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LETTER

International comparison of health care carbon footprints

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Abstract

Climate change confronts the health care sector with a dual challenge. Accumulating climate impacts are putting an increased burden on the service provision of already stressed health care systems in many regions of the world. At the same time, the Paris agreement requires rapid emission reductions in all sectors of the global economy to stay well below the 2 °C target. This study shows that in OECD countries, China, and India, health care on average accounts for 5% of the national CO_2 footprint making the sector comparable in importance to the food sector. Some countries have seen reduced CO_2 emissions related to health care despite growing expenditures since 2000, mirroring their economy wide emission trends. The average per capita health carbon footprint across the country sample in 2014 was 0.6 tCO_2, varying between 1.51 tCO_2/cap in the US and 0.06 tCO_2/cap in India. A statistical analysis shows that the carbon intensity of the domestic energy system, the energy intensity of the domestic economy, and health care expenditure together explain half of the variance in per capita health carbon footprints. Our results indicate that important leverage points exist inside and outside the health sector. We discuss our findings in the context of the existing literature on the potentials and challenges of reducing GHG emissions in the health and energy sector.

Introduction

Deep linkages between climate change and human health require a closer integration of the two areas in the science and policy domains. The linkages are essentially threefold.

First, climate change impacts such as heat waves, storms, floods, droughts and fires, altered infectious disease patterns, air pollution and food shortages will increase the demand for health care services [1–3].

Second, climate-health co-benefits combine the long-term benefits of reduced greenhouse gas (GHG) emissions with more tangible and short term benefits for public health [2, 4]. Two obvious leverage points for integrated climate change mitigation and public health policies [5, 6] are changes in diets [7, 8], particularly reduced meat consumption and changes in the modal split, particularly a shift from private motorized transport to active mobility [9].

Third, the health care sector is a large and socio-economically important sector, and is itself a significant cause of CO_2 emissions. Member countries of the Organization of Economic Co-operation and Development (OECD) spent an average of 9% of GDP on health care in 2016. Growth in health care expenditures over the past decades has often outpaced economic growth, driven by aging populations, life-style related non-communicable diseases and fast medical advances [10]. In the health care sector, as in other service sectors in general, direct emissions are relatively low compared to other sectors. The emissions along the supply chain, induced by purchases of goods and services by the health care sector, can account, however, for a significant share of the national CO_2 footprint [6, 11–16].

Table 1. Health carbon footprints (HCF) in 2014 in absolute terms, per capita and as percentage of the national carbon footprint (CF). Israel and New Zealand are listed at the bottom with the last year where health care expenditures were available.

Country	HCF (Mt)	HCF/cap (tCO_2/cap)	Share of CF (%)
AUS	19.5	0.83	4.2
AUT	6.8	0.8	6.7
BEL	7.5	0.66	7.7
CAN	29.7	0.83	5.1
CHE	5.9	0.73	5.9
CHN	600.6	0.44	6.6
CZE	4.8	0.46	4.5
DEU	55.1	0.68	6.7
DNK	4	0.71	6.4
ESP	19.2	0.41	5.5
EST	1.2	0.88	5.2
FIN	3.9	0.72	5.3
FRA	34.4	0.52	6.9
GBR	41.1	0.64	5.9
GRC	4.2	0.39	3.8
HUN	2.9	0.29	5.4
IND	74.1	0.06	3.5
IRL	3.1	0.68	6.7
ISL	0.2	0.61	4.7
ITA	23.1	0.38	5.1
JPN	114.9	0.9	7.6
KOR	33.1	0.65	5.3
LUX	0.7	1.24	3.6
LVA	0.5	0.26	3.9
MEX	16.6	0.13	3.3
NLD	15.8	0.93	8.1
NOR	3.6	0.7	4.7
POL	17.4	0.46	5.7
PRT	4	0.38	6
SVK	4.1	0.75	6.7
SVN	0.7	0.35	4
SWE	4.1	0.42	4.5
TUR	17.8	0.23	3.9
USA	479.7	1.51	7.9
ISR (2013)	3.5	0.43	4.4
NZL (2007)	1.8	0.42	4.1

The Lancet Commission on Health and Climate Change thus recommended that GHG emissions of health care systems be included as an indicator in assessments on health and climate [3], but emissions from health care have still received little attention in the climate mitigation literature [5, 17]. GHG footprint analyses of the health care sector specifically, are available for four countries. These studies estimated the health care GHG footprint as percentage of the national GHG footprint to be 8%–10% in the US [11, 12], 3% in England [13–15], 7% in Australia [6], and 5% in Canada [16]. An older study of all service sectors in the US estimated the share of health care in the total industrial GHG emissions from just household consumption at around 6% in 1998 [18]. Comprehensive international comparisons of national carbon footprints typically do not report distinct results for the health care sector, but rather for aggregates of health care and other service sectors [19, 20].

Overall, the available evidence highlights the relevance of the health care sector's contribution to climate change in high income countries. Due to the small number of available case studies, different models, time scales, and system boundaries used, so far no systematic cross-country comparison is possible from which to conclude more fundamental insights on the determinants of the health carbon footprint and its development over time.

We provide here the first comparable estimates of CO_2 emissions of health care across all OECD countries (except Chile), China and India, for the years 2000–2014. This country sample was chosen due to the importance OECD countries have for global GHG emissions and due to the availability of harmonized and disaggregated health care expenditure data [21]. We additionally included China and India due to their size and global significance, using aggregated health care expenditure data provided by the World Health Organization/World Bank [22]. The countries in our sample covered around 54% of the world's population and 78% of world GDP [23] in 2014.

Like the existing case studies [6, 11–16] we treat health care as a final demand sector and include CO_2 emissions that occur anywhere along the global supply chain of goods and services purchased by the health care system. This *health carbon footprint* thus accounts for CO_2 emissions embedded in goods and services purchased from different health care providers such as medical retailers, hospitals, ambulatory, long-term, or preventive health care. To calculate the health carbon footprints we used the environmentally-extended multi-regional input–output model (EE-MRIO) Eora [24] in combination with the countries' health care expenditure data.

The novelty of our study is the methodologically consistent cross-country comparison of the health carbon footprint of 36 countries in time-series spanning 15 years. This allows the application of statistical methods to analyze the main determinants of health carbon footprints and to identify promising emission reduction strategies, especially the relative importance of supply-side versus demand-side opportunities.

We report results of the health carbon footprint decomposed by geographic regions, final demand sectors (private consumption, governmental consumption and investments), health care providers, and production sectors. We show the development of health care expenditures and health carbon footprints across countries and years and the effects of health care expenditure, national carbon and energy intensities on the health carbon footprint. Finally, we discuss several leverage points for integrated policies on climate mitigation, health, and energy, which would effectively reduce the health carbon footprint without compromising the level of service it provides, and point out directions for future research.

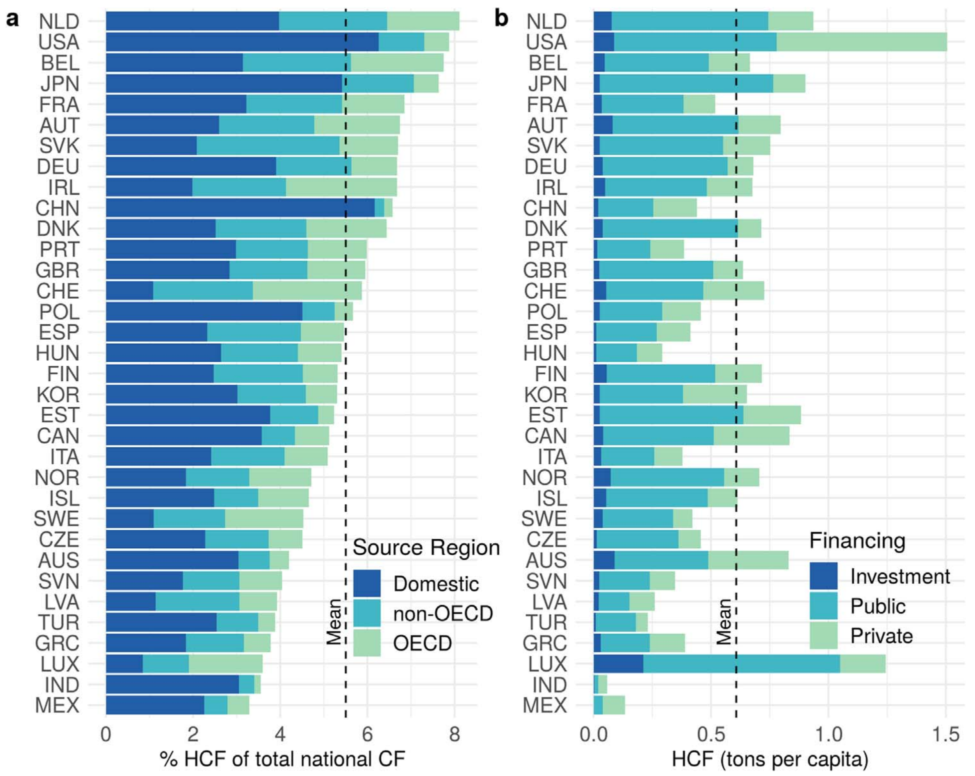

Figure 1. Health carbon footprint (HCF) as percentage of national carbon footprint (CF) grouped by region where the emissions occurred (a) and health carbon footprint per capita grouped by financing scheme (b) in 2014, for all available countries in 2014.

Materials and methods

We used the full version of the EE-MRIO Eora (v199.82) in combination with national health care expenditure data to calculate the health carbon footprint for each country and year. The data and procedures are described in detail in the supplementary information (SI). The health carbon footprints reported in this study include global supply chain CO_2 emissions attributable to private and governmental health care expenditures and to health care related investments. For OECD countries we used health care expenditure data from the OECD's health database [21] which are disaggregated into 10 expenditure provider categories according to the System of Health Accounts [25]. For China and India we used aggregated health expenditure data from the World Health Organization/World Bank [22]. All steps of data preprocessing to properly integrate the health care expenditure data from the OECD and World Bank into the Eora tables are described in the SI. We use our unbalanced panel data (435 observations in total; 36 countries, from 2 to 15 time periods), to estimate a fixed-effects model, based on diagnostic tests described in the SI.

Results

Size and composition

The health carbon footprint in 2014, the most recent year in our sample, varies by three orders of magnitude (from 0.5 Mt CO_2 in Latvia to 601 Mt CO_2 in China). After China, the largest emitters of health care related CO_2 emissions (table 1) were the US (480 Mt CO_2), Japan (115 Mt CO_2), India (74 Mt CO_2) and Germany (55 Mt CO_2). As in the case of the national carbon footprint [19] these numbers reflect primarily the affluence and population size of a country. Table 1 includes two ways of normalizing the health carbon footprint to make it more comparable across countries. It lists it as a percentage of the national carbon footprint and in per capita terms. These numbers are additionally visualized in figures 1(a) and (b), respectively, and on a map in figure S1 in supplementary information is available online at stacks.iop.org/ERL/14/064004/mmedia.

On average, the health carbon footprint in 2014 constituted 5.5% of the total national carbon footprint with a standard deviation of $\sigma = 1.4$ (we calculated all national carbon footprints in Eora to secure comparability between the sectoral and national results). The lowest share was found for Mexico (3.3%), the highest for the Netherlands, the US, Belgium and Japan (8.1%, 7.9%, 7.7% and 7.6%, respectively). On average about half the emissions (52%) in the health carbon footprint occur within the domestic economies but there is

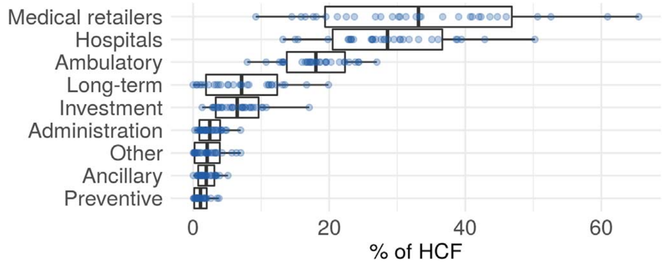

Figure 2. Shares of health carbon footprint (HCF) attributable to OECD health care expenditure categories in 2014 (all OECD countries with available 2014 data, but excluding non-OECD countries China and India). Full names of the expenditure categories are: retailers and other providers of medical goods, hospitals, providers of ambulatory health care, residential long-term care facilities, providers of health care system administration and financing, providers of ancillary services, 'other' is a combined category of 'rest of the economy' and 'rest of the world', and providers of preventive care.

significant variation across the country sample ($\sigma = 19$). On one end, China's supply chain emissions were almost entirely domestic (94%) but also India, Poland and the US had a domestic share of 75% or above. On the other end, the domestic share of the health carbon footprint of Sweden, Luxembourg and Switzerland was a quarter or less (figure 1(a)). An average of 28% ($\sigma = 10$) of the total health carbon footprint occurred within non-OECD countries and 20% ($\sigma = 11$) in other OECD countries. The large share of non-OECD emissions is particularly notable as our sample consists almost entirely of OECD countries.

The average per capita health carbon footprint across the country sample in 2014 was 0.6 tCO_2 ($\sigma = 0.3$). Outliers at the two extremes were the US (1.51 tCO_2/cap) and India (0.06 tCO_2/cap). At the high end, Luxembourg, Japan, Estonia, Slovakia and the Netherlands also had per capita health carbon footprints above 0.85 tCO_2/cap while at the low end Hungary, Latvia, Turkey and Mexico had health carbon footprints below 0.3 tCO_2/cap. China, which had the highest total health carbon footprint (601 Mt CO_2) is well below the average in terms of the per capita footprint (0.44 tCO_2/cap) (figure 1(b)).

The sectoral resolution of Eora does not allow for a systematic distinction between the supply chains of private and public health care expenditure. This means that the contributions of public and private health care to the health carbon footprint are nearly proportional to the respective expenditures. On average, public health care contributed 62%, private health care 31% and investments 6% to the health carbon footprints, but again the variation across countries is large. In Mexico and India, emissions from public health care contributed less than 30%. On the other end, in Japan and Denmark, public health care emissions make up more than 80% of the health carbon footprint.

Figure 2 shows the health carbon footprint broken down into expenditure categories. The largest three categories, medical retail (average share = 33.1%, $\sigma = 13.7$), hospitals (average share = 28.6%, $\sigma = 8.1$), and ambulatory health care services (average share = 18%, $\sigma = 4.3$) on average account for 80% of the health carbon footprint. The high variation, particularly across the three main expenditure categories indicates substantial differences in the structure of the health care systems across individual countries.

The categories in figure 2 indicate where the final demand of the health care sector occurred. Conversely, we can instead follow the supply chain to uncover in which production sectors globally the actual CO_2 emissions occur. We find that about 38% of emissions occur in sectors associated with heating, water and electricity generation and 22% in those associated with transport. About 10% of CO_2 emissions directly occur in pharmaceutical and chemical sectors globally. Figure S4 shows this breakdown with average percentage contributions of a further 19 sectors.

Development of the health carbon footprint

The development of real per capita health care expenditure (in PPP, const. 2011 int. USD), per capita health footprint and the CO_2 intensity of the health care sector (ratio of health carbon footprint to expenditure) between 2000 and 2014 as indexed trend is shown in figure 3 for all years where health care expenditure data were available.

The country trends fall into three camps when classified by the relative change between the 5 year median at the start period (2000–2004) and the 5 year median at the end period (2010–2014). The largest group of 14 mainly European countries (green) has achieved absolute decoupling of health care expenditure from CO_2 emissions by combining growing real health care expenditure with a declining health carbon footprint. The decline in carbon intensities was on average strongest in this group, but with a large variation, ranging from negative 34% in Austria to negative 62%–66% in Norway, France, Portugal, and the Czech Republic. The second group of 10 countries includes the core Anglosphere, the US, Canada and Australia (Great Britain, Ireland and New Zealand could not be classified) and most Asian countries in our sample (South Korea, Japan and India). These countries have

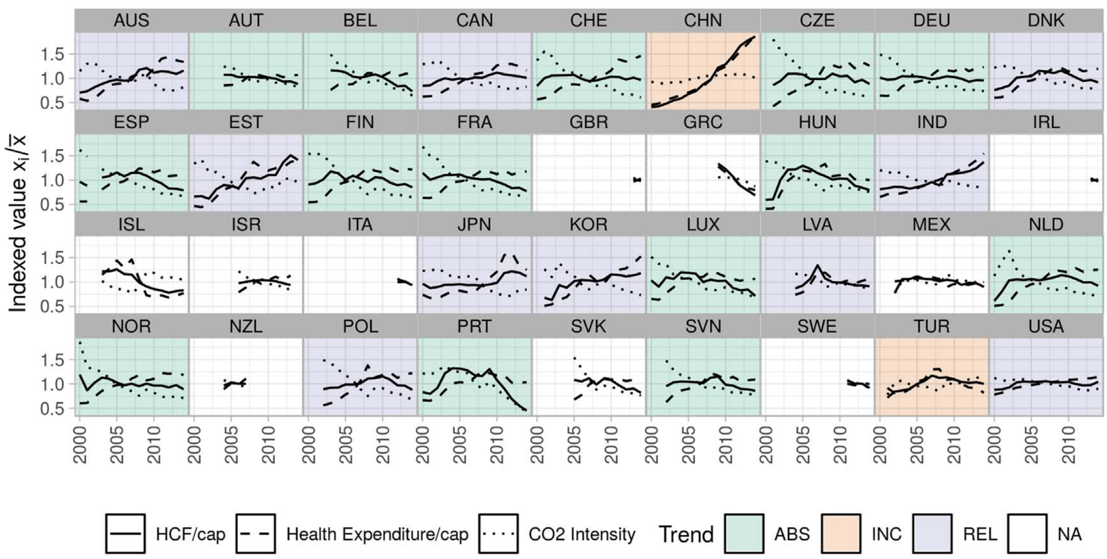

Figure 3. Development of per capita health carbon footprint (HCF/cap), health care expenditures (PPP, const. 2011 int. USD)/cap and CO_2-intensity (HCF/health care expenditure) of health care for the entire country sample between 2000 and 2014 normalized by country means to illustrate trends on a common axis. Gaps in time series reflect data availability in the OECD health statistics. Panel colors illustrate clusters for countries with absolute (ABS) and relative (REL) decoupling between expenditures and emissions, increasing CO_2 intensity (INC), and countries unclassified due to data gaps or no discernible trend (NA).

achieved relative decoupling, i.e. emissions and health care expenditure have both increased, but the emissions grew at a slower pace than expenditure, leading to a decline in the carbon intensity of the health care system between 19% in the US and 55% in Poland. Only two countries, China and Turkey, had health carbon footprints rising faster than health care expenditure, leading to an increase in the carbon intensity of the health care system of 9% in China and 57% in Turkey.

Determinants of the health carbon footprint

About 80% of global CO_2 emissions were attributable to fossil fuel combustion in 2014 [26]. Many countries simply follow the national carbon footprint trends, begging the question of how much the health carbon footprint is influenced by characteristics of the national and global energy supply-systems as opposed to decisions made *within* the health care sector, such as amount and type of goods and service procurement.

Thus, we use our sample of comparable health carbon footprints to statistically investigate three determinants of health care related CO_2 emissions (table 2): the carbon intensity of the domestic energy system, the energy intensity of the domestic production system, and health care expenditure. We estimated separate fixed-effects models for both the population normalized *total* health carbon footprint as the dependent variable (model1) and for its *domestic* part (model2). The domestic part of the health carbon footprint are those emissions occurring in the domestic economy (see figure 1(a)).

All three explanatory variables, carbon intensity of the energy system, energy intensity of the economy, and health care expenditure, are highly significant

Table 2. Economy wide determinants of the health carbon footprint (HCF): two fixed-effects models using total HCF/cap (model1) and domestic HCF/cap (model2) as dependent variables. Independent variables are the carbon intensity of the domestic energy system (CO_2/TFC), measured as CO_2 emissions from fossil fuel combustion per total final energy consumption (TFC), the energy intensity of the domestic economy (TFC/GDP), measured as total final energy consumption (TFC) per GDP in purchasing power parities (ppps) (const. 2011 int. USD), and health care expenditure per capita (Health care expenditure/cap), measured in ppps, const. 2011 int. USD. Coefficients can be interpreted as elasticities, as all variables are logarithmic.

	Dependent variable:	
	model1 log(Total HCF/cap)	model2 log(Domestic HCF/cap)
log(CO_2/TFC)	1.034^{***}	1.399^{***}
	(0.118)	(0.170)
log(TFC/GDP)	0.970^{***}	1.396^{***}
	(0.078)	(0.093)
log(Health care expenditure/cap)	0.611^{***}	0.619^{***}
	(0.029)	(0.040)
Observations	435	435
R^2	0.574	0.510
Adjusted R^2	0.533	0.463
F Statistic ($df = 3; 385$)	177.807^{***}	137.490^{***}

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

($p < 0.01$) and together explain between 46% and 53% of the variance (adjusted R^2) in both models (table 2). Because all variables are in natural logarithms the coefficients can be interpreted as elasticities, i.e. a change of 1% in any independent variable effected a relative change in the health carbon footprint equal to the size of the coefficient. The carbon intensity of the energy system had the largest effect

($\beta = 1.034$) on the total health carbon footprint (model1). If only the domestic emissions (model2) of the health carbon footprint are considered, the effects of the carbon intensity of the energy system ($\beta = 1.399$) and the energy intensity of the economy ($\beta = 1.396$) are considerably larger. In both cases changes in the intensity lead to relatively larger changes in the health carbon footprint. Health care expenditure per capita has the smallest effect in both models ($\beta = 0.611$ in model1 and $\beta = 0.619$ in model2), but is still highly significant.

Discussion and conclusions

Achieving the 2° target with medium probability requires that cumulative CO_2 emissions across all countries and all sectors must not exceed 1170 gigatonnes (Gt) [27]. With constant 2014 CO_2 emissions this carbon budget will be depleted in 32 years. Achieving the 1.5° target (a carbon budget of 420 Gt) without the necessity of negative carbon emissions in the second half of the 21st century requires zero emissions in all sectors by 2050 [27, 28].

The health care sectors of the 36 countries in our sample combined were responsible for 1.6 Gt of CO_2 emissions or 4.4% of the global total in 2014 (35.7 Gt) [29]. The health carbon footprints of China, the US, Japan, India and Germany were similar to the total national footprints of Canada, Italy, Greece, Finland, and Hungary respectively. In an international ranking of total national carbon footprints, the health carbon footprints of China and the US would rank 10th and 14th respectively. The health care sector in most countries is the largest service sector in terms of its carbon footprint and it is comparable in size to the food sector. In most countries it is only surpassed by sectors related to energy, transport, and construction (see figure S5).

Our results thus confirm and add substantial new evidence to the recognition of the health care sector as an important contributor to CO_2 emissions. Compared to the published GHG health footprints for England [13–15], the US [11, 12], Australia [6] and Canada [16] there are some differences in the numerical results that can be explained by differences in models used, the GHG gases included, and the resolution and scope of the health care sector definitions applied. A detailed comparison of our results to the published literature can be found in the SI.

The novel aspect of our study is the international comparison, based on a comparable data set with a significantly large country and time coverage, to gain initial general insights into the scale and the determinants of health care sector related CO_2 emissions.

About half of the variation in our sample is determined by three factors, the carbon intensity of the domestic energy system, the energy intensity of the domestic economy and national health care expenditures (table 2). The core insight is that the domestic energy system has a much higher influence on the size of the health carbon footprint than health care expenditure, around twice as much influence on the domestic part (including only domestic supply chain emissions) and around 1.5 times on the total health carbon footprint (including domestic plus international supply chain emissions). This result is also in accordance with the finding that many countries have achieved relative or even absolute reductions in health carbon footprints while real health care expenditure was increasing, as shown in figure 3.

The carbon footprint of national and urban economies typically scales with expenditure even when territorial (direct) emissions decouple from GDP [30, 31]. For the health care sector, however, in many cases the carbon footprint followed the trend of territorial emissions [29]. This indicates that there is a large potential for mitigation option outside the health care sector, in particular a decarbonization of the domestic energy system.

In addition several emission reduction options exist inside the health care sector, many of which do not compromise the quality of health care provision or would even improve public health. Especially measures that reduce the sector's energy demand have proven cost and health benefits [3, 6, 16, 32]. For hospital buildings, this would imply improving building codes and thermal rehabilitation of the existing building stock together with a careful assessment of other energy saving potentials (e.g. lighting and operation of energy intensive medical machinery and IT equipment). Additionally, a switch to carbon efficient heating and cooling end-use technologies and carbon efficient vehicles could contribute to energy savings in the health care sector [33].

The health care sector could also reduce carbon emissions that occur in the global production chain of medical goods and pharmaceuticals by applying green procurement strategies. Expenditures could be reallocated to less carbon intensive forms of health care provision by changing medical procedures [34–37], or by using functionally equivalent drugs and medical devices with lower carbon intensity of production and packaging [38–41].

Another leverage point to reduce the health care system's carbon footprint lies in avoiding unnecessary or even harmful treatments and medical interventions or misallocation of patients [10]. For example, avoiding intensive care in hospitals [42] or providing telemedicine solutions can reduce costly and resource-intensive forms of care and at the same time improve health outcomes and quality of life, particularly for people with chronic conditions [43]. Finally, a systemic shift from curative to preventive and from hospital to ambulatory care would likely reduce the health carbon footprint [1]. The small share of preventive care in the health care expenditure of OECD countries indicates substantial improvement potential [21].

When emission reductions directly interfere with core medical services, ensuring the quality of these health care services may be challenging [42]. For example, low carbon procurement strategies require specialized expertise and knowledge about the carbon intensities of different medical products and procedures, the cost effectiveness of different options and a careful consideration of the health effects of alternative treatments [16]. Given the complexities of modern supply chains and medical treatments, such capacity building will require considerable time and effort. Where GHG emissions directly result from medical treatment and where alternatives are more expensive and contested, like the use of modern anaesthetic gases, emission reductions might prove even more difficult to achieve [14, 39, 44, 45].

Finally, decarbonization strategies in the health care sector need to take into account that in poor countries billions of people are still without sufficient health care while in the OECD the health care sector is confronted with multiple and unprecedented pressures. Therefore the 'carbon costs of health care' should ultimately be assessed with regard to health outcome. An important topic for future research therefore is to investigate the connection between the health carbon footprint, health care performance and health outcome. This would require taking into account a large and often inconclusive body of literature on indicators of health outcome, how it relates to health care expenditure and health care performance, and to other determinants of public health such as income, inequality, social expenditure, poverty and so on [46–48].

Our results show major mitigation potential that is unconnected to health outcome or would even improve public health. Realizing this potential on the national and international level in combination with climate health co-benefits, such as less meat rich diets and less motorized modes of transport [2, 3, 7, 8, 49], would simultaneously reduce the health carbon footprint and improve public health without adversely affecting the quality of health care services in OECD countries.

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Author contributions

U W and H W designed research; P P P and I S J performed research; P P P, I S J, U W, and H W interpreted results; and P P P, I S J, U W, and H W wrote the paper.

Notes

The authors declare no competing financial interest.

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