range of geographical conditions and examine such socio-economic factors as a determinant for the effectiveness of the strategy. It also calls for collective work with community stakeholder for research-based policy and practice protocols that are context suited.

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