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Carbon footprint of healthcare systems: a systematic review of evidence and methods

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Carbon footprint of healthcare systems: A systematic review of evidence and methods

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ABSTRACT

Objective: Given the demand for net-zero healthcare, the carbon footprint (CF) of healthcare systems has attracted increasing interest in research in recent years. This systematic review investigates the results and methodological transparency of CF calculations of the healthcare system by using input–output or hybrid analyses.

Design and methods: We systematically searched various databases. We included all health care sectors CF calculations. To facilitate a structured extraction of the relevant methodological items, we developed a tool for data extraction and applied it to all studies that were considered. The main outcome was the CF of the healthcare system and its sources of emissions. A transparency checklist for reporting sector level CFs was developed and applied.

Results: The database search yielded 2,469 studies excluding duplicates, while we finally considered 14 of them. The mean ratio of emissions due to the healthcare system to the total national emissions was 4.9% [minimum 1.5%; maximum 9.8%], and the results of the time series showed a growing footprint in most countries. Hospital care led to the largest relative share of the total CF. At least 71% of the items of each study were reported.

Conclusion: The results of this review show that healthcare systems contribute substantially to national carbon emissions, and hospitals are one of the main contributors in this regard. They also show that mitigation measures can help reduce emissions over time. However, the comparison of results is limited because of methodological heterogeneity and a lack of transparency. The standardized reporting of carbon emissions is necessary to be able

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Keywords: life-cycle assessment, input-output, global warming potential

STRENGTHS AND LIMITATIONS OF THE STUDY

- To the best of our knowledge, this is the first study to systematically assess greenhouse gas emissions by healthcare systems.
- The assessment of methodological choices and the transparency of methods when assessing the greenhouse gas emissions of entire sectors in systematic reviews can help deepen our understanding of the results.
- This review was limited to articles in English and German, and excluded assessments, grey literature from public reports, and reports from statistical offices published in other languages.

Word count: 4000

INTRODUCTION

Background

Climate change is one of the most pressing issues of our time ¹. Given the correlation between the gross domestic product (GDP) and carbon emissions ², the healthcare industry is likely an important contributor to greenhouse gas (GHG) emissions. Demographic changes and income effects have likely increased the demand for healthcare services, where this is likely to continue to increase, and have consequently enhanced the economic importance of the healthcare industry ³. Evidence on healthcare's emissions is needed to better understand its role.

Methods to calculate the carbon footprint (CF) can be broadly categorized into bottom-up and top-down approaches. Bottom-up methods, such as the process-based lifecycle assessment (LCA) are too demanding of data to be applied at a sectoral level. However, the CF of different sectors can be estimated by accepting the trade-off of a more uncertain top-down methodology. In this case, all emissions are divided according to the final demand sectors or the economic sectors of emission occurrence. Input–output (I–O) analysis, which follows this approach, is used to estimate the CF⁴. Calculations of the CF use the static open-quantity I–O model in combination with an environmental extension. They rely on two fundamental building blocks: an I-O table and a demand vector. The I-O table describes the interactions between the sectors of production, often in monetary terms, and are usually constructed by national statistics offices. The demand vector represents the expenditures of the relevant sectors. For example, the demand vector of the healthcare sector includes expenditure on diesel fuel to power ambulances, electricity consumed by hospitals, and all other forms of energy consumed. It may be necessary to synchronize the structures of the I-O table and the demand vector by balancing the definitions of different sectors and adjusting the level of sectoral aggregation. I-O models can be grouped into single-region I-O (SRIO) and multi-region I-O (MRIO) models. SRIO models use only an I-O table from a single country, and can therefore account for only domestic production and emissions. MRIO models connect multiple I-O tables from multiple countries, and can thus account for different levels of production and "trade" in emissions (i.e., emissions in one country related to the final demand of another country). The need for synchronized data from multiple countries complicates the development and update of the data of MRIO models.

The results of calculations of the CF of a given sector can be affected by methodological choices, such as the decision to use either the SRIO or the MRIO model, and the GHGs considered. Therefore, standardized reporting is needed to ensure the transparency of methodological choices, the data, and the results. However, our search of the literature yielded neither a standardized procedure nor standardized reporting.

The objective of this study is to systematically review research that has used I–O analysis to calculate the CF of healthcare systems, including the total CF, the CF per capita, and that as a share of the national CF. Furthermore, time series data can help us better understand the trajectory of development of the CF of the healthcare system. As our search of the literature yielded no standardized scheme of reporting the relevant information, we develop a checklist of important elements in the calculation of the CF in our review.

METHODS

Search strategy and selection criteria

This systematic review was performed by following the PRISMA guidelines ⁵ (the checklist has been provided in the Appendix). The databases PubMed, ISI Web of Science, EconBiz, Scopus, and Google Scholar were searched for studies on November 25, 2019. The search was complemented by reference tracking within all the included studies, and was updated on April 25, 2022.

Following the screening of their titles and abstracts, studies were included for further investigation if they had (i) addressed the CF by using a traceable method of calculation, (ii) addressed the healthcare system or subsystem, and (iii) been written in English or German. A healthcare system was defined as the national healthcare system, federal system, and/or state system. Single entities, such as individual hospitals, and specialized branches, such as dentistry, were excluded. In addition to the criteria used for screening the titles and abstracts of articles, full-text articles were excluded if they (i) did not name the specific healthcare (sub)system, (ii) did not calculate the CF, or (iii) did not provide information on the method of calculation used.

Data extraction and analysis

Data from studies that met the above criteria were extracted and analyzed. Two of the authors separately screened their titles and abstracts, read the full text, and extracted data from them (LF, MH, MKe, MKn, and FW).

We used the CO₂e per capita, the contribution of healthcare to the country's total CO₂e emissions, and the distribution of the origins of these emissions as main results of the studies. to calculate the CF. Furthermore, the breakdown of the CF in scopes, demand categories, or places of origin was extracted. The scope of the CF has been described in the Greenhouse Gas Protocol Corporate Accounting and Reporting Standard ⁶, in which three standardized scopes have been proposed. Scope 1 represents direct emissions from owned or controlled sources, Scope 2 represents indirect emissions generated by the purchased energy, and Scope 3 represents all indirect

emissions that occur in the value chain. The categories of demand included the classes of expenditures of the final demand vector, and the places of the origin of emissions were divided into hospitals, ambulatory services, and so on.

We assessed the methodological transparency of the studies considered in addition to their general characteristics and results. A data extraction tool was developed to report information on the CFs of healthcare systems by using the I–O method. It collected data on the methodological choices, demand vector, data synchronization, and uncertainty analysis in13 items. We calculated the transparency score by combining the five items on the reporting of the results and the 13 items related to the reporting of the methods. These items are summarized in Table 1, and a more detailed description has been provided in the Appendix.

Tał	ole	1:	Descript	ion of t	he cr	iteria fo	r transpa	rency
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	Number	Criteria		
	0 *	System description		
	1	Total carbon footprint		
System description and results	2	Carbon footprint as a share of the total national CF		
	3	CF per capita		
	4	CF breakdown		
	5	LCA method		
	6	Source of demand data (detail)		
	7	Year of demand data		
	8	Number of categories of demand or expenditure		
	9	Data source of I–O table		
	10	Year of I–O table		
Method and transparency	11	Multi-regionality of the model		
	12	Number of production sectors		
	13	Source of emission data		
	14	GHGs considered		
	15	Concordance matrix reported		
	16	Sensitivity and uncertainty analysis		
	17	Discussion of limitations		
	* not included in the transp	parency score		

RESULTS

A total of 2,317 records were identified in the initial search (Figure 1). Three additional studies were found through reference tracking and the Google Scholar database. Following the removal of 550 duplicates, 1,770 records were obtained, of which 39 titles and abstracts met the criteria for the further investigation of their full texts. Thirty of these studies met the exclusion criteria, and thus nine studies were considered in the review. An update of the search yielded 1,056 studies, of which 358 were duplicates. A total of 665 were excluded during the screening of the title and the abstract, and 29 were excluded following a screening of the full text. One study was identified through reference tracking and a total of five more studies were added in theupdate. A summary of the finally

-Insert figure 1 around here-

Characteristics of the studies considered

Ten of the finally chosen studies had focused on a single national healthcare system, including those in England ⁷ ⁸, Japan ⁹, USA ^{10 11}, Canada ¹², Scotland ¹³, China ¹⁴, Australia ¹⁵, and Austria ¹⁶. The series of CFs from the Sustainable Development Unit of the English NHS was aggregated, and only the newest available report was cited. One study had examined the healthcare system of the largest Australian state, New South Wales ¹⁷ while three studies had reported on healthcare systems in multiple countries. Pichler, et al. ¹⁸ had reported results for 36 countries, Healthcare without Harm (HCH) for 43 countries ¹⁹, and the investigation by Lenzen, et al. ²⁰ had considered 189 countries. Excluding the one that had assessed the Scottish NHS, all studies had been published after 2016. However, their demand data, which defined the period of the study, deviated. For example, the study by Nansai et al. (11) had been published in 2020 but had used demand data from 2011 ⁹. The number of available categories of demand or expenditure ranged from 13 to 19, with outliers represented by the article by Wu ¹⁴ (eight categories), the study on the English NHS ²¹ (five categories), and work by Malik et al. ¹⁵ (nine categories).

Author (Year)	Healthcare system	Data year	CF in MT	% of total national	tCO ₂ e/cap	Transparency	score
			CO2EQ	CF	-		
Tennison, et al. 7	England	2018	25	n.i.	0,445	88%	
SDU 8	England	2019	25	n.i.	n.i.	71%	
Nansai, et al. 9	Japan	2011	72	4,6	0,49	82%	
Eckelman and Sherman 10	USA	2013	655	9,8	2,07	85%	
Eckelman, et al. 11	USA	2018	554	n.i.	n.i.	76%	
Eckelman, et al. 12	Canada	2015	33	5,7	0,92	94%	
Scotland 13	Scotland	2004	2,6	3,6	0,52	76%	
Wu 14	China	2012	315	2,7	0,23	94%	
Malik, et al. 15	Australia	2015	36	7,0	1,50	85%	
Weisz, et al. 16	Austria	2014	6,8	7	0,8	94%	
Malik, et al. 17	New South Wales,	2017	0,008	6,6	n.i.	71%	
	Australia						
Pichler, et al. 18	OECD countries;	2014	s. Appendix	Ø 5,5 s. Appendix	s. Appendix	94%	
	China, India						
Karliner, et al. 19	43 countries; EU;	2014	s. Appendix	Ø 4,4s. Appendix	s. Appendix	88%	
	rest of the world						
Lenzen, et al. 20	Global	2015	2 290	n.i.	n.i.	88%	
* n.i.= not identified							

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Table 2: Characteristics and main results of the stu	dies considered	in	this	reviev
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Differences in methodology and data

Eleven of the studies considered here had used only top-down data on emissions, while three studies had also used bottom-up data on energy usage ^{7 8 13}. Most single-country studies had used SRIO data from the respective governmental offices, while the studies on British healthcare and those that had considered more than one country had used MRIO data. The most commonly used MRIO database was EORA, one study had used the WIOD database, and two studies had used the MRIO database provided by the British Department for the Environment, Food, & Rural Affairs. The number of production sectors varied, the SRIO studies had considered 178–400 sectors, with the studies by Wu ¹⁴ (46 sectors), and Malik, et al. ¹⁷ (2,880 sectors) being the outliers. The MRIO studies had used larger databases containing around 15,000 sectors, except the MRIO study on the UK that had considered 424 sectors.

All studies had considered CO_2 emissions. However only four studies had considered the six GHGs covered in the Kyoto protocol, three studies had considered CO_2 , methane, and nitrous oxide, two had reported only that they had used CO_2 equivalents, and two studies had not reported any included GHG. The data on emissions had been drawn mostly from national accounts in case of SRIO databases and integrated satellite accounts in case of MRIO databases. One study had not reported the source of its satellite account data.

The demand data had been taken either from national offices and health expenditure accounts, or from international organizations such as the WHO and the World Bank (which itself uses data provided by national offices and accounts). Lenzen, et al. ²⁰ had identified and used data on healthcare-related sectors from the EORA database, where this made it possible to calculate the global time series of the data. The number of reported expenditure accounts varied, but mostly ranged from 13 and 19 accounts, with three studies below this. Weisz, et al. ¹⁶ had used nine accounts, Wu ¹⁴ had used eight accounts, and the study on the NHS in England had used five accounts ⁸. Owing to the different methodology used by Lenzen, et al. ²⁰ as well as the structure of the EORA, which reports country-specific sectors, they had used 163 sectors from the EORA as demand data.

The periods covered by the demand data and the I–O data were mostly consistent. Some studies that had reported time series had used only one reference year for the I–O database, and had adjusted the demand data for inflation ¹⁰⁻¹². The lag between the time at which the data had been collected and the time of publication of the corresponding study ranged from three to six years, with deviations in the studies by Nansai, et al. ⁹ Eckelman, et al. ¹¹ (two years), and in the report by the SDU ⁸. The latter had periodically reported the CF, and the lag between the latest publication and the latest data was one year ⁸. Further information on this has been provided in the Appendix.

Reporting of the results

Four studies had reported their concordance matrices, which bridge the categories of demand with the industrial sectors. The authors of one study had made their matrix available upon request, and two articles had referred to a matrix that had been previously used in another study. Five studies did not report their concordance matrices, and 50% of the articles had not normalized the results by reporting the CF per capita. The origins of emissions had been reported five times in the scopes, eight times in the (sub)categories of final demand, and once in the economic sector of emission occurrence one time. Two studies had reported a breakdown of emissions by using more than one reporting structure. Several differences were observed in the reported results in the scopes. Some studies had directly referenced the GHG protocol while others had reported emissions in divisions, such as travel, energy, procurement, and so on.

Overall transparency

Except for the reporting of the concordance matrix, uncertainty analysis, and the CF per capita, all criteria were fulfilled by more than 75% of the studies considered here (Figure 2). The rate of satisfaction of the criteria by each study varied from 70.5% to 94%, with a mean of 85% (Figure 3). Lich

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OUTCOMES

Time series

The results of the time series revealed successful efforts to mitigate the CF by the NHS in England and Scotland (Figure 4). In the nearly three decades from 1990 to 2019, the English NHS managed to reduce its CF by 25%. The four remaining countries (Japan, Canada, USA, and Australia) examined in the studies considered here as well as the global trend showed an increase in the CF due to healthcare (Figure 4). The annual increase in the CF ranged from 0.7% (USA, 2010–2018) to 3.8% (Japan, 2011–2015) over the observed period, with the CFs of Canada (1.9%, 2009–2015), USA (2.8%, 2011–2015), and Australia (2.9%. 2013–2015) in between these extremes. The global trend showed an increase in the CF of 2.7% per year from 2000 to 2015.

-Insert figure 4 around here-

Breakdown

The sources of emission had been mainly reported by using the scope system from the GHG protocol or the categories of expenditure, i.e., the categories of final demand. The largest dataset that had used the categories of final demand had been provided by Pichler et al. ¹⁸, who had applied it to 36 countries and reported the average values. Medical retail, hospitals, and ambulatory healthcare services constituted 80% of the CF of healthcare, with medical retail contributing 33.1%, hospitals responsible for 28.6%, and ambulatory healthcare services at 18%. Medical services thus accounted for 46% of total emissions. They also made a major contribution to the CF in Japan (hospitals, 25.1%; ambulatory services, 22.7%) ⁹, USA in 2013 (hospital care, 36%; physician and clinical services, 12%) ¹⁰ and 2018 (hospital care, 34.9%; physician and clinical services, 12.6%; ambulatory medical services, 4.8%) ¹², Australia (public hospitals, 34.4%; private hospitals, 10.2%; ambulatory medical services, 18%) ¹⁵, China (public hospitals, 47%; private hospitals, 4%) ¹⁴, and Austria (hospitals, 32%; ambulatory services, 18%) ¹⁶. Other important categories of emissions were construction and pharmaceutical products, at around 10% ^{10 15 18}, with a higher share in China (pharmaceuticals, 18%; construction, 15%) ¹⁴.

Another approach involved dividing emissions into direct emissions, indirect emissions through electricity production, and other indirect emissions. The division along these lines could also be made by using the three scopes of the GHG protocols. By averaging the data from 43 countries, the HCWH reported a share of 17% for scope 1 emissions, 12% for scope 2 emissions, and 71% for scope 3 emissions ¹⁹. These results, especially the importance of scope 3 emissions, are supported by evidence from the single-country studies ^{7 10 11 13 21}. The scope 3 emissions were further divided into those due to travel (patient and visitor travel, and staff commutes), production of pharmaceuticals, and medical instruments and equipment, which accounted for the largest share of scope 3 emissions. Scotland's scope 3 travel emissions in 2004 were 18% ¹³ while those of England accounted for 13% in 2015 ²¹ and 9.6% in 2018 ⁸. The share of emissions owing to pharmaceutical production ranged from 11% and 18%, and that owing to medical instruments and equipment accounted for 7%–10% of the total CF ^{12 13 21}.

The ratio of emissions by the healthcare sector to the total CF in studies that had focused on a single country ranged from 2.7% in China in 2012 ¹⁴ to 9.8% in the USA in 2013 ¹⁰. The three cross-national studies considered here had estimated that healthcare had contributed 5.5% ¹⁸ on average to the national CF in 2014 and 4.4% in 2015 ²⁰.

DISCUSSION

Interpretation of results

The results indicate that healthcare makes a noteworthy contribution to the CF, both in terms of absolute numbers as well as in relation to the overall emissions of a country and its per capita emissions. However, the results varied among the studies, and their methods of calculation were heterogeneous and frequently not fully transparent. The results of the time series showed that the trend of emissions due to healthcare was positive, i.e., they were increasing, except in Scotland and England. These results are in line with the graphical results provided by Lenzen, et al. ²⁰. The breakdown of the sources of emissions revealed the major contribution made by hospitals.

To the best of our knowledge, this is the first study to systematically consider research on GHG emissions by healthcare systems and develop a catalogue of transparency for a systematic review of studies on the CFs of different sectors. However, it has several limitations. First, most of the data used here were from the OECD countries, China, and India. The only exception was the work by Lenzen, et al.²⁰, who considered 189 countries in their analysis ²⁰. However, even if the distribution of countries limits the representativeness of the results, the findings are consistent with the fact that OECD countries are the main emitters of GHGs. The evidence provided here is further limited by the use of I–O methods in the studies considered because they can introduce uncertainties to the assessment. I-O studies use a top-down approach based on aggregated sectors of the industry. When heterogeneous products of emission with varying production and structures of emission are grouped into one industry, an aggregation error might occur such that the aggregated industry does not appropriately reflect the emissions. This leads to either overestimated (in case of expensive goods that yield lower emissions) or underestimated results (in case of cheap goods that yield higher emissions)²². Second, the review process used here was limited due to restrictions on the language used in the study and those related to access. It is possible that several assessments of the CF have been published in the official languages of many countries in the grey literature, such as publications by national statistics offices or governmental agencies. Because this review included only publications in English and German, many such studies have likely been neglected. Third, the reporting scheme and transparency score used in this study had associated limitations. Both were based only on a consensus among the authors. The instruments used to assess the quality of the published studies are typically chosen based on a broad consensus among experts, such as in case of the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) ²³. However, we did not find similar guidance for I–O analyses.

The results of the time series showed that the trend of emissions due to healthcare was positive in all the countries considered, i.e., they were increasing, except in Scotland and England. These results are in line with the graphical

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results provided by Lenzen, et al. ²⁰. Furthermore, they showed that the efforts of the British NHS systems to reduce their carbon footprint based on the Greener NHS program had been effective in reducing GHG emissions. The breakdown of the sources of emissions verified the important contribution of hospitals. However, hospitals often provide the majority of medical care in many countries. Therefore, their large CF is not a surprising result, but might motivate the relevant authorities to better handle their emissions. The breakdown further showed that a large portion of the CF of healthcare stemmed from scope 3 emissions. Policymakers may find that the greatest reduction in emissions can be obtained by addressing travel by staff and patients. Therefore, "greening" the healthcare sector requires a sustainable transportation system and green healthcare goods.

While heterogeneity in methodology in general can lead to more robust results and a more informative perspective on the issue at hand, the differences in I-O methodologies to calculate the CF of healthcare may reduce the comparability of the results. When computing the CF of an economic sector by using the I-O method, a choice needs to be made between the SRIO and MRIO models. Both offer certain advantages. The MRIO approach is more complete because it captures not only the supply chains within the country in question, but also those in other countries. In particular in small, open economies with a large share of trade, a significant part of total GHG emissions may be "embodied" emissions; i.e., emissions generated by foreign producers during the production of imported goods. A drawback of the MRIO approach is that MRIO tables are sometimes less accurate than SRIO tables because the latter are typically constructed by national statistics offices, which have access to highly detailed (and classified) firm-specific data. On the contrary, MRIO tables are formulated by other organizations that may not have access to such data. Furthermore, MRIO tables are often more aggregated than SRIO tables, which implies a further loss of information compared with the highly disaggregated SRIO tables. Therefore, some researchers prefer the SRIO approach, but this hinders a direct comparison of the results of different studies. Such a comparison may also be hindered by different choices of systemic boundaries or general differences between healthcare systems (e.g., a healthcare service may be included in the data on public healthcare expenditure in one country but excluded from those in another). A standardized approach to setting the boundary of the system may help increase the comparability of future results.

Future research should assess the potential effects of efforts to reduce emissions on the system, and should seek pathways to a low-carbon healthcare system. Finally, future research should examine errors of aggregation when using the I–O methodology in the context of healthcare. Moreover, the differences obtained in the outcomes when making different methodological choices (SRIO or MRIO, systemic boundaries, etc.) should be analyzed to guide future research.

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DECLARATIONS

Author contributors

Mattis Keil: Methodology, Screening, Formal Analysis, Writing – Original Draft, Writing-Review and Editing, Visualization; Leonie Frehse: Methodology, Screening, Formal Analysis, Writing – Original Draft; Marco Hagemeister: Methodology, Screening, Formal Analysis, Writing – Original Draft Mona Knieß: Methodology, Screening, Formal Analysis, Writing – Original Draft Oliver Lange: Conceptualization, Methodology, Writing – Review and Editing, Tobias Kronenberg: Methodology, Writing – Review and Editing Wolf Rogowski: Conceptualizing, Methodology, Writing - Review and Editing, Supervision, Project administration. All authors have read and approved the final manuscript for publication.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data statement

The data that support the findings of this study are available in Appendix 4a "System description and results" and Appendix 4b "Methods and transparency." Further data are available from the corresponding author, [MK], upon reasonable request.

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Figure 1: Prisma Flow Diagram, based on Page et al. (2021)

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PRISMA 2020 Checklist

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1 2	PRISM	MA 20)20 Checklist	omjopen-	
3 4 5	Section and Topic	ltem #	Checklist item	2023-07	Location where item is reported
6	TITLE		ng	8 46	
7	Title	1	Identify the report as a systematic review.	4	Title, Methods
8	ABSTRACT	I		- <u>5</u>	
9	Abstract	2	See the PRISMA 2020 for Abstracts checklist.	0 A	Page 1
10	INTRODUCTION	<u>.</u>			
12 13	Rationale	3	Describe the rationale for the review in the context of existing knowledge.	2024.	Introduction on Page 3
14 15	Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.		Introduction on Page 3
16	METHODS	1			
17 18 19	Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	ded from	Methods section on Page 4
20 21 22	Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted.	I to identify studies. Specify	Methods section on Pages 3-4
23 24	Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used	omjop	Supplementary materials
25 26 27	Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many record and each report retrieved, whether they worked independently, and if applicable, details of automation to a content of the review of a content of the review of the	reviewers screened each lsused in the process.	Methods section on Page 4
28 29 30	Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each independently, any processes for obtaining or confirming data from study investigators, and if applicable, details the process.	port, whether they worked of automation tools used in	Methods section on Page 4
31 32 33	Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with grading study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which grading of the source of	ctontcome domain in each sulls to collect.	Methods section on Pages 4-5
34 35 36		10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, and assumptions made about any missing or unclear information.	nd ଅଟୁ sources). Describe any ମୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁୁ	Methods section on Pages 4-5
37 38	Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how each study and whether they worked independently, and if applicable, details of automation tools used in the pro-	neny reviewers assessed	n.a.
39 40 41	Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or present	an of results.	Methods section on Page 4
42 43	Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study in and comparing against the planned groups for each synthesis (item #5)).	tervention characteristics	n.a.
44 45		13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing sur conversions. For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml	mmary statistics, or data	n.a.
46 47					

PRISMA 2020 Checklist

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1 2	PRISM	/A 20)20 Checklist	
3 4 5	Section and Topic	ltem #	Checklist item	Location where item is reported
6		13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	n.a
/ 8 0		13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	n.a.
9 10		13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	n.a.
11		13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	n.a
12 13	Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting).	n.a.
14 15	Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	n.a
16	RESULTS			
17 18	Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to t	Results on page 5
19 20		16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they ware excluded.	n.a.
21 22	Study characteristics	17	Cite each included study and present its characteristics.	Results on pages 5-6
23 24	Risk of bias in studies	18	Present assessments of risk of bias for each included study.	n.a.
25 26	Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) and the effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Results on pages 6-7
27	Results of	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	n.a.
28 29	syntheses	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summar destinate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	n.a.
30		20c	Present results of all investigations of possible causes of heterogeneity among study results.	n.a.
32		20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	n.a.
33	Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis a	n.a.
34 35	Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	n.a.
36	DISCUSSION			
37 38	Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion on page 8
39 40		23b	Discuss any limitations of the evidence included in the review.	Discussion on page 8
41 42		23c	Discuss any limitations of the review processes used.	Discussion on page 8
43 44		23d	Discuss implications of the results for practice, policy, and future research.	Discussion on page 9
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PRISMA 2020 Checklist

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Section and Topic	ltem #	Checklist item	t, incluc	2023-07	Location where item is reported
OTHER INFORMA	TION		ling	8 46	
Registration and	24a	Provide registration information for the review, including register name and registration number, or state th	at th ge re	bew was not registered.	Page 9
protocol	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	sn.	n 3(Page 9
o	24c	Describe and explain any amendments to information provided at registration or in the protocol.	es I	A	n.a.
1 Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsol	s in the	Review.	Page 10
 ² Competing ³ interests 	26	Declare any competing interests of review authors.	ted to	2024. [Page 10
 Availability of data, code and other materials 	27	Report which of the following are publicly available and where they can be found: template data collection studies; data used for all analyses; analytic code; any other materials used in the review.	text and	ata extracted from included	Appendix
y 1 2 3 4 5 5 7 3 9 0 1 2 3 4 5 5 7 3 9 0 1 2 3 4 5 5 7 3 9 0 1 2 3 4 5 5 7 3 9 0 1 1 2 3 4 5 5 7 7 3 9 0 1 1 2 3 4 5 5 7 7 3 9 0 1 1 1 2 3 1 1 1 1 1 1 1 1 1 1 1 1 1			ng, Al training, and similar technologies.	http://bmjopen.bmj.com/ on June 10, 2025 at Department GE	

S1: Further description of the transparency criteria

#	Criteria	Further description
System description and res	sults	· · ·
0 (not included in the transparency score)	System description	It should be reported which national healthcare system was assessed. Healthcare system was defined, closely to the definition of the WHO as follows: <i>"A health system consists of organizations, people and</i> <i>actions whose primary intent is to promote, restore or</i> <i>maintain health."</i>
1	Total Carbon Footprint	The total CF of a healthcare system can help to understand the total impact the system has on climate change
2	Carbon Footprint as a share of the total national CF	The share of healthcare's CF of the total national CF can help to understand the importance of the healthcare system to mitigate the climate impact of a country as well as to analyze systematic differences in the importance of the healthcare systems in mitigating the national CF between countries
3	CF per capita	The CF per capita can help to compare healthcare systems between different-sized countries.
4	CF breakdown	The division of total CFs in scopes or subcategories can help to understand the "hot spots" in GHG emissions within healthcare systems.
Method and Transparency		
5	LCA method	The LCA method can be distinguished between Top- Down (i.e. Using only Input-Output Data), Bottom-Up (i.e. using only Process-based data), and Hybrid (Using both data types). Each type has its advantages and disadvantages and should be reported to enable a first assessment of the used method.
6	Demand Date source (detail)	To avoid inaccurate, outdated, or unfitting data the data source is important to report for transparency.
7	Demand Data year	To avoid inaccurate, outdated, or unfitting data the data year is important to report for transparency.
8	Number of demand or expenditure categories	The number of demand or expenditure categories can help to assess the level of detail in which the healthcare system is modeled. The more expenditure categories are used, the higher the level of detail might be.
9	I-O table data source	Similar to the demand vector, the data source of the I- O table is important to ensure the data quality and transparency
10	I-O table year	Similar to the demand vector the data year of the I-O table is of importance to ensure the data quality and transparency
11	Multiregionality of the model	I-O tables can be distinguished in SRIO, which aggregates the economic sectors of a single country, or MRIO, which aggregates the sectors of multiple countries. As each of the models has its implications it is important to report the model type.
12	Number of production sectors	The number of production sectors within the I-O model can help to estimate the level of aggregation. The more production sectors are used the less aggregated the model might be.

13 Source or emission data The report or emissions data quality. 14 Included GHGs The results might vary dependen with more included GHG leadin leaves room for 15 Concordance matrix reported The bridge matrix connects the d IO table. Each value in the demar a demand from a certain econd connected to one or multiple table. The bridge matrix defines makes the connection operatio matrix can be either presented table classifying the demand ve sectors. 16 Sensitivity and Uncertainty analysis Quantitative analysis of uncertaint resported to the overall uncertainty reported to the overall uncertainty analysis 17 Discussion of limitations A variety of limitations can aris with IO models (e.g. insufficie aggregation, etc.). Therefore, a limitations can increase transpare	
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Full search strategies for all databases

SEARCH TERM
TITLE-ABS(((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "health-care" OR "health-care" OR "health sector" OR "health system" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended))) AND NOT DOCTYPE(ed) AND NOT DOCTYPE(er) AND NOT DOCTYPE(le) AND NOT DOCTYPE(no) AND NOT DOCTYPE(pr)
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(((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended)))
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nsai et al. 7	2020 Carbon footprint of	Japan	2011:62.5mt CO2 equivalent; 2012: 69,4mt CO2eq; 2013: 71 mt	c.n.	4,6% of the total domestic GHG emission	Capital vs. Service: Service:86%; Capital formation 14%
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hler et al.	2019 International	OECD (Australia: Austria: Beleium:	2012:843 MI CO2eq: 2013:855 MI CO2eq ~Australia: 19.5 mtCO2e: ~Austria: 6.8 mtCO2e: ~Beloium: 7.5	~Australia: 0.83 tCO2/cars: ~Austria: 0.8 tCO2/cars: ~Belgium: 0.66	~Australia: 4.2%: ~Austria: 6.7%: ~Belaium: 7.7%:	and Equipment: 10,4% -Public health care: 67% Private health care: 31% Investment: 6%
	comparison of health care carbon footprints	Canada; Chile; Czech Republic; Germany; Denmark; Spain; Estonia;	mtCO2e; ~Canada: 29,7 mtCO2e; ~Chile: 5,9 mtCO2e; ~China: 600,6 mtCO2e; ~Czech Republic: 4,8 mtCO2e; ~Germany: 55,1	tCO2/cap; ~Canada: 0,83 tCO2/cap; ~Chile: 0,73 tCO2/cap; ~China:0,44 tCO2/cap; ~Caech Republic: 0,46 tCO2/cap; ~Germany: 0,68 tCO2/cap;	-Canada:5,1%; -Chile:5,9%; -China: 6,6%; -Czech Republic: 4,5%; -Germany: 6,7%; -Denmark:6,4%; -Spain: 5,5%;	-Broad Categoriss: Medical retail: 33%; Hospital; 28,6%; ambulatory health care services:18%; Others: 20%; -Detailed Categoriss: Hospital Care: 2003: 184 (Mt CO2-e); 2004: 188; 2005: 195; 2006: 200; 2007: 206; 2008: 210; 2009: 218; 2010: 222; 2011: 226; 2012: 233; 2013
		Finalnd; France; Great Britain; Greece; Hungary; Ireland; Iceland; Judo: Jonan Kanas Juramhuray	mtCO2e; ~Denmark: 4 mtCO2e; ~Spain: 19,2 mtCO2e; ~Estonia: 1,2 mtCO2e; ~Finland: 3,9 mtCO2e; ~France: 34,4 mtCO2e; ~Genet Beitein: 41.1 mtCO2e; ~Generat: 4.2 mtCO2e;	~Denmark: 0,71 tCO2(cap; ~Spain: 0,41 tCO2(cap; ~Estonia: 0,88 tCO2(cap; ~Finland: 0,72 tCO2(cap; ~France: 0,52 tCO2(cap; ~Great Britrin: 0,64 tCO2(cap; ~Great 0,28 tCO2))	-Estonia: 5,2%; -Finland: 5,3%; -France: 6,9%; -Great Britain: 5,9%; -Greece: 3,8%; -Hangary: 5,4%; -India: 3,5%; -Ireland: 6,7%; - Lealand: 4,7%; - India: 5,1%; - Leana: 7,6%; - Konne;	Physician and Clinical Services: 2008; 577: 2004; 60, 2005; 195; 2006; 65; 2007; 68; 2008; 68; 2009; 69; 2010; 70; 2011; 72; 2012; 74; 2013; 77; Other Professional Ser 7, 2004; 8, 2005; 8, 2006; 8, 2007; 8; 2008; 8; 2009; 9; 2010; 9; 2011; 9; 2012; 10; 2013; 10; Dental Services: 2003; 11; 2004; 12; 2005; 12; 2006; 12; 2007; 12; 2008; 12; 2008; 12; 2007; 12; 2008; 12; 2007; 12; 2008;
		Latvia; Mexico; Netherlands; Norway; Poland; Portugal; Slovakia;	~Hungary: 2,9 mtCO2e; ~India: 74,1 mtCO2e; ~Ireland: 3,1 mtCO2e; ~Iceland: 0,2 mtCO2e; ~Italy: 23,1 mtCO2e; ~Japan:	ICO2/cap; ~India: 0,06 tCO2/cap; ~Irekand:0,68 tCO2/cap; ~Iceland: 0,61 tCO2/cap; ~Italy: 0,38 tCO2/cap; ~Japan: 0,9 tCO2/cap; ~Korea: 0,65	5,3%; ~Luxemburg: 3,6%; ~Latvia: 3,9%; ~Mexico:3,3%; ~Netherlands: 8,1%; ~Norway: 4,7%; ~Poland: 5,7%;	2012;25; 2013; 26; Home Health Care: 2003; 9; 2004; 10; 2005; 11; 2006; 12; 2007; 13; 2008; 13; 2009; 14; 2010; 15; 2011; 15; 2012; 16; 2013; 17; Nursing Care Facil Continuing Care Retirement Communities: 2003; 35; 2004; 36; 2005; 37; 2006; 37; 2007; 38; 2008; 39; 2009; 39; 2010; 39; 2011; 40; 2012; 40; 2013; 41; Prescription
		Slovenia; Sweden; Turkey; United States; Israel; New Zealand); China; India	114,9 mtCO2e; ~Korea: 33,1 mtCO2e; ~Laxemburg: 0,7 mtCO2e; ~Latvia: 0,5 mtCO2e; ~Mexico: 16,6 mtCO2e; Nathadande: 15.8 mtCO2e; ~Mexico: 16,6 mtCO2e;	ICO2/cap: ~Laxemburg: 1,24 ICO2/cap: ~Latvin: 0,26 ICO2/cap: ~Mexico 0,13 ICO2/cap: ~Netherlands: 0,93 ICO2/cap: ~Nerway: 0,7 ICO2/cap: Polond. 0.65 ICO2/cap: ~Netherlands: 0,38 ICO2/cap: ~Nerway: 0,7 ICO2/cap: Polond. 0.65 ICO2/cap: ~Portners. 0.38 ICO2/cap: ~Nerway: 0,7 ICO2/cap: ~	: ~Portugab6%; ~Slovakia:6,7%; ~Slovenia: 4%; ~Sweden: 4,5% ~Turkey: 3,9%; ~United States: 7,9%; ~Israel(2013): 4,4%; New Zeologd (2017):4.1%	2003: 59; 2004: 63; 2005: 65; 2006: 68; 2007: 71; 2008: 71; 2009: 72; 2010: 69; 2011: 68; 2012: 67; 2013: 68; Duable Medical Equipment: 2003: 12; 2004: 13; 2005: 14 2007: 16; 2008: 16; 2009: 16; 2011: 17; 2012: 17; 2013: 18; Other Non-Durable Medical Products: 2003: 11; 2004: 11; 2005: 12; 2006: 12; 2007: 13; 2008: 11 2010: 13; 2011: 14; 2012: 15; 2010: 15; Granumana Andinationation and Andia Statistical Statis
			17,4 mtCO2e; ~Portugal: 4 mtCO2e; ~Slovakia: 4,1 mtCO2e; ~Slovenia: 0,7 mtCO2e; ~Sweden: 4,1 mtCO2e; ~Turkey: 17,8	CO2(ap) - Slovenia (0.5) CO2(ap) - Sweden: 0.42 (CO2(ap) - Turkey: 0.23 (CO2(ap) - United States: 1,51 (CO2(ap) : -Israel(2013).0,43	The second	Net Cost O Heid, Instrumer: 2003; 7; 2004; 7; 2006; 7; 2006; 8; 2007; 8; 2008; 8; 2009; 8; 2010; 8; 2011; 8; 2012; 8; 2013; 8; 2013; 9; 2014; 8; 2013; 9; 2014; 9;
			mtCO2e; ~United States: 479,7 mtCO2e; ~Israel(2013): 3,5 mtCO2e; ~New Zealand (2017):1,8 mtCO2e	tCO2/cap; ~New Zealand (2017):0,42 tCO2/cap		2010: 13; 20111: 12; 2012: 12; 2013: 11; Structures and Equipment: 2003: 45; 2004: 47; 2005: 50; 2006: 51; 2007: 57; 2008: 62; 2009: 59; 2010: 60; 2011: 65; 2012: 70
man et al.	2018 Life cycle environmenta	il Canada	2009:29,6million Mt CO2e; 2010: 31,2; 2011: 31,4; 2012:31,5;	2014: 0.9; n.c.	2014: 4,6%; n.c.	Hospitals (Private): 2009: 0,7 million Mt CO2e; 2010: 0,7; 2011: 0,7; 2012: 0,7; 2013: 0,7; 2014: 0,8; 2015: 0,8; Hospitals (Public): 2009: 6,5; 2010: 6,8; 2011: 7,0; 20
	emissions and health damages from the		2013:31,4; 2014:32,0; 2015:33,0;			2013: 7,1; 2014: 7,1; 2015: 7,1; Other Institutions (Private): 2009: 0,7; 2010: 0,7; 2011: 0,7; 2012: 07; 2013: 0,8; 2014: 0,8; 2015: 0,9; Other Institutions (Public): 200 1,2; 2011: 1,2; 2012: 1,2; 2013: 1,2; 2014: 1,2; 2015: 1,3; Physicians: 2009: 3,7; 2010: 3,9; 2011: 4,0; 2012: 4,1; 2013: 4,2; 2014: 4,3; 2015: 4,4; Dental Services: 2009: 1,2; 2014: 4,2; 2015: 1,4; 2014: 4,2; 2015: 4,4; 2015: 4,4; 2014: 4,2; 2015: 4,4; 201
	system: An economic- environmental-					0.4; 2011: 0.4; 2012: 0.5; 2013: 0.5; 2014: 0.5; 2015: 0.6; Prescribed Drugs: 2009: 6.3; 2010: 6.9; 2011: 6.8; 2012: 6.7; 2013: 6.7; 2014: 6.8; 2015: 7.0; Nonprescribed 2009: 1.2; 2010: 1.2; 2011: 1.2; 2012: 1.2; 2013: 1.2; 2014: 1.2; 2015: 1.3; Capital: 2009: 2.5; 2010: 2.8; 2011: 2.7; 2012: 2.7; 2013: 2.3; 2014: 2.3; 2015: 2.4; Public Her
	epidemiological analysi					1,6; 2010: 1,6; 2011: 1,7; 2012: 1,7; 2013: 1,7; 2014: 1,8; 2015: 1,9; Administration: 2009: 0,7; 2010: 0,7; 2011: 0,7; 2012: 0,7; 2013: 0,7; 2014: 0,7; 2015: 0,6; Health F 2009: 0,4; 2010: 0,4; 2011: 0,4; 2012: 0,4; 2013: 0,4; 2014: 0,4; 2015: 0,4; 2016: 0,4; 2010: 0,4; 2011: 1,7; 2012: 1,7; 2013: 1,7; 2014: 1,8; 2015: 2,0;
ik et al.	2018 The carbon footprint of	Australia	~2013: 33.796 kt CO2e(0,034mt co2e); ~2014: 34.840 kt CO2	сл.	7%	~2013: Public Hospital 34,59%; Private Hospitals 9,62%; All other medications 9,25%; Benefit paid Pharmaceuticals 9,81%; Capital expenditures (Buildings) 7,61%
	Australian health care		(0,035 co2e); ~2015: 35.772 kt CO2e (0,036 co2e) ;			medicals services 5,88% Community Health and other 5,29% General Practice 4,21% Dental services 3,28% Ads and Appliances 2,88% Other health practition Research 2,1% Administration 1,3% Patient Transport Services 1,16% Public Health 0,35% - 2014: Public Hospital 353% Private Hospitals 9,79% All other 1 2.1% Danadar the Bharonacuting 0,61% Canada Danadar Danadar Danadar Danadar Danadar 2016 Communics 5, 2006 Communics 5,00% Comm
						Active Burker pair Linking pair Linking and Applicates 2: Applications and Applicates 2: Application and Applicates 2: Applications and Applicates 2: Applications 2: Appli
						7,70%; Referred medicals services 6,00%; Community Health and other 5,16%; General Practice 4,22%; Dental services 3,31%; Aids and Appliances 2,95%; Othe practitioner 2,16%; Research 1,94%; Administration 1,43%; Patient Transport Services 1,19%; Public Health 0,82%;
2	2019 The carbon footprint of the Chinese health-care	China	315 Mt CO2e	0,2	2,70%	-Hospitals 51%; Public Hospitals 47%; Private Hospitals 4%; -NHP pharmaceuticals 18% -Community health care 10% -Public Health 4% -Other health-care ins -Construction 15% -Research 0.3% -Administration 0.7%
	system: an environmentally extended invest outcome					
	and structural path analysis study					
SScotland 2	2008 National Health Service Scotland Carbon Footprint of NHS	Scotland	~1998: 2,74 mt CO2e; ~1998: 2,57 mt CO2e; ~2004: 2,63 mt CO2e	c.n.	3,60%	-Soutand: ~1990. ~Travel 23,73%: Patient own travel 10,95% (visitor Travel 4,75%; Staff Committing 2,19%; NBS Travel 23,75%; Chashing Energy Use Grid-supplied electricity 7,3%; On-site fossil fuel gas 6,94%; On-site fossil fuel oil 10,95%; On-site fossil fuel oil 2,76%; Renewables n.d.; ~Procurement 41,89% Pharmaconticule, 12,41% (Molical Internuestationimumes 4,28%) Holder Societies 7,10%; Freidat Transmatt, 73%; On-site fossil fuel gas 6,94%; On-site fossil fuel oil 10,95%; On-site fossil fuel oil 2,76%; Renewables n.d.; ~Procurement 41,89%
	Scotland(1990-2004)					Manufactured Products 2.56%; Manufactured fuels, chemical, glasses 1,83%; Food and catering 2,92%; Construction 1,46%; Information and Communication teel 0,73%; Water and Sanitation 0,73%; Waste products and recycling 0,37%; Other Procurement 1,1%; ~1998: ~Travel 27,63%; Patient own travel 12,84 %; Visitor T
						Staff Commuting 2,72%, NHS Travel business 5,84%, -Building Energy Use 26,07%: Grid-supplied electricity 8,56%; On-site fossil fuel gas 12,06%; On-site fossil 4,28%; On-site fossil fuel coal 1,17%; Renewables n.d.; -Procurement 46,30%; Pharmacentical 14,4%; Medicial Instrumenta/equipment 7%; Health Services 4,677 Teamanent 20,00%; Usedane Sanita 6,20%; Dama Boolow 2,34%; One-Manufertune Medure 7,234%; Manufertune fuel, admini admini admini 2,35%; Food and Good Sanita 6,25%; Dama
						2.33%; Construction 1,95%; Information and Communication technologies 0,78%; Water and Sanitation 0,78%; Waste products and recycling 0,39%; Other Proct -2004: ~Travel 24%: Patient own travel 10%; Visitor Travel 6%; Staff commuting 3%; NHS travel business 6%; ~Building Energy Use 23%; Grid-supplied Electri
						site foosil fleek gas 12%; On-site foosil fleek oil 2%; On-site foosil fleek coal 0%; Renevables 0%; -Procurement 52%; Pharmaceuticuls 18%; Medical instruments 7%; Fleah Services 6%; Freight Transport 0%; Basiness Service 5%; Paper Podcate 4%; Other manufactured Podcate 3%; Manufactured fleek, chemicals, glasses mid catering 2%; Construction 2%; Enformation and Comparison for Archivacous 1%; Wares Bochava, and Paparis, -Pro-
						-England 2004: - Travel 18%: Patient own travel 8%; Visitor Travel 2%; Statis Travel and samtus 1%; waster resource and necesyonal (0%; OHer Product - England 2004: - Travel 18%: Patient own travel 8%; Visitor Travel 2%; Statis Tomordang 4%; Shalidang Energy Use 27%; Grid-anpapti 12%; On-site fossil fiel gas 9%; On-site fossil fiel oil 1%; On-site fossil fiel coal 0%; Renewables 0%; -Procurement 59%; Pharmacenticals 12%; Medical
						Instrumenti/equipment 12%; Health Services n/a; Freight Transport 4%; Business Services 5%; Paper Products 5%; Other Manufactured Products 3%; Manufact chemical, glasses 3%; Foot and catering 2%; Construction 2%; Information and Communication technologies 2%; Water and Sanitation 1%; Wate products and 10/her Procurement 1%
Useries 7	2016 Carbon update for the health and care sector in	NHS England	~1992: 16.58 Mt CO2 ~1993: 15.46 Mt CO2	ca.	cn.	-Bailding Energy Uie 18%;Travel 13%;Commissioned health and care Services from outsinde system 11%;Procurement 57%: Pharmaceuticala (excluding b Indulery) 11%; Bioiness Services 11%; Medical Instruments/Equipment 10%; Food and Catering 5%; Freight Transport 3%; Meter Dose Inhalters 3%; Construction
	England 2015(1)		~1994: 15.52 Mt CO2 ~1995: 15.48 Mt CO2 ~1996: 15.93 Mt CO2			Manufactured fuels, chemicals and glasses 2%; Paper Products 2%; Waste Products and Recycling 2%; Anaesthesic gases 2%; Other manufactured products 2%; I and communication Technology 2%; Water and Sanitation 1%
			~1997: 15.40 Mt CO2 ~1998: 15.77 Mt CO2			
			~1999: 16.62 Mt CO2 ~2000: 16.51 Mt CO2 ~2001: 17.97 Mt CO2			
			~2002: 17.33 Mt CO2 ~2003: 18.36 Mt CO2			
			~2004: 18.62 Mt CO2 ~2007: 21.2 Mt CO2 ~2012: 25 Mt CO2			
			~2012 25 MCO2 ~2014: 24.7 Mt CO2 ~2015: 26,6 Mt CO2			
н :	2019 Health Care's Climate	Global; Australia; Austria; Belgium;	~2017: 27,119 Mt CO2 Global 2 Gt United States 546.54 Mt; China 342.46Mt; European	Global 0,28 t CO2e; Australia 1,29 tCO2e; Austria 0,59 tCO2e; Belgium	United States 7,6; China 3,1; European Union 4,7; Japan 6,4;	Scopes
	rooprin	Croatia; Cyprus; Carech Repub-lic; Denmark; Estonia; Finland; France;	Germany 57.51M; Brazil 43.84M; United Kingdom 42.5M; India 38.8M; South Korea 37.26M; Canada 35.96M; Australia	China 0.25 tCO2e; Brand 0.21 tCO2e; Balgaria 0.57 tCO2e; Canalar 1.70 tCO2e; China 0.25 tCO2e; Croatia 0.19 tCO2e; Cyprus 0.3 tCO2e; Czech Republic 0.35 tCO2e; Denmark 0.78 tCO2e; Estonia 0.66 tCO2e; Finland	Kussan Pederation 4; Germany 3,2; Brazi 4,4; United Kingdom 5,4; India 1,5; South Korea 5,3; Canada 5,2; Australia 5,1; France 4,6; Mexico 3,4; Italy 4; Spain 4,5; Turkey 3,2; Indonesia	Sutient 2.0 (CO22: "Healin care tradinics and neurin care owner venices 17%, marece removing 12%, recover 17%, "Scope 2.0%, Scope 17%, Scope 2.0%, Scope 17%, Scope 2.0%, Scope 17%, Scope 2.0%, Scope 17%, Scope 2.0%, Scope 2.0%, Scope 17%, Scope 2.0%, Scop
		Germany; Greece; Hungary; India; Indonesia; Ireland; Italy; Japan;	30.17Mt; France 28.98Mt; Mexico 22.53Mt; Italy 21.31Mt; Spain 16.72Mt; Turkey 14.83Mt; Indonesia 13.59Mt; Netherlands	0,64 tCO2e; France 0,44 tCO2e; Germany 0,71 tCO2e; Greece 0,38 tCO2e; Hangary 0,26 tCO2e; India 0,03 tCO2e; Indonesia 0,05 tCO2e; India 0,	1.9: Netherlands 5,9; Poland 3,7; Taiwan 4,6; Belgiam 5,5; Switzerland 6,7; Austria 5,2; Sweden 4,4; Denmark 6,3; Greece	Scope3 71%; -Cyprus: Scope1 6%; Scope2 16%; Scope3 78%; -Czech Republic: Scope1 12%; Scope2 5%; Scope3 83%; -Denmark: Scope1 12%; Scope2 8%; S -Estonia: Scope1 6%; Scope2 5%; Scope3 4%; -Finiand: Scope1 7%; Scope2 13%; Scope3 82%; -Finiand: Scope1 12%; Scope3 82%; -Cermary
		Latvia; Lithuania; Luxembourg; Malta; Mexico; Netherlands; Norway Poland; Portugal; Romania; Russia;	15.52MI; Potand 15.02MI; Tatwan 12.27MI; Belgium 9.5MI; Switzerland 8.32MI; Austria 5.04MI; Sweden 4.5MI; Denmark 4.4MI; Greece 4.15MI; Czech Republic 3.71MI; Portugal 3.61MI;	Ireland 0,61 ICO2e; Haly 0,55 ICO2e; Japan 0,81 ICO2e; Latvia 0,25 ICO2e; Lithuania 0,17 ICO2e; Luxembourg 0,84 ICO2e; Maha 0,45 ICO2e; Mexico 0,18 ICO2e; Netherlands 0,79 ICO2e; Norway 0,64/CO2e;	3,7; Czech Republic (3,6 Portugal 4,8; Finland 5; Romania 2,7; Norway 4,3; Ireland 4,4; Bulgaria 6; Hangary 4,3; Slovak Republic 2,8; Slovenia 4,6; Estonia 4,7; Croatia 3,2; Lithuania 2;	Scope2 18%; Scope3 6%; «treeze: Scope1 18%; Scope2 34%; Scope3 fb7%; scope3 fb7%; Scope3 76%; Scope3 77%; «hult; Scope3 77%; «h
		Slovak Republic; Slovenia; Spain; South Korea; Sweden; Switzer-land;	Finland 3.51Mt; Romania 3.08Mt; Norway 3.08Mt; Ireland 2.83Mt; Bulgaria 2.7Mt; Hangary 2.55Mt; Slovak Republic	Poland 0,34 tCO2e; Portugal 0,35 tCO2e; Romania 0,15 tCO2e; Russia 0,53 tCO2e; Slovak Republic 0,22 tCO2e; Slovenia 0,45 tCO2e; Spain	Latvia 3,2; Luxembourg 3,7; Cyprus 2,9; Malta 4,8; Global 4,4%	Scope3 82%; -Malta: Scope1 7%; Scope2 11%; Scope3 82%; -Mexico: Scope1 18%; Scope2 34%; Scope3 48%; -Netherlands: Scope1 12%; Scope2 34%; Scope3 82%; -Mexico: Scope1 12%; Scope2 34%; Scope3 82%; -Romany; Scope1 12%; Scope2 44%; Scope3 84%; -Poland; Scope1 12%; Scope2 34%; Scope3 84%; -Romany; Scope1 12%; Scope2 44%; Scope3 84%; -Romany; Scope1 12%; Scope3 84%; -Romany; -Romany; Scope3 84%; -Romany;
		United States; Rest-of-World; European Union	1. Jywe; Slovenia 0.93va; Esonia 0.86va; Croana 0.88va; Lithuania 0.5Mt; Latvia 0.5Mt; Luxembourg 0.47Mt; Cyprus 0.34Mt; Malta 0.2Mt	1,02 HCO2e; Souh Kerea 0, 5 HCO2e; Sweeten 0,06 HCO2e; Swaeten 1,0 1,02 HCO2e; Taiwan 0,52 HCO2e; Turkey 0,19 HCO2e; United Kingdom 0,66 HCO2e; United States 1,72 HCO2e; Rest-of-World 0,16 HCO2e;		Link Scope 10%, Scope 10%, Scope 12%, Scope 35%, Calumna Scope 11%, Scope 21%, Scope 12%, Scope 13%, Scope 12%, Scope 11%, Scope 12%, Scope 12%, Scope 12%, Scope 12%, Scope
				European Union 0,49 tCO2e;		Scope1 12%; Scope2 5%; Scope3 83%; -United States: Scope1 21%; Scope2 15%; Scope3 64%; -Rest-of-World: Scope1 %; Scope2 %; Scope3 %; -European U 14%; Scope2 11%; Scope3 75%
isz et al.	2020 Carbon emission trends	Austria	6.8 Mt CO2eq	0.8	7%	~-Economic Sectors: Generation and distribution of electricity, gas and heat or cooling 49%; Heath care facilities operational emissions 15%; Utiler manufacture Agriculture 9%; Other sectors and services 8%; Transport 7%; Pharmaceutical and chemical products 5%; Waste treatment 3%; Other primary Industry 3% Hospitals 23%; Josethenets 9%; Medical retail 20%; Other 20%; Ambalanoy 18%
	and sustainability options in Austrian					
lik et al. 2	incariti care					
	2021 Environmental impacts of Australia's largest	New South Wales, Australia	7908t CO2eq	c.n.	6,6%	
velman et al.	2021 Environmental impacts of Australia's largest health system 2020 Health Care Pollution And Public Health	New South Wales, Australia USA	7908t CO2eq 2010: 520.5Mt CO2eq; 2011: 514.2 CO2eq; 2012: 486.6 CO2eq; 2013; CO2eq; 2014: 518.6 CO2eq; 2015: 525.6 CO2eq; 2016:	c.n.	6,6% c.n.	 - Will equadrate categories: - Will equadrate categories: - Will and are 35.444 (Protein and Clinical Services: 11.476; Other Professional Services: 2219; Dental Services: 10.974; Other Health, Residential, and Services: 11.476; Other Health, Services: 11.476; Other Health, Services: 11.476; Other Health, Services: 11.476; Other Health, Se
elman et al.	2021 Environmental impacts of Australia's largest health system 2020 Health Care Pollution And Public Health Damage In The United States: An Update	New South Wales, Australia USA	7988; CO2eq 2010; 530; 544; CO2eq; 2011; 514;2; CO2eq; 2012; 486;6; CO2eq; 2013; CO2eq; 2014; 518;6; CO2eq; 2015; 525;6; CO2eq; 2016; 559;8; CO2eq; 2017; 538;1; CO2eq; 2018; 553;5; CO2eq	сл. сл.	6,6% C.n.	
zhman et al.	2021 Environmental impacts of Australia's largest health switem 2020 Health Case Pollution And Public Health Damage In The United States: An Update	New South Wales, Australia USA	7988.CO2eq 2010: 520.598.CO2eq; 2011: 514.2 CO2eq; 2012: 486.6 CO2eq; 2013: CO2eq; 2014: 518.6 CO2eq; 2015: 52.6 CO2eq; 2016: 529.8 CO2eq; 2017: 538.1 CO2eq; 2018: 553.5 CO2eq	са. Са.	6.6% ca.	
elman et al.	2021 Environmental impacts of Australia's largest health system 2020 Health Case Pollution And Public Health Damage In The United States: An Update	New South Wales, Australia USA	9486 CO204 316 (2384) ACO204 2011 5142 (CO204 2017 4864/CO204 315 (2384) 2017 4864 (CO204 2018 2516 (CO204 2018 2518 (CO204 2017 538 (CO204 2018 5515 (CO204 2518 (CO204 2017 538 (CO204 2018 5515 (CO204	64 64	6.05. CA	- SOII equivalence videocity SOII e
elman et al.	2021 Environmental impacts of Australia largest health ovstem 2020 Health cere Pollation 2020 Health cere Pollation Danage In Tac United States: An Update	New South Wales, Australia USA	948 CO2a 310 C1364 (2014) 311 512 5120 (2014) 312 566 (2016) 310 C126 (2014) 315 515 512 512 512 512 512 512 512 512 5	66. 68.	6/5. (A	
elman et al.	2021 Environmental impact of Australia largest <u>headh overen</u> 2003 Headh cere Pollation And Public Headh Damage In The United States: An Update	New South Wales, Australia USA	948 CO2a 310 5136 CO2a 310 5136 CO2a 311 512 512 500a 312 564 CO2a 310 CO2a 314 516 CO2a 315 515 CO2a 316 518 CO2a 317 518 1 CO2a 318 513 CO2a 518 CO2a 317 518 1 CO2a 318 513 CO2a	68. 68.	6/6 C&	NIE rependince categories: NIE rependince categories:
elman et al.	2021 Environmental impact of Australia Impact beddh oxisem Diselfa Deser Distinto And Public Health Damaget in Tau Chinde States: An Update	New South Wales, Australia	948 CO24 310 5136 CO24 513 513 513 513 500 516 310 5136 CO24 514 515 514 500 517 518 515 518 518 518 518 518 518 518 518	68. 68.	6/6 C&	NBE expenditure categories: NBE expenditure categories: NBE expenditure categories: NBE hyperbolic care: 58 MeV, ep. 21 No. No. No. No. 11 APN, Oher Professional Services: 22 No. 2004; Services: 3109; Oher Hash, Reschander, NBE expenditure: 58 MeV, ep. 21 No. No. No. 11 MeV, Developer and Categories (Categories): Categories (Categories): NBE expenditure: No. NoDasket Meddar Products: 2005; Forder Marcines and Expension: 11 No. 2005; Forder MeV, Name and Categories (Categories): NBE expension: 11 No. 2005; Physician and Categories: 2007; Structures and Expension: 2007; Development: 2007; Oher Hash, Archiver, 11 No. 2006; Physician and Categories: 2007; Development: 2007;
elman et al.	2020 Environmental Impact. of Australia Usagest Neath Archard Control (1998) (1998) Antice Control (199	New South Wales, Australia	9486 CODag 3010 53384 CODag 3011 5142 CODag 3012 4864 CODag 3010 (CODag 3015 5142 CODag 3015 5324 CODag 2016 5384 CODag 2017 5381 CODag 2018 5333 CODag	54	5.65	
celman et al.	2020 Environmental Impact. et A donational Langest et Andread Case Proceedings And Public Neirabin Damage In The United States: An Update	New South Wales, Asutodia	9486 CODag 2010: 533 Mar CODag, 2011: 5142 CODag, 2012: 86.6 CODag 2010: CODag, 2017: 5381 CODag, 2016: 5333 CODag 2016: CODag, 2017: 5381 CODag, 2016: 5333 CODag	54. 54.	5.65. 5.	
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chman et al.	2020 Environmental Impacts of Automatical Impact of Automatical Impact Automatical International Conference Auto Packie Conference Auto Packie Conference Disease Automatical International Disease Automatical	New South Wales, Asutodia USA	9486 CODag 2010: STM 2010, 2011: 5142 CODag, 2012: 86.6 CODag 2010: CODag, 2017: 5142 CODag, 2015: 52.5 CODag 2014: CODag, 2017: 518.1 CODag, 2018: 5513 CODag 2018: CODag, 2017: 518.1 CODag, 2018: 5513 CODag	56. 55.	5.05. 5.	
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Method	Demand Data source (detail)	Demand Data year	Number of demand/Expen diture categories	I-O table data source	I-O table data year	I-O model	Number of production sectors	Source of emission data/satelite account	Included Greenhouse Gases	Concardance matrix reported	Sensitivity/Unc ertainty Analysis	Discussion of limitations
ſop-Down	"National Medical Expenses Statistics"	2011	16	Ministry of internal Affairs and Communication	2011	SRIO (ЛОТ)	397	Japan National Report of GHGs Inventory (NRI)	CO2, CH4, N2O, HFCs, PFCs, SF6 and NF3	No	No	Yes
lop-Down	US National Health Expenditure Accounts	2003–2013	15	Federal Bureau of Economic Analysis	2002	SRIO	400+	EIOLCA	Equivalents	Yes	No	Yes
fop-Down	OECD: OECD health statistics database; China+India: World Bank health care expenditure	2014	OECD: 19	Eora	2014	MRIO (Eora)	14839	EDGAR	CO2	Available upon request	No	Yes
°op-Down	National Health Expenditures (NHEX) database maintained by the Canadian Institute for Health Information (CIHI)	2009-2015	13	(Statistics Canada)	2009	SRIO (Open IO- Canada)	112 sectors, 238 commodities	Statistics Canada Environmental Accounts and the Canadian National Pollutant Release Inventory	carbon dioxide, methane, and nitrous	Yes	No	Yes
Гор-Down	Australian Institute of Health and Welfare (AIHW)	2015	16	Australian Bureau of Statistics	2014-2015	SRIO (Individually constructed)	360	Sydney University IELab	Equivalents	No	Monte-Carlo	Yes
Top-Down	national input-output table, China Health and Family Planning Statistics, China Construction Statistics, and China Science and Technology Statistics yearbooks	2013	8	National Bureau of Statistics of China		SRIO	46	Climate Change Department of National Development and Reform Commission of the People's Republic of China. The People's Republic of China First Biennial Update Report on Climate Change	CO2, CH4, and N2O emissions	No	Monte-Carlo + Robustness (w/ onsite-emission in the medical institution sector) + Sensitivity (w/ energy intensities of floorspace of commercial buildings)	Yes
Iybrid	Scottish Government health expenditure	1990-2004	17	Scottish Government	1990-2004	SRIO (Scottish Government Input- Output tables)	123	UK National Statistics Environmental Accounts	CO2	Allocation without quantitative description	No	No
Hybrid	English Government	2004-2015	5	DEFRA	2004-2015	MRIO (UK-MRIO)	178	National Statistics Environmental Accounts	CO2 Beginning in 2010: CH4, N2O, HFCs, PFCs, SF6	Allocation without quantitative description	No	No
Fop-Down	OECD health statistics database; World Health Organization, "Global Health Expenditure Database,"	2014	No	WIOD	2014	MRIO (WIOD)	2408	CO2: WIOD; Methane and Nitrous oxide: PRIMAP	carbon dioxide, methane and nitrous oxide gases	Reference to Pichler et al. (2019)	No	Yes
Fop-Down	OECD Health Statistics 2017 supplied by the Austrian national statistical office	2014	9	Eora	2014	MRIO (Eora)	15909	EORA taken from EDGAR	CO2	Reference to Pichler et al. (2019)	No	Yes
Гop-Down	Australian Institute of Health and Welfare	2016-2017	16	Australian Bureau of Statistics (ABS)	2017	SRIO (Individually constructed)	2880	No	No	No	No	Yes
Top-Down	National Health Expenditure Accounts of the Centers for Medicare and Medicaid Services (CMS)	2010-2018	16	Bureau of Economic Analysis	2012	SRIO (US Environmentally- Extended Input-Output model)	405	Inventory of U.S. Greenhouse Gas Emissions and Sinks	No	Yes	No	Yes
Iybrid	Public Expenditure Statistical Analysis Supply and Use tables from HM Treasury	1990-2019	19	DEFRA	1997-2016	MRIO (UK-MRIO)	424	UK MRIO	carbon dioxide [CO2], methane [CH4], nitrous oxide [N2O], and some categories of fluorinated gases/all Kyoto Protocol greenhouse gases	Yes	No	Yes
Fop-Down	EORA	2000-2015	163	Eora	2000-2015	MRIO (Eora)	14838	EORA taken from EDGAR	carbon dioxide [CO2], methane, nitrous oxide, hydrofluorocarb on	No	Uncertainty	Yes

BMJ Open Appendix: Transparency Score Please use Ctrl + Scroll to zoom in this electronic appendex

Image: Normal biology Verset Grade marker Base year State year <th< th=""><th>Author</th><th>Year</th><th>Author</th><th>Title</th><th>Health</th><th>Total</th><th>tCO2/capi</th><th>% of total</th><th>Breakdow</th><th>Method</th><th>Demand</th><th>Demand</th><th>Number</th><th>I-O table</th><th>I-O table</th><th>Multiregio</th><th>Numb</th><th>Source of</th><th>Included</th><th>Concarda</th><th>Sensitivity</th><th>Dis-</th><th>I</th><th>I</th></th<>	Author	Year	Author	Title	Health	Total	tCO2/capi	% of total	Breakdow	Method	Demand	Demand	Number	I-O table	I-O table	Multiregio	Numb	Source of	Included	Concarda	Sensitivity	Dis-	I	I
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Carbon footprint of healthcare systems: A systematic review of evidence and methods

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ABSTRACT

Objective: Given the demand for net-zero healthcare, the carbon footprint (CF) of healthcare systems has attracted increasing interest in research in recent years. This systematic review investigates the results and methodological transparency of CF calculations of healthcare systems. The methodological emphasis lies specifically on Input-Output based calculations.

Design: Systematic Review according to the PRISMA guideline.

Data sources: PubMed, Web of Science, EconBiz, Scopus, and Google Scholar were initially searched on November 25, 2019. Search updates in Pubmed and Web of Science were considered until December 2023. The search was complemented by reference tracking within all the included studies.

Eligibility Criteria: We included original studies that calculated and reported the CF of one or more healthcare systems. Studies were excluded if the specific systems were not named or no information on the calculation method was provided.

Data extraction and synthesis: Within the initial search, two independent reviewers searched, screened, and extracted information from the included studies. A checklist was developed to extract information on results and methodology and assess the included studies' transparency.

Results: 15 studies were included. The mean ratio of healthcare system emissions to total national emissions was 4.9% [minimum 1.5%; maximum 9.8%], and CFs were growing in most countries. Hospital care led to the largest relative share of the total CF. At least 71% of the methodological items were reported by each study.

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Conclusions: The results of this review show that healthcare systems contribute substantially to national carbon emissions, and hospitals are one of the main contributors in this regard. They also show that mitigation measures can help reduce emissions over time. The checklist developed here can serve as a reference point to help make methodological decisions in future research reports as well as report homogeneous results.

Keywords: life-cycle assessment, input-output, global warming potential, healthcare

STRENGTHS AND LIMITATIONS OF THE STUDY

- The assessment of methodological choices and the transparency of methods when assessing the greenhouse gas emissions of entire sectors in systematic reviews can help deepen our understanding of the results.
- The systematic review of all available evidence on greenhouse gas emissions of and within healthcare can help to understand its impact and to identify reduction potentials.
- This review was limited to articles in English and German, and excluded assessments, grey literature from public reports, and reports from statistical offices published in other languages.

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INTRODUCTION

Background

Climate change is one of the most pressing issues of our time[1]. Considering the correlation between the gross domestic product (GDP) and carbon emissions[2], the healthcare industry is likely an essential contributor to greenhouse gas (GHG) emissions. Demographic shifts and income effects have likely spurred greater demand for healthcare services, a trend projected to persist and further elevate the economic significance of the healthcare industry[3]. Evidence on healthcare's GHG emissions is needed to understand its role better.

Methods for calculating a carbon footprint (CF) can be broadly categorized into bottom-up and top-down approaches. Bottom-up methods, such as process-based lifecycle assessments (LCA), require extensive data, which currently limits their application at a sectoral level. However, the CF of various sectors can be estimated using a more uncertain top-down-methodology, providing a trade-off for broader coverage. In this case, emissions are divided according to the final demand or economic sectors of emission occurrence.

Input–output (I–O) analysis, which follows this approach, can be used to estimate sectoral CF[4]. Calculations of the CF use the static open-quantity I–O model in combination with an environmental extension. They rely on two fundamental building blocks: an I–O table and a demand vector. The I–O table describes the interactions between the sectors of production, often in monetary terms, and are usually constructed by national statistics offices. With additional information on their environmental impact, the emission intensity of a sector and its upstream production processes can be calculated. The demand vector represents the expenditures of the relevant sectors. For example, the demand vector of the healthcare sector includes expenditure on diesel fuel to power ambulances, electricity consumed by hospitals, and all other forms of energy. It may be necessary to synchronize the structures of the I–O table and the demand vector by balancing the definitions of different sectors and adjusting the level of sectoral aggregation.

I–O models can be grouped into single-region I–O (SRIO) and multi-region I–O (MRIO) models. SRIO models utilize I-O data from a single country, thus restricting their scope to domestic production and emissions only. MRIO models connect multiple I–O tables from multiple countries, and can thus account for different levels of production and "trade" in emissions (i.e., emissions occurring in one country related to the final demand of another country). The need for synchronized data from multiple countries complicates the development and update of the data of MRIO models.
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The results of CF calculations for a specific sector can be influenced by methodological choices, including the selection between SRIO or MRIO models and the GHGs taken into account. Therefore, comprehensive reporting is needed to ensure the transparency of methodological choices, the data, and the results. However, our search of the literature yielded neither a standardized procedure nor standardized reporting.

Objective

The aim of this study is to conduct a systematic review of research utilizing I-O analysis to quantify the CF of systems, encompassing total CF, CF per capita, and its proportion relative to the national CF. Furthermore, data on emission trends over time, can deepen the understanding of the trajectory of the CF of healthcare systems. Finally, an assessment of the methodological choices and their transparency within the reviewed studies can help to discuss the state of the methodology and provides a foundation to discuss methodological differences between the studies.

METHODS

Search strategy and selection criteria

This systematic review was performed by following the PRISMA guidelines[5] (the checklist is provided in the Appendix). The databases PubMed, Web of Science, EconBiz, Scopus, and Google Scholar were searched for studies on November 25, 2019. The search was complemented by reference tracking within all the included studies. The updated search considered hits in Pubmed and Web of Science up to December 2023.

Following the screening of the titles and abstracts, studies were included for further investigation if they had (i) addressed the method of CF calculation (ii) addressed one or more healthcare systems or subsystems, and (iii) been written in English or German. A healthcare system was defined as the national healthcare system, federal system, and/or state system. Single entities, such as individual hospitals, and specialized branches, such as dentistry, were excluded. In addition to the criteria used for screening the titles and abstracts of articles, full-text articles were excluded if they (i) did not name the specific healthcare (sub)system, (ii) did not calculate the CF, or (iii) did not provide any information on the method of calculation used. In the initial search, two of the authors separately screened titles and abstracts, read the full text, extracted data and assessed the transparency. In the case of disagreement, decisions were made through discussion until a consensus was reached. During the search update these steps were conducted by one person.

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Data extraction and analysis

The CF per capita, the contribution of healthcare to the country's total CF emissions, and the origins of emissions were used as main results of the studies. The breakdown of the emission sources could be in scopes, demand categories, or places of origin. The Greenhouse Gas Protocol Corporate Accounting and Reporting Standard[6] proposes three standardized scopes. Scope 1 represents direct emissions from owned or controlled sources, Scope 2 represents indirect emissions generated by the purchased energy, and Scope 3 represents all indirect emissions that occur in the value chain. The categories of demand included the classes of expenditures of the demand vector, and the places of the origin of emissions were divided into hospitals, ambulatory services, and so on.

In addition to evaluating their general characteristics and results, we developed and applied a checklist to assess the methodological transparency of the studies under consideration. We opted to use the term 'transparency' rather than 'quality' to address the issue that even a flawless study could receive a low score if the authors failed to adequately report their methodology. The checklist served as both a qualitative extraction tool and a quantitative transparency tool. The qualitative extraction tool facilitated the assessment of information from each included study, with responses to each criterion collected accordingly. As a quantitative transparency tool, it was evaluated whether the criteria were adequately addressed. When information was provided, the criterion was considered fulfilled, resulting in an increase in the transparency score. All criteria were weighted equally, therefore for each "fulfilled" criterion one point was added to the transparency score, with a maximum of 17 points per study.

The utilization of I-O data can introduce uncertainties into the assessment, given that the top-down approach relies on aggregated information from industrial sectors. When heterogeneous products with varying emission intensities are grouped into one industry, aggregation errors might occur: the average emission intensity of the aggregated industry would not appropriately reflect the emissions caused by the specific product within the industry[7]. Therefore, information on the extend of usage of I-O method (criterion 5), and the number of industry sectors (criterion 12) could help to understand the scope of this uncertainty.

The choice between MRIO and SRIO (criterion 11) can also help to understand the level of uncertainty. While MRIOs can account for differences between countries and trade between these countries, SRIO might provide a more detailed framework of the domestic economy. Finally, the specific source of the I-O tables (criterion 9) and emission data (criterion 13) can help the reader to assess the quality of the used data.

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Similar to the I-O data, the level of aggregation within the demand data can impact the accuracy of the results. The number of demand or expenditure categories (criterion 8) can indicate on the level of aggregation and the source of demand data (criterion 6) could help to assess the quality of the data source. The quality of the outcomes is also influenced by the alignment between the temporal representativeness of the demand data (criterion 7) and the I-O data (criterion 10). Changes over time (e.g. in technology, import and exports) can impact the results and in the best case both data sources refer to the same year. Finally, information on the matching process of demand categories and industry sectors, the publication of the concordance matrix (criterion 15), increases transparency for the reader.

The quantitative (criterion 16) and qualitative (criterion 17) assessment of uncertainty helps the readers to contextualize the results. A list of the included GHGs can indicate the scope of the study, in this case 0.5 were given, when the unit (typically CO_2 equivalents (CO_2 eq)) was mentioned and another 0.5 points if all included GHGs were listed. For the final transparency checklist, the criteria on outcomes (table 1a) and on methodology (table 1b) were combined.

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Table 1a: Extracted outcomes

	Number	Criterion			
	0 *	System description			
System description and outcomes	1	Total carbon footprint			
	2	Carbon footprint as a share of the			
		total national CF			
	3	CF per capita			
* not included in the transparency score					

Table 1b: Extracted methodological items

	5	LCA method
	6	Source of demand data (detail)
	7	Year of demand data
	8	Number of categories of demand
		or expenditure
	9	Data source of I–O table
	10	Year of I–O table
Method	11	Multi-regionality of the model
	12	Number of production sectors
	13	Source of emission data
	14	GHGs considered
	15	Concordance matrix reported
	16	Sensitivity and uncertainty
		analysis
	17	Discussion of limitations

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Emissions over time

To assess trends in GHG emissions of healthcare, data from all studies that reported total emissions for more than one year were taken. The data were normalized to the respective starting point of the report as a base year. Therefore, GHG emissions of time period t were divided by the GHG emissions of the base year t_0 and used in a descriptive analysis.

Patient and public involvement

None

RESULTS

A total of 4,285 records were identified in the three searches (figure 1). After removing duplicates and searching for eligible title, abstracts, and full texts, 15 reports were included in this review (figure 1). A summary of included studies is provided in Table 2. The detailed results of the data collection are listed in the appendix.

-Insert figure 1 around here-

Characteristics of the studies considered

Eleven studies focused on a single national healthcare system, including England [8 9], Japan [10], USA [11 12], Canada [13], Scotland [14], China [15], Australia [16], Austria [17], and the Netherlands[18]. The series of CFs from the Sustainable Development Unit of the English NHS was aggregated, and only the newest available report was cited. One study examined the healthcare system of the largest Australian state, New South Wales [19], while three studies reported on healthcare systems in multiple countries. Pichler et al. [20] reported results for 36 countries, Healthcare without Harm (HCH) for 43 countries [21], and the investigation by Lenzen et al. [22] considered 189 countries.

Excluding the one that assessed the Scottish NHS, all studies were published after 2016. However, it's worth noting that the year of the analysis could be older. For instance, the study by Nansai et al. [10] was published in 2020 but utilized demand data from 2011.

Table 2: Characteristics and main results of the studies considered in this review; CF: carbon footprint, Mt: megatonnes CO2eq: CO2 equivalents, t: tonnes, cap: capita

Author (Year)	Healthcare system	Data year	CF in Mt CO ₂ eq	% of total national CF	tCO2eq/cap	Transparency score
Tennison et al. [8]	England	2018	25	n.i.	0,445	88%
SDU [9]	England	2019	25	n.i.	n.i.	71%
Nansai et al. [10]	Japan	2011	72	4,6	0,49	82%
Eckelman and Sherman [11]	USA	2013	655	9,8	2,07	85%
Eckelman et al. [12]	USA	2018	554	n.i.	n.i.	76%
Eckelman et al. [13]	Canada	2015	33	5,7	0,92	94%

Health Facilities Scotland [14]	Scotland	2004	2,6	3,6	0,52	76%
Wu [15]	China	2012	315	2,7	0,23	94%
Malik et al. [16]	Australia	2015	36	7,0	1,50	85%
Weisz et al. [17]	Austria	2014	6,8	7	0,8	94%
Steenmeijer et al. [18]	Netherlands	2016	17,575	17,6	n.i.	88%
Malik et al. [19]	New South Wales, Australia	2017	0,008	6,6	n.i.	71%
Pichler et al. [20]	OECD countries; China, India	2014	s. Appendix	Ø 5,5 s. Appendix	s. Appendix	94%
	43 countries; EU; rest of the world	2014	s. Appendix	Ø 4,4s. Appendix	s. Appendix	88%
Lenzen et al. [22]	Global	2015	2 290	n.i.	n.i.	88%
* n.i.= not identified						

Differences in methodology and data

Eleven studies considered top-down data on emissions, while three studies employed bottom-up data on energy usage [8 9 14]. Steenmeijer et al. [18] incorporated bottom-up data regarding the quantities of anesthetic gases, inhalers and travel.

Most single-country studies used SRIO data from the respective governmental offices. In contrast, the studies on British and Dutch healthcare, and those that considered more than one country, used MRIO data. Additionally, Malik et al. [23] used MRIO data, however, the database only included data from Australian regions. The EORA database emerged as the most frequently utilized MRIO database (three times), with one study each employing the WIOD database, the EXIOBASE database, and the MRIO database provided by the British Department for the Environment, Food, & Rural Affairs.

The number of production sectors varied among the SRIO studies, ranging from 46 to 405 sectors. The MRIO studies typically utilized more extensive databases comprising approximately 15,000 sectors, although the MRIO study focusing on the UK considered 424 sectors.

All studies considered CO_2 emissions. However, only five studies considered the six GHGs covered in the Kyoto Protocol; three studies considered CO2, methane, and nitrous oxide; two reported only that they had used CO2eq as unit; and two studies did not report any included GHG or the unit in which the outcomes were reported. The data on emissions were drawn mostly from national accounts in the case of SRIO databases and integrated accounts in the case of MRIO databases. One study did not report the source of its emission account data.

The demand data was taken either from official health expenditure accounts or from international organizations such as the WHO and the World Bank (which uses data provided by national offices and accounts). Lenzen et al. [22] identified and directly used data on healthcare-related sectors from the MRIO database EORA. The number of reported expenditure accounts varied, mostly ranging from 13 to 19, although three studies reported fewer accounts. Weisz et al. [17] utilized nine accounts, Wu [15] used eight accounts, and the study on the NHS

in England employed five accounts [9]. Due to the distinct methodologies employed by Lenzen et al. [22] and the structure of the EORA database, which reports country-specific sectors, they utilized 163 sectors from the EORA as demand data.

The time periods covered by the demand data were largely consistent with those covered by the respective I-O data. Some studies reporting outcomes for more than one year only used one reference year for the I-O database and adjusted the demand data for inflation. [11-13]. The lag between the time at which the data were collected and the time of publication of the corresponding study ranged from three to six years, with deviations in the studies by Nansai et al. [10] Eckelman et al. [12] (two years) and in the report by the SDU [9]. The latter reported the CF periodically; the lag between the latest publication and the latest data was one year [9]. Further information on this is provided in the appendix.

Five studies provided their concordance matrices, which link the categories of demand with the industrial sectors. The authors of one study had made their matrix available upon request, and two articles had referred to a matrix previously used in another study. Five studies did not report their concordance matrices.

Reporting of the results

 The origins of emissions were documented six times in the three scopes defined by the GHG protocol. Emission sources were reported eight times in the (sub)categories of final demand, such as hospitals or pharmaceuticals. Two studies reported the economic sector in which the emissions occurred, e.g., the textile sector or the manufacture of fuels. Furthermore, three studies reported a breakdown of emissions by employing more than one reporting structure. Several differences were observed in the scopes of the reported results. Some studies directly referenced the GHG protocol while others reported emissions in divisions, such as travel, energy, procurement, etc. 47% of the articles did not normalize the results by reporting the CF per capita.

Overall transparency

Except for the three criteria "reporting of the concordance matrix", "uncertainty analysis", and "CF per capita", all criteria were fulfilled by at least 75% of the studies (Figure 2). The studies fulfilled between 70.5% and 94% of all criteria with a mean of 85% (Figure 3).

-Insert figure 2 around here-

-Insert figure 3 around here-

OUTCOMES

Emissions over time

The results of the time series revealed successful efforts to mitigate the CF by the NHS in England and Scotland (Figure 4). In the nearly three decades from 1990 to 2019, the English NHS reduced its CF by roughly 25%. The four remaining countries (Japan, Canada, USA, and Australia) examined in the studies considered here and the global trend showed increased CF due to healthcare (Figure 4). The annual increase in the CF ranged from 0.7% (USA, 2010–2018) to 3.8% (Japan, 2011–2015) over the observed period, with the CFs of Canada (1.9%, 2009–2015), USA (2.8%, 2011–2015), and Australia (2.9%. 2013–2015) in between these extremes. The global trend showed an increase in the CF of 2.7% per year from 2000 to 2015.

-Insert figure 4 around here-

Breakdown

The emission sources were mainly reported using the scope system from the GHG protocol or the categories of expenditure, i.e., the categories of final demand. The largest dataset that used the categories of final demand was provided by Pichler et al. [20], who applied this to 36 countries and reported the average values. Medical retail (i.e., provider of healthcare products without medical services, e.g., pharmacies), hospitals, and ambulatory healthcare services constituted 80% of the CF of healthcare, with medical retail contributing 33.1%, hospitals 28.6%, and ambulatory healthcare services 18%. They also made a major contribution to the CF in Japan (hospitals, 25.1%; ambulatory services, 22.7%), USA in 2013 (hospital care, 36%; physician and clinical services, 12%) [11] and in 2018 (hospital care, 34.9%; physician and clinical services, 12.6%; ambulatory medical services, 4.8%) [13], Australia (public hospitals, 34.4%; private hospitals, 10.2%; ambulatory medical services, 15%) [16], China (public hospitals, 47%; private hospitals, 4%) [15], and Austria (hospitals, 32%; ambulatory services, 18%) [17]. Other important categories of emissions were construction and pharmaceutical products, at around 10% [11 16 20], with a higher share in China (pharmaceuticals, 18%; construction, 15%) [15].

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An alternative approach involved categorizing emissions into direct emissions, indirect emissions through electricity production, and other indirect emissions. This division along these lines could also align with the three GHG protocol scopes.

By averaging data from 43 countries, HCWH reported a distribution of 17% for scope 1 emissions, 12% for scope 2 emissions, and 71% for scope 3 emissions [21]. These findings, particularly the significance of scope 3 emissions, are corroborated by evidence from single-country studies. [8 11 12 14 24]. The scope 3 emissions

were further divided into those due to travel (patient and visitor travel, and staff commutes), production of pharmaceuticals, and medical instruments and equipment, which accounted for the largest share of scope 3 emissions.

Scotland's scope 3 travel emissions in 2004 were 18% while those of England accounted for 13% in 2015 and 9.6% in 2018 [9]. The share of emissions owing to pharmaceutical production ranged from 11% and 18%, and that owing to medical instruments and equipment accounted for 7%–10% of the total CF [13 14 24].

The ratio of emissions by the healthcare sector to the total CF in studies focused on a single country ranged from 2.7% in China in 2012 [15] to 9.8% in the USA in 2013 [11]. The three cross-national studies considered here estimated that healthcare had contributed 5.5% [20] on average to the national CF in 2014 and 4.4% in 2015 [22].

DISCUSSION

Interpretation of results

The results indicate that healthcare significantly contributes to the CF, both in absolute numbers and in relation to a country's overall emissions and its per capita emissions. However, the results varied among the studies, and their calculation methods were heterogeneous and frequently not fully transparent. The breakdown of the sources of emissions revealed the major contribution made by hospitals.

The time series results showed that the trend of emissions due to healthcare was positive in all the countries considered, i.e., they were increasing, except in Scotland and England. These results align with the graphical results provided by Lenzen et al. [22]. Furthermore, they indicated that the efforts of the British NHS systems to reduce their carbon footprint based on the Greener NHS program was effective in reducing GHG emissions. The breakdown of the sources of emissions verified the important contribution of hospitals. However, hospitals provide the majority of medical care in many countries. Therefore, their large CF is not surprising but might motivate the relevant decision-makers to allocate scarce resources more efficiently. The breakdown further showed that a large portion of the CF of healthcare stemmed from scope 3 emissions. Decision-makers may conclude that the most considerable reduction in emissions can be obtained by considering staff and patient travel. Therefore, "greening" the healthcare sector requires a sustainable transportation system and green healthcare goods.

Most data were from the OECD countries, China, and India. The only exception was the work by Lenzen et al. [22], who considered 189 countries in their analysis [22]. However, even if the distribution of countries limits

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While heterogeneity in methodology, in general, can lead to more robust results and a more informative perspective on the issue at hand, the differences in I–O methodologies to calculate the CF of healthcare may reduce the comparability of the results. However, the choice of method depends on the corresponding research question, for example, while SRIO may be more up to date and include a more detailed description of the domestic production sectors, MRIO can account for international trade and differences in production emissions between countries.

Limitations

This review has several limitations. First, the review process used here was limited due to restrictions on the language used in the study and those related to access. Second, it is possible that further CF assessments exist which were published in the official languages of many countries in the grey literature, such as publications by national statistics offices or governmental agencies. Because this review included only publications in English and German, many such studies have likely been neglected. Third, the reporting scheme and transparency score used in this study may have limitations. Both were based only on a consensus among the authors. The instruments used to assess the quality of the published studies are typically chosen based on a broad consensus among experts, such as in the case of the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) [25]. However, we did not find similar guidance for I–O analyses. Finally, the review is limited as the studies only report averages instead of confidence intervals (CI) or data ranges. Only Malik et al. [16] report the 68% CI with a range of 20,748 kt CO2eq in the results (68% CI 25,398kt CO2eq –46,146 kt CO2eq). Therefore, the results presented in both the individual studies and in this review should not be regarded as precise measurements, but rather as indicative trends or directions.

Implications for further research

This review identified research gaps that should be investigated by future research. First, there is a need to assess the potential effects of efforts to reduce emissions on the system and pathways to a low-carbon healthcare system. Second, it should be examined errors of aggregation when using the I–O methodology in the healthcare context. Third, the differences in the outcomes when making different methodological choices (SRIO or MRIO, systemic boundaries, etc.) should be analyzed to guide future research.

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The transparency checklist used in this study can serve as an initial reference point for future developments. For example, in the checklist's current state, all criteria are weighted equally. However, some might be less crucial to delivering harmonized study findings. An extended consensus process with further experts is proposed to validate the checklist further and increase its value for research and practice.

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DECLARATIONS

Author contributors

Mattis Keil: Methodology, Screening, Formal Analysis, Writing – Original Draft, Writing-Review and Editing, Visualization; Leonie Frehse: Methodology, Screening, Formal Analysis, Writing – Original Draft; Marco Hagemeister: Methodology, Screening, Formal Analysis, Writing – Original Draft Mona Knieß: Methodology, Screening, Formal Analysis, Writing – Original Draft Oliver Lange: Conceptualization, Methodology, Writing – Review and Editing, Tobias Kronenberg: Methodology, Writing – Review and Editing Wolf Rogowski: Conceptualizing, Methodology, Writing - Review and Editing, Supervision, Project administration. All authors have read and approved the final manuscript for publication.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data statement

The data that support the findings of this study are available in Appendix 4a "System description and results" and

Appendix 4b "Methods and transparency." Further data are available from the corresponding author, [MK], upon

reasonable request.

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Figure legends/captions

Figure 1: Prisma Flow Diagram, based on Page et al. (2021)

Figure 2: Fulfilment rate of the transparency and reporting criteria

Figure 3: Transparency score in % per article

Figure 4: Emission trends over time

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Figure 3: Transparency score in % per article

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RISMER PRIS	MA 2	020 Checklist	
Section and Topic	ltem #	Checklist item	Location where item is reported
TITLE		ir 84	
Title	1	Identify the report as a systematic review.	Title, Methods
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Page 1
INTRODUCTION	T		
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction on Page 3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction on Page 3
METHODS	1		
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Methods section on Page 4
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Methods section on Pages 3-4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used	Supplementary materials
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how magy regiewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation wools used in the process.	Methods section on Page 4
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each epoint, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of sutomation tools used in the process.	Methods section on Page 4
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which esures to collect.	Methods section on Pages 4-5
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, and g sources). Describe any assumptions made about any missing or unclear information.	Methods section on Pages 4-5
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	n.a.
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Methods section on Page 4
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	n.a.
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions. For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml	n.a.

PRISMA 2020 Checklist

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1	PRIS	MA 2	020 Checklist	
3 4 5	Section and Topic	ltem #	Checklist item	Location where item is reported
6		13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	n.a
7 8		13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was petformed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	n.a.
9		13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup a ally s, meta-regression).	n.a.
10		13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	n.a
11 12 13	Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting).	n.a.
14 15	Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	n.a
16	RESULTS			
17 18	Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to t	Results on page 5
19		16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	n.a.
20 21	Study characteristics	17	Cite each included study and present its characteristics.	Results on pages 5-6
22 23	Risk of bias in studies	18	Present assessments of risk of bias for each included study.	n.a.
24 25	Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) are effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Results on pages 6-7
26 27	Results of	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	n.a.
28 29	syntheses	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summar between the summ	n.a.
30		20c	Present results of all investigations of possible causes of heterogeneity among study results.	n.a.
31		20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	n.a.
32	Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis a set.	n.a.
33 34 25	Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	n.a.
36	DISCUSSION	1		
37 38	Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion on page 8
39 40		23b	Discuss any limitations of the evidence included in the review.	Discussion on page 8
41 42		23c	Discuss any limitations of the review processes used.	Discussion on page 8
43 44		23d	Discuss implications of the results for practice, policy, and future research.	Discussion on page 9
45	OTHER INFORMA	TION	For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml	
46 47				



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PRISMA 2020 Checklist

		BMJ Open		0.1130/		Page 24 of 31
PRIS	MA 2	020 Checklist		convria		
3 Section and 4 Topic	ltem #	Checklist item	it, 11010	.zuzo-u		Location where item is reported
6 Registration and	24a	Provide registration information for the review, including register name and registration number, or	state that th	e re	ew was not registered.	Page 9
7 protocol	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	<u>.</u>		2	Page 9
8	24c	Describe and explain any amendments to information provided at registration or in the protocol.	2	ξ <u>υ</u>	2 2 2	n.a.
9 Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or	sponsors in	he ji	Seview.	Page 10
10 Competing 11 interests	26	Declare any competing interests of review authors.		Era:	<u>.</u>	Page 10
13 Availability of 14 data, code and 15 other materials	27	Report which of the following are publicly available and where they can be found: template data col studies; data used for all analyses; analytic code; any other materials used in the review.	llection form	smushog	ta extracted from included	Appendix
18 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44		For more information, visit: <u>http://www.prisma-statement.org/</u>		bol . bol . late mining Altraining and similar technologies		

S1: Further description of the transparency criteria

#	Criteria	Further description
System description and res	sults	
0 (not included in the transparency score)	System description	It should be reported which national healthcare system was assessed. Healthcare system was defined, closely to the definition of the WHO as follows: <i>"A health system consists of organizations, people and</i> <i>actions whose primary intent is to promote, restore or</i> <i>maintain health."</i>
1	Total Carbon Footprint	The total CF of a healthcare system can help to understand the total impact the system has on climate change
2	Carbon Footprint as a share of the total national CF	The share of healthcare's CF of the total national CF can help to understand the importance of the healthcare system to mitigate the climate impact of a country as well as to analyze systematic differences in the importance of the healthcare systems in mitigating the national CF between countries
3	CF per capita	The CF per capita can help to compare healthcare systems between different-sized countries.
4	CF breakdown	The division of total CFs in scopes or subcategories can help to understand the "hot spots" in GHG emissions within healthcare systems.
Method and Transparency		
5	LCA method	The LCA method can be distinguished between Top- Down (i.e. Using only Input-Output Data), Bottom-Up (i.e. using only Process-based data), and Hybrid (Using both data types). Each type has its advantages and disadvantages and should be reported to enable a first assessment of the used method
6	Demand Date source (detail)	To avoid inaccurate, outdated, or unfitting data the data source is important to report for transparency.
7	Demand Data year	To avoid inaccurate, outdated, or unfitting data the data year is important to report for transparency.
8	Number of demand or expenditure categories	The number of demand or expenditure categories can help to assess the level of detail in which the healthcare system is modeled. The more expenditure categories are used, the higher the level of detail might be.
9	I-O table data source	Similar to the demand vector, the data source of the I- O table is important to ensure the data quality and transparency
10	I-O table year	Similar to the demand vector the data year of the I-O table is of importance to ensure the data quality and transparency
11	Multiregionality of the model	I-O tables can be distinguished in SRIO, which aggregates the economic sectors of a single country, or MRIO, which aggregates the sectors of multiple countries. As each of the models has its implications it is important to report the model type.
12	Number of production sectors	The number of production sectors within the I-O model can help to estimate the level of aggregation. The more production sectors are used the less aggregated the model might be.

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13	Source of emission data	The report of emissions data sources ensures the quality.
14	Included GHGs	The results might vary dependent on the included GHGs with more included GHG leading to a higher CF. This leaves room for biases and reduced comparability between the studies. A list of the included GHGs and the used unit for the results can help to identify differences between the studies and contextualizes the results.
15	Concordance matrix reported	The bridge matrix connects the demand vector with the IO table. Each value in the demand vector, representing a demand from a certain economic sector, has to be connected to one or multiple sectors within the IO table. The bridge matrix defines these connections and makes the connection operationalizable. The bridge matrix can be either presented in matrix form or as a table classifying the demand vector values to IO table sectors.
16	Sensitivity and Uncertainty analysis	Quantitative analysis of uncertainty can add clarity and transparency to uncertainty reporting to the reader. Furthermore, it can help prioritize efforts to improve data quality in those areas of uncertainty which contribute most to the overall uncertainty of the results
17	Discussion of limitations	A variety of limitations can arise from CF calculations with IO models (e.g. insufficient data, high level of aggregation, etc.). Therefore, a critical discussion of limitations can increase transparency.

Full search strategies for all databases

DATABASE	SEARCH TERM
SCOPUS	TITLE-ABS(((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended))) AND NOT DOCTYPE(ed) AND NOT DOCTYPE(er) AND NOT DOCTYPE(le) AND NOT DOCTYPE(no) AND NOT DOCTYPE(pr)
WEB OF SCIENCE	 TOPIC: ((((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health care" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "health care" OR "health care" OR "health services"))) OR ("input-output" AND (("health care" OR "health care" OR "health care" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended)))))Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.
ECONBIZ	(((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended)))
PUBMED	Search (((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health- care" OR "health sector" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended))))

Author Nansai et al.	Year 2020	Title Carbon footprint of	Health Care System Japan	Carbon Footprint 2011:62.5mt CO2 equivalent; 2012: 69,4mt CO2eq; 2013: 71 mt CO2eq: 2014:02.2mt CO2eq; 2015: 73 mt CO2eq; 2015: 71 mt	tCO2/capita c.n.	% of total emission 4,6% of the total domestic GHC emission	Breakdown -Capital vs. Service: Service 86%: Capital formation 14%. -Capital vs. Service: The Service Break Strandorm (S. 15): Head and Darlins 1, 20. Head and the Service 2. Mo. Matter and the Service Serv
		Japanese health care services from 2011 to 2015		CO2eq: 2014 70.2ml CO2eq: 2015 72 mlCO2eq			Rotal categories Fixed Capital Formation: 13295; Narsing services 16.10%; Health and Hygners 15%; Household medications, 24%; Medical services 66,7% Debailed Categories: Medical services (hop-hilization): 23.12%; Medical services (non-hop-hilintation): 22.73%; Medical services (pharmacy diposmio) 13.13%; Home medication: 1.84%; Nursing care (facility services) 6.64%; Nursing care (eschuding facility services): 9,47%; Private fixed capital formation for medical services 10,228%;
Eckelman et al.	2016	Environmental Impacts of the U.S. Health Care System and Effects on Public Health	USA	2003:511 Mt CO2eq; 2004:529 Mt CO2eq; 2005:547 Mt CO2eq; 2006:563 Mt CO2eq; 2007:584 Mt CO2eq; 2008:600 Mt CO2eq; 2009: 608 Mt CO2eq; 2010:615 Mt CO2eq; 2011:626 Mt CO2eq; 2012:643 Mt CO2eq; 2013:655 Mt CO2eq	c.n.	2003: 7,2%; 2004: 7,3%; 2005: 7,6%; 2006: 7,8%; 2007: 8,0%; 2008: 8,5%; 2009: 9,2%; 2010: 9,0%; 2011: 9,3%; 2012: 9,9%; 2013: 9,8%;	Data Dian Chen, S. K. Santana far annual and J. Shi. Yu. Newsyrine Dang. 105: Other Professional Streves 1(4): Streves 1(4): Other Heads. Readonalist Newsork (1997) (2007) (2
Pichder et al.	2019	International comparison of health care carbon footprints	ORCD Chier Cocks Register, Canada Chier Cocks Republic Canada Chier Cocks Republic Resolution Former Combinist Frances Changery Itelandi, Icolandi, Baly Japan, Korea, Lavenshurg, Larvia Mexico, Netherlanda Baly Japan, Korea, Lavenshurg, Larvia Mexico, Netherlanda Storway, Polandi, Portugi, Slowida, Slowenia, Sweden, Turkey, United Statues; Israel; New Zealand); China; India	$\begin{array}{llllllllllllllllllllllllllllllllllll$	Ammin 60 (2020) Ammin 60 (2020) Ammin 60 (2020) Ammin 60 (2020) Ammin 60 (2020) Ammin 60 (2020) Ammin 60 (2020) Ammin 60 (2020	Journal, G.N., Annie, G.N., Anglue, T.N., Canada, S.N., Chilkey, Cana, Gai, Y., Cana, Kapelle, K.M., Comung C.W., Donanda K.M., Sophan, D.W., Kapelle, C.M., Chiller, C.M., Chill, C.M., Markov, K.M., Canze, J.W., Margary, S.M., Malda, D.N., Indrad, G.N., edited, X.N., Halp, S.N., Hang, D.N., Kanzel, K.M., Canze, J.W., Margary, S.M., Malda, D.N., Hand, G.N., Statuski, S.M., Kana, D.N., Sakawa, D.N., Kang, J.M., Shan, K.M., Shang, S.M., Shang, J.M., Andrag, M.N., Hand, S.M., Shang, T.M., Sang, Z.M., Andrag, M.N., Hand, S.M., Sang, T.M., Sang, Z.M., Ann, J.M., Shanda, D.N., Shang, Y.M., Sang, Zhi, J., Ann, J.M., Shanda, D.N., Shang, Y.M., Sang, Zhi, J., Ann, J.M., Shanda, D.N., Shang, Y.M., Shang, Zhi, J., Ann, J.M., Shanda, D.N., Shang, X.M., Shang, Zhi, J., Ann, Zhing, W.H., Shang, K.M., Shang, Zhi, Yu, Shang, Zhi, Yu, Shang, X.J., Ann, Zhing, K.M., Shang, K.M., Shang, X.M., Shang, X.M., Ann, Zhang, ZhiYi, J.Y., Shang, X.M., Shang, Zhi, Yu, Shang, X.J., Ann, Zhing, X.M., Shang, Shang, Yu, Shang, Xiao, Yu, Shang, Xiao, Shang, Xia	-Abdie Martin ausr. 255, 1976a bieland nor. 175, Inversiones 696. - Bendia Cangetto: Machine TSN, Hoyaka Lako, andadanay badie and services 1196, Odines 200; - Bendia Cangetto: Machine and 175, Hoyaka Lako, andadanay badie and services 1196, Odines 200; - Bendia Cangetto: Machine Lako, and 184, 044 (COA), 226, 041, 053, 200; 198, 2000; 198, 2000; 198, 2000; 191, 2000; 192, 2011; 226, 2017; 217, 2013; 218, - Bendia Cangetto: Machine Lako, and 2000;
Eckelman et al.	2018	Life cycle environmenta emissions and health damages from the Canadian healthcare system: An economic- environmental- epidemiological analysis	Canada	2009-29.6million McCO2r, 2010: 31,2, 2011: 31,4, 2012;31,5; 2013:31,4, 2014:32,0; 2015:33,0;	2014 0.9 a.c.	2014: 4,6%; n.c.	Hequida (Hrwar) 2009 0.7 million ML CO22, 2010 0.7, 2011 0.7, 2012 0.7, 2013 0.7, 2014 0.8, 2015 0.8, Hequida (Hrwar) 2009 6.5, 2010 4.8, 2017 1.0, 2012 1.0
Malik et al.	2018	The carbon footprint of Australian health care	Australia	-2013: 33.796 \$r CO2x(0,034mt co2x); -2014: 34.840 \$r CO2 (0,035 co2a); -2015: 35.772 \$r CO2x (0,036 co2a) ;	C.A.	7%	S213 Public Huggel 25 90; Potor Huggel 5 (2); All data modiation 3 220; Bardy Japid Pharaseended 5137; Cipid experisions (Bioling) 7 (20); Relation 2 (20); Cipid experisions (Bioling) 7 (20); Relation 2 (20)
Wu NHSScotland	2019	The carbon footprint of the Chinese health-care system: an environmentally extended input-output and structural path analysis study National Health Service	China	315 Mt CO2e -1998: 2,74 mt CO2e; -1998: 2,57 mt CO2e; -2004: 2,63 mt	са.	3.69%	-Ropinds PB, Pade Hospink PD, Frien Hospink Ne, NBP planneerdech IIN - Community leads care 109 - Pade Healt As - Other heads - ore institution - Comments of the -Ropink DD, Friend Hospink DD, State Community Leads and the - Community Leads and the - Community - Ropink Health As - Other heads - ore institution - Scotland - 1990. "Travel 21795: Patient own lavel R0955, Water Tavel 4.795; Matt Community 21955, INB Travel Danies C176 - shuilding Heargy Lee 31315.
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SDU series	2016	Carbon pedate for the handh and care sector in England 2015(1)	NIS England	-1972 - 153 M CO2 -1978 - 153 M CO2 -1978 - 153 M CO2 -1978 - 153 M CO2 -1978 - 153 M CO2 -1977 - 153 M CO2 -1977 - 154 M CO2 -1977 - 154 M CO2 -1977 - 154 M CO2 -1977 - 154 M CO2 -1978 - 154 M		6.8. 	-Initiating program (La Files, "Truet Thys.", Commissioned health and care Services from structured system TSN, "Processment 25% Thermacrochoic (scheding Meets Ordinalization TSN, "International System TSN, Services and Services TSN,
HCH	2019	Health Care's Climate Footprint	eldohla Australia Austria Relgiane. Brauft, Budgirat, Canada, China, Panzili, Fudgirat, Canada, China, Pommark, Eborino, Falland, Finance, Germany, Greece, Hangary, India: Indonesia; Ireland, Haly, Japan: Larvis (Lihuania; Luscenborg; Mahta, Mesico, NecherLands, Norway Poland, Portugal; Romania; Rossia; Storuk Republic; Sloveinia; Spain; South Kores; Sweden; Switzer-Jand; Taiwan; Tarkey; Sloveinia; Spain; United Status; Rest-of-Workl; European Union	$\label{eq:2} \begin{array}{l} Global J G (March 1994) Kein March 124 Abb. Hompson J March 2014 March 1994 (March 1994) March 2014 M$	Galad 2.37 (CD2), Assisti 1, 29 (CD2), Assisti 1, 20 (CD2), Balaya 31 (CD2), CD2, Marin 1, 20 (CD2), CD2, Malaya 31 (CD2), Malaya 31 (CD2)	Mand Taney AG, Chan JJ, Banyon Chan S, JJapan AG, Mand Tagalam, S Zhan HL, G Huan Dagalam, S Zhan HL, G Huan Dagalam, J C Mark JA, Shan KA, Shan KA, Shan S, Shan S	Kopp Child 20 gt CD Child 20 gt CD- Child 20 gt CD
Weisz et al.	2020	Carbon emission trends and sustainability options in Austrian health care	Azəstria	6.8 Mt CO2eq	0.8t	7%	— Economic Stevier, Gaussian and Alerbeitsian of electricity, gas and hour or cooling 40% (Head) near facilities quantum heat hour or cooling 40% (Head) near facilities quantum heat hour produces Vie Water streament Proc (Mary Johnson VIE). Housing 20% (Head) Head (Head) 20% (Mar 20%), Andredancy 106
Małłk et al.	2021	Environmental impacts of Australia's largest health system	New South Wales, Australia	79081 CO2cq	сл.	6,6%	
Tuning of d	2021	And Fulitic Health Damage In The United States: An Update		3011; COQ4, 3014 5784 COQ4, 3015 558 COQ4, 3016 5 2014 COQ4, 2017, 318 I COQ4, 3018, 3133 COQ4 2017, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2017, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2017, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2017, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2017, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2017, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3017, 318 I COQ4, 3018, 3133 COQ4 2018, 318 I COQ4, 3		4	-2010 Hopping ares: 35(49), Paysian and Chinal Services 11/29), Other Potersiand Services 12/19, Denail Articles 21(4), Danail Carl 1279, Noning Hang, Fadhan and Chinal Carl Eventeeness (2004), China Carl 1279, Noning Hang, Fadhan and Chinal Carl 1279, Noning Hang, Fadhan and Chinal Carl 1279, Noning Hang, Fadhan and Sanghan (2004), China Carl 1279, Noning Hang, Fadhan and Sanghan and
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Lenen et al	2020	The environmental froqueries of health care: a global assessment	Gabhd (199 connrise)	2001 GML 1200 CObs 3001 GML 1200 CObs 4001 GML 1200 CObs 4000 CObs	Sarong, O. S., Isacha, B. S., Sarohand, O. R., Kai, K. K. Hand, M. M. Anaratin, ed. Y., Hochards, C. S., Cramay, O. S., Raigue, O. K. Jang, M. S. Marka, C. S. Kan, Y. S. Kai, S.	[SA 4099, June 20% Genuer 4 494 (Chin 1 K), https://www.lfw.linki.0068, Buo.21 (K), http: 218 (Chin4 479), Annula 12%, https://www.lfw.linki.0068, https://www.lfw.linki.0068, Buo.21 (K), Apprint 3198, Annula 4548, Intel 4998, Fahnel Apprint 3198, Annula 4548, Intel 4998, Fahnel Apprint 3198, Annula 4548, Intel 4998, Fahnel Annula 1398, Sandar 4548, Intel 4998, Fahnel Annula 1298, Intel 300, Sangare 73, Ohr Forugat 4399, Tahanak 2298, Intel 3998, Sandara 200, Fahnel Annuel 1398, Sandar 2298, Chin4 200, Sandar 200, Hanne 1398, Sandar 200, Sangare 73, Ohr Forugat 4399, Tahanak 2399, Intel 3998, Sandara 200, Hannel 1398, Balappinz 2198, Fannak 21998, Mayin 2009, Lawis, Songare 1399, Fannak 21998, Kanzin 178, Bonni 2306, Gengie 4139, Pangare 1398, The Intern Yungdor David, Gengie 4139, Pangare 1398, The Intern Yungdor Manifus 1398, Canzen 6999, Kipgrane 1398	

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Method	Demand Data source (detail)	Demand Data year	Number of demand/Expen diture	I-O table data source	I-O table data year	I-O model	Number of production sectors	Source of emission data/satelite account	Included Greenhouse Gases	Concardance matrix reported	Sensitivity/Unc ertainty Analysis	Discussion of limitations
op-Down	"National Medical Expenses Statistics"	2011	categories 16	Ministry of internal Affairs and	2011	SRIO (JIOT)	397	Japan National Report of GHGs Inventory (NRI)	CO2, CH4, N2O, HFCs, PFCs, SF6 and	No	No	Yes
op-Down	US National Health Expenditure	2003–2013	15	Federal Bureau of Economic	2002	SRIO	400+	EIOLCA	Equivalents	Yes	No	Yes
p-Down	OECD: OECD health statistics database; China+India: World Bank health care expenditure	2014	OECD: 19	Eora	2014	MRIO (Eora)	14839	EDGAR	CO2	Available upon request	No	Yes
p-Down	National Health Expenditures (NHEX) database maintained by the Canadian Institute for Health Information (CIHI)	2009-2015	13	(Statistics Canada)	2009	SRIO (Open IO- Canada)	112 sectors, 238 commodities	Statistics Canada Environmental Accounts and the Canadian National Pollutant Release Inventory	carbon dioxide, methane, and nitrous	Yes	No	Yes
op-Down	Australian Institute of Health and Welfare (AIHW)	2015	16	Australian Bureau of Statistics	2014-2015	SRIO (Individually constructed)	360	Sydney University IELab	Equivalents	No	Monte-Carlo	Yes
op-Down	national input-output table, China Health and Family Planning Statistics, China Construction Statistics, and China Science and Technology Statistics yearbooks	2013	8	National Bureau of Statistics of China	2012	SRIO	46	Climate Change Department of National Development and Reform Commission of the People's Republic of China. The People's Republic of China First Biennial Update Report on Climate Change	CO2, CH4, and N2O emissions	No	Monte-Carlo + Robustness (w/ onsite-emission in the medical institution sector) + Sensitivity (w/ energy intensities of floorspace of commercial buildings)	Yes
ybrid	Scottish Government health expenditure	1990-2004	17	Scottish Government	1990-2004	SRIO (Scottish Government Input- Output tables)	123	UK National Statistics Environmental Accounts	CO2	Allocation without quantitative description	No	No
ybrid	English Government	2004-2015	5	DEFRA	2004-2015	MRIO (UK-MRIO)	178	National Statistics Environmental Accounts	CO2 Beginning in 2010: CH4, N2O, HFCs, PFCs, SF6	Allocation without quantitative description	No	No
op-Down	OECD health statistics database; World Health Organization, "Global Health Expenditure Database,"	2014	No	WIOD	2014	MRIO (WIOD)	2408	CO2: WIOD; Methane and Nitrous oxide: PRIMAP	carbon dioxide, methane and nitrous oxide gases	Reference to Pichler et al. (2019)	No	Yes
`op-Down	OECD Health Statistics 2017 supplied by the Austrian national statistical office	2014	9	Eora	2014	MRIO (Eora)	15909	EORA taken from EDGAR	CO2	Reference to Pichler et al. (2019)	No	Yes
op-Down	Australian Institute of Health and Welfare	2016-2017	16	Australian Bureau of Statistics (ABS)	2017	SRIO (Individually constructed)	2880	No	No	No	No	Yes
op-Down	National Health Expenditure Accounts of the Centers for Medicare and Medicaid Services (CMS)	2010-2018	16	Bureau of Economic Analysis	2012	SRIO (US Environmentally- Extended Input-Output model)	405	Inventory of U.S. Greenhouse Gas Emissions and Sinks	No	Yes	No	Yes
ybrid	Public Expenditure Statistical Analysis Supply and Use tables from HM Treasury	1990-2019	19	DEFRA	1997-2016	MRIO (UK-MRIO)	424	UK MRIO	carbon dioxide [CO2], methane [CH4], nitrous oxide [N2O], and some categories of fluorinated gases/all Kyoto Protocol greenhouse gases	Yes	No	Yes
op-Down	EORA	2000-2015	163	Eora	2000-2015	MRIO (Eora)	14838	EORA taken from EDGAR	carbon dioxide [CO2], methane, nitrous oxide, hydrofluorocarb on, chlorofluorocarb	No	Uncertainty	Yes
lybrid	Centraal Bureau voo	2016	3	EXIOBASE	2016	MRIO (EXIOBASE)	7.987	EXIOBASE	CO2, CH4,	Yes	No	Yes

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					Pleas	e use	e Ctr	Appe l + <mark>S</mark>	endix croll	a: Tra to zo	anspa oom i	irenc	y Sco is ele	ore ectror	nic aj	nt, incluting	-2023-0746						
uthor Y	Year	Author (Year)	Title	Health Care System	Total Carbon Footprint	tCO2/capi- ta	% of total emission	Breakdow n	Method	Demand Data source	Demand Data year	Number of demand/ Expend- iture cate-	I-O table data source	I-O table data year	Multiregio nality of the model	Number of produssi n sector	Source of emission o caa/ s satelite	f Included Green- house Gases	Concarda nce matrix reported	Sensitivity /Un- certainty Analysis	Dis- cussion of limitations		
lansaiet 3 ıl.	2020	Nansai et al. (2020)	Carbon footprint of Japanese health care services from 2011 to	Japan	1	0	1	1	1	1	1	1	1	1	1	1 ated to	l[_2024. Erasmu	1	0	0	1	14	82,35%
ickelman 2 ⊧t al.	2016	Eckelman et al. (2016)	Environmental Impacts of the U.S. Health Care System and Effects on Public Health	USA	1	°	1	1	1	1	1	1	1	1	1	text and	pownloa shogesc	0,5	1	0	1	14,5	85,29%
ichler et 2 1.	2019	Pichler et al. (2019)	International comparison of health care carbon footprints	OECD countries; China;	1	1	1	1	1	1	1	1	1	1	1	data n	ded fro hool .	1	1	0	1	16	94,12%
ckelman :	2018	Eckelman et al. (2018)	Life cycle environmental emissions and health damages from the Canadian healthcare system: An economic- environmental- epidemiological	Canada	1	1	1	1		1		1	1	1	1	tining, Al trainir	m http://bmjop	1	1	0	1	16	94,12%
1alik et I.	2018	Malik et al. (2018)	The carbon footprint of Australian health	Australia	1	0	1	1	1	1	1	1	1	1	1	1 g, an	₽ <mark>ე.</mark> bm	0,5	0	1	1	14,5	85,29%
Vu :	2019	Wu (2019)	The carbon footprint of the Chinese health- care system: an environmentally extended input-output and structural path	China	1	1	1	1	1	1	1	1	1		1	d similar tecl	<mark>.com/</mark> on Ju	1	0	1	1	16	94,12%
IHSScoti 2 Ind	2008	NHSScotl and (2008)	National Health Service Scotland Carbon Footprint of NHS Scotland(1990-	Scotland	1	0	1	1	1	1	1	1	1	1	1	nologies	nę 10, 20	1	0	0	0	13	76,47%
DU 2 eries	2016	SDU series (2016)	Carbon update for the health and care sector in England 2015	NHS England	1	0	0	1	1	1	1	1	1	1	1	1	2 <u>5</u> at De	1	0	0	0	12	70,59%
ICH 2	2019	HCH (2019)	Health Care's Climate Footprint	43 countries	1	1	1	1	1	1	1	0	1	1	1	1	≯partment	1	1	0	1	15	88,24%

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Weisz et al.	2020	Weisz et al. (2020)	Carbon emission trends and sustainability options in Austrian health	Austria	1	1	1	1	1	1	1	1	1	1	1	ht, incluc	1- <u>2</u> 023-07	1	1	0	1	16	94,12%
Malik et al.	2021	Malik et al. (2021)	Care Environmental impacts of Australia's largest health system	New South Wales,	1	0	1	0	1	1	1	1	1	1	1	¹ ¹ ¹	84 <u>6</u> 4 on	0	1	0	1	12	70,59%
Eckelman et al.	2020	Eckelman et al. (2020)	Health Care Pollution And Public Health Damage In The United States: An	Australia USA	1	0	0	1	1	1	1	1	1	1	1	uses rela	30 April	0	1	0	1	13	76,47%
Fennison ət al.	2021	Tennison et al. (2021)	Health care's response to climate change: a carbon footprint assessment of the NHS in England	England	1		0	1	1	1	1	1	1	1	1	ted to text a	2024. Downl asmushoge	1	1	0	1	15	88,24%
_enzen et al.	2020	Lenzen et al. (2020)	The environmental footprint of health care: a global assessment	189 countries	1	1	1	0	1	1	1	1	1	1	1	1 data n	oaded fro	1	0	1	1	15	88,24%
Steenmeije	2022	Steenmeij	er et al. (2022)	Netherland	d 1	0	1	1	2	1	1	1	1	1	1	nining, A	m http:/	1	1	0	1	15	88,24%
					15	7	12	13	15	15	15	14	15	15	15	15 trair	/b̪mjc	12	11	3	13	┢	
					100,00%	46,67%	80,00%	86,67%	100,00%	100,00%	100,00%	93,33%	100,00%	100,00%	100,00%	د 100,0	7 <mark>8</mark> 33%	80,00%	73,33%	20,00%	86,67%		
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Carbon footprint of healthcare systems: A systematic review of evidence and methods

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ABSTRACT

Objective: Given the demand for net-zero healthcare, the carbon footprint (CF) of healthcare systems has attracted increasing interest in research in recent years. This systematic review investigates the results and methodological transparency of CF calculations of healthcare systems. The methodological emphasis lies specifically on Input-Output based calculations.

Design: Systematic Review according to the PRISMA guideline.

Data sources: PubMed, Web of Science, EconBiz, Scopus, and Google Scholar were initially searched on November 25, 2019. Search updates in Pubmed and Web of Science were considered until December 2023. The search was complemented by reference tracking within all the included studies.

Eligibility Criteria: We included original studies that calculated and reported the CF of one or more healthcare systems. Studies were excluded if the specific systems were not named or no information on the calculation method was provided.

Data extraction and synthesis: Within the initial search, two independent reviewers searched, screened, and extracted information from the included studies. A checklist was developed to extract information on results and methodology and assess the included studies' transparency.

Results: 15 studies were included. The mean ratio of healthcare system emissions to total national emissions was 4.9% [minimum 1.5%; maximum 9.8%], and CFs were growing in most countries. Hospital care led to the largest relative share of the total CF. At least 71% of the methodological items were reported by each study.

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Conclusions: The results of this review show that healthcare systems contribute substantially to national carbon emissions, and hospitals are one of the main contributors in this regard. They also show that mitigation measures can help reduce emissions over time. The checklist developed here can serve as a reference point to help make methodological decisions in future research reports as well as report homogeneous results.

Keywords: life-cycle assessment, input-output, global warming potential, healthcare

STRENGTHS AND LIMITATIONS OF THE STUDY

- The assessment of methodological choices and the transparency of methods when assessing the greenhouse gas emissions of entire sectors in systematic reviews can help deepen our understanding of the results.
- The systematic review of all available evidence on greenhouse gas emissions of and within healthcare can help to understand its impact and to identify reduction potentials.
- This review was limited to articles in English and German, and excluded assessments, grey literature from public reports, and reports from statistical offices published in other languages.

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INTRODUCTION

Background

Climate change is one of the most pressing issues of our time[1]. Considering the correlation between the gross domestic product (GDP) and carbon emissions[2], the healthcare industry is likely an essential contributor to greenhouse gas (GHG) emissions. Demographic shifts and income effects have likely spurred greater demand for healthcare services, a trend projected to persist and further elevate the economic significance of the healthcare industry[3]. Evidence on healthcare's GHG emissions is needed to understand its role better.

Methods for calculating a carbon footprint (CF) can be broadly categorized into bottom-up and top-down approaches. Bottom-up methods, such as process-based lifecycle assessments (LCA), require extensive data, which currently limits their application at a sectoral level. However, the CF of various sectors can be estimated using a more uncertain top-down-methodology, providing a trade-off for broader coverage. In this case, emissions are divided according to the final demand or economic sectors of emission occurrence.

Input–output (I–O) analysis, which follows this approach, can be used to estimate sectoral CF[4]. Calculations of the CF use the static open-quantity I–O model in combination with an environmental extension. They rely on two fundamental building blocks: an I–O table and a demand vector. The I–O table describes the interactions between the sectors of production, often in monetary terms, and are usually constructed by national statistics offices. With additional information on their environmental impact, the emission intensity of a sector and its upstream production processes can be calculated. The demand vector represents the expenditures of the relevant sectors. For example, the demand vector of the healthcare sector includes expenditure on diesel fuel to power ambulances, electricity consumed by hospitals, and all other forms of energy. It may be necessary to synchronize the structures of the I–O table and the demand vector by balancing the definitions of different sectors and adjusting the level of sectoral aggregation.

I–O models can be grouped into single-region I–O (SRIO) and multi-region I–O (MRIO) models. SRIO models utilize I-O data from a single country, thus restricting their scope to domestic production and emissions only. MRIO models connect multiple I–O tables from multiple countries, and can thus account for different levels of production and "trade" in emissions (i.e., emissions occurring in one country related to the final demand of another country). The need for synchronized data from multiple countries complicates the development and update of the data of MRIO models.

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The results of CF calculations for a specific sector can be influenced by methodological choices, including the selection between SRIO or MRIO models and the GHGs taken into account. Therefore, comprehensive reporting is needed to ensure the transparency of methodological choices, the data, and the results. However, our search of the literature yielded neither a standardized procedure nor standardized reporting.

Objective

The aim of this study is to conduct a systematic review of research utilizing I-O analysis to quantify the CF of systems, encompassing total CF, CF per capita, and its proportion relative to the national CF. Furthermore, data on emission trends over time, can deepen the understanding of the trajectory of the CF of healthcare systems. Finally, an assessment of the methodological choices and their transparency within the reviewed studies can help to discuss the state of the methodology and provides a foundation to discuss methodological differences between the studies.

METHODS

Search strategy and selection criteria

This systematic review was performed by following the PRISMA guidelines[5] (the checklist is provided in the supplementary file 1). The databases PubMed, Web of Science, EconBiz, Scopus, and Google Scholar were searched for studies on November 25, 2019. The full search strategy is provided in supplementary file 2. The search was complemented by reference tracking within all the included studies. The updated search considered hits in Pubmed and Web of Science up to December 2023.

Following the screening of the titles and abstracts, studies were included for further investigation if they had (i) addressed the method of CF calculation (ii) addressed one or more healthcare systems or subsystems, and (iii) been written in English or German. A healthcare system was defined as the national healthcare system, federal system, and/or state system. Single entities, such as individual hospitals, and specialized branches, such as dentistry, were excluded. In addition to the criteria used for screening the titles and abstracts of articles, full-text articles were excluded if they (i) did not name the specific healthcare (sub)system, (ii) did not calculate the CF, or (iii) did not provide any information on the method of calculation used. In the initial search, two of the authors separately screened titles and abstracts, read the full text, extracted data and assessed the transparency. In the case of disagreement, decisions were made through discussion until a consensus was reached. During the search update these steps were conducted by one person.

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Data extraction and analysis

The CF per capita, the contribution of healthcare to the country's total CF emissions, and the origins of emissions were used as main results of the studies. The breakdown of the emission sources could be in scopes, demand categories, or places of origin. The Greenhouse Gas Protocol Corporate Accounting and Reporting Standard[6] proposes three standardized scopes. Scope 1 represents direct emissions from owned or controlled sources, Scope 2 represents indirect emissions generated by the purchased energy, and Scope 3 represents all indirect emissions that occur in the value chain. The categories of demand included the classes of expenditures of the demand vector, and the places of the origin of emissions were divided into hospitals, ambulatory services, and so on.

In addition to evaluating their general characteristics and results, we developed and applied a checklist to assess the methodological transparency of the studies under consideration. We opted to use the term 'transparency' rather than 'quality' to address the issue that even a flawless study could receive a low score if the authors failed to adequately report their methodology. The checklist served as both a qualitative extraction tool and a quantitative transparency tool. The qualitative extraction tool facilitated the assessment of information from each included study, with responses to each criterion collected accordingly. As a quantitative transparency tool, it was evaluated whether the criteria were adequately addressed. When information was provided, the criterion was considered fulfilled, resulting in an increase in the transparency score. All criteria were weighted equally, therefore for each "fulfilled" criterion one point was added to the transparency score, with a maximum of 17 points per study.

The utilization of I-O data can introduce uncertainties into the assessment, given that the top-down approach relies on aggregated information from industrial sectors. When heterogeneous products with varying emission intensities are grouped into one industry, aggregation errors might occur: the average emission intensity of the aggregated industry would not appropriately reflect the emissions caused by the specific product within the industry[7]. Therefore, information on the extend of usage of I-O method (criterion 5), and the number of industry sectors (criterion 12) could help to understand the scope of this uncertainty.

The choice between MRIO and SRIO (criterion 11) can also help to understand the level of uncertainty. While MRIOs can account for differences between countries and trade between these countries, SRIO might provide a more detailed framework of the domestic economy. Finally, the specific source of the I-O tables (criterion 9) and emission data (criterion 13) can help the reader to assess the quality of the used data.

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Similar to the I-O data, the level of aggregation within the demand data can impact the accuracy of the results. The number of demand or expenditure categories (criterion 8) can indicate on the level of aggregation and the source of demand data (criterion 6) could help to assess the quality of the data source. The quality of the outcomes is also influenced by the alignment between the temporal representativeness of the demand data (criterion 7) and the I-O data (criterion 10). Changes over time (e.g. in technology, import and exports) can impact the results and in the best case both data sources refer to the same year. Finally, information on the matching process of demand categories and industry sectors, the publication of the concordance matrix (criterion 15), increases transparency for the reader.

The quantitative (criterion 16) and qualitative (criterion 17) assessment of uncertainty helps the readers to contextualize the results. A list of the included GHGs can indicate the scope of the study, in this case 0.5 were given, when the unit (typically CO₂equivalents (CO₂eq)) was mentioned and another 0.5 points if all included GHGs were listed. For the final transparency checklist, the criteria on outcomes (table 1a) and on methodology (table 1b) were combined. A more detailed description of the transparency criteria are provided in the supplementary file 3.

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Table 1a: Extracted outcomes

	Number	Criterion					
	0 *	System description					
	0 *	Years for which total emissions are					
System description and		reported					
System description and	1	Total carbon footprint					
outcomes	2	Carbon footprint as a share of the					
		total national CF					
	3	CF per capita					
* not included in the transparency score							

Table 1b: Extracted methodological items
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	5	LCA method
	6	Source of demand data (detail)
	7	Year of demand data
	8	Number of categories of demand
		or expenditure
	9	Data source of I–O table
	10	Year of I–O table
Method	11	Multi-regionality of the model
	12	Number of production sectors
	13	Source of emission data
	14	GHGs considered
	15	Concordance matrix reported
	16	Sensitivity and uncertainty
		analysis
	17	Discussion of limitations

Emissions over time

To assess trends in GHG emissions of healthcare, data from all studies that reported total emissions for more than one year were taken. The data were normalized to the respective starting point of the report as a base year. Therefore, GHG emissions of time period t were divided by the GHG emissions of the base year t_0 and used in a descriptive analysis. è le

Patient and public involvement

None

RESULTS

A total of 4,285 records were identified in the three searches (figure 1). After removing duplicates and searching for eligible title, abstracts, and full texts, 15 reports were included in this review (figure 1). A summary of included studies is provided in Table 2. The detailed results of the data collection are listed in the supplementary file 4 and

-Insert figure 1 around here-

Characteristics of the studies considered

Eleven studies focused on a single national healthcare system, including England [8 9], Japan [10], USA [11 12], Canada [13], Scotland [14], China [15], Australia [16], Austria [17], and the Netherlands [18]. The series of CFs from the Sustainable Development Unit of the English NHS was aggregated, and only the newest available report was cited. One study examined the healthcare system of the largest Australian state, New South Wales [19], while three studies reported on healthcare systems in multiple countries. Pichler et al. [20] reported results for 36

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countries, Healthcare without Harm (HCH) for 43 countries [21], and the investigation by Lenzen et al. [22] considered 189 countries.

Excluding the one that assessed the Scottish NHS, all studies were published after 2016. However, it's worth noting that the year of the analysis could be older. For instance, the study by Nansai et al. [10] was published in 2020 but utilized demand data from 2011.

Table 2: Characteristics and main results of the studies considered in this review; CF: carbon footprint, Mt: megatonnes CO2eq: CO2 equivalents, t: tonnes, cap: capita

Author (Year)	Healthcare system	Years total emissions reported	Latest year of emissions reported	CF in Mt CO ₂ eq	% of total national CF	tCO2eq/cap	Transparency score		
Tennison et al. [8]	England	1990-2019	2019	25	n.i.	0,445	88%		
SDU [9]	England	1992-2017	2017	25	n.i.	n.i.	71%		
Nansai et al. [10]	Japan	2011-2015	2015	72	4,6	0,49	82%		
Eckelman and Sherman [11]	USA	2003-2013	2013	655	9,8	2,07	85%		
Eckelman et al. [12]	USA	2010-2018	2018	554	n.i.	n.i.	76%		
Eckelman et al. [13]	Canada	2009-2015	2015	33	5,7	0,92	94%		
Health Facilities Scotland [14]	Scotland	1990-2004	2004	2,6	3,6	0,52	76%		
Wu [15]	China	2012	2012	315	2,7	0,23	94%		
Malik et al. [16]	Australia	2013-2015	2015	36	7,0	1,50	85%		
Weisz et al. [17]	Austria	2014	2014	6,8	7	0,8	94%		
Steenmeijer et al. [18]	Netherlands	2016	2016	17,575	17,6	n.i.	88%		
Malik et al. [19]	New South Wales, Australia	2017	2017	0,008	6,6	n.i.	71%		
Pichler et al. [20]	OECD countries; China, India	2014	2014	s. supplemen tary file 4	Ø 5,5 s. supplementar y file 4	supplementar y file 4	94%		
Karliner et al. [21]	43 countries; EU; rest of the world	2014	2014	supplemen tary file 4	Ø 4,4s. supplementar y file 4	supplementar y file 4	88%		
Lenzen et al. [22]	Global	2007-2015	2015	2 290	n.i.	n.i.	88%		
* n.i.= not identified									

Differences in methodology and data

Eleven studies considered top-down data on emissions, while three studies employed bottom-up data on energy usage [8 9 14]. Steenmeijer et al. [18] incorporated bottom-up data regarding the quantities of anesthetic gases, inhalers and travel.

Most single-country studies used SRIO data from the respective governmental offices. In contrast, the studies on British and Dutch healthcare, and those that considered more than one country, used MRIO data. Additionally, Malik et al. [23] used MRIO data, however, the database only included data from Australian regions. The EORA database emerged as the most frequently utilized MRIO database (three times), with one study each employing the WIOD database, the EXIOBASE database, and the MRIO database provided by the British Department for the Environment, Food, & Rural Affairs.

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The number of production sectors varied among the SRIO studies, ranging from 46 to 405 sectors. The MRIO studies typically utilized more extensive databases comprising approximately 15,000 sectors, although the MRIO study focusing on the UK considered 424 sectors.

All studies considered CO_2 emissions. However, only five studies considered the six GHGs covered in the Kyoto Protocol; three studies considered CO2, methane, and nitrous oxide; two reported only that they had used CO2eq as unit; and two studies did not report any included GHG or the unit in which the outcomes were reported. The data on emissions were drawn mostly from national accounts in the case of SRIO databases and integrated accounts in the case of MRIO databases. One study did not report the source of its emission account data.

The demand data was taken either from official health expenditure accounts or from international organizations such as the WHO and the World Bank (which uses data provided by national offices and accounts). Lenzen et al. [22] identified and directly used data on healthcare-related sectors from the MRIO database EORA. The number of reported expenditure accounts varied, mostly ranging from 13 to 19, although three studies reported fewer accounts. Weisz et al. [17] utilized nine accounts, Wu [15] used eight accounts, and the study on the NHS in England employed five accounts [9]. Due to the distinct methodologies employed by Lenzen et al. [22] and the structure of the EORA database, which reports country-specific sectors, they utilized 163 sectors from the EORA as demand data.

The time periods covered by the demand data were largely consistent with those covered by the respective I-O data. Some studies reporting outcomes for more than one year only used one reference year for the I-O database and adjusted the demand data for inflation. [11-13]. The lag between the time at which the data were collected and the time of publication of the corresponding study ranged from three to six years, with deviations in the studies by Nansai et al. [10] Eckelman et al. [12] (two years) and in the report by the SDU [9]. The latter reported the CF periodically; the lag between the latest publication and the latest data was one year [9]. Further information on this is provided in the supplementary file 5.

Five studies provided their concordance matrices, which link the categories of demand with the industrial sectors. The authors of one study had made their matrix available upon request, and two articles had referred to a matrix previously used in another study. Five studies did not report their concordance matrices.

Reporting of the results

The origins of emissions were documented six times in the three scopes defined by the GHG protocol. Emission sources were reported eight times in the (sub)categories of final demand, such as hospitals or

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pharmaceuticals. Two studies reported the economic sector in which the emissions occurred, e.g., the textile sector or the manufacture of fuels. Furthermore, three studies reported a breakdown of emissions by employing more than one reporting structure. Several differences were observed in the scopes of the reported results. Some studies directly referenced the GHG protocol while others reported emissions in divisions, such as travel, energy, procurement, etc. 47% of the articles did not normalize the results by reporting the CF per capita.

Overall transparency

Except for the three criteria "reporting of the concordance matrix", "uncertainty analysis", and "CF per capita", all criteria were fulfilled by at least 75% of the studies (Figure 2). The studies fulfilled between 70.5% and 94% of all criteria with a mean of 85% (Figure 3). The full transparency assessment is provided in supplementary file 6.

-Insert figure 2 around here-

-Insert figure 3 around here-

OUTCOMES

Emissions over time

The results of the time series revealed successful efforts to mitigate the CF by the NHS in England and Scotland (Figure 4). In the nearly three decades from 1990 to 2019, the English NHS reduced its CF by roughly 25%. The four remaining countries (Japan, Canada, USA, and Australia) examined in the studies considered here and the global trend showed increased CF due to healthcare (Figure 4). The annual increase in the CF ranged from 0.7% (USA, 2010–2018) to 3.8% (Japan, 2011–2015) over the observed period, with the CFs of Canada (1.9%, 2009–2015), USA (2.8%, 2011–2015), and Australia (2.9%. 2013–2015) in between these extremes. The global trend showed an increase in the CF of 2.7% per year from 2000 to 2015.

-Insert figure 4 around here-

Breakdown

The emission sources were mainly reported using the scope system from the GHG protocol or the categories of expenditure, i.e., the categories of final demand. The largest dataset that used the categories of final demand was provided by Pichler et al. [20], who applied this to 36 countries and reported the average values. Medical retail (i.e., provider of healthcare products without medical services, e.g., pharmacies), hospitals, and ambulatory healthcare services constituted 80% of the CF of healthcare, with medical retail contributing 33.1%, hospitals

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28.6%, and ambulatory healthcare services 18%. They also made a major contribution to the CF in Japan (hospitals, 25.1%; ambulatory services, 22.7%), USA in 2013 (hospital care, 36%; physician and clinical services, 12%) [11] and in 2018 (hospital care, 34.9%; physician and clinical services, 12.6%; ambulatory medical services, 4.8%) [13], Australia (public hospitals, 34.4%; private hospitals, 10.2%; ambulatory medical services, 15%) [16], China (public hospitals, 47%; private hospitals, 4%) [15], and Austria (hospitals, 32%; ambulatory services, 18%) [17]. Other important categories of emissions were construction and pharmaceutical products, at around 10% [11 16 20], with a higher share in China (pharmaceuticals, 18%; construction, 15%) [15].

An alternative approach involved categorizing emissions into direct emissions, indirect emissions through electricity production, and other indirect emissions. This division along these lines could also align with the three GHG protocol scopes.

By averaging data from 43 countries, HCWH reported a distribution of 17% for scope 1 emissions, 12% for scope 2 emissions, and 71% for scope 3 emissions [21]. These findings, particularly the significance of scope 3 emissions, are corroborated by evidence from single-country studies. [8 11 12 14 24]. The scope 3 emissions were further divided into those due to travel (patient and visitor travel, and staff commutes), production of pharmaceuticals, and medical instruments and equipment, which accounted for the largest share of scope 3 emissions.

Scotland's scope 3 travel emissions in 2004 were 18% while those of England accounted for 13% in 2015 and 9.6% in 2018 [9]. The share of emissions owing to pharmaceutical production ranged from 11% and 18%, and that owing to medical instruments and equipment accounted for 7%–10% of the total CF [13 14 24].

The ratio of emissions by the healthcare sector to the total CF in studies focused on a single country ranged from 2.7% in China in 2012 [15] to 9.8% in the USA in 2013 [11]. The three cross-national studies considered here estimated that healthcare had contributed 5.5% [20] on average to the national CF in 2014 and 4.4% in 2015 [22].

DISCUSSION

Interpretation of results

The results indicate that healthcare significantly contributes to the CF, both in absolute numbers and in relation to a country's overall emissions and its per capita emissions. However, the results varied among the studies,

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and their calculation methods were heterogeneous and frequently not fully transparent. The breakdown of the sources of emissions revealed the major contribution made by hospitals.

The time series results showed that the trend of emissions due to healthcare was positive in all the countries considered, i.e., they were increasing, except in Scotland and England. These results align with the graphical results provided by Lenzen et al. [22]. Furthermore, they indicated that the efforts of the British NHS systems to reduce their carbon footprint based on the Greener NHS program was effective in reducing GHG emissions. The breakdown of the sources of emissions verified the important contribution of hospitals. However, hospitals provide the majority of medical care in many countries. Therefore, their large CF is not surprising but might motivate the relevant decision-makers to allocate scarce resources more efficiently. The breakdown further showed that a large portion of the CF of healthcare stemmed from scope 3 emissions. Decision-makers may conclude that the most considerable reduction in emissions can be obtained by considering staff and patient travel. Therefore, "greening" the healthcare sector requires a sustainable transportation system and green healthcare goods.

Most data were from the OECD countries, China, and India. The only exception was the work by Lenzen et al. [22], who considered 189 countries in their analysis [22]. However, even if the distribution of countries limits the representativeness of the results, the findings are consistent with the fact that OECD countries are the main emitters of GHGs.

While heterogeneity in methodology, in general, can lead to more robust results and a more informative perspective on the issue at hand, the differences in I–O methodologies to calculate the CF of healthcare may reduce the comparability of the results. However, the choice of method depends on the corresponding research question, for example, while SRIO may be more up to date and include a more detailed description of the domestic production sectors, MRIO can account for international trade and differences in production emissions between countries.

Limitations

This review has several limitations. First, the review process used here was limited due to restrictions on the language used in the study and those related to access. Second, it is possible that further CF assessments exist which were published in the official languages of many countries in the grey literature, such as publications by national statistics offices or governmental agencies. Because this review included only publications in English and German, many such studies have likely been neglected. Third, the reporting scheme and transparency score used in this study may have limitations. Both were based only on a consensus among the authors. The instruments used to assess the quality of the published studies are typically chosen based on a broad consensus among experts, such as in the case of the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) [25]. However, we did not find similar guidance for I–O analyses. Finally, the review is limited as the studies only report averages instead of confidence intervals (CI) or data ranges. Only Malik et al. [16] report the 68% CI with a range of 20,748 kt CO2eq in the results (68% CI 25,398kt CO2eq –46,146 kt CO2eq). Therefore, the results presented in both the individual studies and in this review should not be regarded as precise measurements, but rather as indicative trends or directions.

Implications for further research

This review identified research gaps that should be investigated by future research. First, there is a need to assess the potential effects of efforts to reduce emissions on the system and pathways to a low-carbon healthcare system. Second, it should be examined errors of aggregation when using the I–O methodology in the healthcare context. Third, the differences in the outcomes when making different methodological choices (SRIO or MRIO, systemic boundaries, etc.) should be analyzed to guide future research.

The transparency checklist used in this study can serve as an initial reference point for future developments. For example, in the checklist's current state, all criteria are weighted equally. However, some might be less crucial to delivering harmonized study findings. An extended consensus process with further experts is proposed to validate the checklist further and increase its value for research and practice.

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DECLARATIONS

Author contributors

Mattis Keil: Methodology, Screening, Formal Analysis, Writing – Original Draft, Writing-Review and Editing, Visualization; Leonie Frehse: Methodology, Screening, Formal Analysis, Writing – Original Draft; Marco Hagemeister: Methodology, Screening, Formal Analysis, Writing – Original Draft Mona Knieß: Methodology, Screening, Formal Analysis, Writing – Original Draft Oliver Lange: Conceptualization, Methodology, Writing – Review and Editing, Tobias Kronenberg: Methodology, Writing – Review and Editing Wolf Rogowski: Conceptualizing, Methodology, Writing - Review and Editing, Supervision, Project administration. All authors have read and approved the final manuscript for publication.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data statement

The data that support the findings of this study are available in supplementary file 4 "System description and results" and supplementary file 5 "Methods and transparency." Further data are available from the corresponding author, [MK], upon reasonable request.

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Figure legends/captions

Figure 1: Prisma Flow Diagram, based on Page et al. (2021)

Figure 2: Fulfilment rate of the transparency and reporting criteria

Figure 3: Transparency score in % per article

Figure 4: Emission trends over time

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Figure 1: Prisma Flow Diagram, based on Page et al. (2021)



100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0% C1 C2 C3 C4 C5 C11 C12 C13 C15 C6 C7 C8 C9 C10 C14 C16 C17

Figure 2: Fulfilment rate of the transparency and reporting criteria

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Figure 3: Transparency score in % per article

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1 2	PRIS	MA 2	020 Checklist	
3 4 5	Section and Topic	ltem #	Checklist item	Location where item is reported
6	TITLE		din 840	
7	Title	1	Identify the report as a systematic review.	Title, Methods
8	ABSTRACT	1		
9	Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Page 1
10	INTRODUCTION	1		
12	Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction on Page 3
14	Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction on Page 3
15	METHODS			
10 17 18	Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Methods section on Page 4
19 20 21	Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Methods section on Pages 3-4
22 23	Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used	Supplementary materials
24 25 26	Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how magy regiewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation to log used in the process.	Methods section on Page 4
27 28 29	Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each geo t, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of sutomation tools used in the process.	Methods section on Page 4
30 31 32	Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with gach outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which esures to collect.	Methods section on Pages 4-5
33 34 35		10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, and g sources). Describe any assumptions made about any missing or unclear information.	Methods section on Pages 4-5
36 37	Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	n.a.
58 39 40	Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Methods section on Page 4
42 43	Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	n.a.
44 45		13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions. For peer review only - http://bmjopen.bmj.com/site/about/quidelines.xhtml	n.a.
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3 4 5	Section and Topic	ltem #	Checklist item	Location where item is reported
6		13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	n.a
7 8		13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	n.a.
9		13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup a galy s, meta-regression).	n.a.
10		13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	n.a
12 13	Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting).	n.a.
14 15	Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	n.a
16	RESULTS			
17 18	Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the search to the search in the review, ideally using a flow diagram.	Results on page 5
19		16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they we excluded.	n.a.
20 21	Study characteristics	17	Cite each included study and present its characteristics.	Results on pages 5-6
22 23	Risk of bias in studies	18	Present assessments of risk of bias for each included study.	n.a.
24 25	Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) a get of the stimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Results on pages 6-7
20 27	Results of	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	n.a.
28 29	syntheses	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summar estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	n.a.
30		20c	Present results of all investigations of possible causes of heterogeneity among study results.	n.a.
31		20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	n.a.
32	Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis a	n.a.
33 34	Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	n.a.
36	DISCUSSION	r		
37 38	Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion on page 8
39 40		23b	Discuss any limitations of the evidence included in the review.	Discussion on page 8
41 42		23c	Discuss any limitations of the review processes used.	Discussion on page 8
43 44		23d	Discuss implications of the results for practice, policy, and future research.	Discussion on page 9
45	OTHER INFORMA	TION	For peer review only - http://bmjopen.bmj.com/site/about/guideiines.xintmi	
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1 2	PRIS	MA 2	020 Checklist	
3 4 5	Section and Topic	ltem #	Checklist item	Location where item is reported
6	Registration and	24a	Provide registration information for the review, including register name and registration number, or state that the regiev was not registered.	Page 9
7	protocol	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Page 9
8		24c	Describe and explain any amendments to information provided at registration or in the protocol.	n.a.
9 10	Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the priview.	Page 10
11 12	Competing interests	26	Declare any competing interests of review authors.	Page 10
13 14	Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms and a extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Appendix
18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43			For more information, visit: http://www.prisma-statement.org/	

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DATABASE	SEARCH TERM
SCOPUS	TITLE-ABS(((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended))) AND NOT DOCTYPE(ed) AND NOT DOCTYPE(er) AND NOT DOCTYPE(le) AND NOT DOCTYPE(no) AND NOT DOCTYPE(pr)
WEB OF SCIENCE	TOPIC: ((((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health care" OR "health sector" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended))))Timespan: All years. Indexes: SCI- EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.
ECONBIZ	(((footprint OR "carbon emission" OR "greenhouse gas*")) AND (("health care" OR "healthcare" OR "health-care" OR "health sector" OR "health system" OR "health services"))) OR ("input-output" AND (("health care" OR "health care" OR "health sector" OR "health sector" OR "health services")) AND ((footprint OR "carbon emission" OR "greenhouse gas*" OR environmental* extended)))
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S1: Further description of the transparency criteria

#	Criteria	Further description
System description and res	sults	· · ·
0 (not included in the transparency score)	System description	It should be reported which national healthcare system was assessed. Healthcare system was defined, closely to the definition of the WHO as follows: "A health system consists of organizations, people and actions whose primary intent is to promote, restore or maintain health."
1	Total Carbon Footprint	The total CF of a healthcare system can help to understand the total impact the system has on climate change
2	Carbon Footprint as a share of the total national CF	The share of healthcare's CF of the total national CF can help to understand the importance of the healthcare system to mitigate the climate impact of a country as well as to analyze systematic differences in the importance of the healthcare systems in mitigating the national CF between countries
3	CF per capita	The CF per capita can help to compare healthcare systems between different-sized countries.
4	CF breakdown	The division of total CFs in scopes or subcategories can help to understand the "hot spots" in GHG emissions within healthcare systems.
Method and Transparency		
5	LCA method	The LCA method can be distinguished between Top- Down (i.e. Using only Input-Output Data), Bottom-Up (i.e. using only Process-based data), and Hybrid (Using both data types). Each type has its advantages and disadvantages and should be reported to enable a first assessment of the used method
6	Demand Date source (detail)	To avoid inaccurate, outdated, or unfitting data the data source is important to report for transparency.
7	Demand Data year	To avoid inaccurate, outdated, or unfitting data the data year is important to report for transparency.
8	Number of demand or expenditure categories	The number of demand or expenditure categories can help to assess the level of detail in which the healthcare system is modeled. The more expenditure categories are used, the higher the level of detail might be.
9	I-O table data source	Similar to the demand vector, the data source of the I- O table is important to ensure the data quality and transparency
10	I-O table year	Similar to the demand vector the data year of the I-O table is of importance to ensure the data quality and transparency
11	Multiregionality of the model	I-O tables can be distinguished in SRIO, which aggregates the economic sectors of a single country, or MRIO, which aggregates the sectors of multiple countries. As each of the models has its implications it is important to report the model type.
12	Number of production sectors	The number of production sectors within the I-O model can help to estimate the level of aggregation. The more production sectors are used the less aggregated the model might be.

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13	Source of emission data	The report of emissions data sources ensures the quality.
14	Included GHGs	The results might vary dependent on the included GHGs with more included GHG leading to a higher CF. This leaves room for biases and reduced comparability between the studies. A list of the included GHGs and the used unit for the results can help to identify differences between the studies and contextualizes the results.
15	Concordance matrix reported	The bridge matrix connects the demand vector with the IO table. Each value in the demand vector, representing a demand from a certain economic sector, has to be connected to one or multiple sectors within the IO table. The bridge matrix defines these connections and makes the connection operationalizable. The bridge matrix can be either presented in matrix form or as a table classifying the demand vector values to IO table sectors.
16	Sensitivity and Uncertainty analysis	Quantitative analysis of uncertainty can add clarity and transparency to uncertainty reporting to the reader. Furthermore, it can help prioritize efforts to improve data quality in those areas of uncertainty which contribute most to the overall uncertainty of the results
17	Discussion of limitations	A variety of limitations can arise from CF calculations with IO models (e.g. insufficient data, high level of aggregation, etc.). Therefore, a critical discussion of limitations can increase transparency.
17	Discussion of limitations	A variety of limitations can arise from CF cal with IO models (e.g. insufficient data, high aggregation, etc.). Therefore, a critical discu limitations can increase transparency.

)	Author Nansai et al.	2020	Table Carbon footprint of Japanese health care services from 2011 to 2015	Health Care System Japan	Carbon Footpriat 2011:62.5mt CO2 equivalent; 2012: 69,4mt CO2eq; 2013: 71 mt CO2eq; 2014 70.2mt CO2eq; 2015 72 mtCO2eq	tCD2/capita c.n.	% of total emission 4,6% of the total domestic GHG emission	Brakdow - Capital V. Soviet, Skyke Edbil, Capital formation 1940 - Board Capital Foundation Capital Foundation 15: 1574, Medial arrives (non-longitalization); 22/25, Medical arrives (harmany dispensing) 13. To, Hum- - Dealind Capitage (non-land) arrives (non-land) 25: 1574, Medial arrives (non-longitalization); 22/25, Medical arrives (harmany dispensing) 13. To, Hum- - Dealind Capitage (non-land) arrives (non-land) arrives (non-longitalization); 22/25, Medical arrives (harmany dispensing) 13. To, Hum-
	Eckelman et al.	2016	Environmental Impacts of the U.S. Health Care System and Effects on Public Health	USA	2003:511 Mr CO2eq; 2004:529 Mr CO2eq; 2005:547 Mr CO2eq; 2006:563 Mr CO2eq; 2007:584 Mr CO2eq; 2008:600 Mr CO2eq; 2009: 608 Mr CO2eq; 2010:615 Mr CO2eq; 2011:626 Mr CO2eq; 2012:643 Mr CO2eq: 2013:655 Mr CO2ea	ca.	2003: 7,2%; 2004: 7,3%; 2005: 7,6%; 2006: 7,8%; 2007: 8,0% ; 2008: 8,5%; 2009: 9,2%; 2010: 9,0%; 2011: 9,3%; 2012: 9,9% ; 2013: 9,8%;	Prine Electronist formation for matter are 1.2%. Hypola Care: Why Hypola Care: Why Hypola Care: 15%, Hypolyno Barry, Other Probabilistics (15%, Henti Services L/M; Other Hendi, Besidental, Proceed Care: 25%, Hene Teldi Care: 25%, Straining Care Facilities and Continuing Care Referencet Communices (5%, Beardt Medical Eleptones: 26%, Other Neu- Data Matter (15%, Henti Teldi Care: 25%, Straining Care Facilities and Continuing Care: Referencet Communices (5%, Beardt Medical Eleptones: 26%, Other Neu- Data Matter (15%, Henti Teldi Care: 25%, Straining Care: 25\%, Strainin
+ ; ; ;	Pichler et al.	2019	International comparison of health care carbon footprints	OECD (Anstruka, Austru, Belgium; Canada; Chile; Cacoh Republic; Gernany; Demanic; Spain; Jistonia; Finalad; Prance; Great Britian; Greece; Binagyr; Jiedani, Jelandi, Indy; Japan, Korea; Laxentburg; Latwic, Beicos; Ochechrands; Norway; Poland; Portugal; Slovakis; Slovenia; Swedn; Turky; Utiali Storea; Iraci, New Zealand; China; India	Associate 15 at 00021, - Associate 6 at 00021, - Medigan 7.5, 0001 at 00022, Associate 6 at 00022, Medigan 7.6, 0001 at 00022, Cost Republic 4 of 00022, Groundy 5.0, 0001 at 00022, Cost Republic 4 of 00022, House 14.0, House 12 at 0002, - House 14.0, House 14.0, House 12 at 0002, - House 14.0, House 14.0, House 12 at 0002, - House 14.0, House 14.0, House 12.0, House 14.0, House 14.0,	$\begin{array}{l} \label{eq:control of the CODege - Ansatza (DCD) equi- Religiant. 60: \\ \mbox{COD} equi- Cont Republic tide (CDD) equi- Religiant. 60: \\ \mbox{COD} equi- Cont Republic tide (CDD) equi- Generary (ed CDD) equi- Reline (D) RCDD equi-Reline (D) RCDD equi-Reli$	Janzida XU, SAARIG CN, Balgian TN, Ganzara XU, SAARIG CN, Balgian TN, CH, Chang XY, Thomas KAN, Sagas XS, Shania XS, Fandara KN, Sharina KM, Ganz Raini KM, Chen XW, Hangy KM, Hanka XN, Handi XM, Hang PA, Sharina XN, Sharing X, Sharina XH, Sharing M, Sharina XH, Sharing X, Sharina XH, Sharing M, Sharina XN, Sharing XA, Sharina XH, Sharing M, Sharina XH, Sharina XH, Sharina XH, Sharing M, Sharina XH, Sharina XH, Sharina XH, Sharing M, Sharina XH, Sharina XH, Sharina XH, Sharina XH, XH	 Markin Landau et al., Physical and Rev. 174, Intercentance 109, Indexity are versional 109, (Pdates, 200). Markin Landau et al., Physical and Rev. 174, Intercentance 109, Indexity are versional 109, (Pdates, 200). Hongard Can, 2001, H. & McCole, J., 2001, H. S. 2001, P. S. 2000, P. S. 2000, 2000, 2000, 2010, 2010, 220, 2011, 2001, 2200, 2100, 2010,
) 0 1	Eckelman et al.	2018	Life cycle environmental emissions and health damages from the Canadian healthcare system: An economic- environmental- epidemiological analysis	Canada	2099-29,4million M. CD.2; 2010; 31.2; 2011; 31.4; 2012-31.5; 2013-31.4; 2014-32,0; 2015; 33.0;	2014 09; s.c.	2014: 4,6%; n.c.	Heighta, Physics 2009 4,37 million MC 0202, 2019 4,7, 2011 6,7, 2012 6,7, 2014 6,7, 2014 6,8, 2015 4,8, Heighta, Parker, 2009 4,5, 2010 4,6, 2017 1,2, 2012 7,8, 2013 1,2, 2012
2 3 4	Malik et al.	2018	The carbon footprint of Australian health care	Australia	-2013: 33 796 kt CO2e(0.054mf or2e);-2014: 34.840 kt CO2 (0.035 or2e);-2015: 33.772 kt CO2e (0.036 or2e) ; 315 Mk CO2e	ca. 01	2.3%	2013 TMM: Inspired X-395: Prote in Hospital ACM, 2014 offer endotionis 2:355; Beerl og Harmansentist 9:357; Cignal expectation: (Dallarge) 2:4076. Beerler and Dallarge 2:4076. Beerler 2:4076.
15 16 17	NHSScotland	2008	the Chinese health-care system: an environmentally extended input-output and structural path analysis study National Health Service Scottand Carbon Footprint of NHS Scottand (1990-2004)	Scotland	-1998: 2.74 nnt CO2e; -1998: 2.57 nnt CO2e; -2004: 2.63 nnt CO2e	ča.	3.6%	-Cumencine 15% -Recerk 0,7% -Administration 0,7% -Scoland, -1990 - Fared 237/76, Patient own used 10,99%, Waiter Tarerd 57%, SBR Commung 2,19%, NBR Taret basines 6,21%, -Building Barey De 33,11%, -Scoland, -1990 - Fared 237,776, Patient own used 10,99%, Waiter Tarerd 5,7%, SBR Commung 2,19%, NBR Taret basines 6,21%, -Building Barey De 33,11%, Patient Scolar 12,47%, Michael Taremannicuppenet 4,48%, Balla Scrives 5,11%, Patient Taregott 2,75%, Balance Scrives 1,69%, Pater Tareback, 25%, Oktoor 14,7%, Balance 2,9%, Martheever Tareback, 25%, Oktoor 14,7%, Balance 2,9%, Martheever Tareback, Javes 1,01%, Carl and Carriert 2,9%, Communicate 1,89%, Barling and Communication Hoodings
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23 24 25 26 27	autu senes	2016	Carbon upune socior in Bendh and care sector in England 2015(1)	NYS Priginal			L L	Stadard IP, Kakano Service JT, Mohard Jammen Fujiquen (19): Food and Caring XV, Fright Transport N: Mar Due Induces Th: Controlse 2: Market Link (1998) (2008) (
28 29 80 81 82	нсн	2019	Health Care's Climate Footprint	Global, Anstralia, Austria, Belgium, Brault, Bulgaria, Ganada, China, Chanda, Cypen, Cace Repub-lei, Damata, Cypen, Cace Repub-lei, Damata, Shania, Fishand, Francis, Madownia, Broteini, Shayi, Yu, Juan, Lavis, Lihamini, Laronthourg Puhan, Pertupp, Romanie, Rossie, Navak, Republic, Shovein, Spain, Sandh Kores, Sweden, Switzer-Jand, Shawa, Tarkyo, Ukuta Kagadom, Lukad Statis, Res-of-Workl, Ranopan Luion	3017. 21:10 M COL. 2017. 21:10 M COL. 2017. 21:10 M COL. 2017. 21:10 M COL. 21:10 M COL. 21:20 M COL 2017. 21:10 M COL 21:20 M COL 21:20 M COL 2017. 21:20 M COL 21:20 M COL 21:20 M COL 2017. 21:20 M COL 21:20 M COL 21:20 M COL 2017. 21:20 M COL 21:20 M COL 21:20 M COL 2017. 21:20 M COL 21:2	Called 3.21 (CDL: Assume 1, 19) (CDL: Assume 1, 19) (CDL: Assume 1, 19) (CDL: Assume 1, 19) (CDL: CDL: CDL: Assume 1, 19) (CDL: CDL: CDL: CDL: CDL: CDL: CDL: CDL:	Linda Garo, S. Chan, L. Honyen, D. Haw, A. Shaye, A. Chan, B. Shan, Tarkarine G. Kang, S. Zhu H, G. Hand, B. Lin, K. Lin, S. Shan, K. Son, S. Li, and J. S. Lin, M. Shang, S. Lin, S. Lin, S. Shan, K. Sang, S. Lin, S. Lin, S. Kang, S. Lin, S. Lin, S. Lin, S. Lin, S. Lin, S. Kang, K. Lin, S. Lin, S. Lin, S. Lin, S. Lin, S. Kang, K. Lin, S. Lin, S. Lin, S. Lin, S. Lin, S. Kang, S. Lin, S. Sang, S. Li, S. Lin, S. Lin, S. Kang, S. Lin, S. Sang, S. Lin, S. Lin, S. Lin, S. Kang, S. Lin, S. Sang, S. Lin, S. Lin, S. Lin, S. Kang, S. Lin, S. Sang, S. Lin, S. Lin, S. Lin, S. Lin, S. Kang, S. Lin, S. Lin, S. Lin, S. Lin, S. Lin, S. Lin, S. Kang, S. Lin, S. Lin, S. Lin, S. Lin, S. Lin, S. Lin, S. Lin, S. Sang, S. Lin, S. Lin, S. Lin, S. Lin, S	- Adoption Control 2012 - Health our facilities and health care owned vehicles 17%, Indirect Brainston 12%, Nouverneet 71%,Anstrukt, Stoppi 17%, Stoppi 27%, Stoppi 77%,Martin, Stoppi 17%, Stoppi 77%,Martin, Stoppi 17%,Martin, Stoppi 17%,Marti
33 34	Weisz et al.	2020	Carbon emission trends and sustainability options in Austrian health care	Austria New Yooth Walter, Australia	6.8 Mt CO2eq	0.8	7%	— Economic Science Gauration and Entrobusion of Activity, para and boar or cooling 409; Hahh are Ecalities operational emissions 199; Oher manufacturing 119; Auracher 99; Oher and a crisco 89; Transmitted and denoia prodees 59; Wast treatment PH, Oher printery Indenty 79; Waspital 209; Eventment 99; Melcul real 209; Oher 209; Autobalancy 199;
35 36 37 38 39 40 41 42 43	Eckelman et al.	2020	of Avenith's togets high recent And Polit Keah Dange in Be Using Dange in Be Using Dange in Be Using States: An Updat	LSA England	300 (533) COLug 2011 14.2 (COLug 2012 466-(COLug 2010 (COLug 2015 536 (COLug 2015 535 (COLug 2016 534 (COLug 2017 534 (COLug 2018 535 COLug 2014 (COLug 2017 534 (COLug 2018 535 COLug -1090 538 36 (COLug	-190 6.79	5A	 NBR expediator singerits. -2010 Registration computer. -2010 Registration c
15 16 17 18 19 50 51 52 53			to climate change: a carbon footprint auccument of the SNR in England		- 1491 1.194 COSay - 1492 1.134 COSay - 1496 2.131 A COSay - 1496 2.131 A COSay - 1496 2.131 A COSay - 1496 2.134 COSay - 1498 2.134 COSay - 1499 2.134 COSay - 1499 2.134 COSay - 1499 2.134 COSay - 1499 2.134 COSay - 1302 2.144 COSay	-1991 (2007) -1994 (2007) -1994 (2007) -1994 (2007) -1996 (2017) -1996 (2017) -1996 (2017) -1996 (2017) -1996 (2017) -2000 (2018) -2000 (2018) -2		 -1911. Dietry of auf. 1278. Sapp) Oaai. 64096. Commissional Balahaure 06195. Trant 64096. -1902. Dakery of auf. 6138. Sapp) Oaai. 64396. Commissional Balahaure 06096, Trant 64399. -1904. Dakery of auf. 64295. Sapp) Oaai. 64395. Commissional Balahaure 06996. Trant 64396. -1904. Dakery of auf. 64295. Sapp) Oaai. 64395. Commissional Balahaure 06996. Trant 64395. -1905. Dakery of auf. 64495. Sapp) Oaai. 64395. Commissional Balahaure 12086, Trant 64396. -1906. Dakery of auf. 64495. Sapp) Oaai. 64396. Commissional Balahaure 12086, Trant 64396. -1906. Dakery of auf. 64495. Sapp) Oaai. 64396. Commissional Balahaure 12086, Trant 71396. -1909. Dakery of auf. 64495. Sapp) Oaai. 64396. Commissional Balahaure 12086, Trant 71396. -1909. Dakery of auf. 64495. Sapp) Oaai. 64396. Commissional Balahaure 12086, Trant 71396. -1909. Dakery of auf. 64495. Sapp) Oaai. 64396. Commissional Balahaure 12086, Trant 71396. -1909. Dakery of auf. 64495. Sapp) Oaai. 64396. Commissional Balahaure 12086, Trant 71396. -2002. Dakery of auf. 64495. Sapp) Oaai. 64396. Commissional Balahaure 12086, Trant 71396. -2002. Dakery of auf. 61495. Sapp) Oaai. 64396. Commissional Balahaure 12086. Trant 4396 -2002. Dakery of auf. 61495. Sapp) Oaai. 64396. Commissional Balahaure 12486. Trant 4396 -2002. Dakery of aut. 61495. Sapp) Oaai. 64396. Commissional Balahaure 12486. Trant 4396 -2002. Dakery of aut. 81495. Sapp) Oaai. 64396. Commissional Balahauer 12486. Trant 4396 -2002. Dakery of aut. 81495. Sapp) Oaai. 64396. Commissional Balahauer 12486. Trant 4396 -2010. Dakery of aut. 81495. Sapp) Oaai. 65496. Commissional Balahauer 12486. Trant 4396 -2010. Dakery of aut. 81495. Sapp) Oaai. 65496. Commissional Balahauer 12486. Trant 4396 -2010. Dakery of aut. 81495. Sapp) Oaai. 65496. Commissional Balahauer 12496. Trant 4396 -2010. Dakery of aut. 74495. Sapp) Oaai. 75596. Commiss
54 55 56 57 58 59 50	Lenzen et al	2020	The environmental floopring of health care of piblal accessors	Gabdi (199 constries)	300 GAU 190 CON 300 GAU 300 CON 300 CON 300 GAU 300 CON 300 GAU 300 CON 3	Namor G. R., Schenel G. R., Schenkand G. M. (201, 198, Final 2017) Wenth G. W. Schwart, D. K. Persson, C. N. Kangen, G. S. Japer, J. R. Bennel, O. S. Canda, L. H. Funcz, O. Z., Martin, G. N. Leon, D. S. Japon, F. S. G. Genhan, Y. W. K. S. D. Bank, M. S. Yang, G. S. Japon, J. Japon, J. S. Japon, J. Japon, J. Japon, J. Japon, J. S. Japon, J. Japon, J. Japon, J. Japon, J. Japon, J. S. Japon, J. Japon,	Sch, ed. W., Hu, C., Hu, C., Han, Y. Hu, Chan, Y. W., Hone, T. Pity, R. S. Namin, J. 2008, Phys. Lett. 1118, hep- 2119; Chanda et al. 900, Annualiz. 1219, Mayn: 2009. Methods 40, 990, Annualiz. 1239, Maynes 2009. Methods 40, 990, Annualiz. 1200, Maynes 2009. Computing and the start of the start of the start of the start of the start of the start of the start of the start of the start of the start of the start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start start of the start of the start of the start of the start of the start start of the start of the start of the start of the start of the start start of the start	

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	Steenmeijer et al. 21	022 The environmental impact of the Datch health-care sector beyond climate change:	Netherlands	17575 kt CO2eq	сл.	7,30%	Stope 1 (Operational impacts (including anaesthetic gases)): 90%; Scope 2 (total): 11,1%, Scope 2 (Electricity (total): 79%, Scope 3(Coat & pertoleum): 11%, Scope 3(Coat arcsicolin): 15%, Scope 3(Coat arcsicolin):
$\begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 21 \\ 3 \\ 14 \\ 15 \\ 16 \\ 17 \\ 18 \\ 19 \\ 20 \\ 21 \\ 22 \\ 23 \\ 24 \\ 25 \\ 26 \\ 27 \\ 28 \\ 29 \\ 30 \\ 31 \\ 32 \\ 33 \\ 45 \\ 36 \\ 37 \\ 38 \\ 39 \\ 40 \\ 41 \\ 42 \\ 44 \\ 45 \\ 46 \\ 47 \\ 48 \\ 9 \\ 51 \\ 52 \\ 52 \\ 52 \\ 52 \\ 52 \\ 52 \\ 52$	Second of a large second	(22) The averagement impact of the Death halls, fort action in approximation of the Death halls, fort action in approximation of the Death halls, fort action in approximation of the Death halls, forther halls, forther halls, forther halls, forther halls, forther hall,					Step 1. Opcontaining parts the hubbag manothese genes 19 Min. Soop 2. Youking 11 U. N. Soop 2. Hubbard, does also also parts and all parts
46 47 48 49 50 51 52 53 54 55 56 57 58 59 60							

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2						Appendi	x: Method and t	ransparenc	V					
4					Please us	e Ctrl + Sc	roll to zoom in t	his electror	nic appendix					
5 6 7	Method	Demand Data source (detail)	Demand Data year	Number of demand/Expen diture	I-O table data source	I-O table data year	I-O model	Number of production sectors	Source of emission data/satelite account	Included Greenhouse Gases	Concardance matrix reported	Sensitivity/Unc ertainty Analysis	Discussion of limitations]
8 9	Top-Down	"National Medical Expenses Statistics"	2011	16	Ministry of internal Affairs and	2011	SRIO (JIOT)	397	Japan National Report of GHGs Inventory (NRI)	CO2, CH4, N2O, HFCs, PFCs, SF6 and	No	No	Yes	
1	Top-Down	US National Health Expenditure Accounts	2003–2013	15	Federal Bureau of Economic Analysis	2002	SRIO	400+	EIOLCA	Equivalents	Yes	No	Yes	-
1: 1: 1: 1:	Z Top-Down 3 4 5	OECD: OECD health statistics database; China+India: World Bank health care	2014	OECD: 19	Eora	2014	MRIO (Eora)	14839	EDGAR	C02	Available upon request	No	Yes	Pro
1 1 1 1 1	Top-Down 7 3	expenditure National Health Expenditures (NHEX) database maintained by the Canadian Institute for Health Information (CIHI)	2009-2015	13	(Statistics Canada)	2009	SRIO (Open IO- Canada)	112 sectors, 238 commodities	Statistics Canada Environmental Accounts and the Canadian National Pollutant Release Inventory	carbon dioxide, methane, and nitrous	Yes	No	Yes	tected by cor
2	Top-Down	Australian Institute of Health and Welfare (AIHW)	2015	16	Australian Bureau of Statistics	2014-2015	SRIO (Individually constructed)	360	Sydney University IELab	Equivalents	No	Monte-Carlo	Yes	yrigh
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	Fop-Down 3 4 5 5 7 3	national input-output table, China Health and Family Planning Statistics, China Construction Statistics, and China Science and Technology Statistics yearbooks	2013	8	National Bureau of Statistics of China	2012	SRIO	46	Climate Change Department of National Development and Reform Commission of the People's Republic of China. The People's Republic of China First Biennial Update Report on Climate Change	CO2, CH4, and N2O emissions	No	Monte-Carlo + Robustness (w/ onsite-emission in the medical institution sector) + Sensitivity (w/ energy intensities of floorspace of commercial buildings)	Yes	<u>t, including for uses</u>
2 3 3	Hybrid)	Scottish Government health expenditure	1990-2004	17	Scottish Government	1990-2004	SRIO (Scottish Government Input- Output tables)	123	UK National Statistics Environmental Accounts	CO2	Allocation without quantitative description	No	No	Eras relatec
3: 3: 3:	Hybrid 3 1	English Government	2004-2015	5	DEFRA	2004-2015	MRIO (UK-MRIO)	178	National Statistics Environmental Accounts	CO2 Beginning in 2010: CH4, N2O, HFCs, PFCs, SF6	Allocation without quantitative description	No	No	mushoge to text a
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	Top-Down 5 7 3	OECD health statistics database; World Health Organization, "Global Health Expenditure Database,"	2014	No	WIOD	2014	MRIO (WIOD)	2408	CO2: WIOD; Methane and Nitrous oxide: PRIMAP	carbon dioxide, methane and nitrous oxide gases	Reference to Pichler et al. (2019)	No	Yes	school . Ind data min
4	Top-Down) 	OECD Health Statistics 2017 supplied by the Austrian national statistical office	2014	9	Eora	2014	MRIO (Eora)	15909	EORA taken from EDGAR	CO2	Reference to Pichler et al. (2019)	No	Yes	ing, Altr
4	Top-Down 3	Australian Institute of Health and Welfare	2016-2017	16	Australian Bureau of Statistics (ABS)	2017	SRIO (Individually constructed)	2880	No	No	No	No	Yes	ainin
4 4 4 4 4	Top-Down 5 5 7 3	National Health Expenditure Accounts of the Centers for Medicare and Medicaid Services (CMS)	2010-2018	16	Bureau of Economic Analysis	2012	SRIO (US Environmentally- Extended Input-Output model)	405	Inventory of U.S. Greenhouse Gas Emissions and Sinks	No	Yes	No	Yes	g, and simila
4 5 5 5 5 5 5	Hybrid) 2 3 1	Public Expenditure Statistical Analysis Supply and Use tables from HM Treasury	1990-2019	19	DEFRA	1997-2016	MRIO (UK-MRIO)	424	UK MRIO	carbon dioxide [CO2], methane [CH4], nitrous oxide [N2O], and some categories of fluorinated gases/all Kyoto Protocol greenhouse gases	Yes	No	Yes	<u>r technologies.</u>
5 5 5 5	top-Down 5 7 3	EORA	2000-2015	163	Eora	2000-2015	MRIO (Eora)	14838	EORA taken from EDGAR	carbon dioxide [CO2], methane, nitrous oxide, hydrofluorocarb on, chlorofluorocarb	No	Uncertainty	Yes	
6	Hybrid	Centraal Bureau voo	2016	3	EXIOBASE	2016	MRIO (EXIOBASE)	7.987	EXIOBASE	CO2, CH4, N2O	Yes	No	Yes]

BMJ Open Appendix: Transparency Score Please use Ctrl + Scroll to zoom in this electronic appendix

Author	Year	Author	Title	Health	Total	tCO2/capi	% of total	Breakdow	Method	Demand	Demand	Number	I-O table	I-O table	Multiregio	Number	Source of	Included	Concarda	Sensitivity	Dis-	1	Ι
Aution	1.54	(Year)		Care	Carbon	ta	emission	n	incuiou	Data	Data vear	of	data	data vear	nality of	of	enission	Green-	nce matrix	/Un-	cussion of		
		(Tear)		System	Footprint	10	CITILOGIOIT			source	Dulu your	demand/	source	uulu your	the model		dena/	house	reported	certainty	limitations		
				e yeteini	. ootbrint					000.00		Expend-	000.00			n sectors	satelite	Gases	roponou	Analysis	initiationo		
												iture cate-					acount	Cubbo		/			
												nories				<u> </u>	Ÿ						
Nansai et	2020	Nansai et	Carbon footprint of	Japan	1	0	1	1	1	1	1	1	1	1	1			1	0	0	1	14	82,35%
al.		al. (2020)	Japanese health care													i g a	Ö						
			services from 2011 to													¥≣	12						
E el el en en	0040	E el el en en	2015	110.4		0	4	4	4	4	4	4	4	4	4	<u> </u>		0.5		0	4	445	05.000/
Eckelman	2016	Eckelman	Environmental	USA	1	0	1	1	1	1	1	1	1	1	1	te	10	0,5	1	0	1	14,5	85,29%
et al.		(2016)	Health Care System													I ¥&	ξ						
		(2016)	nealth Care System													<u>a</u> 6	2						
			Health														3 8						
Pichler et	2019	Pichler et	International	OECD	1	1	1	1	1	1	1	1	1	1	1	1 0	10	1	1	0	1	16	94,12%
al.		al. (2019)	comparison of health	countries;												<u>a</u> 8	à						
		` '	care carbon footprints	China;												- نف	t⊒						
			•	India												Ξ.	ō						
Eckelman	2018	Eckelman	Life cycle	Canada	1	1	1	1	1	1	1	1	1	1	1	1 5	13	1	1	0	1	16	94,12%
et al.		et al.	environmental													, S	5						
		(2018)	emissions and health													, ç	Ē						
			damages from the													⊳	N.						
			Canadian healthcare													-	9						
			system: An economic-													a	3						
			environmental-													- iii	ō						
			epidemiological													, S							
Malik et	2018	Malik et	The carbon footprint	Australia	1	0	1	1	1	1	1	1	1	1	1	1 Q	1	0,5	0	1	1	14,5	85,29%
al.		al. (2018)	of Australian health													<u>0</u>	<u>o</u>						
		· ,	care													no	<u>, 1</u>						
Wu	2019	Wu	The carbon footprint	China	1	1	1	1	1	1	1	1	1	1	1	1 ഗ	10	1	0	1	1	16	94,12%
		(2019)	of the Chinese health-													i i i	2						
			care system: an													≓	2						
			environmentally													ar	<u>0</u>						
			extended input-output													a di la di	5						
			and structural path													ĸ							
NHSScotl	2008	NHSScotl	National Health	Scotland	1	0	1	1	1	1	1	1	1	1	1		12	1	0	0	0	13	76 47%
and	2000	and	Service Scotland	oconana	Ľ	Ŭ		l'	Ľ	l'		ľ	·	l'	Ľ	Ō	<u> </u>	Ľ	Ŭ	Ŭ	Ŭ	10	10,4170
ana		(2008)	Carbon Footprint of													ō	0						
		(2000)	NHS Scotland(1990-													gi	N						
			2004)													Se	2						
SDU	2016	SDU	Carbon update for the	NHS	1	0	0	1	1	1	1	1	1	1	1	1	107	1	0	0	0	12	70,59%
series		series	health and care	England		1	1				1						at	1	1				
		(2016)	sector in England															1					
			2015														e						
HCH	2019	HCH	Health Care's	43	1	1	1	1	1	1	1	0	1	1	1	1	Ja	1	1	0	1	15	88,24%
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Weisz et al.	2020	Weisz et al. (2020)	Carbon emission trends and sustainability options in Austrian health	Austria	1	1	1	1	1	1	1	1	1	1	1	ght, includi	n-2023-078	1	1	0	1	16	94,12
Malik et al.	2021	Malik et al. (2021)	Environmental impacts of Australia's largest health system	New South Wales,	1	0	1	0	1	1	1	1	1	1	1	ng for u	464 on	0	1	0	1	12	70,59
Eckelman et al.	2020	Eckelman et al. (2020)	Health Care Pollution And Public Health Damage In The United States: An	USA	1	0	0	1	1	1	1	1	1	1	1	1 ses rela	30 April	0	1	0	1	13	76,47
Tennison et al.	2021	Tennison et al. (2021)	Health care's response to climate change: a carbon footprint assessment of the NHS in England	England	1		0	1	1	1	1	1	1	1	1	ted to text a	2024. Downl rasmushoge	1	1	0	1	15	88,24
Lenzen et al.	2020	Lenzen et al. (2020)	The environmental footprint of health care: a global assessment	189 countries	1	1	1	0	1	1	1	1	1	1	1	nd data r	oaded fro	1	0	1	1	15	88,24
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