Received: 18 October 2022 | Revised: 1 March 2023 | Accepted: 7 April 2023

DOI: 10.1111/jan.15671

REVIEW

JAN Leading Global Nursing Research WILEY

The carbon footprint of healthcare settings: A systematic review

Lucas Rodríguez-Jiménez[1] | Macarena Romero-Martín[2] | Timothy Spruell[3] | Zoe Steley[1,4] | Juan Gómez-Salgado[5,6]

[1]Emergency Department, Royal Free London NHS Foundation Trust, London, UK

[2]Faculty of Nursing, Universidad de Huelva, Huelva, Spain

[3]Anaesthetics Department, Croydon Health Services NHS Trust, London, UK

[4]Environmental Special Interest Group, The Royal College of Emergency Medicine, London, UK

[5]Department of Sociology, Social Work and Public Health, Faculty of Labour Sciences, Universidad de Huelva, Huelva, Spain

[6]Safety and Health Postgraduate Programme, Universidad Espíritu Santo, Guayaquil, Ecuador

Correspondence
Macarena Romero-Martín, Facultad de Enfermería, Campus El Carmen, Avda. Tres de Marzo s/n, Huelva 21071, Spain.
Email: macarena.romero@denf.uhu.es

Abstract

Healthcare systems are responsible for 4%–5% of the emissions of greenhouse gases worldwide. The Greenhouse Gas Protocol divides carbon emissions into three scopes: scope 1 or direct emissions secondary to energy use; scope 2 or indirect emissions secondary to purchased electricity; and scope 3 for the rest of indirect emissions.

Aim: To describe the environmental impact of health services.

Design: A systematic review was conducted in the Medline, Web of Science, CINAHL, and Cochrane databases. Studies that focused their analysis on a functional healthcare unit and which included. This review was conducted from August to October 2022.

Results: The initial electronic search yielded a total of 4368 records. After the screening process according to the inclusion criteria, 13 studies were included in this review. The reviewed studies found that between 15% and 50% of the total emissions corresponded to scopes 1 and 2 emissions, whereas scope 3 emissions ranged between 50% and 75% of the total emissions. Disposables, equipment (medical and non-medical) and pharmaceuticals represented the higher percentage of emissions in scope 3.

Conclusion: Most of the emissions corresponded to scope 3, which includes the indirect emission occurring as a consequence of the healthcare activity, as this scope includes a wider range of emission sources than the other scopes.

Implications for the profession and/or patient care: Interventions should be carried out by the healthcare organizations responsible of Greenhouse Gas emissions, and also every single individual that integrates them should make changes. The use of evidence-based approaches to identify carbon hotspots and implement the most effective interventions in the healthcare setting could lead to a significant reduction of carbon emissions.

Impact: This literature review highlights the impact that healthcare systems have on climate change and the importance of adopting and carrying out interventions to prevent its fast development.

Protocol Registration: PORSPERO ID CRD42022365121.

Reporting Method: This review adhered to PRISMA guideline. PRISMA 2020 is a guideline designed for systematic reviews of studies that analyse the effects of heath interventions, and aim is to help authors improve the reporting of systematic review and meta-analyses.

Patient or Public Contribution: No Patient or Public Contribution.

KEYWORDS

carbon footprint, environmental impact, greenhouse gases emissions, healthcare settings, life cycle assessment

1 | INTRODUCTION

Climate change has forced many countries and institutions to declare a climate emergency and carry out changes in different sectors of society in an attempt to reduce Greenhouse Gases (GHGs) (Intergovernmental Panel on Climate Change, 2018). Romanello et al. (2021) described climate change as one of the worst healthcare threats of the 21st century. Climate change can be defined as the alteration of the climate patterns provoked by changes in the environment and the variability of its characteristics and that keeps happening for a long period of time (Intergovernmental Panel on Climate Change, 2018). Climate change can be caused by natural internal and/or external processes, as well as human activity. GHGs emitted by human activity intensify global warming, increasing the chances of heatwaves, floods, droughts and/or air pollution, among others. These variations in the climate are directly related to an increase in pathologies such as cardiovascular, respiratory and/or infectious diseases, as well as malnutrition or mental health issues secondary to the lack of resources and the growth of situations of high emotional distress (Chua et al., 2019). The Intergovernmental Panel on Climate Change (IPCC) report (2018) analysed data from different models of projected risks and found that exposure to climate change could increase heat-related morbidity and mortality up to 16 times. Diseases such as malaria or dengue are expected to be intensified due to climate change, which could potentially put 2.25 billion people at risk (IPCC, 2018). The food industry may also be affected by climate change, posing a risk of malnutrition. Furthermore, climate change could lead to conditions of severe poverty affecting more than 100 million people worldwide and, therefore, to a significant increase in migration processes (Hallegatte et al., 2016). This increased migration along with the intensification of natural disasters could result in a significantly greater number of healthcare demands, thus having an especially significant impact on those countries in which healthcare systems are already fragile (Watts et al., 2018). The COVID-19 pandemic has showed the vulnerability of healthcare systems worldwide and the difficulties experienced when dealing with situations of extreme emergency, so prevention, adaptation and preparation are key to reduce and slow down the consequences of climate change (Fournier et al., 2022).

Carbon footprint can be defined as the best possible estimation of the impact that something has on climate change (Spruell et al., 2021). Carbon footprint is the sum of direct and indirect emissions of GHGs secondary to a process, a product or an organization and is calculated in Carbon Dioxide equivalent (CO_2e). This concept entitles the seven GHGs established by the United Nations Framework Convention on Climate Change (The Paris Agreement, 2015): carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulphur hexafluoride (SF_6); and nitrogen trifluoride (NF_3). CO_2 represents 86.0% of the GHGs emissions, hence why GHGs emissions, carbon emissions and carbon footprint are often used interchangeably. The Greenhouse Gas Protocol (2022) classifies carbon emissions in three scopes; scope 1 or direct emissions are those related to the use of energy (without including purchased electricity) and on which the organization has direct control, for example the use of fuel for heating; scope 2 or indirect emissions are those related to purchased electricity or the use of electricity that has been produced somewhere else; and scope 3, which encompasses the rest of indirect emissions emitted by an organization and of which production is not controlled by the organization. There are three main methodologies for measuring the carbon footprint or Life Cycle Assessment (LCA): bottom-up life cycle assessment; top-down cycle assessment or economic input–output analysis; and the combination of both or hybrid model. Bottom-up LCAs measure all the materials used to produce an item or a process and multiply each material or item by a conversion factor. Top-down cycle assessment or economic input–output analysis uses the money spent in a product or a process, and this is multiplied by a conversion factor. Finally, the hybrid model is a combination or both (Lin et al., 2013).

> **What does this paper contribute to the wider global clinical community?**
>
> - Awareness of the carbon emission caused by the healthcare activity.
> - Identification of the hotspots carbon emission within the healthcare system.
> - Guidance for more effective interventions aimed at reducing carbon emissions.

Over the last years, there has been a surge of interventions aimed at reducing the effects of climate change (Spruell et al., 2021). The Sustainable Development Unit (SDU) carried out a survey of NHS workers between 2017 and 2019 and found that 98% of them believed in the importance of building a sustainable healthcare service (NHS England, 2017). As different situations serve as evidence of necessary interventions, laws change, as can be seen in the Climate Change Act passed in the UK, which aims to reduce carbon emissions to zero by 2050 (UK Government, 2008). On their part, healthcare systems are responsible of 4%–5.0% of the emissions of GHGs worldwide (Pichler et al., 2019), so health services have a responsibility in fighting climate change not just to reduce their own carbon footprint but also to decrease the consequences of healthcare activity on health and to act as a role model for the society (SDU, 2018). The IPCC report (2018) stated that climate resilience could have a strong potential for ameliorating climate change impact on health and that transformational changes would be more effective if they are responsive to regional and local knowledge, considering the many dimensions of vulnerability. The development and implementation of programmes and policies in health systems has followed an evidence-based model over the last years (Hess et al., 2014). The use of evidence-based approaches to identify carbon hotspots and implement the most effective interventions in healthcare could bring about a significant reduction of carbon emissions (Hess et al., 2014). Therefore, the analysis of healthcare settings emissions is essential to decrease the impact of health services on the environment. The contribution and novelty of this literature review lies on collecting the most recent evidence available regarding the carbon footprint of healthcare systems. The results of this study will help to analyse the carbon footprint of the healthcare systems and identify those areas of higher greenhouse gases intensity.

1.1 | Aim

This review aims to describe the environmental impact of healthcare services by answering the following questions: What is the carbon footprint of healthcare settings? How much greenhouse gas emissions do healthcare services emit? Which are the hotspots of carbon emissions in the healthcare sector?

1.2 | Methodology

To give answer to the study questions, a systematic review was conducted in accordance with the PRISMA 2020 Statement (Page et al., 2021). The review was registered at PORSPERO ID CRD42022365121.

1.3 | Eligibility criteria

The eligibility criteria were structured according to the components of the Population, Intervention, Comparator, Outcome (PICO) framework (Booth et al., 2019), in which health care units were considered the population, care activity the intervention, absence of care activity the comparator, carbon footprint and outcome.

Regarding the population, studies that focused their analysis on a functional healthcare unit, that is a complete patient care service, from admission to discharge, were included. Analyses of a single procedure or device were excluded for not performing a holistic assessment of user care. In relation to the intervention, studies carried out in the healthcare field, which analyse patient care, were included, and studies carried out in other fields, such as industrial, economic, waste management or studies not centred on the patient, were excluded. As for the outcome, cross-sectional studies that measured the carbon footprint, life cycle assessment or GHG emissions of healthcare functional units and which incorporated the three scopes recommended in the Greenhouse Gas Protocol (2022) were included. Reviews, opinion or popularization articles, research projects or other reports that did not provide results of an environmental impact assessment were excluded. Studies published between 2012 and 2022 were included so as to identify the latest evidence, and which were written in English and Spanish, as they are the most frequent languages in the scientific literature.

1.4 | Information sources

The Medline, Web of Science, CINAHL and Cochrane databases were searched. Furthermore, a snowball search was performed to retrieve studies not identified in the database search. Reference lists of publications which were eligible for full-text review and references from systematic review reports on a similar topic were reviewed. The initial search was conducted between February and April 2022, and updated in July 2022 after incorporating the results obtained from the snowball process.

1.5 | Search strategy

The search terms were identified by consulting the titles, abstracts and keywords of relevant reviews and articles. Several combinations of search terms were tested in the databases beforehand to select the strategy that could identify relevant studies in the most focused way. This process was agreed upon by two of the researchers. The search strategy used was ("carbon footprint" OR "greenhouse gas emission" OR "life cycle assessment") AND (health*). The filters used were year of publication and language.

1.6 | Selection and data collection process

The retrieved records were downloaded into a Microsoft Excel spreadsheet that allowed for the identification and elimination of duplicate records. The records were blindly screened by two independent researchers. The titles were reviewed, and the records were pooled to discuss inconsistencies and unify criteria. Then, the abstracts were screened and those that met the inclusion criteria were selected. Discrepancies in the selection were resolved by consensus. In case of doubt, it was agreed upon to include them for full-text review. The same researchers independently reviewed the full text of the selected studies, and discrepancies were resolved by consensus, resorting to a third researcher when necessary.

Data collection was carried out by one of the researchers and verified by two others. A form was designed to extract the data, including country, year of publication, functional unit, methodology, categories analysed, carbon emissions, data collection (including data source and data type) and emissions factors (Table 2).

Once the data were extracted, they were analysed and grouped according to the dimensions described by the Greenhouse Gas Protocol (2022): scope 1 (gases directly emitted by the institution, such as anaesthetic gases); scope 2 (indirect cause of gases derived from primary resources, such as electricity); and scope 3 (indirect cause of gases derived from products used by the institution in its production chain, such as medical devices).

1.7 | Study risk of bias assessment

Two main sources of biases were considered in this review. On the one hand, biases arising from methodological quality, and on the other hand, biases arising from inaccuracies in the measurements made by the reviewed studies. These inaccuracies may lie in the calculation method employed (top-down or bottom-up), the inventory boundaries and the accuracy of data and assumptions made by the reviewed studies. Therefore, the risk of bias assessment was carried out through an ad hoc tool with elements drawn from the most relevant critical appraisal tools for assessing methodological quality (Pussegoda et al., 2017; Zeng et al., 2015) and elements from the reference guidelines (Greenhouse Gas Protocol, 2022). This assessing method has been used by Rizan et al. (2020) in a previous similar review. The assessment was conducted independently by two researchers who agreed on the discrepancies.

2 | RESULTS

The initial electronic search yielded a total of 4368 records. Duplicated articles were excluded, and, after carrying out a title screening, 90 met the inclusion criteria. The abstract review further reduced the number of records to 41, and a full-text reading was carried out. Finally, 13 studies were selected for this literature review (Figure 1). Regarding the quality assessment of the studies, all of them scored over 17 out of 24. All the articles were accepted as the magnitude of their analysis and the methodological quality were considered appropriate (Table 1).

The chosen studies were all written in English and conducted in different locations between 2012 and 2022: one in Morocco; one in Japan; two in the United States; three in Australia; two in Switzerland; one in the UK; one in China; and two in Canada. This literature review included studies that calculated the carbon footprint of a functional unit in a healthcare setting using one of the following methods: bottom-up life cycle assessment (Keller et al., 2021; Lim et al., 2013;

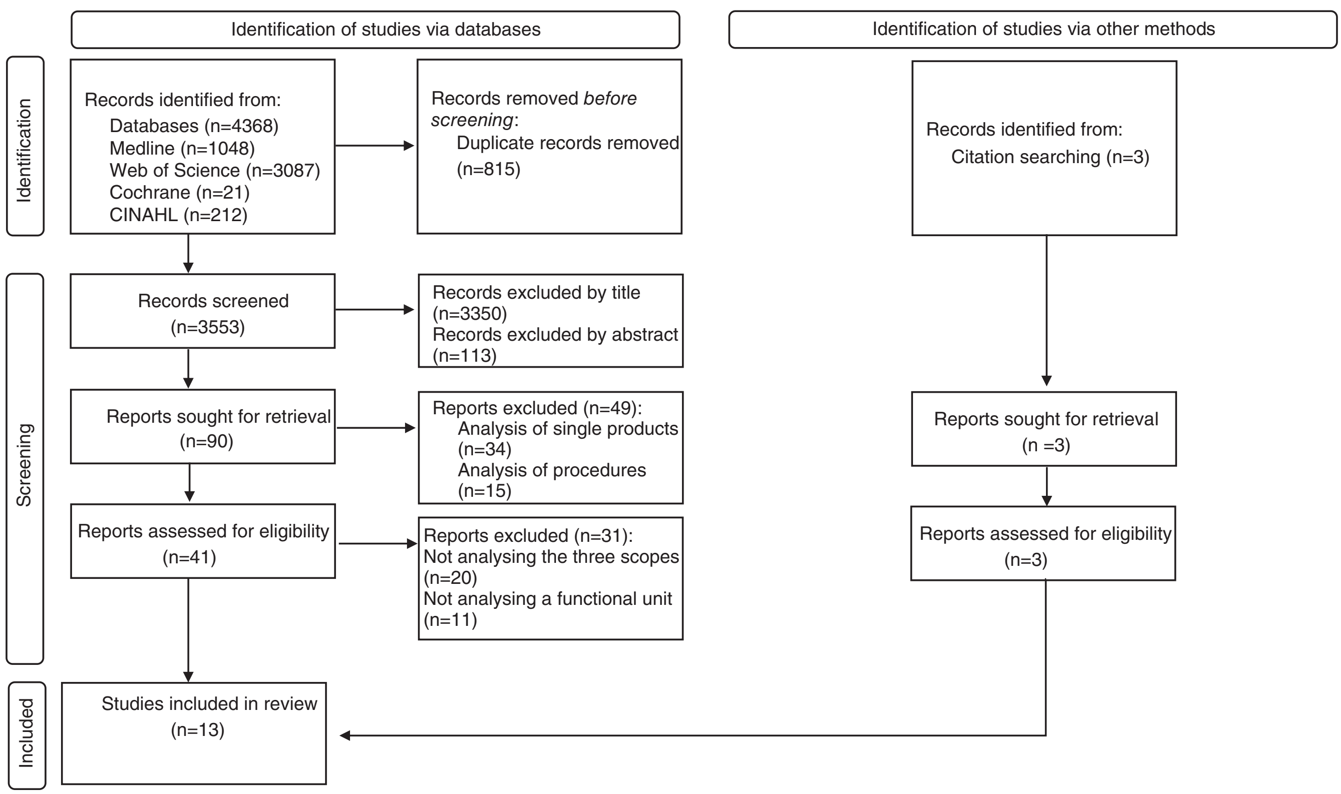

FIGURE 1 Article selection flowchart.

TABLE 1 Quality assessment results.

Category	Scoring system	Mtioui et al. (2021)	Nansai et al. (2020)	Prasad et al. (2022)	Malik et al. (2021)
Completeness	(a) To what extent are study inventory boundaries complete for a given functional unit? *Includes all reasonable factors* (2) *Includes limited/ambiguous factors* (1) *Narrow focus* (0)	2	2	2	2
	(b) Does the study account for all 3 scopes of GHG associated with the functional unit? *All 3 scopes measured* (2) *2 scopes measured* (1) *scopes limited to 1* (0)	2	2	2	2
Consistency	(a) To what extent is the study consistent with a recognized carbon footprinting guideline? *Stated and referenced* (2) *Stated, not referenced* (1) *No guideline stated* (0)	2	2	2	1
	(b) For comparative studies, how consistently are methods applied? *Consistently applied throughout* (2) *Limited consistency* (1) *Poor consistency* (0)	2	2	2	2
Transparency	(a) Are the hypothesis(/es) and study objectives clearly stated? *Both clearly stated* (2) *Either hypothesis or study objectives stated* (1) *Neither stated* (0)	1	2	1	2
	(b) To what extent are the GHGs included clearly stated? *Number of GHGs included clearly stated* (2) *Number of GHGs deducible* (1) *Number of GHGs not deducible* (0)	1	2	1	1
	(c) To what extent are study assumptions and exclusions clearly stated? *Both assumptions and exclusions stated* (2) *Limited* (1) *Neither stated* (0)	1	2	2	2
	(d) To what extent are the number of data points collected per process clearly stated? *Clear for all processes* (2) *Clear for limited processes* (1) *Not stated for any processes* (0)	2	2	2	2
	(e) How transparent are reported GHG results? *Numerical data for all sub-processes* (2) *Limited numerical data for some sub-processes* (1) *Descriptive or graphical data only* (0)	2	2	2	2°
Accuracy	(a) What is the specificity of the data sources to the study site? *1° data only* (2) *Both 1° & 2° data* (1) *2° data only* (0)[a]	1	1	1	0
	(b) Does the study determine parameter uncertainty? *Clear statistical plan with CI reported* (2) *CI reported, no clear plan* (1) *No CI or plan* (0)	2	0	0	0
	(c) Does the study determine scenario uncertainty? *Yes, demonstrating minimal uncertainty* (2) *Yes, demonstrating large uncertainty* (1) *No* (0)	2	0	1	1
Total	Scores out of 24	20	19	18	17

[a]1° = primary, 2° = secondary, CI = confidence interval, GHG = greenhouse gas.

MacNeill et al., 2017; Mtioui et al., 2021); top-down cycle assessment or economic input–output analysis (Eckelman et al., 2018; Eckelman & Sherman, 2016; Malik et al., 2018; Nansai et al., 2020; Wu, 2019); or a combination of both, also known as hybrid model (Malik et al., 2021; Nicolet et al., 2022; Prasad et al., 2022; Tennison et al., 2021).

The functional unit for analysis was stablished by the author/s of each study. Seven studies took the healthcare system of a whole country or a large state within a country as functional unit (Eckelman et al., 2018; Eckelman & Sherman, 2016; Malik et al., 2018, 2021; Nansai et al., 2020; Tennison et al., 2021). Three studies were multicentred: one of them in thirty-three hospitals (Keller et al., 2021); another one in three hospitals (MacNeill et al., 2017); and the third one in ten private primary care settings (Nicolet et al., 2022). The other three studies were carried out in units within a hospital: two of them in haemodialysis units (Lim et al., 2013; Mtioui et al., 2021) and one in an intensive care unit (Prasad et al., 2022).

Not all the studies analysed the same categories and that might be due to the complexity of such analysis. For example, those articles that analysed the entire healthcare system distributed their data in different areas of healthcare (such as public hospitals, primary

Keller et al. (2021)	Tennison et al. (2021)	Lim et al. (2013)	Malik et al. (2018)	MacNeill et al. (2017)	Nicolet et al. (2022)	Wu (2019)	Eckelman et al. (2018)	Eckelman and Sherman (2016)
2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2
2	2	2	2	2	1	2	2	1
1	2	0	1	1	1	2	2	2
2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2
2	2	1	2	2	2	2	2	2
2	2	2	1	2	2	0	0	0
2	0	0	2	0	1	2	2	2
2	2	0	2	0	0	2	2	2
23	22	17	20	19	19	23	22	21

healthcare, pharmaceutical industry), whereas those studies carried out in smaller functional units divided the data in more specific categories (such as water, waste, medical equipment, etc.). The main findings of the reviewed studies are summarized in Table 2.

2.1 | Scope 1 emissions

Scope 1 emissions ranged between 10% and 30% in the analysed studies. Studies that assessed healthcare systems found that scope 1 emissions were around 10% (Eckelman et al., 2018; Eckelman & Sherman, 2016; Malik et al., 2018, 2021; Nansai et al., 2020; Tennison et al., 2021), whereas in those analysing hospital settings or primary healthcare centres, these were around 20% (Keller et al., 2021; Lim et al., 2013; MacNeill et al., 2017 and Nicolet et al., 2022).

There were two exceptions of studies that found disparate results: one that found low levels of emissions, 0.4% (Mtioui et al., 2021) and another one which found high levels, 25.2% (Prasad et al., 2022). Only three of the studies assessed the use of medical gases, that ranged between 1.9% (Prasad et al., 2022) and 83.7%

(MacNeill et al., 2017). Transport freight or transport of goods by the organization was also part of the direct emissions and they accounted for less than 5% in the studies that looked into them (Mtioui et al., 2021; Nansai et al., 2020; Nicolet et al., 2022).

2.2 | Scope 2 emissions

Emissions secondary to purchased electricity differs between the studies analysed. Nicolet et al. (2022) found very low levels of emissions due to electricity (0.3%); however, their scope 1 emissions were higher than those of other studies. Three studies analysed energy and electricity together, thus hindering the individual analysis. Two of them showed higher percentages of emissions for energy and electricity (MacNeill et al., 2017; Prasad et al., 2022). On the other hand, Lim et al. (Lim et al., 2013) found relatively low levels, compared to the other two.

2.3 | Scope 3 emissions

Scope 3 emissions ranged between 50% and 75%. The largest emissions in scope 3 were found to be due to disposables or consumables, equipment (medical and non-medical) and pharmaceuticals. Disposables or consumables were analysed in different ways, yet most of the studies found that the carbon footprint related to them was greater than 20.0%. Studies that analysed healthcare systems found pharmaceuticals to account for between 7.6% (Wu, 2019) and 35.7% (Lim et al., 2013) of the emissions. Carbon emissions derived from medical equipment were generally high, ranging between 0.4% (Nicolet et al., 2022) and 32.2% (Prasad et al., 2022). Although there were some studies that calculated medical equipment, disposables and infrastructure together, this was still a significant percentage of the carbon footprint. Only two studies (Lim et al., 2013; Nicolet et al., 2022) found relatively low levels of emissions secondary to disposables. Two other categories, staff travel and building infrastructure, represented around 3.0% (Lim et al., 2013) and 16.6% of the total emissions each (Mtioui et al., 2021). Water, waste and patient travel generally represented less than 10.0%. The results for catering differed, ranging from 1.9% (Wu, 2019) to 30.3% (Prasad et al., 2022). The two studies that calculated the emissions secondary to food consumption for the whole national healthcare system found the levels relatively low, 3.6% (Nansai et al., 2020) and 6.1% (Tennison et al., 2021), respectively. However, the other two studies calculating catering carbon footprint found higher percentages, of 17.0% (Keller et al., 2021) and 30.3% (Prasad et al., 2022), and this might be so because these studies were carried out in hospital settings, where the provision of food to patients is expected to be high. Furthermore, Prasad et al. (Prasad et al., 2022) found higher percentages of emissions due to catering, and that is likely to be related to the fact that both staff and patient food consumption were calculated together.

3 | DISCUSSION

The aim of this systematic review was to analyse studies measuring the carbon footprint of healthcare settings and identify hotspots of carbon emissions. Overall, the studies reviewed showed that scopes 1 and 2 emissions were between 15% and 50% of the total emissions. Scope 3 emissions accounted for the rest, ranging between 50% and 75%, in which disposables, equipment (medical and non-medical) and pharmaceuticals represented the highest percentage of emissions. Staff travel and building infrastructure were also found to have a significant impact on the emissions, ranging between 10% and 15%. Water, waste and patient travel represented low levels of emissions. Data regarding carbon emissions secondary to catering were limited.

Regarding scopes 1 and 2, the geographic location of the analysed functional unit might influence the results. For instance, Mtioui et al. (2021) measured the carbon footprint in a dialysis unit in Casablanca (Morocco) and found energy only being responsible of 0.2% of carbon emissions; however, electricity represented a 27.7%. The authors explained this finding as due to the little use of heating and air conditioner in this functional unit because of the specific weather conditions in Casablanca (Mtioui et al., 2021). Another factor that could influence scopes 1 and 2 emissions was the age of the buildings. When analysing three different hospitals, MacNeill et al. (2017) noticed that two new hospitals produced less carbon emissions derived from energy and electricity than an old one. Overall, scopes 1 and 2 emissions proved to be linked, as those studies that found higher levels of emissions in scope 1 had lower emissions in scope 2, and vice versa. Reducing scopes 1 and 2 emissions can be achieved by introducing renewable energy in healthcare units as well as the use of insulation materials in the renovation and construction of new buildings (Campion et al., 2016). Furthermore, optimized electrical installations by improving air conditioning and heating systems could lead to a further reduction in energy use (García-Sanz-Calcedo et al., 2018). Montiel-Santiago et al. (2020) carried out a simulation of a digital system to model new systems of lighting and found that energy efficiency improvements could lead to a 47.0% reduction in energy use.

The use of certain anaesthetic gases can have a significant impact on the environment. The study conducted by MacNeill et al. (2017) in three hospitals of different countries (Canada, United States and United Kingdom) identified that the use of anaesthetic gases such as desflurane versus isoflurane and/or sevoflurane could lead to a 46.0% increase. Vollmer et al. (2015) suggested that the use of anaesthetic gases with low global warming potential, as well as limiting their use when possible, could reduce the carbon footprint. Hence, healthcare professionals and organizations should support and demand the use of anaesthetic gases that have a minimal impact on the environment.

The reviewed studies revealed that scope 3 emissions represented between 50% and 75% of the total emissions in healthcare. A previous study carried out in England found that the two largest contributors of scope 3 carbon emissions were medical equipment

TABLE 2 Main results from the reviewed studies.

Authors' year Functional unit Methodology	Categories analysed	Data collection Carbon emissions CO_2e (%)				Data source	Data type	Emission factor	Comments
Mtioui et al. (2021) Haemodialysis Unit Bottom-up LCA	Energy/heating	0.86 t CO_2e (0.2%)				Invoice and billing	P	IPCC, Base Carbone, ADEME	No use of heating as per location of the study
	Freight transport	0.74 t CO_2e (0.2%)				Invoice and billing	P		High carbon footprint electricity due to large proportion of fossil energy used for its production.
	Electricity	113.5 t CO_2e (27.7%)				Daily measurement	P		
	Water	0.5 t CO_2e (0.1%)				Source of water supply	P		Medical equipment and/or non-medical equipment and building infrastructure were measured together. It included building infrastructure, IT, biomedical equipment, and furniture.
	Waste	25.34 t CO_2e (6.1%)				Company providing the service	S		
	Staff travel	36.67 t CO_2e (8.9%)				Survey (distance/transport)	P		
	Patient travel	54.86 t CO_2e (13.4%)				Survey (distance/transport)	P		
	Disposable	109 t CO_2e (26.6%)				Service's accounting register	P		
	Equipment	68 t CO_2e (16.6%)				Service's accounting register	P		
	TOTAL	408.98 tons of CO_2e							
Nansai et al. (2020) National healthcare system Economic input–output analysis		**Medical Services**[a]	**Health & hygiene**[a]	**Nursing services**[a]	**Fixed Capital**[a]				
	On-site emissions	5.4 (13.0)	0.08 (9.3)	2.83 (28.1)	0.25 (2.7)	National report of GHGs inventory	S	IPCC, National report of GHGs inventory	Medical services included hospitalization, non-hospitalization, dentistry and miscellaneous medical services.
	Freight transport	1.3 (3.1)	0.17 (1.6)		0.12 (1.3)				
	Electricity	7.5 (18.1)	0.22 (27.2)	2.66 (26.4)					Health and hygiene included non-profit and for-profit.
	Waste	1.0 (2.4)	0.04 (5.4)	0.28 (2.7)					
	Staff/Patient travel	1.0 (2.4)	0.02 (3.1)	0.38 (3.7)					Nursing services included facility services and excluding facility.
	Disposables	2.1 (5.1)	0.02 (2.5)	0.18 (1.7)	0.36 (4.0)				Fixed capital formation included private and public for all the previous categories.
	Equipment	1.2 (2.8)			0.94 (10.5)				
	Pharmaceuticals	11.3 (27.2)	0.03 (3.4)						Total emissions 62.5 (4.69%) of the total national GHG emissions
	Building infrastructure	1.0 (2.4)			4.98 (55.6)				
	Catering			0.37 (3.6)					
	TOTAL	41.5 (66.4)	0.81	10.07	8.95				
Prasad et al. (2022) Intensive care unit and Acute Care Unit Hybrid model		**ICU**[b]	**ACU**[b]						
	Energy/electricity	30.5 (25.2)	30.8 (67.6)			Invoice and billing	P	Ecoinvent 3.4 unit process database	Carbon footprint calculated by floor area and by staff allocation. This table only shows by floor area.
	Medical gases	2.4 (1.9)	2.4 (5.3)						ACU produces the largest portion of the hospital's Non-RCRA Hazardous Pharmaceutical Wastes, 743 kg per year or 15%.
	Water	0.3 (0.2)	0.3 (0.6)						
	Waste	4.3 (3.5)	3.4 (7.4)			Auditing over 5 days.	P		
	Staff travel	10.4 (8.6)	4.9 (10.7)			Working days/distance/transport	S		
	Disposables	44.4 (36.7)	12.0 (26.3)			Inventory of the products and the expenditure	P	2013 US EEIO LCA model v1.1	
	Equipment	30.5 (32.2)	6.5 (14.2)						
	Catering	13.8 (11.4)	13.8 (30.3)			Assumption of 3 meals/patient/year.	S		
	TOTAL	120.8 per bed day	45.5 per bed day						

TABLE 2 Continued

Malik et al. (2021) Largest state in Australia Hybrid model	GHG emissions	7908 kt CO_2e (6.6%)	Expenditure on the health system in New South Wales (Australia). Customized MRIO table using a government computer platform.	S	Leontief framework	Coal 63%, gas 21%, hydroelectricity 5%, and wind 4% of national energy sources. No conversion to carbon emissions was done for this study.
	Water	246 gigalitres of water use per year				
	Waste	1624 kt of waste per year				
Keller et al. (2021) 33 Swiss hospitals Bottom-up LCA	Energy/heating	26.0%	Invoice and billing of annual demand	P	IPCC, USEtox 2.02	The GWP per hospital changes from 3.2 to 4.9 t CO_2-eq which increases the share of electricity on total impact from 9% to 42%. Wastewater was the same as water use. Five areas contribute more than 10% in some categories on waste assessment. Nitrile gloves are responsible for 45% of medical products and plastics contribute around 70% of housekeeping
	Electricity	9.0%.	Electricity provider	P		
	Water	0.5%.		P		
	Waste	4.5%.	Inventory data from 2 hospitals.	P		
	Medical equipment	3.0% – medical products 4% – housekeeping	Auditing	P		
	Pharmaceuticals	12.0%	Invoice and billing.	P		
	Building infrastructure	15.0%	Energy reference area. Average from three hospitals.	P		
	Catering	17.0%	Meals for patients, staff, visitors.	P		
	TOTAL	3.2 tonnes CO_2eq per FU average/year				
Tennison et al. (2021) National healthcare system Hybrid model	Energy and heating	2520 Kt CO_2-e (10.0%)	Inventory (ERIC)	P	From UK Government energy ministry publications, IPCC AR5, BEIS and UK MRIO satellite	Travel emissions include fleet travel (Scope 1), business and staff commuting (scope 3), and personal patient and visitors. Acute services are the largest contributors of total emissions (56%) or 125Kg CO_2-e/bed-day. 76 Kg CO_2-e/outpatient appointment in acute care. 66 Kg CO_2-e/GP visit. 75 Kg CO_2-e/ambulance emergency response.
	Medical gases	1290 Kt CO_2-e (5.1)	NHS pharmacy electronic data.	P		
	Electricity	0.70 Kt CO_2-e (2.8%)	Inventory (ERIC)	P		
	Water and waste	1300 Kt CO_2-e (5.1%)				
	Staff travel	2400 Kt CO_2-e _ (9.5%)	Fleet travel was from expenditure. Staff travelling from the department of transport: 2015–2019.	P		
	Patient travel	123 Kt CO_2-e (4.9%)		S		
	Visitors travel	29 Kt CO_2-e (1.1%)				
	Disposables	6030 Kt CO_2-e (24.0%)	From UK MRIO and Public Expenditure Statistical Analysis Supply and Use tables from HM Treasury	S		
	Medical equipment	2520 Kt CO_2-e (10%)				
	Non-medical equipment	1960 Kt CO_2-e (7.8)				
	Pharmaceuticals	5060 Kt CO_2-e or (20.2%)				
	Building infrastructure	80 Kt CO_2-e or (5.0%)				
	Catering	154 Kt CO_2-e (6.1%)				
	TOTAL	25,040 Kt CO_2-				

TABLE 2 Continued

Lim et al. (2013) Haemodialysis unit Bottom-up LCA	Energy and heating	22,716 Kt CO_2-e (18.6%)	Activity data/auditing.	P	From Australian government publications, individual providers	Electricity and energy were calculated together. Electricity use alone was 18,313 Kt CO_2-e or 15%. Water treatment and supply was 1470 Kt CO_2-e or 1.2% and sewerage treatment and management was 7773 Kt CO_2-e or 6.4%. Landfill was 1375 Kt CO_2-e or 1.1%, incinerated 3780 Kt CO_2-e or 3.1% and recycled – 992 Kt CO_2-e or −0.8%.
	Water	9243 Kt CO_2-e (7.6%)	Estimation from haemodialysis machines			
	Waste	4163 Kt CO_2-e (3.4%)	Auditing/measurement over one week			
	Staff travel	3369 Kt CO_2-e (3%)	Survey (distance/transport)	P		
	Patient travel	7043 Kt CO_2-e (5.8%)				
	Equipment	28,490 Kt CO_2-e (23.4%)		P		
	Pharmaceuticals	5060 Kt CO_2-e (35.7%)				
	Aids and appliances	1054 Kt CO_2-e (2.9%)				
	TOTAL	121.9 t CO_2-e/year or 10.2 t CO_2 e/year/patient				
		VGH[b] / **UMMC**[b] / **JRH**[b]				
MacNeill et al. (2017) 3 hospitals (Canada, US and UK) Bottom-up LCA	Energy and heating/Electricity	2,034,277 (63.2) / 2,129,841 (50.9) / 211,212 (4.1)	Invoice and billing.	P	DEFRA	Energy, heating and electricity were considered to be scope 2 as the energy is not produced within the operating theatre. The difference among medical gases can be due to the use of desflurane.
	Medical gases	534,194 (16.5) / 1,515,763 (36.2) / 4,344,150 (83.7)	Invoice and billing (pharmacy purchasing records)	P		
	Waste	650,436 (20.2) / 536,260 (12.8) / 632,574 (12.1)	Auditing over 3 weeks.	P		
	TOTAL	3,218,907 year / 4,181,864 year / 5,187,936 year				
Malik et al. (2018) National healthcare system Economic input–output analysis	Public hospitals	12,295 Kt CO_2-e (34.3%)	Health expenditure Australia report (Australian Institute of Health and Welfare) that includes all government and non-government costs. Private and public services were included. Expenditure collected for 16 different categories.	S	Leontief framework. Input–output mathematical equations.	Scope 2 and 3 emissions shown together. Healthcare in Australia contributes 7.2% of the total emissions. The four largest financial cost categories were: public and private hospitals (39%), pharmaceuticals (12%), specialist medical services (12%) and unreferred medical services (7%)
	Private hospitals	3635 Kt CO_2-e (10.2%)				
	All other medications	3347 Kt CO_2-e (9.3%)				
	Pharmaceuticals	3257 Kt CO_2-e (9.1%)				
	Building infrastructure	2776 Kt CO_2-e (7.7%)				
	Patient transport	427 Kt CO_2-e (1.2%)				
	TOTAL	35,772 Kt CO_2-e				
Nicolet et al. (2022) 10 private primary care practices Hybrid model	Energy and heating	9106 kg CO_2-e/year (29.8%)	Invoicing and billing.	P	COINVENT	Energy included electric solar, gas and oil. Electricity included energy consumption of in-house computer server and x-ray device. General waste 321 kg CO_2-e/year, special waste (radioactive) was 164 kg CO_2-e/year and paper waste 6 kg CO_2-e/year. Equipment was divided into medical equipment (such as stethoscope, examination bed, saturometer, ECG, Xray devices, etcetera) and non-medical (such as computer, printer, desk, chair, table)
	Electricity	95 kg CO_2-e/year (0.3%)	Invoicing and billing.	P		
	Waste	491 kg CO_2-e/year (1.6%)	Invoicing billing and staff observation	P		
	Staff travel	3816 kg CO_2-e/year (12.5%)	Survey	P		
	Patient travel	10,145 kg CO_2-e/year (33.2%)	Survey	P		
	Medical consumables	1678 kg CO_2-e/year (5.5%)	Invoicing and billing.	P		
	Non-medical consumables	338 kg CO_2-e/year (1.1%)				
	Equipment	110 kg CO_2-e/year (0.4%)	Inventory	P		
	Building infrastructure	1239 kg CO_2-e/year (4.1%)	Invoicing and billing	P		
	Total	30.5 tons of CO_2-e/year				

TABLE 2 Continued

Wu (2019) National Healthcare system Economic input–output analysis	Electricity and steam	33 mt CO_2-e (10.6%)	Data sources for health expenditure include the national input–output table, China Health and Family Planning Statistics, China Construction Statistics, and China Science and Technology Statistics yearbooks.	S	Leontief framework. Input–output mathematical equations.	
	Agriculture	25 mt CO_2-e (7.9%)				
	Pharmaceuticals	24 mt CO_2-e (7.6%)				
	Medical equipment	13 mt CO_2-e (4.1%)				
	Catering	6 mt CO_2-e (1.9%)				
	TOTAL	315 mt CO_2-e				
Eckelman et al. (2018) National healthcare system Economic input–output analysis	Public Hospitals	7.1 mt CO_2-e (21.5%)	Data obtained from Statistics Canada Environmental Accounts, the Canadian National Pollutant Release Inventory and then creation of an environmentally extended input–output (EEIO) tables and the National Health Expenditures database maintained by the Canadian Institute for Health Information.	S	Open IO – Canada model b IMPACT2002 + LCA model	
	Physicians	4.4 mt CO_2-e (13.3%)				
	Dental Services	1.8 mt CO_2-e (5.4%)				
	Prescribed Drugs	7.0 mt CO_2-e (21.2%)				
	Capital	2.4 mt CO_2-e (7.3%)				
	Public Health	1.9 mt CO_2-e (5.7%)				
	TOTAL	33.0 mt CO_2-e (4.6% of the national emissions)				
Eckelman and Sherman (2016) National healthcare system Economic input–output analysis	Hospital care	238 Mt CO_2-e (36%)	US National Health Expenditure Accounts for the decade 2003–2013.	S	IMPACT2002 + LCA model	Total: Suppliers of energy, goods, and services: power generation (36%), government services (8%), non-residential commercial and health care construction (4%) and basic organic chemicals manufacturing (3%)
	Clinical Services	77 Mt CO_2-e (11.7%)				
	Nursing Care Facilities	41 Mt CO_2-e (6.2%)				
	Prescribed drugs	68 Mt CO_2-e (10.3%)				
	Public Health Activities	29 Mt CO_2-e (4.4%)				
	Structures and equipment	71 Mt CO_2-e (10.8%)				
	TOTAL	655 Mt CO_2-e in 2013 (9.8% of the national total)				

Abbreviations: ACU, acute care unit; ADEME, Agence de l'environnement et de la maîtrise de l'énergie (the French Environment and Energy Management Agency); BEIS, Department for Business, Energy and Industrial Strategy; EEIO, environmentally extended input–output; ERIC, Estates Return Information Collection; FU, functional unit; GHG, greenhouse gas; GWP, global warming potential; HM, high majesty; ICU, intensive care unit; IPCC, Intergovernmental Panel on Climate Change; JRH, John Radcliffe Hospital; LCA, life cycle assessment; MRIO, multi-regional input output modelling; P, primary; S, secondary; VGH, Vancouver General Hospital; UMMC, University of Minnesota Medical Center.

[a]mt CO_2e (%).

[b]Kg CO_2e (%).

(13.1%) and pharmaceuticals (12.1%), and that is mainly due to the emissions caused by manufacturing, packaging and transport of goods (NHS England, 2008). For example, the carbon footprint of pharmaceuticals without including the energy used to produce them has been estimated at 5.0%, showing that most of the emissions come from the energy used in their production and distribution (Karliner et al., 2020). It is important to understand that the carbon footprint of an item represents indirect emissions for the user; however, its production will require energy and electricity (scopes 1 and 2); thus, most carbon emissions come from energy that might be direct or indirect depending on where it is used.

Interventions such as the installation of solar panels in roofs and parking lots in hospitals, changing to a vegetable-based hospital menu, replacing telemedicine for face-to-face appointments when possible, promoting active transport and/or introducing effective lighting and energy appliances, have shown to have a significant impact in the reduction of carbon footprint (Bozoudis & Sebos, 2021; Bozoudis et al., 2022). Nansai et al. (2020) stated that the carbon footprint of a hospital supply chain could be minimized by reducing the demand of goods and services. This can be achieved by restricting unnecessary patient attendance and diagnostic testing, minimizing human error and/or avoiding duplication of processes, such as previous consultations or testing in different services (Malhotra et al., 2016). Ouslander et al. (2016) found that 23% of the emergency visits, hospital admissions and/or readmissions were preventable. Freund et al. (2013) carried out semi-structured interviews with 12 primary care physicians from 10 primary care clinics in Germany regarding 104 hospitalizations of 81 patients and found that 41% of those hospitalizations were avoidable and could have been managed in ambulatory services. However, this raises the question whether admissions versus ambulatory patients would increase or decrease carbon emissions as, for example, the use of transport-related emissions would be greater. The COVID-19 pandemic has shown how telemedicine can be used as a feasible, acceptable and effective way of healthcare practice (Hong et al., 2020). Studies such as the one carried out by Purohit et al. (2021) found that telemedicine could significantly reduce the carbon emissions secondary to travelling as well as the demand in healthcare settings. The use of telemedicine could mean an opportunity to reduce attendances in settings such as primary healthcare, where the carbon emissions secondary to patient and staff travelling are much higher than in other healthcare settings (Nicolet et al., 2022).

McAlister et al. (2022) carried out a prospective life cycle assessment of five imaging modalities: chest X-Ray, mobile chest X-ray, computerized tomography (CT), magnetic resonance imaging (MRI) and ultrasound (US). They found that CT and MRI produced 17 and 9 times more carbon emissions than X-rays and US. They recommended using low-impact imaging when appropriate and limiting unnecessary testing in order to reduce the carbon footprint. Human errors such as incidents related to drugs or treatments may also lead to an increase in the carbon footprint. Panagioti et al. (2019) in their metanalysis found that one in twenty hospitals admissions some kind of preventable error was made. For example, the wrong administration of a drug can lead to anaphylaxis and, therefore, to an increase in the items and resources used. Another example could be a surgery that is not properly performed, and, as a result, another surgery needs to be carried out, leading to the utilization of more resources as well as longer hospital stay of the patient. Consequently, it is important to put in place measures to reduce human errors not only to improve patient's care but also to reduce the carbon footprint.

The promotion of a healthy lifestyle may also help to reduce the carbon footprint as well as improving physical health. Several studies have shown that shifting towards a healthy diet could contribute to minimizing the carbon footprint by adopting diets with low calories or reducing animal-based food (Scarborough et al., 2014; Tukker et al., 2011). Furthermore, the promotion and maintenance of physical activity such as walking or cycling will reduce the carbon emissions secondary to transport and also improve health by decreasing the incidence of cardiovascular diseases, among others (Lindsay et al., 2011; Woodcock et al., 2009). In addition to this, the reduced incidence of certain diseases after adopting healthy lifestyles could diminish the demand for health services, thus reducing the carbon footprint of healthcare settings (Lee et al., 2017).

However, sustainable practice can only be achieved with the commitment of all healthcare professionals and their organizations (IPCC, 2018). As mentioned by NHS England (2022) recommendations, advanced health professionals and their teams should reduce the environmental impact of equipment and resources by, for example, applying the 5 R's: reduce, reuse, reprocessed, renewable and recycle. In this sense, healthcare professionals should demand manufacturers of healthcare equipment ways of reducing the carbon footprint of their products whenever possible (Chiarini et al., 2017). Furthermore, the move from a linear economy to a circular one, where items are not wasted or replaced by new ones, but fixed or used for different purposes, is also a way of reducing the carbon footprint, so these approaches should be further explored (NHS England, 2020).

The limitations of the present study include those inherent to the systematic review methodology. It is possible that some relevant studies were not identified, although the search strategy was broad and targeted, and measures were taken to retrieve studies such as the review of reference lists. A possible interpretation bias is also acknowledged, yet the data were analysed and peer-reviewed. In addition, possible biases are recognized when comparing the results of the articles reviewed, due to differences in the assessment methodology employed by the researchers or the scope of the study in terms of the service assessed or the level of detail.

4 | CONCLUSION

The studies analysed in this literature review found that scopes 1 and 2 emissions were between 15% and 50% of the total, whereas scope 3 emissions ranged between 50% and 75%. Disposables, equipment (medical and non-medical) and pharmaceuticals represented the higher percentage of scope 3 emissions. Other variables such as transport and building infrastructure were also significant contributors of carbon emissions.

This literature review highlights the effect that healthcare systems have on climate change and the importance of adopting and carrying out interventions to reduce the impact of healthcare on the development of climate change. Interventions must be carried out by the organizations responsible for those emissions, but also every single individual that integrates them should make changes. In fact, scope 3 emissions represent a high percentage of the total, and individuals in the organizations could have a significant impact on reducing these, or demanding manufacturers to do so, whereas scopes 1 and 2 emissions are more likely to be managed at organizational level. Current healthcare practice should be assessed at all levels, for example by creating or reviewing pathways and policies to not only reduce the carbon footprint but also improve patient's care and the service provided.

To effectively reduce carbon emissions secondary to healthcare activities, in-depth analysis of individual units is recommended. Evidence-based approaches may facilitate the identification of carbon hotspots, thus achieving a more effective development and application of interventions aimed at reducing carbon emissions. Further research in healthcare's carbon footprint is recommended, as well as the development of tools to measure carbon emissions and identify carbon hotspots, so as to reduce the impact of healthcare activity on the environment.

AUTHOR CONTRIBUTIONS

Lucas Rodriguez-Jimenez: Conceptualization, Methodology, Project administration. Macarena Romero-Mrtín: Methodology, Data curation, Writing – Original draft preparation. James Chan: Visualization, Investigation. Timothy Spruell: Investigation, Data curation. Zoe Steley: Software, Validation, Formal analysis. Juan Gómez-Salgado: Writing – Reviewing and Editing.

FUNDING INFORMATION

No fundings were received for this paper.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare that are relevant to the content of this article.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/jan.15671.

DATA AVAILABILITY STATEMENT

Data sharing not applicable.

ORCID

Macarena Romero-Martín https://orcid.org/0000-0003-3022-3339
Timothy Spruell https://orcid.org/0000-0003-1939-193X
Juan Gómez-Salgado https://orcid.org/0000-0001-9053-7730

REFERENCES

Booth, A., Noyes, J., Flemming, K., Moore, G., Tunçalp, Ö., & Shakibazadeh, E. (2019). Formulating questions to explore complex interventions within qualitative evidence synthesis. *BMJ Global Health*, *4*(Suppl 1), e001107. https://doi.org/10.1136/bmjgh-2018-001107

Bozoudis, V., & Sebos, I. (2021). The carbon footprint of transport activities of the 401 military general Hospital of Athens. *Environmental Modeling and Assessment*, *26*(2), 155–162. https://doi.org/10.1007/s10666-020-09701-1

Bozoudis, V., Sebos, I., & Tsakanikas, A. (2022). Action plan for the mitigation of greenhouse gas emissions in the hospital-based health care of the Hellenic Army. *Environmental Monitoring and Assessment*, *194*(3), 221. https://doi.org/10.1007/s10661-022-09871-3

Campion, N., Thiel, C. L., Focareta, J., & Bilec, M. M. (2016). Understanding green building design and healthcare outcomes: Evidence-based design analysis of an oncology unit. *Journal of Architectural Engineering*, *22*(3), 04016009. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000217

Chiarini, A., Opoku, A., & Vagnoni, E. (2017). Public healthcare practices and criteria for a sustainable procurement: A comparative study between UK and Italy. *Journal of Cleaner Production*, *162*, 391–399. https://doi.org/10.1016/j.jclepro.2017.06.027

Chua, P. L., Dorotan, M. M., Sigua, J. A., Estanislao, R. D., Hashizume, M., & Salazar, M. A. (2019). Scoping review of climate change and Health Research in The Philippines: A complementary tool in research agenda-setting. *International Journal of Environmental Research and Public Health*, *16*(14), 2624. https://doi.org/10.3390/ijerph16142624

Eckelman, M. J., & Sherman, J. (2016). Environmental impacts of the U.S. health care system and effects on public health. *PloS One*, *11*(6), e0157014. https://doi.org/10.1371/journal.pone.0157014

Eckelman, M. J., Sherman, J. D., & MacNeill, A. J. (2018). Life cycle environmental emissions and health damages from the Canadian healthcare system: An economic-environmental-epidemiological analysis. *PLoS Medicine*, *15*(7), e1002623. https://doi.org/10.1371/journal.pmed.1002623

Fournier, A., Laurent, A., Lheureux, F., Ribeiro-Marthoud, M. A., Ecarnot, F., Binquet, C., & Quenot, J. P. (2022). Impact of the COVID-19 pandemic on the mental health of professionals in 77 hospitals in France. *PLoS One*, *17*(2), e0263666. https://doi.org/10.1371/journal.pone.0263666

Freund, T., Campbell, S. M., Geissler, S., Kunz, C. U., Mahler, C., Peters-Klimm, F., & Szecsenyi, J. (2013). Strategies for reducing potentially avoidable hospitalizations for ambulatory care-sensitive conditions. *Annals of Family Medicine*, *11*(4), 363–370. https://doi.org/10.1370/afm.1498

García-Sanz-Calcedo, J., Al-Kassir, A., & Yusaf, T. (2018). Economic and environmental impact of energy saving in healthcare buildings. *Applied Sciences*, *8*(3), 440. https://doi.org/10.3390/app8030440

Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., & Vogt-Schilb, A. (2016). *Shock waves: Managing the impacts of climate change on poverty*. Climate Change and Development. World Bank. https://openknowledge.worldbank.org/handle/10986/22787

Hess, J., Eidson, M., Tlumak, J., Raab, K., & Luber, G. (2014). An evidence-based public health approach to climate change adaptation. *Environmental Health Perspectives*, *122*(11), 1177–1186.

Hong, Z., Li, N., Li, D., Li, J., Li, B., Xiong, W., Lu, L., Li, W., & Zhou, D. (2020). Telemedicine during the COVID-19 pandemic: Experiences from Western China. *Journal of Medical Internet Research*, *22*(5), e19577. https://doi.org/10.2196/19577

Intergovernmental Panel on Climate Change. (2018). *Special Report on Global Warming of 1.5°C (SR15)*. https://www.ipcc.ch/sr15/

Karliner, J., Slotterback, S., Boyd, R., Ashby, B., Steele, K., & Wang, J. (2020). Health care's climate footprint: The health sector contribution and opportunities for action. *European Journal of Public Health*, *30*(5), 311. https://doi.org/10.1093/eurpub/ckaa165.843

Keller, R. L., Muir, K., Roth, F., Jattke, M., & Stucki, M. (2021). From bandages to buildings: Identifying the environmental hotspots of hospitals. *Journal of Cleaner Production*, *319*, 128479. https://doi.org/10.1016/j.jclepro.2021.128479

Lee, I. C., Chang, C. S., & Du, P. L. (2017). Do healthier lifestyles lead to less utilization of healthcare resources? *BMC Health Services Research*, *17*(1), 243. https://doi.org/10.1186/s12913-017-2185-4

Lim, A. E., Perkins, A., & Agar, J. W. (2013). The carbon footprint of an Australian satellite haemodialysis unit. *Australian Health Review: A Publication of the Australian Hospital Association*, *37*(3), 369–374. https://doi.org/10.1071/AH13022

Lin, J., Liu, Y., Meng, F., Cui, S., & Xu, L. (2013). Using hybrid method to evaluate carbon footprint of Xiamen City, China. *Energy Policy*, *58*, 220–227.

Lindsay, G., Macmillan, A., & Woodward, A. (2011). Moving urban trips from cars to bicycles: Impact on health and emissions. *Australian and New Zealand Journal of Public Health*, *35*(1), 54–60. https://doi.org/10.1111/j.1753-6405.2010.00621.x

MacNeill, A. J., Lillywhite, R., & Brown, C. J. (2017). The impact of surgery on global climate: A carbon footprinting study of operating theatres in three health systems. *The Lancet. Planetary Health*, *1*(9), e381–e388. https://doi.org/10.1016/S2542-5196(17)30162-6

Malhotra, A., Maughan, D., Ansell, J., Lehman, R., Henderson, A., Gray, M., Stephenson, T., & Bailey, S. (2016). Choosing wisely in the UK: Reducing the harms of too much medicine. *British Journal of Sports Medicine*, *50*(13), 826–828. https://doi.org/10.1136/bjsports-2016-h2308rep

Malik, A., Lenzen, M., McAlister, S., & McGain, F. (2018). The carbon footprint of Australian health care. *The Lancet. Planetary Health*, *2*(1), e27–e35. https://doi.org/10.1016/S2542-5196(17)30180-8

Malik, A., Padget, M., Carter, S., Wakiyama, T., Maitland-Scott, I., Vyas, A., Boylan, S., Mulcahy, G., Li, M., Lenzen, M., Charlesworth, K. E., & Geschke, A. (2021). Environmental impacts of Australia's largest health system. *Resources Conservation and Recycling*, *169*, 105556.

McAlister, S., McGain, F., Breth-Petersen, M., Story, D., Charlesworth, K., Ison, G., & Barratt, A. (2022). The carbon footprint of hospital diagnostic imaging in Australia. *The Lancet Regional Health—Western Pacific*, *24*, 100459. https://doi.org/10.1016/j.lanwpc.2022.100459

Montiel-Santiago, F. J., Hermoso-Orzáez, M. J., & Terrados-Cepeda, J. (2020). Sustainability and energy efficiency: BIM 6D. Study of the BIM methodology applied to hospital buildings. Value of interior lighting and daylight in energy simulation. *Sustainability*, *12*, 5731. https://doi.org/10.3390/su12145731

Mtioui, N., Zamd, M., Ait Taleb, A., Bouaalam, A., & Ramdani, B. (2021). Carbon footprint of a hemodialysis unit in Morocco. *Therapeutic Apheresis and Dialysis*, *25*(5), 613–620. https://doi.org/10.1111/1744-9987.13607

Nansai, K., Fry, J., Malik, A., Takayanagi, W., & Kondo, N. (2020). Carbon footprint of Japanese health care services from 2011 to 2015. *Resources Conservation and Recycling*, *152*, 104525.

National Health Service England. (2017). *Sustainable development unit study*. https://www.england.nhs.uk/greenernhs/wp-content/uploads/sites/51/2021/02/Sustainability-and-the-NHS-Staff-survey-2017.pdf

National Health Service England. (2020). *Delivering a 'Net Zero' National Health Service*. https://www.england.nhs.uk/greenernhs/wp-content/uploads/sites/51/2020/10/delivering-a-net-zero-national-health-service.pdf

National Health Service England. (2022). *Reducing the environmental impact of equipment, medicines and resources*. https://www.england.nhs.uk/ahp/greener-ahp-hub/specific-areas-for-consideration/reducing-the-environmental-impact-of-equipment-medicines-and-resources/

National Health Service England. Sustainable Development Unit. (2008). *NHS England carbon emissions. Carbon Footprinting report*. https://www.sd-commission.org.uk/data/files/publications/NHS_Carbon_Emissions_modelling1.pdf

National Health Service England. Sustainable Development Unit. (2018). *Reducing the use of natural resources in health and social care 2018 report*. https://networks.sustainablehealthcare.org.uk/sites/default/files/resources/20180912_Health_and_Social_Care_NRF_web.pdf

Nicolet, J., Mueller, Y., Paruta, P., Boucher, J., & Senn, N. (2022). What is the carbon footprint of primary care practices? A retrospective life-cycle analysis in Switzerland. *Environmental Health: A Global Access Science Source*, *21*(1), 3. https://doi.org/10.1186/s12940-021-00814-y

Ouslander, J., Naharci, I., Engstrom, G., Shutes, J., Wolf, D., Alpert, G., Rojido, C., Tappen, R., & Newman, D. (2016). Root cause analyses of transfers of skilled nursing facility patients to acute hospitals: Lessons learned for reducing unnecessary hospitalizations. *Journal of the American Medical Directors Association*, *17*(3), 256–262.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ (Clinical Research Ed.)*, *372*, n71. https://doi.org/10.1136/bmj.n71

Panagioti, M., Khan, K., Keers, R. N., Abuzour, A., Phipps, D., Kontopantelis, E., Bower, P., Campbell, S., Haneef, R., Avery, A. J., & Ashcroft, D. M. (2019). Prevalence, severity, and nature of preventable patient harm across medical care settings: Systematic review and meta-analysis. *BMJ (Clinical Research Ed.)*, *366*, l4185. https://doi.org/10.1136/bmj.l4185

Pichler, P., Jaccard, I., Weisz, U., & Weisz, H. (2019). International comparison of health care carbon footprints. *Environmental Research Letters*, *14*(6), 064004.

Prasad, P. A., Joshi, D., Lighter, J., Agnis, J., Allen, R., Collins, M., Pena, F., Velletri, J., & Thiel, C. (2022). Environmental footprint of regular and intensive inpatient care in a large US hospital. *International Journal of Life Cycle Assessment*, *27*, 38–49. https://doi.org/10.1007/s11367-021-01998-8

Purohit, A., Smith, J., & Hibble, A. (2021). Does telemedicine reduce the carbon footprint of healthcare? A systematic review. *Future Healthcare Journal*, *8*(1), e85–e91. https://doi.org/10.7861/fhj.2020-0080

Pussegoda, K., Turner, L., Garritty, C., Mayhew, A., Skidmore, B., Stevens, A., Boutron, I., Sarkis-Onofre, R., Bjerre, L. M., Hróbjartsson, A., Altman, D. G., & Moher, D. (2017). Systematic review adherence to methodological or reporting quality. *Systematic Reviews*, *6*(1), 131. https://doi.org/10.1186/s13643-017-0527-2

Rizan, C., Steinbach, I., Nicholson, R., Lillywhite, R., Reed, M., & Bhutta, M. (2020). The carbon footprint of surgical operations. *Annals of Surgery*, *272*(6), 986–995.

Romanello, M., McGushin, A., Di Napoli, C., Drummond, P., Hughes, N., Jamart, L., Kennard, H., Lampard, P., Solano Rodriguez, B., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Cai, W., Campbell-Lendrum, D., Capstick, S., Chambers, J., Chu, L., Ciampi, L., Dalin, C., … Hamilton, I. (2021). The 2021 report of the lancet countdown on health and climate change: Code red for a healthy future. *Lancet (London, England)*, *398*(10311), 1619–1662. https://doi.org/10.1016/S0140-6736(21)01787-6

Scarborough, P., Appleby, P. N., Mizdrak, A., Briggs, A. D., Travis, R. C., Bradbury, K. E., & Key, T. J. (2014). Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK.

Climatic Change, *125*(2), 179–192. https://doi.org/10.1007/s10584-014-1169-1

Spruell, T., Webb, H., Steley, Z., Chan, J., & Robertson, A. (2021). Environmentally sustainable emergency medicine. *Emergency Medicine Journal: EMJ*, *38*(4), 315–318. https://doi.org/10.1136/emermed-2020-210421

Tennison, I., Roschnik, S., Ashby, B., Boyd, R., Hamilton, I., Oreszczyn, T., Owen, A., Romanello, M., Ruyssevelt, P., Sherman, J. D., Smith, A., Steele, K., Watts, N., & Eckelman, M. J. (2021). Health care's response to climate change: A carbon footprint assessment of the NHS in England. *The Lancet. Planetary Health*, *5*(2), e84–e92. https://doi.org/10.1016/S2542-5196(20)30271-0

The Paris Agreement. (2015). United Nations. https://www.un.org/en/climatechange/paris-agreement

Tukker, A., Goldbohm, R. A., de Koning, A., Verheijden, M., Kleijn, R., Wolf, O., Perez- Dominguez, I., & Rueda-Cantuche, J. M. (2011). Environmental impacts of changes to healthier diets in Europe. *Ecology Economics*, *70*(10), 1776–1788.

UK Government Legislation. (2008). *Climate Change Act*. https://www.legislation.gov.uk/ukpga/2008/27/contents

Vollmer, M., Rhee, T., Rigby, M., Hofstetter, D., Hill, M., Schoenenberger, F., & Reimann, S. (2015). Modern inhalation anesthetics: Potent greenhouse gases in the global atmosphere. *Geophysical Research Letters*, *42*(5), 1606–1611.

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Berry, H., Bouley, T., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Chambers, J., Daly, M., Dasandi, N., Davies, M., Depoux, A., Dominguez-Salas, P., Drummond, P., Ebi, K. L., … Costello, A. (2018). The 2018 report of the lancet countdown on health and climate change: Shaping the health of nations for centuries to come. *Lancet (London, England)*, *392*(10163), 2479–2514. https://doi.org/10.1016/S0140-6736(18)32594-7

Woodcock, J., Edwards, P., Tonne, C., Armstrong, B. G., Ashiru, O., Banister, D., Beevers, S., Chalabi, Z., Chowdhury, Z., Cohen, A., Franco, O. H., Haines, A., Hickman, R., Lindsay, G., Mittal, I., Mohan, D., Tiwari, G., Woodward, A., & Roberts, I. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: Urban land transport. *Lancet (London, England)*, *374*(9705), 1930–1943. https://doi.org/10.1016/S0140-6736(09)61714-1

World Resources Institute. (2022). *Greenhouse gas protocol*. https://www.wri.org/initiatives/greenhouse-gas-protocol

Wu, R. (2019). The carbon footprint of the Chinese health-care system: An environmentally extended input-output and structural path analysis study. *The Lancet: Planetary Health*, *3*(10), e413–e419. https://doi.org/10.1016/S2542-5196(19)30192-5

Zeng, X., Zhang, Y., Kwong, J. S., Zhang, C., Li, S., Sun, F., Niu, Y., & Du, L. (2015). The methodological quality assessment tools for preclinical and clinical studies, systematic review and meta-analysis, and clinical practice guideline: A systematic review. *Journal of Evidence-Based Medicine*, *8*(1), 2–10. https://doi.org/10.1111/jebm.12141

How to cite this article: Rodríguez-Jiménez, L., Romero-Martín, M., Spruell, T., Steley, Z., & Gómez-Salgado, J. (2023). The carbon footprint of healthcare settings: A systematic review. *Journal of Advanced Nursing*, *79*, 2830–2844. https://doi.org/10.1111/jan.15671