The environmental footprint of health care: a global assessment

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Summary

Background Health-care services are necessary for sustaining and improving human wellbeing, yet they have an environmental footprint that contributes to environment-related threats to human health. Previous studies have quantified the carbon emissions resulting from health care at a global level. We aimed to provide a global assessment of the wide-ranging environmental impacts of this sector.

Methods In this multiregional input-output analysis, we evaluated the contribution of health-care sectors in driving environmental damage that in turn puts human health at risk. Using a global supply-chain database containing detailed information on health-care sectors, we quantified the direct and indirect supply-chain environmental damage driven by the demand for health care. We focused on seven environmental stressors with known adverse feedback cycles: greenhouse gas emissions, particulate matter, air pollutants (nitrogen oxides and sulphur dioxide), malaria risk, reactive nitrogen in water, and scarce water use.

Findings Health care causes global environmental impacts that, depending on which indicator is considered, range between 1% and 5% of total global impacts, and are more than 5% for some national impacts.

Interpretation Enhancing health-care expenditure to mitigate negative health effects of environmental damage is often promoted by health-care practitioners. However, global supply chains that feed into the enhanced activity of health-care sectors in turn initiate adverse feedback cycles by increasing the environmental impact of health care, thus counteracting the mission of health care.

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Introduction

Although the health impacts of pollution and environmental change are well recognised,[1–3] the environmental impacts of health care have received less attention. Health-care evaluation traditionally focuses on direct health outcomes and financial costs. However, the environmental footprint of health-care provision, which includes a wide variety of air, water, and soil pollutants, also has an unintended and negative impact on health.[4]

Health care is a large economic sector and employer in many countries. The average spending on health care among member countries of the Organisation for Economic Co-operation and Development is about 9% of gross domestic product (GDP).[5] There is a pressing need to understand the health impact of the environmental footprint of health care, because as investment in health care increases around the world, there is considerable potential for increasing harm to health from pollution and environmental change. People who are harmed by the environmental footprint of health care often live far away from those who benefit from the health care provided. Hence, doctors and other health sector leaders have a practical and ethical responsibility to measure, monitor, and address the environmental footprint of health care.

Greenhouse gas emissions and climate change are an important pathway of the negative health impact resulting from the environmental footprint of health care. The carbon footprint of health care has been calculated previously in specific countries, including the UK,[6] the USA,[7] Australia,[8] Canada,[9] China,[10] Japan,[11] and in international comparisons.[12,13] To the best of our knowledge, this is the first assessment of the global environmental footprint of health care, based on available data, and using a panel of indicators that are relevant to health outcomes and that enable a cycle of adverse feedback to be captured. These indicators include greenhouse gas emissions, particulate matter (PM), air pollutants (nitrogen oxides [NO_x] and sulphur dioxide [SO_2]), malaria risk, reactive nitrogen in water, and scarce water use. Changing climate due to an increase in greenhouse gas emissions will lead to an increase in disease[14] and injury incidents—eg, as a result of heat waves,[15] cyclones,[16] floods,[17] and droughts,[18] which in turn will lead to a potential increase in health-care costs[2,19,20] and greenhouse gas emissions. The same cycle of adverse feedback exists for emissions of PM (we report PM_{10} or less because this is recognised to carry most of the health impact[21]), NO_x, and SO_2, which cause an increase in air pollution and health-care costs because of respiratory disease incidence,[22] in turn further increasing

Research in context

Evidence before this study
Although our understanding of the impact of climate change on human health has increased in recent years, little is known about the negative environmental impact of health-care services. We searched the Web of Science and PubMed from Jan 1, 1990, to July 7, 2019, for studies in English, using the keywords "healthcare", "greenhouse gas emissions", "environmental footprint", "input-output analysis", and "global environmental impact". The search found no studies comprising a comprehensive global environmental footprint assessment of health care. We found studies that assessed the greenhouse gas emissions for individual countries, and a global comparative study focusing on member countries of the Organisation for Economic Co-operation and Development, China, and India. However, to our knowledge, none of the studies published to date have used a comprehensive suite of environmental indicators for assessing the global environmental footprint of health care.

Added value of this study
We report the first assessment of the global environmental footprint of health care using a panel of indicators that are relevant to health outcomes and that enable cycles of adverse feedback to be captured: greenhouse gas emissions, particulate matter, air pollutants (nitrogen oxides and sulphur dioxide), malaria risk, reactive nitrogen in water, and scarce water use. Our findings suggest that the environmental impact of health care ranges across these indicators, and is not confined to greenhouse gas emissions as previously studied.

Implications of all the available evidence
An assessment of the environmental impact of health-care provision is crucial to make informed decisions about health-care operations and expenditures. In this study, we fill this knowledge gap, and highlight that it is vital for health-care practitioners to take steps to mitigate negative environmental impacts in order to avoid health implications. Practical actions must be taken by health-care organisations to incentivise, normalise, and exemplify climate-safe and healthy models of care, protecting resources and natural assets, and adopting sustainable procurement practices.

the air pollution footprint of health care. Water scarcity is measured as water consumption weighted by a scarcity index.[23] It is responsible for insufficient access to clean water, resulting in cholera,[24] diarrhoea,[25] and typhoid fever.[26] Finally, deforestation creates favourable conditions for the spread of malaria and other vectors,[27] which again increases health-care costs and the environmental footprint of infectious disease treatment.[28]

In this study, we used a global supply-chain model harbouring data on international trade between 189 countries to assess trends in total and per-capita global environmental footprint of health care from 2000 to 2015; individual supply chains to subcategorise the health-care footprint into contributions from individual greenhouse gas species; and the drivers of global environmental footprint of health care, in particular the effects of expenditure and efficiency.

Methods

Study design

We did a multiregional input-output analysis for 189 countries from 2000 to 2015 to enumerate the environmental footprint of global health care. Multiregional input-output analysis builds on Leontief's Nobel Prize-winning calculus, and therefore yields comprehensive estimates for environmental footprints, including entire upstream supply chains. As a result, our analysis covers the entire supply-chain network underpinning the operation of health-care services (for a list of health-care-related sectors see appendix pp 7–9), including transportation of goods, power generation, manufacture of equipment, and extraction of raw ores, coal, oil, and gas (appendix pp 24–28). Multiregional

input-output analysis uses data issued regularly by more than 100 statistical agencies around the world, adhering to common standards governed by the UN. The methodology underlying input-output studies is well established and is explained in a large number of publications.

Data analysis

We used the Eora multiregional input-output database (version 199.82) because of its high sector resolution (14 838 country-sector pairs; appendix pp 3–14), adherence to original data sources, and high country detail (appendix p 3). The Eora database has been applied to many high-impact footprint studies, including studies on biodiversity, nitrogen emissions, and carbon emissions from global tourism.

The environmental footprint F of health care is the matrix product $F=\mathbf{q}L\mathbf{y}*$, where the $N\times1$ vector $\mathbf{y}*$ is the global expenditure on health-care products and services in current US\$, the $N\times N$ matrix

$$\mathbf{L}=(\mathbf{I}-\mathbf{T}\hat{\mathbf{x}}^{-1})^{-1}$$

is Leontief's inverse describing the entire global supply-chain network (the hat symbol denotes vector diagonalisation), and the $K\times N$ matrix

$$\mathbf{q}=\mathbf{Q}\hat{\mathbf{x}}^{-1}$$

holds the environmental intensity for K=13 environmental indicators (carbon dioxide [CO_2] methane, nitrous oxide, hydrofluorocarbon, chlorofluorocarbon, sulphur hexafluoride, nitrogen trifluoride, SO_2, NO_x, PM, malaria risk, reactive nitrogen in water and scarce water use) and

all N sectors in the global economy, in appropriate units of kg CO_2 equivalent (CO_2e), g, or L, per US\$. Here, $\mathbf{x}=\mathbf{T1}+\mathbf{y}$ is $N\times1$ total output, balanced as the sum of $N\times N$ intermediate demand $\mathbf{T}$ and $N\times1$ final demand $\mathbf{y}$, with $\mathbf{I}$ being the $N\times N$ identity matrix and $\mathbf{1}=\{1,...,1\}$ an $N\times1$ summation operator. Various breakdowns of the aggregate environmental footprint F by countries, final products (eg, pharmaceutical products), or intermediate inputs (eg, hospital equipment) can be obtained by unravelling the matrix product $\mathbf{qLy}^*$ into a sum

$$\sum_{k,i,j} q_{ki} L_{ij} y_j^*$$

and isolating summation indices. For example, possible breakdowns read

$$\hat{\mathbf{q}}\mathbf{Ly}^* = \sum_{k,j} q_{ki} L_{ij} y_j^* \text{ for all } i \text{ (by intermediate inputs),}$$

$$\mathbf{q}\widehat{\mathbf{Ly}^*} = \sum_{k,i} q_{ki} L_{ij} y_j^* \text{ for all } j \text{ (by final products), and}$$

$$1 - \frac{\text{tr}[\hat{\mathbf{q}}\widehat{\mathbf{Ly}^*}]}{F} \text{ (proportion of imports).}$$

Data for $\mathbf{x}$, $\mathbf{T}$, and $\mathbf{y}$ are taken from the Eora multiregional input-output database, which in turn takes these from the UN National Accounts Official Country Database (appendix p 14) and national input-output tables. Because

$$\{y_i^*\} \subset \{y_i\},$$

health-care data for $\mathbf{y}^*$ are also taken from the Eora multiregional input-output database (appendix pp 3–14). $\mathbf{Q}$ is a so-called satellite account ($K\times N$) comprising the following environmental indicators: emissions of greenhouse gases (CO_2 [global warming potential=1], methane [25], nitrous oxide [298], chlorofluorocarbon [18925], hydrofluorocarbon [3772], sulphur hexafluoride [22800], and nitrogen trifluoride [17200]), PM, air pollutants NO_x and SO_2, malaria risk, reactive nitrogen in water, and scarce water use. Eora uses data from a range of sources, such as EDGAR, AQUASTAT, and the malaria atlas (appendix pp 4–14).

Uncertainty analysis

Data taken from primary sources (appendix pp 7–9) are associated with measurement errors. Multiregional input-output databases are compiled from these primary data, and therefore, uncertainties propagate from the raw data, via a compiled multiregional input-output analysis, to final environmental footprint measures. We applied Monte-Carlo techniques for quantifying the uncertainties in the environmental footprint of health care. More specifically, we propagated uncertainty using standard deviations σ_Q, σ_T, and σ_y (sourced from the Eora multiregional input-output database) for perturbing the basic input-output quantities $\mathbf{Q}$, $\mathbf{T}$ and $\mathbf{y}$, then calculated perturbed carbon footprints, and then gathered these for a large number of perturbation runs. Standard deviations of derived environment footprint measures were then taken from the statistical distribution of the perturbations (appendix pp 32–33).

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Global health care has an environmental impact that, depending on which indicator is considered, accounts for between 1% and 5% of the total global impact, and more than 5% for some national impacts (figure 1, appendix pp 20–23). These estimates are valid within
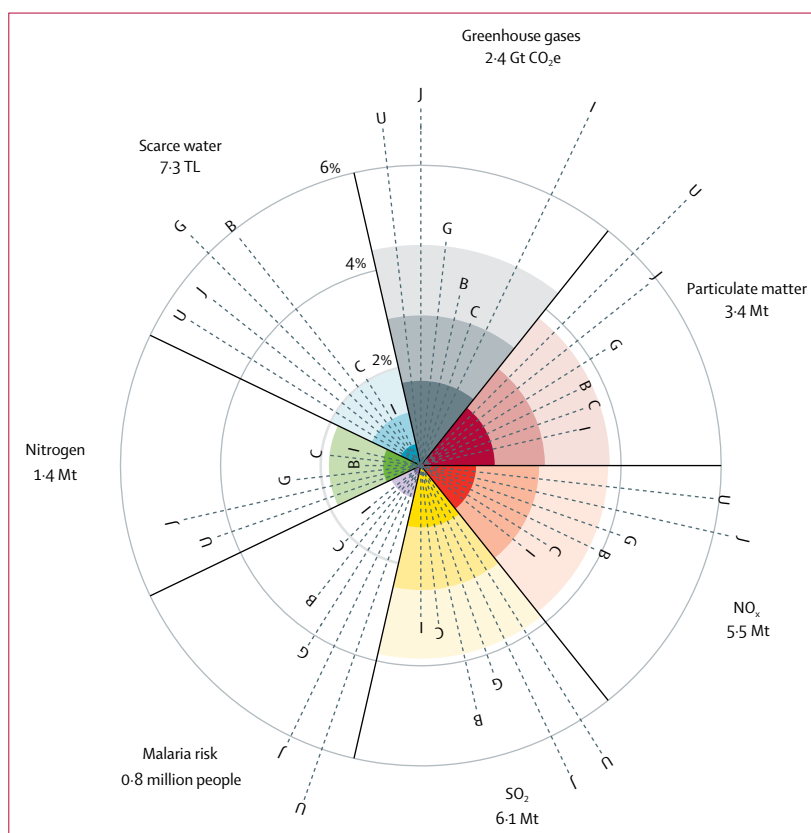
Figure 1: **Environmental footprints of health care for 2015**
The impact of health care is shown as a percentage of total impact, for the world (segments) and selected countries (spokes), in terms of greenhouse gas emissions (global total=54·4 Gt CO_2e), particulate matter (122·2 Mt), NO_x (161·9 Mt) and SO_2 (167·3 Mt) emissions, malaria risk (113·1 million people),[28] nitrogen to water (79·0 Mt),[29] and scarce water use (483·9 TL).[24] Spokes represent data for the USA (U), Japan (J), the UK (G), Brazil (B), China (C), and India (I). Direct (lightest shade), first-order (middle shade), and supply-chain (darkest shade) refer to impacts caused by health care directly, by health care's immediate suppliers, and the remainder, respectively. CO_2e=carbon dioxide equivalent. Gt=gigatons. Mt=megatons. NO_x=nitrogen oxides. SO_2=sulphur dioxide. TL=teralitres.
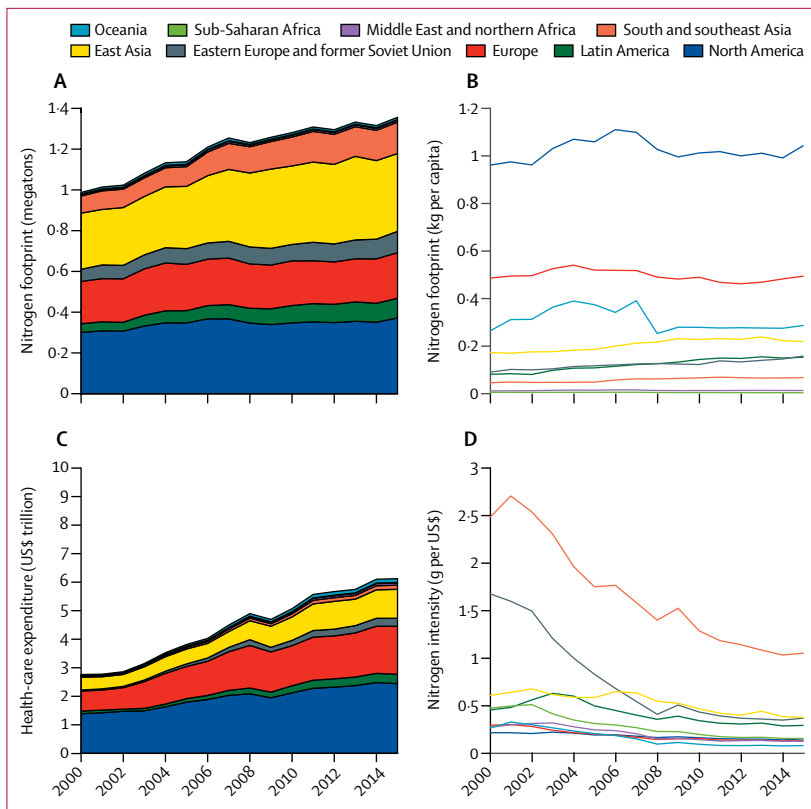
Figure 2: Trends in the nitrogen footprint of global health care, 2000–15
(A) Global nitrogen footprint of health care. (B) Nitrogen footprint per capita. (C) Global health-care expenditure in current US$ at basic prices. (D) Nitrogen footprint per US$ spent on health care. The countries in each region are specified in the appendix (pp 63–67).

standard deviations of less than 5% (appendix pp 31–46). In terms of emissions of greenhouse gases and air pollutants, the health-care sector causes a large share of the total footprint (4·4% of greenhouse gases, 2·8% of PM, 3·4% of NO$_x$, and 3·6% of SO$_2$), because substantial direct emissions are caused by operations such as patient transport[30] or space and water heating.[31] Direct impacts are negligible in terms of malaria risk, nitrogen, and water use, because these impacts occur predominantly in agriculture and forestry, and they enter health-care operations mainly through supply chains.

Despite substantial efficiency improvements in energy, material, and water consumption,[32] and reductions in the emission intensities of greenhouse gases and pollutants,[33] all environmental impacts studied increased over the period 2000 to 2015, from an increase of 9% for PM to an increase of 29% for greenhouse gases (appendix p 53), which was mainly due to a doubling of global expenditures on health care from $2·7 trillion at 2000 basic prices (8·5% of global GDP) to $5·5 trillion at 2015 basic prices (10%; figure 2C). Here, we present assessments for selected indicators; full results are provided in the appendix.

As an example of the trends in the environmental footprint from 2000 to 2015, the nitrogen footprint of global health care increased from about 1 megaton (Mt)

in 2000 to about 1·4 Mt in 2015 (figure 2A), representing a constant 1·9% of global emissions and a constant 155 g per capita (figure 2B). These global estimates carry uncertainties of about 15% or less (pp 31–46). The footprint increase occurs despite the nitrogen intensity of health care decreasing from 0·36 g per $ in 2000 to 0·22 g per $ in 2015 (figure 2D) due to improvements in nitrogen use efficiency (eg, from a reduction in fertiliser use[34]), because of the strong increase in global health-care expenditure, which has outstripped any efficiency gains. Similar situations apply to the footprints of greenhouse gases, PM, NO$_x$, SO$_2$, scarce water, and malaria risk (appendix pp 15–19).

The footprints for individual countries varied considerably. For example, for PM emissions, variation in national footprints was partly because of variation in health-care expenditure (eg, India spent $73 billion, $56 per capita, or 7·1% of GDP; the USA spent $2·3 trillion, $7164 per capita, or 24·5% of GDP[35]), and partly because of the national economy's PM intensity (India 10 g per $; UK 1·4 g per $).

There are numerous ways to dissect the global PM footprint into underlying constituents. Here we extract some significant findings for countries with detailed health-care and input-output information (appendix pp 4–14), in absolute terms (figure 3A, C) and per capita (figure 3B, D). PM footprints do not necessarily follow health-care expenditure; despite their health-care expenditure being lower, China and India have higher footprints than Japan (figure 3A). Similarly, for per-capita results (figure 3B), France and Brazil have similar PM footprints per capita, but France's health-care expenditure per capita is much higher than Brazil's. This variation is due to the PM intensity differing substantially between countries (figure 3D), which in turn is mainly because PM is low in many high-income countries, such as Japan, Germany, or the UK, and high in many low-income countries, such as Indonesia and India.[36] Another factor determining the low PM of health care in high-income countries is the high proportion of wages and salaries within operating inputs, because these are not associated with emissions.[37] Finally, for the same reasons, although health-care expenditure as a percentage of national GDP remains fairly stable over time,[38] the PM footprint as a percentage of a country's total PM footprint varies considerably, between 2% and 10% (figure 3C).

In addition to direct impacts that vary across countries, health care draws on PM-intensive operating inputs, such as the manufacturing of coke or power generation.[39] This is shown by the relative proportions of direct emissions (around 25%), emissions occurring within the premises of immediate suppliers (around 25%), and emissions occurring within the distant reaches of the health care's supply-chain network (around 50%; figure 3). The unequal distribution of PM emissions across the globe[40] further explains why PM is concentrated
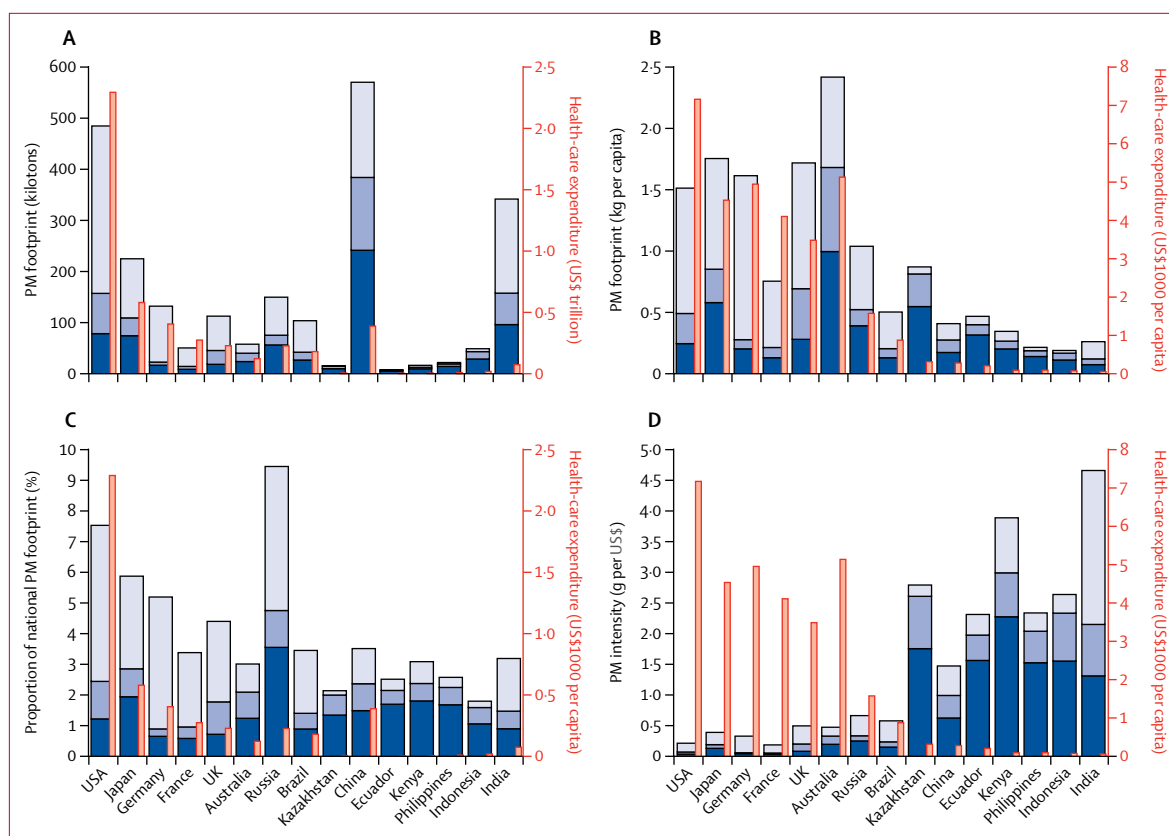
Figure 3: PM footprints for health care in selected countries in 2015
(A) PM footprint for health care in each country. (B) PM footprint per capita. (C) PM footprint of health care as a percentage of the country's total PM footprint. (D) PM footprint per US$. Countries are ordered according to their national health-care expenditure. Left axes and blue columns show PM footprints; right axes and red columns show health-care expenditure. Shades of blue represent direct (dark blue), first-order (mid-blue), and second-order (light blue) supply-chain contributions. These national estimates are affected by uncertainties of between 15% (large countries) and 40% (small countries). PM=particulate matter.

in the higher-order supply-chain inputs for high-income countries, because many of these inputs are sourced through inputs from PM-intensive economies. Between 2000 and 2015, about 25% of the PM footprint of global health care was associated with internationally traded goods (appendix p 53).[41]

A breakdown of health care's global greenhouse gas footprint into contributions from individual greenhouse gas species (appendix pp 29–30) shows that CO_2 (51%; mainly from fuel combustion and land use change occurring in the supply-chain network underpinning health care) represents the majority of the impact, followed by nitrous oxide (22%; mainly agriculture), methane (16%; mainly agriculture and energy transformation), and fluorinated gases (11%; mainly industrial processes).

Multiregional input-output analysis offers the possibility of exploring individual supply chains.[42] Here, we provide an example for the global health-care system. 63·1 Mt CO_2e are emitted directly from the buildings and vehicles of health care-providers (figure 4), representing 3% of the global health care-related carbon footprint.

The most important supply chains are of first order (ie, they represent emissions from businesses supplying

to households). Amongst second-order paths, fossil-fuelled electricity and gas used by health-care services accounts for 137·4 Mt CO_2e, and medical or pharmaceutical products used by health-care providers are responsible for 27·8 Mt CO_2e, together accounting for about 8% of the total greenhouse gas footprint of health care. Electricity features prominently as a direct operating input,[31] or indirectly via raw chemicals, equipment, wholesale and retail trade, construction, and mains water required by health care. Another notable supply-chain contribution comes from livestock, from which gelatin (extracted from tissues of pigs and cattle) is used for making the shells of capsules. Inputs from bovine animals, horses, mice, and other animals are required for the production of a range of pharmaceutical products.[43] Together with seam gases from coal mines feeding power plants, these represent important sources of methane in the health-care supply chain. Other items in the top 100 contributors to the environmental footprint of health care are nitrous oxide from crop cultivation; CO_2 from combusting diesel in trucks and freight ships, and aviation kerosene in planes; CO_2 from cement manufacturing processes; emissions from chemical processes
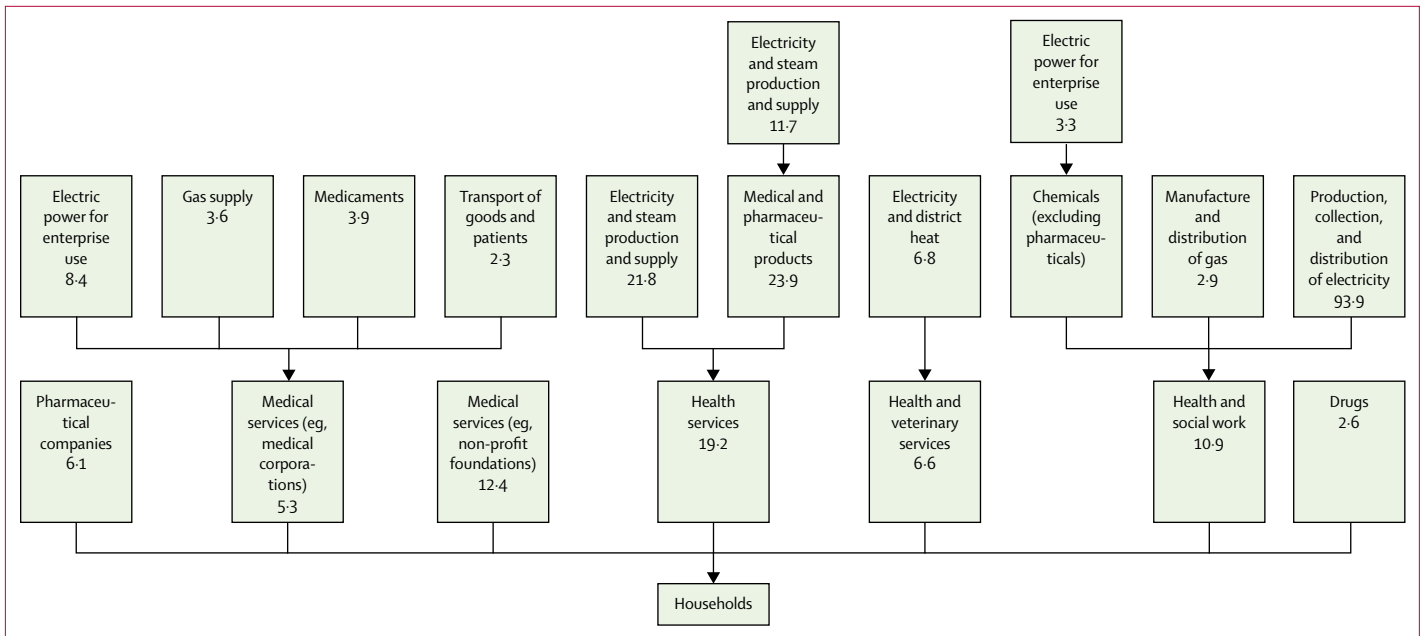
Figure 4: First-order to third-order supply-chain contributions to the global health-care footprint
Contributions are presented as megatons of carbon dioxide equivalent. Some third-order paths, such as electricity and steam feeding into medical and pharmaceutical products for health services, are more important than some second-order paths.

and pipe leaks in petroleum refining and gas supply; CO_2 from fuel use in textile factories, manufacturing of steel, paper, and sugar, and sawmills. Often, these emissions occur in businesses not supplying health care directly, but its ancillary inputs such as telecommunication, glassware and rubberware, education and training, and business services. All direct, first-order, and second-order supply-chain contributions combined represent 11% of the global health-care-related CO_2e footprint.

A similar complexity is seen in China's health-care system (appendix p 29), which relies on imports, such as chemical products from Japan, machines and pharmaceutical products from Germany, and textiles and clothing from Pakistan. These imports cause emissions in the territories of the countries of origin. Prominent indirect imports are raw chemicals from Russia, Japan, Malaysia, South Korea, Indonesia, and Germany for use in Chinese pharmaceutical manufacturing; and crude oil from Angola, Oman, Saudi Arabia, and Iran for refining petrol for use in health care in China.

Further into the supply-chain network, multinode international links are seen, such as Saudi, Qatari and Kuwaiti crude oil for South Korean basic chemicals for Chinese pharmaceuticals, or Cambodian natural rubber for processing in Malaysia into rubber products for China's health-care providers. Cyclical trade routes also exist—eg, raw chemicals made in China are used in South Korea, Japan, and Malaysia to produce chemical products destined for Chinese health care, or Chinese microelectronics are embedded in German health-care equipment that is exported back to China.

Between 2000 and 2015, health-care expenditures have increased markedly over time in almost every country in our sample (appendix pp 4–14), not just because of a growing world population, but also per capita. At the same time, due to technological innovations leading to increased process efficiency,[44] the water intensity of health-care provision has declined rapidly (figure 5A). The decrease in water intensity has not been sufficient to offset the increase in per-capita health expenditure so that overall, the per-capita water footprint of health care has increased (figure 5B). For the upper expenditure bracket (>$3160 per capita; appendix p 48), the relationship is elastic and the water footprint increases at a greater rate than increases in per-capita health-care expenditure. This finding indicates that as low-income countries develop and their health-care expenditure increases, their water footprint will increase disproportionately. Similar findings apply to other environmental indicators (appendix pp 48–53).

Across all indicators, countries with large populations or economies dominate the results in absolute terms. The highest values are found for the USA (greenhouse gases, nitrogen, NO_x, and scarce water) or China (SO_2 and PM), with the exception of the malaria risk indicator, which was highest for India. South Korea and China also had the strongest trends across most indicators; China had the highest growth between 2000 and 2015 in SO_2, NO_x, and PM and South Korea had the greatest decline in all categories except nitrogen and scarce water. During the study period, indicator values for SO_2 (increase of 173%), NO_x (increase of 153%), and PM (increase of 91%) doubled or more in China. In South Korea, emissions of greenhouse

gases, SO_2, NO_x, and PM decreased by between 27% and 60%. In terms of per capita impacts, Singapore had the highest values for SO_2 (7·8 kg per capita), NO_x (6·9 kg per capita), and PM (5·7 kg per capita) and Uruguay had the highest value for nitrogen (1·5 kg per capita). The two central Asian states of Kyrgyzstan and Uzbekistan showed high intensities (unit per US$) across all indicators, whereas Canada had the lowest overall intensities for nitrogen, SO_2, NO_x, and PM. The Russian health system had the largest impacts measured as a share of the country's total impact across most indicators (greenhouse gases, SO_2, NO_x, PM, and scarce water).

Discussion

In this analysis, we have provided an assessment of the negative environmental impacts of health care, which include scarce water use, air pollution, reactive nitrogen in water, and other factors, in addition to greenhouse gas emissions.

Environmentally extended multiregional input-output analyses are the only method available to consistently account for global environmental footprints of health care, yet they also have limitations. One limitation is incomplete data, which need to be estimated using reconciliation techniques, such as constrained optimisation. This limitation particularly applies to low-income countries. Another limitation is that this type of analysis provides a static, ex-post snapshot of the situation and does not in general provide a basis for future projections. Also, the sectoral disaggregation of available national input-output tables is limited and varies between countries. Aggregation biases could be introduced, leading to higher uncertainty for countries with low sectoral disaggregation. In addition, substantial differences between health-care systems across countries and the use of a global approach, such as ours, is necessarily incompatible with identifying detailed local drivers of impact and specific recommendations of mitigation.

Various environmental impacts of the operation and procurement practices of health-care sectors harm population health. This insight is novel because environmental footprints of health care have so far been calculated only for CO_2 or greenhouse gas emissions, for which health effects can be estimated only very approximately.[45] Our study comprises a wider range of environmental indicators, known to harm human health, and a global scope at unprecedented country and time resolution, using the only method that allows such quantifications and also allows numerous ways of further analysing the presented results.

We cannot directly infer health consequences from the scale of environmental footprints of global health care because of intervening factors, such as the geographical distribution of impacts and the health status or age structure of affected populations. However, we can illustrate the severity of the problem with global estimates of the health impacts of environmental factors. Overall,
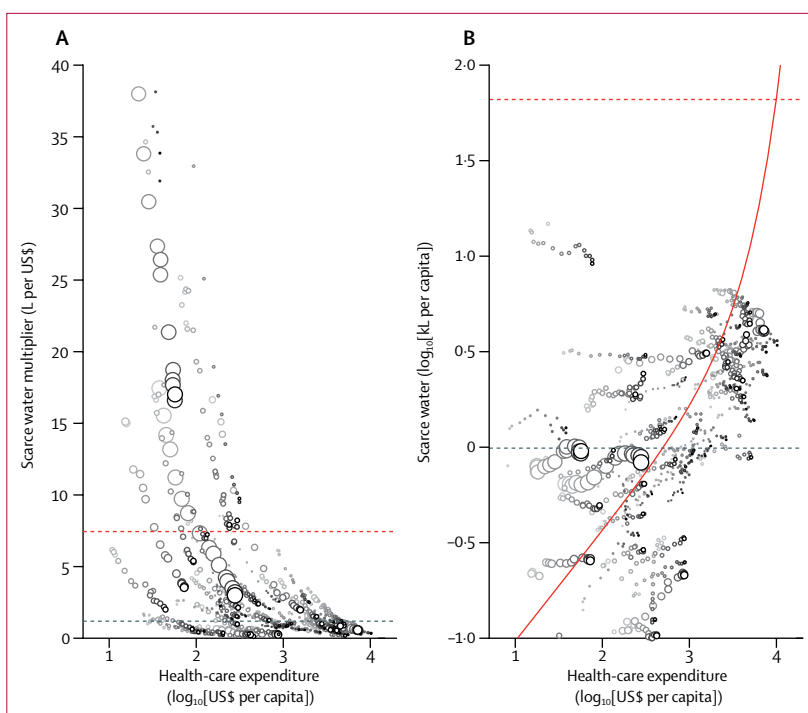
Figure 5: Effects of expenditure and efficiency on the scarce water footprint of global health care
(A) Scarce water multiplier. (B) Per-capita scarce water footprint. Each circle represents a particular country and year. Circle size represents population. The colour of the circle indicates the year, from light grey in 2000 to black in 2015. The solid curved line in part B is the best fit of the data, based on a weighted least-squares regression. Horizontal lines indicate the 2015 global averages for health care (grey dashed lines) and the entire world economy (red dashed lines).

WHO attributes 13·7 million (24·3%) deaths in 2016 to environmental factors.[62] According to WHO, 4·2 million deaths are attributable to ambient air pollution,[20] and the *Lancet* Countdown on health and climate change attributes 2·9 million deaths to ambient $PM_{2.5}$ pollution and 7 million deaths to overall air pollution.[46] Scarce water and poor sanitation and hygiene were responsible for 829 000 deaths in 2016.[47] In 2018, an estimated 228 million cases of malaria worldwide resulted in approximately 405 000 deaths.[45] Increasingly, the evidence shows that deforestation is creating much better ecological conditions for the main malaria vector *Anopheles*.[48,49] The methods and findings presented in this report also highlight important roles and responsibilities of health-care organisations and their direct and indirect suppliers around the world in this accelerating environmental emergency.

Differences in health-care challenges between high-income and low-income countries, and how these challenges relate to environmental impact, are important considerations. In many low-income countries, health-care provision is insufficient and population health is often low.[50] Our analysis adds to the insight that poor countries' health-care expenditure per capita and health-care environmental footprints are typically small, but the environmental intensity of health expenditure is often very

high. Our study also shows that the origin of environmental impacts is distributed differently between on-site contributions and supply chains in low-income countries compared with middle-income and high-income countries. This finding suggests that for health-care systems in developing countries, interventions that improved the technical efficiency of basic provisioning systems (eg, energy, buildings, and transport) could allow better health-care provision while reducing environmental impact.

The situation is different for health-care systems in high-income countries, where much higher environmental efficiency is accompanied by high health-care expenditures and reported wasteful practices.[11,51] In these countries, interventions should focus on reducing waste (particularly reducing the use of unnecessary plastics, single-use items, drugs, journeys, and interventions more generally). Reducing pollution is equally important, especially greenhouse gas emissions, including anaesthetic gases and asthma inhaler propellants, and air pollution, especially from health-care-related transport. Notably, the health and social care services in England generate 5% of all road traffic, producing air pollution, greenhouse gases, road trauma, and noise. Examples of tangible actions that can be taken were provided by the Chief Executive Officer of England's National Health Service at a conference in 2019, including investing in energy efficiency and green building design.[52]

Two further priorities apply to health-care systems in both high-income and low-income countries. First, they must adapt the current models of health-care provision to the environmental impacts already occurring, including more frequent, more intense, and longer heatwaves, floods, fires, and other extreme events. The second priority is to understand that health services can not only reduce harm, but can also add social and health benefits to the communities they serve in addition to the direct health benefits from high-quality care (adding so-called social value). Four practical areas for action are summarised in the appendix (pp 63–65).

As in other sectors and industries, progress needs to be integrated into existing forms of reporting (notably financial reporting and reporting of health-care outcomes). Integrated reporting allows every part of the global health system to monitor progress and be alerted to where better health can be created, and less harm caused. Each health-care organisation should develop systems of reporting that address progress on health and social benefits, financial savings, and environmental benefits. This so-called triple bottom line (or integrated) reporting is underpinned by globally consistent, explicit, and valid methods such as those reported here.[53]

Ultimately, we will need to relate health environmental footprints not only to health expenditure but also to the quality of health-care provision, to health outcomes, and to inequality. This task is challenging because it requires taking into account a large body of relevant but also controversial literature about composite indicators for health-care performance, health outcomes, determinants of population health, and drivers of health inequality.[54–60] Environmental aspects have so far played no role in these debates.[61] However, with the availability of sufficiently complete and consistent global accounts of the environmental footprints of health care, such as those presented in this study, we can now begin to analyse the social, economic, and environmental aspects of health-care systems in an integrated and systemic way.

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