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# Health-care systems' resource footprints and their access and quality in 49 regions between 1995 and 2015: an input-output analysis



Baptiste Andrieu, Laurie Marraud, Olivier Vidal, Mathis Egnell, Laurent Boyer, Guillaume Fond



## Summary

**Background** Strategies to reduce the environmental impact of health care are often limited to greenhouse gas emissions. To broaden their scope, our aim was to determine the evolution of the resource footprints, dependency, and efficiency of health-care systems and to determine the relationship between this evolution and their Healthcare Access and Quality (HAQ) index.

**Methods** We carried out an input-output analysis of 49 health-care systems from 1995 to 2015. We harmonised the EXIOBASE v3.8.2 database—providing data for 49 world regions—to the World Health Organization Health Expenditures Database. We then performed a panel data analysis to understand the relationship between Healthcare Access and Quality index and energy footprint per capita of health-care systems. EXIOBASE3 does not provide measurement errors so it was not possible to propagate the uncertainties as can be done with other input-output databases.

**Findings** Health-care systems' footprint increased over the past two decades, reaching 7% of global non-metallic minerals footprint, 4% of global metal ores footprint, and 5% of global fossil fuels footprint in 2013. This increase was mostly due to China, rising from 7% of the non-metallic minerals footprint in 1995 to 45% in 2013. 80% of the health-care systems studied were dependent at more than 50% on fossil fuel imports. The energy footprint per capita was correlated exponentially with the HAQ index but some countries performed much better than others at a given energy footprint. Health-care systems have not become more efficient between 2002 and 2015.

**Interpretation** Health-care systems' resources footprint are exponentially linked to their HAQ. Both prevention and efficiency measures will be needed to change this relationship. If it is not enough, high-income countries will have to choose between further reducing the resource consumption of their health-care systems or shifting the efforts to other sectors, health being considered an incompressible need. We call for the creation of a HAQE (health-care access, quality, and efficiency) index that would add resource efficiency to access and quality when ranking health-care systems.

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## Introduction

Health-care systems represent 1–5% of the global emissions of greenhouse gases, particulate matter, air pollutants, reactive nitrogen in water, and scarce water use.<sup>1</sup> These environmental impacts induce negative health effects that further increase the need for health care. Individuals should not have to take such considerations into account, which ought instead to be addressed by public health policies. However, for policy makers to implement the right strategy, a thorough understanding of the interactions between health care and the environment is needed. Health-care systems' impacts on climate change have been studied both at the country<sup>2–8</sup> and multiregional level,<sup>1,9,10</sup> leading more than 50 countries to sign the UN commitment to a resilient, low-carbon health system at the 26th United Nations Climate Change Conference in Glasgow.<sup>11</sup> Resource footprints—defined as all resources used directly and

indirectly by an economic sector—are responsible for more than 90% of global biodiversity loss and water stress impacts, as well as half of global greenhouse gas emissions.<sup>12</sup> Health-care's resource footprints include non-metallic minerals (used for the construction of buildings, such as hospitals), metal ores (used for the production of buildings and machines), or fossil fuels (used to produce drugs, build hospitals, or power ambulances). Although they are good proxies of environmental damage,<sup>13</sup> we lack data on these footprints, which were therefore missing from the Glasgow agreements. So far, only two studies have assessed the raw materials footprints of health-care sectors. The health-care sector was found to be responsible for 13% of the national material extraction footprint for the Netherlands and 5% for Germany.<sup>14,15</sup>

A further concern relates to the inherent reliance of health-care systems on imported resources, a factor that

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Institut de Sciences de la Terre (ISTerre), CNRS–University of Grenoble, Grenoble, France (B Andrieu MSc, O Vidal PhD); The Shift Project, Paris, France (B Andrieu, L Marraud PhD); Faculté des sciences médicales et paramédicales, AP-HM, Aix-Marseille Université, Marseille, France (G Fond MD, L Boyer MD); CEReSS-Centre d'Etude et de Recherche sur les Services de Santé et la Qualité de vie, Marseille, France (G Fond, L Boyer); Fondation FondaMental, Créteil, France (G Fond, L Boyer); P4H Network-World Health Organization, Geneva, Switzerland (M Egnell MSc); Université Rennes, EHESP, CNRS, Inserm, Arènes—UMR 6051, RSMS (Recherche sur les Services et Management en Santé)—U 1309, Rennes, France (L Marraud)

Correspondence to: Mr Baptiste Andrieu, Institut de Sciences de la Terre (ISTerre), CNRS–University of Grenoble, Grenoble 38041, France [baptiste.andrieu@outlook.fr](mailto:baptiste.andrieu@outlook.fr)

### Research in context

#### Evidence before this study

Health care, as any economic sector, relies on physical stocks and flows. The carbon emissions associated with health care have been assessed both at the regional and the global scale. The PubMed database was explored from inception to June 1, 2022, for studies in English, using the keywords “healthcare” or “health care” with either “energy footprint”, “raw materials”, “environmental footprint” or “resource footprint”. After reviewing the titles, a single study assessed the scarce water use associated with health care globally, together with other environmental impacts. Two studies have assessed the resource footprint of the health-care sector in the Netherlands and Germany. To the best of our knowledge, no study has thus far estimated the resource footprint of health-care systems at a multiregional level, apart from scarce water use.

#### Added value of this study

This study advances existing research by assessing more than 1000 environmental and social impacts of health-care systems, across the whole value chain, including infrastructures. The added value of our methods compared with previous work is; the harmonisation of the expenditure data with WHO reference data, the endogenisation of capital in input–output

calculations, the correction of purchasing power parity for the analysis of intensities, and the comparison of the results with health-care access and quality (HAQ) indexes. Among the impacts studied, resource footprints (divided into non-metallic minerals, metal ores, and fossil fuels) and dependencies were assessed for the first time. Energy footprint was used as an indicator representative of all resource footprints. High-income countries and China were responsible for the majority of the global health-care resource footprint. We found an exponential relationship between resource footprint and health-care access and quality.

#### Implications of all the available evidence

Low-income and middle-income countries not only have lower HAQ indexes compared with high-income countries, but also suffer from some of the impacts associated with the high HAQ indexes of rich countries. In a world with limited access to low-carbon energy sources, it is crucial to limit the growth of the global health-care energy demand. The most effective compromise would be to target the reduction of health-care footprints in high-income countries to ensure fair access to high-quality health-care systems in low-income and middle-income countries. This objective could be reached by a combination of sociotechnical interventions and prevention.

endows the health-care sector with a high degree of vulnerability to crises.<sup>16</sup> For example, if the energy transition is not fast enough, the risks of energy crisis due to decreasing fossil fuels quality—and thus available quantity—could threaten health care with shortages.<sup>16,17</sup> Furthermore, the USA, Canada, Europe, Israel, Australia, New Zealand, Japan and China are together responsible for 92% of the global resource use in excess of equitable and sustainable boundaries.<sup>18</sup> Such levels of consumption in high-income countries have been allowed by resource imports from the emerging and developing economies.<sup>19</sup> To stay within safe and just earth system boundaries,<sup>20</sup> examining and repairing the structural discriminations that drive resource footprints is urgent.<sup>21</sup>

Strategies differ on how to address the problem, ranging from green growth to degrowth or post-growth approaches.<sup>22</sup> For green growth to work, decoupling would need to be absolute (ie, growth in gross domestic product and degrowth in impacts) and of an adequate magnitude. A systematic review showed that a rapid reduction in resource use could not be achieved with the existing decoupling rate.<sup>23</sup> Data on the quantity of resources used per unit of health expenditures would help understand whether past technological progress has contributed to a reduction in the footprint of health care. Since health expenditures are not an end in themselves but a means for citizens to access good quality health care, comparing the multiregional resource footprints of health-care systems as a function of time and health-care quality

would also help understand possible pathways to achieve both Sustainable Development Goal 3 (good health and well-being) and Goals 13–15 (environmental targets).

We aimed to determine the evolution of health-care systems’ resource footprints (in tonnes and tons per capita) at a multiregional level—divided between non-metallic minerals, metal ores, and fossil fuels—between 1995 and 2013 as well as their resource dependency. Our secondary objectives were to calculate an aggregated energy footprint indicator (in joules of final energy) between 1995 and 2015, representative of all the resources used; to determine the relationship between this indicator and the evolution of health-care access and quality; and to disaggregate the energy footprint along the value chain to better understand variations across countries.

## Methods

### Study design

We carried out an input–output analysis of regional health-care systems using EXIOBASE3 for 44 countries and five rest of the world regions from 1995 to 2015. The rest of the world regions correspond to all other countries in Asia and the Pacific, America, Europe, Africa, and the Middle East (see appendix 1 pp 27–36 for a correspondence table between UN and EXIOBASE regions). EXIOBASE3 is an open-access multiregional input-output database.<sup>24</sup> EXIOBASE3 does not provide measurement errors so it was not possible to propagate the uncertainties as can be

See Online for appendix 1

done with other input–output databases. Input–output analysis is a top-down approach to trace the worldwide industrial output necessary to produce the final consumption of a given product in a given region.<sup>25</sup> Environmental extensions link the factors of production, such as resource footprint or environmental impacts, to the industrial output. Thus tracing the resource footprint of a specific sector of final consumption, such as health, is possible. Resource footprints in a given region can be disaggregated by region of production to calculate a share of resource imports.

To have a common and trustworthy source for health expenditure data, we used WHO's Global Health Expenditure database<sup>26</sup> and completed it with the Organisation for Economic Co-operation and Development's health expenditure database.<sup>27</sup> Health expenditures were mapped to six EXIOBASE sectors (appendix 1 pp 2–3): health and social work services (85); chemicals nec (not elsewhere classified); retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods (52); insurance and pension funding services, except compulsory social security services (66); public administration and defence services; compulsory social security services (75); and private households with employed persons (95). The numbers between parentheses are given by EXIOBASE only for some sectors and not for others, without further explanation of what they correspond to (appendix 1 pp 3–4 for the equations used in the calculation process).

A limit of classic input-output databases is that capital formation (ie, investments) is reported as final consumption and not as intermediate consumption. For example, the cement and steel required to build a hospital is not accounted for in health and social work services but in construction work. The Global Health Expenditure database provides capital health expenditure for some years and some regions, but data are neither complete nor disaggregated in capital sub-sectors.<sup>26</sup> To overcome this limit, we have endogenised capital use in EXIOBASE3 using capital use matrixes.<sup>28,29</sup> Part of the investments were thereby considered intermediate consumption.

### Resource footprints and dependency

Once EXIOBASE3 was modified to account for capital use, we calculated resource footprints, measured in tonnes (1000 kg) and tons per capita. Non-metallic minerals, metal ores, and fossil fuels were distinguished because they are associated with different environmental impacts and supply risks. Tracing footprints also allowed us to assess resource dependencies, defined as the percentage of imported resources. Resources data ended in 2013.<sup>30</sup> Within the three resource categories, only fossil fuels<sup>31</sup> and some metallic ores<sup>31</sup> were found to be crucial, whereas other metallic ores and non-metallic minerals were not. The dependencies are still calculated for each category, as it also gives insights to where resources are produced and thus to the offshoring of the associated impacts.

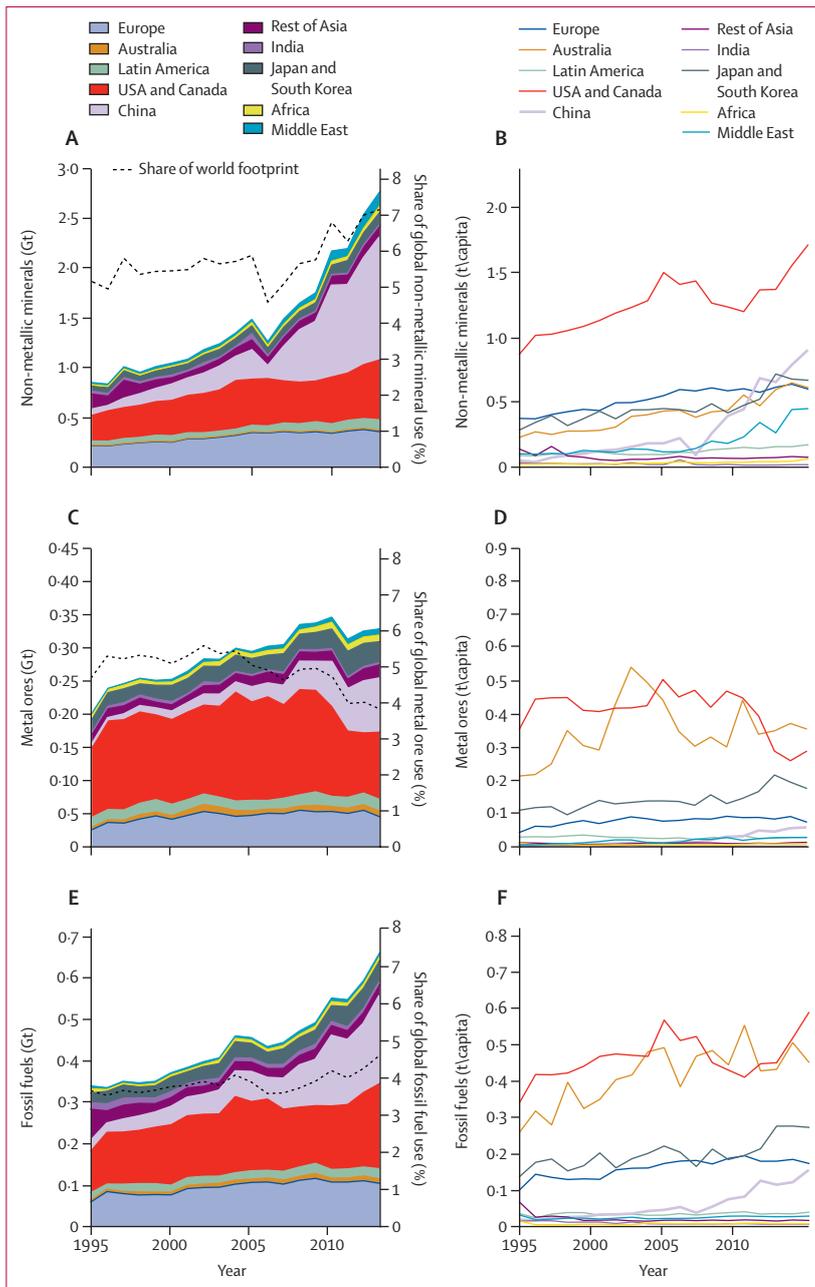
### Relationship between total energy footprint and health-care access and quality

The materiality of health care can be expressed by its total energy footprint, in joules. Resources need energy to be produced. For example, metals require energy to extract and crush the rocks, then to separate the ore from the rock, and separate the metal from the ore.<sup>32</sup> Resources can also be energy sources themselves, such as fossil fuels, but energy is also required to extract them.<sup>17</sup> A total energy footprint across all the value chain includes all of the energy needed to produce the resources, but also the energy to transform these resources into machines or infrastructures and then to make these machines work. For example, energy is required to extract iron ore (the resource), to transform this iron into steel, to transform the steel into medical equipment, and to power the medical equipment. All of these steps are accounted for in the total energy footprint. Energy footprints in EXIOBASE3 cover the 1995–2015 period and are expressed in joules of final energy.<sup>24</sup>

Energy is not used for its own sake but to provide energy services.<sup>33</sup> In the present study, the energy service is to provide access to quality health care. The Healthcare Access and Quality (HAQ) index has been developed to measure this access to quality health care.<sup>34</sup> The HAQ index is built for 195 countries for six reference years between 1990 and 2015.<sup>34</sup> This index considers 32 factors that could cause death but would not do so if people had access to a quality health system. Each year, every country is assigned a score per factor on a scale of 0 (1% worst performing countries) to 100 (1% best performing countries) during the 1990–2015 period. The final index is a score from 0 to 100 per country per year, constructed from the 32 causes studied.<sup>34</sup> For the five rest of the world EXIOBASE3 regions, we have aggregated this index using population-weighted means.

We performed a panel data analysis to understand the relationship between HAQ and energy footprint per capita of health care systems. Panel data analysis allows us to study data that is measured for the same objects (here regions) at different points in time. We chose the natural logarithm of the energy footprint per capita as the dependent variable and the HAQ index as the independent variable. We carried out a preliminary Hausmann test to choose the regression model. The result, giving a p value of 0.0004 proved that the individual characteristics were correlated with the regressor and that the fixed-effect model was more appropriate than the random-effect. It makes sense as there are reasons to think that cultural or political characteristics of the various regions affect the HAQ index. We used the Python Statsmodel module to carry out the analysis.

As we found significant differences in energy footprints for countries with a similar HAQ index, we disaggregated the energy footprint of the ten countries with the highest HAQ index. We compared the energy used directly by health-care sectors with that used for chemical



**Figure 1: Evolution of resource footprints of health-care systems between 1995 and 2013**  
 (A) Non-metallic minerals footprint. (B) Non-metallic minerals footprint t per capita. (C) Metal ores footprint. (D) Metal ores footprint t per capita. (E) Fossil fuels footprint. (F) Fossil fuels footprint t per capita. Data for the USA and Canada have been smoothed across 3 years to avoid sawtooths (up to 38% of difference between the smoothed and non-smoothed data for USA and Canada). See the appendix (pp 4–6) for the t per capita data used in parts B, D, and F.

production, production of other raw materials, transport, equipment, construction, food, energy production, and other for all other EXIOBASE sectors.

**Health-care systems efficiency**

Energy efficiency is defined as the inverse of energy intensity (energy use per unit of expenditure). To compare intensities between regions and across time,

expenditures must be corrected to account for purchasing power parity (PPP) and inflation. One US\$PPP buys the same basket of goods in any region, whereas one US\$ buys goods according to market exchange rates. However, \$PPP data do not account for inflation. Consumer Price Indexes account for inflation across time in a given country. We used expenditure data in \$PPP from the Global Health Expenditure database and corrected them using US health care Consumer Price Indexes for the years 2002–15, previous years not being available.<sup>35</sup>

Changes in the obtained energy intensity can be explained by actual efficiency gains (ie, using less energy to perform the same task) but also by changes in the input structure of the sector, for example of the cost of employment, which corresponds to zero energy input. To analyse this, we calculated the share of the cost of employment in the total inputs of the sector (ie, the sum of intermediate consumption and value added).

**Role of the funding source**

The funder of this study had no role in the study design; the collection, analysis, and interpretation of data; the writing of the manuscript; or the decision to submit the paper for publication.

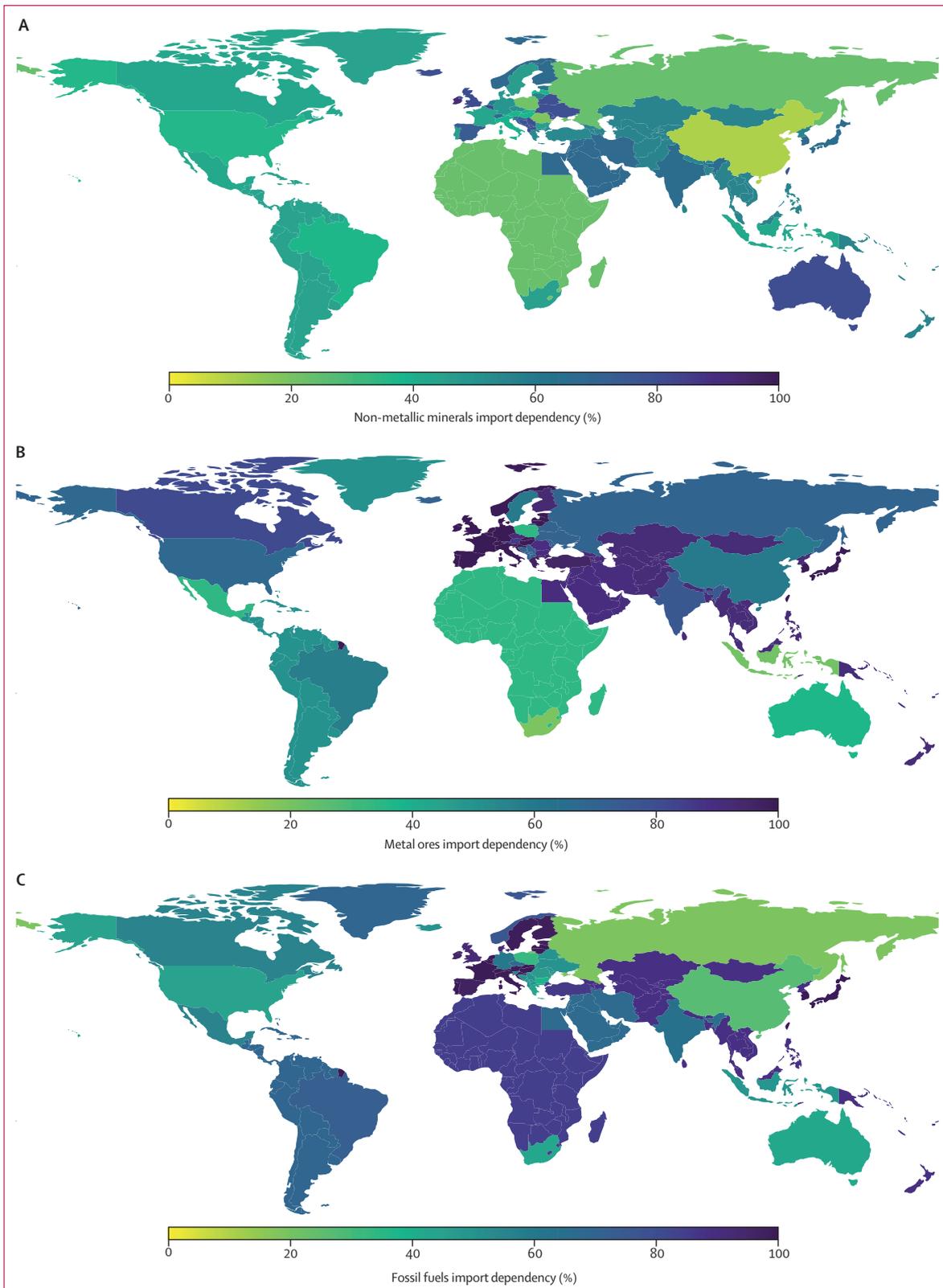
**Results**

The non-metallic minerals footprint of the world health-care system has tripled over the 1995–2013 period to reach 2.8 Gt for 2013. This increase was mostly due to China, which represents 7% (0.059 Gt) of the footprint in 1995 but 45% (1.2 Gt) in 2013. An increase of health-care systems’ share in the world non-metallic minerals footprint is observed during the period, rising from 5% (0.85 Gt) in 1995 to 7% (2.8 Gt) in 2013 (figure 1). In 2013, a North American individual had a non-metallic minerals footprint 96-times higher than an Indian individual (1.7 t/capita vs 0.018 t/capita).

The metal ores footprint (figure 1) increased from 198 Mt in 1995 to 328 Mt in 2013. However, health-care systems’ share in the global footprint decreased from 5% to 4% during the period. In 2013, an Australian individual had a metal ores footprint 131 times higher than an Indian individual (0.35 t/capita vs 0.0027 t/capita).

Fossil fuels footprint (figure 1) reached 662 Mt in 2013. Health care represents 4% (340 Mt) of global fossil fuel use in 1995 but 5% (662 Mt) in 2013. In 2013, a North American individual had a fossil fuels footprint 72 times higher than an Indian individual (0.59 t/capita vs 0.0081 t/capita).

In 2013, the footprint associated with capital goods and services (obtained via capital endogenisation) represented 35% (0.98 Gt) of the global footprint of non-metallic minerals, 44% (0.14 Gt) of metal ores, and 21% (0.14 Gt) of fossil fuels. Important variations exist in between countries on the share of the footprint due to capital expenditures. These differences could partly explain the differences in country rankings in figure 1 (appendix 1 pp 6–7).

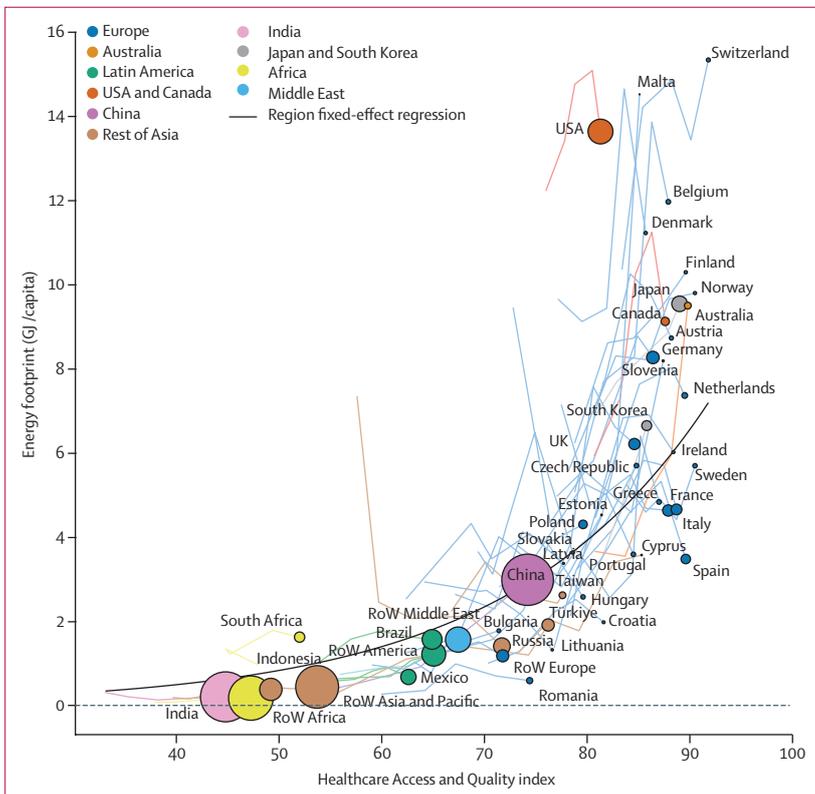


**Figure 2: Health-care systems' resource dependency in 2013**

(A) Non-metallic minerals import dependency. (B) Metal ores import dependency. (C) Fossil fuels import dependency. Appendix (pp 8–12).

	R <sup>2</sup> (between)	R <sup>2</sup> (within)	R <sup>2</sup> (overall)	Log-likelihood	p value	Slope (95% CI)	Origin (95% CI)
Fixed-effect regression results	0.726	0.360	0.692	-36.8	<0.0001	0.0513 (0.0416 -0.0610)	-2.73 (-4.45 to 2.02)

**Table: Regression results between the Healthcare Access and Quality index (independent variable) and the natural logarithm of the energy footprint (dependent variable) with region-fixed effects**



**Figure 3: Energy footprint of health-care systems scales exponentially with the Healthcare Access and Quality index**

Lines represent the evolution for years 1995, 2000, 2005, 2010, and 2015. Dots are proportional to the populations in 2015. The black line represents the regression with country fixed effects (table). Luxembourg is an outlier and has therefore not been shown (appendix p 14). For Canada, Switzerland, Finland, Malta, Norway, Netherlands, Slovenia, Slovakia, United States and Taiwan, data has been smoothed across 3 years to avoid sawtooths that did not reflect real dynamics (the maximum difference between the smoothed and unsmoothed data was of 24%). RoW=rest of the world.

In 2013, 26 (53%) of 49 health-care systems depended at more than 50% on imports of non-metallic minerals and six (12%) at more than 80% (figure 2). This dependence was greater for metal ores, for which 43 (88%) of 49 systems relied at more than 50% on imports and 35 (71%) at more than 80% on imports (figure 2). Finally, 39 (80%) of 49 relied at more than 50% on fossil fuel imports and 28 (57%) at more than 80% (figure 2). This dependency considers exports re-imported. For example, the Middle East relies at 67% on fossil fuel imports (appendix 1 pp 12–13) even though it produces an important share of the fossil fuels used by health-care sectors globally (appendix 1 p 11).

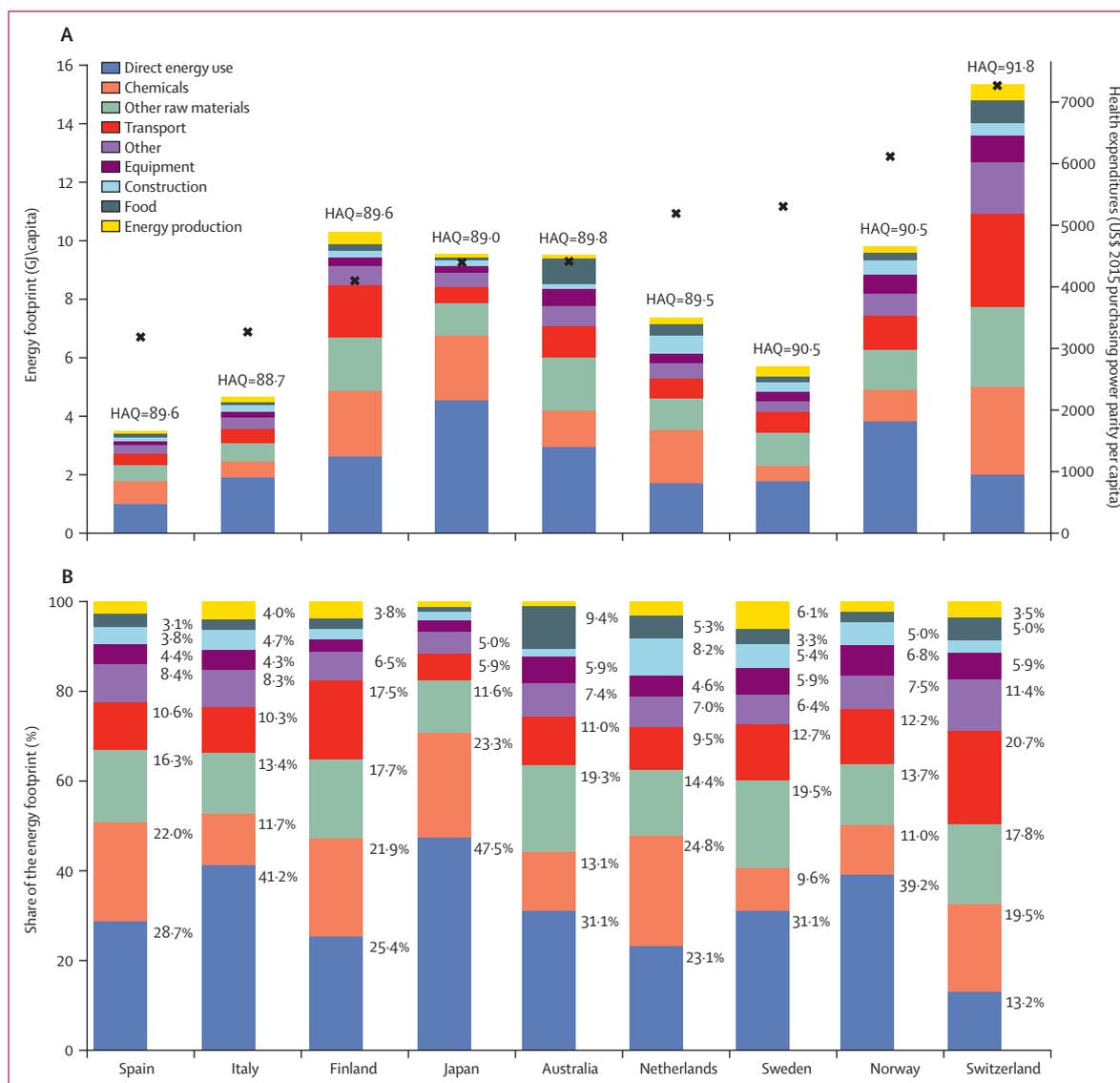
Health-care systems' energy footprint per capita follows a power law of health-care access and quality between regions (but not within regions; table; figure 3).

Though the power law is visually clear for the cross-sectional data, the time-series data of some countries do not follow a power law. This is confirmed by the panel data analysis, for which the R<sup>2</sup> between regions (0.73) is twice higher than the R<sup>2</sup> within regions (0.36; table). Some countries, such as the USA or Switzerland, underperformed whereas others, such as Spain or Croatia, overperformed (appendix 1 pp 14–16). During the 1995–2015 period, the HAQ indexes increased in all 49 EXIOBASE3 regions. However, five regions—India, rest of the world Africa, Indonesia, South Africa, and rest of the world Asia and Pacific—representing half of the world's population, still had HAQ indexes less than 55 in 2015.

High-income countries not only have lower HAQ indexes than low-income and middle-income countries but also suffer from some of the impacts associated with the high HAQ indexes of rich countries. For example, 64% of the impacts associated with health-care-related non-ferrous metal ore extraction takes place in the low-income and middle-income countries without China, though this region's consumption is responsible for only 19% of the impacts (appendix 1 p 9).

In 2015, ten countries had an HAQ index between 88.7 and 91.8, but the per capita energy footprint of their health sectors varied by more than four times, from 3.5 GJ per capita in Spain to 15.3 GJ per capita in Switzerland (figure 4). These differences are partly explained by the amount of per capita spending on health care, which is twice higher in Switzerland than in Spain (black crosses of figure 4). Notable differences remain, for example, Sweden's footprint is 55% lower than Finland's, while its per capita health expenditure is 29% higher. Disaggregating the footprint by sector also reveals differences. Direct energy use is almost always the largest energy use sector, ranging from 13% of energy use in Switzerland to 48% in Japan (figure 4). The next largest energy use sectors are chemicals, other raw materials, and transport which, together with direct energy use, account for 80% of the total footprint. The remaining 20% includes equipment, construction, food, energy production, and other. The low share of the energy production sector is due to the fact that final energy and not primary energy is studied here.

Future variations in energy efficiency could also modify energy demand. When calculated in current US\$, energy intensities (the inverse of efficiency) decreased as a function of expenditures and time (figure 5). When calculated in constant 2015 US\$ PPP, no global trend was seen as a function of expenditures or time (figure 5). China was the only country whose energy



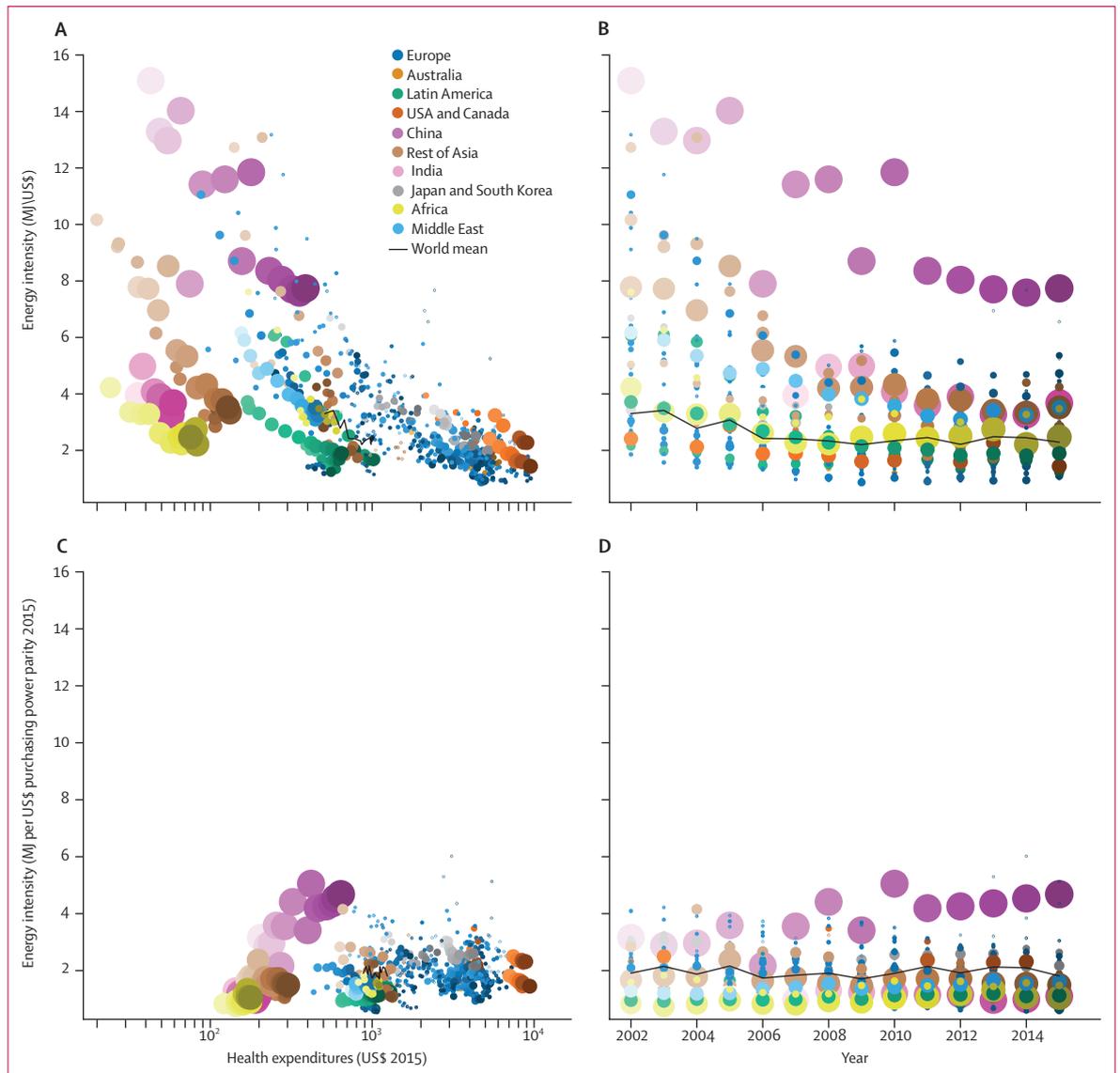
**Figure 4: Energy footprint disaggregation for regions with HAQ indexes ranging from 88.7 to 91.8**

(A) The stacked bars represent the energy footprint GJ per capita of health-care sectors, units are on the left y axis and colours correspond to sectors. The black crosses represent the health expenditures per capita; units are read on the right y axis. (B) Percentage disaggregation over the value chain of health-care's energy footprint. Results for all countries are available in the appendix (pp 16–19). HAQ=Healthcare Access and Quality indexes.

intensity in constant 2015 US\$ PPP clearly increased, both as a function of time and expenditures. This could be partly explained by the changes in the input structure of the sector. Across the 2002–15 period, an increase in the cost of employment in the total inputs of the sector was correlated to a decrease of energy intensity (appendix 1 p 23). For China, the cost of employment in total inputs dropped by 25% (appendix 1 pp 19–21) while the energy intensity in constant 2015 US\$ PPP increased by 49% (appendix 1 pp 21–22). However, as the cost of employment is linked to inflation, and that we corrected expenditure data for inflation, the exact role of the cost of employment in the energy intensity remains unclear.

## Discussion

Health-care's resource footprints increased from 1995 to 2015, reaching 7% of global non-metallic minerals, 4% of global metal ores, and 5% of global fossil fuel use. In 2013, 80% of the health-care systems relied at more than 50% on fossil fuel imports and 88% at more than 50% on metal ores imports. We found that the per capita energy footprint of health-care scales exponentially with the HAQ index between regions (but not within regions). Moreover, the reference of the HAQ index being relative to the best reference region, the energy footprint for a given index could increase even more if health-care systems keep shifting towards energy-intensive treatments. The energy footprint should therefore be



**Figure 5: Evolution of health-care systems' energy intensities (inverse of efficiency) between 2002 and 2015**

Dot sizes are proportional to the population size. The darker the dots, the more recent the years. (A) Energy intensity in MJ per US\$ as a function of health expenditures. (B) Energy intensity in US\$ as a function of time. (C) Energy intensity in US\$ as a function of health expenditures. (D) Energy intensity in US\$ as a function of time.

considered in any new treatment or innovation in health-care systems. Important differences exist between countries with a comparable HAQ index, showing that the exponential relationship could be changed. Direct energy use and chemical production represents around 50% of the energy footprint. Finally, energy efficiency has not improved significantly between 2002 and 2015.

As no other study has assessed the global energy footprint of health-care systems, we compare our greenhouse gas emissions results with previous studies. Our results for CO<sub>2</sub> emissions in 2014 were similar to the previous multiregional estimates using the Eora EE-MRIO database<sup>9</sup> (appendix 1 p 24). Our results were

also close to the values reported for 2015 in the Health Care Without Harm,<sup>10</sup> which used the Global Trade Analysis Project database to assess health-care systems' climate footprint in 43 countries (appendix 1 p 25). In contrast, our results for greenhouse gases in 2015 differed significantly from those of Lenzen and colleagues<sup>1</sup> (appendix 1 p 26). Unlike the other two multiregional studies, they used the health-care-related sectors directly from Eora, without harmonising the expenses with WHO's Global Health Expenditure database. This method has the advantage of providing the best possible disaggregation of regional footprints but limits international comparisons due to different health-care

definitions. Furthermore, we account for the consumption of capital, which is not the case for Lenzen and colleagues.<sup>1</sup>

Only top-down data were available for the present study, contrary to national studies that might have included bottom-up or hybrid approaches. The footprints of Austria,<sup>2</sup> the Netherlands,<sup>14</sup> Canada,<sup>6</sup> and Australia<sup>7</sup> could therefore have been underestimated respectively by 27%, 25%, 12%, and 11% whereas those of Japan,<sup>3</sup> China,<sup>8</sup> England,<sup>5</sup> and the USA<sup>4</sup> could have been overestimated respectively by 41%, 36%, 13%, and 6%. Discrepancies can be explained by various definitions of health-care systems along with more precise data available for single-country analysis due to the bottom-up or hybrid approaches used. For example, the top-down approach used in the present study does not include emissions by personal vehicles of patients, staff, and visitors.

The exponential relationship between energy footprint and health-care access and quality (figure 4) can be explained by the fact that the disease burden—measured as disability-adjusted life years (DALYs) per 100 000 individuals—does not decrease linearly with health expenditures per capita.<sup>36</sup> At low levels of expenditures, DALYs per 100 000 decrease exponentially but this steep decrease stops at around US\$500 health expenditures per capita.<sup>37</sup> DALYs decrease slightly or not at all between \$500 and \$9500. The steep decline corresponds to the drastic decrease of communicable diseases.<sup>37</sup> However, once DALYs due to communicable diseases are low, avoiding DALYs due to non-communicable diseases is much harder.

We found that energy efficiencies of health-care systems have not changed significantly between 2002 and 2015. A previous study<sup>1</sup> has shown that environmental intensities (impact per unit of expenditures) of a number of environmental indicators were steeply decreasing. However, these intensities were calculated using expenditures in current US\$ and not in constant US\$ PPP, which accounts both for inflation and for differences in purchasing power. Energy transition scenarios rely heavily on energy intensity reduction to reach climate targets. An inter-comparison of three models has shown that a reduction of energy intensity by 2·4% to 6·8% per year for the next decade is necessary to reach the 2°C goal.<sup>38</sup> Our results show that the health-care sector is not on target.

Our analysis shows that the environmental impacts of health care are not limited to greenhouse gas emissions but rely on important resource use. The extraction and processing of these resources in turn impacts human health and the environment.<sup>39</sup> The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services states that “mining on land [...] has had significant negative impacts on biodiversity, emissions of highly toxic pollutants, water quality and water distribution, and human health”.<sup>40</sup> Most of the resources used by health-care sectors in high-income countries

comes from the low-income and middle-income countries, which have a lower HAQ index. Focusing on the decarbonisation of energy systems will therefore not be enough for a transition towards just and sustainable health care and to navigate back into planetary boundaries.<sup>41</sup>

Reducing health-care systems' resource footprints is an imperative, especially in high-income countries. In an analysis of Germany's health-care sector's raw materials footprint combining quantitative data with desk research, interviews, and a written survey, four priority areas were identified for resource efficiency: pharmaceuticals, medical devices, construction, and supply of food and beverages.<sup>15</sup> Detailed strategies were elaborated for each of these areas and will be of great help for any health organisation wishing to reduce its footprint.<sup>15</sup>

There are ethical reasons to argue that the reduction of health-care's environmental footprint should not be patient-facing.<sup>42</sup> Here, we develop two parallel strategies that could be followed to reduce health-care systems' footprint with neutral or positive impacts on health.

The first strategy consists in engineering and sociotechnical interventions. These interventions could reduce the energy use of the England's National Health System by up to 40%.<sup>5</sup> All health-care stakeholders should carry out material flow analysis on top of carbon footprint assessments. For example, surgical interventions are material intensive and unsustainable<sup>43</sup> but assessments that include resource and energy footprints for surgery are scarce.<sup>44</sup> The use of appropriate auditing tools would help identify opportunities to reduce the footprint of surgical interventions.<sup>45</sup> Resource footprints would also be reduced by better designs of medical products and increased recycling.<sup>46</sup> Health care is also vulnerable to oil supply crises.<sup>16</sup> For example, changes in energy prices affect ambulance systems' performance and safety characteristics.<sup>47</sup> To protect public health from future crises, energy scarcity must be anticipated and prepared for, by reducing the demand and adapting systems.<sup>48</sup> Some petroleum use consists of wasteful practices and can be simply reduced, such as using fewer single-use plastics. Others are lifesaving, such as ambulances. Thermic ambulances could be replaced by electric ones as the electric mix shifts towards renewables. Though they would still rely on important resource consumptions, electric ambulances would be more resilient to oil crises and have a smaller climate impact. Other options to limit energy and resource consumption include developing telemedicine, limiting distances travelled for training and conferences, reducing food waste, and systematically offering vegetarian meals sourced locally and in season.

The second strategy is based on the prevention of lifestyle-related non-communicable diseases. These diseases are responsible for the increased demand of health-care systems. Reducing their prevalence would therefore reduce energy demand. For example, cardiovascular diseases, cancer, and depressive disorders are three

major causes of quality adjusted life years loss in high-income countries.<sup>49</sup> The increasing prevalence of depressive disorders<sup>50</sup> has been associated with multiple environmental factors associated with the Western lifestyle relying on environmental degradation (eg, impaired food quality,<sup>51</sup> air pollution,<sup>52</sup> tobacco smoking,<sup>53</sup> and a productivity-based society inducing burnout and professional bullying within the workplace<sup>54</sup>). Addressing these risk factors would help improve both the risk of depressive and cardiovascular disorders and reduce their associated costs, reducing demand for health-care systems. Diet is a good example: Western diet includes high proportions of red meat and ultra-processed food that have high energy costs for their production. Red meat consumption has been associated with increased risk of colon cancer and the consumption of ultra-processed food with increased risk of obesity. Promoting the Mediterranean diet (including reduced meat and fish consumption and increased organic legumes, fruits, and vegetables) has a low environmental impact and is effective in the prevention of non-communicable diseases.<sup>55</sup> Similarly, cycling and walking can help reduce transport energy cost and at the same time prevent non-communicable diseases induced by a sedentary lifestyle.<sup>56</sup> Pricing that favours prevention and health promotion, not just fee-for-service, could encourage professionals to change their model more quickly.

The implementation of these strategies should take place in the broader planetary health-care framework for which the principles are to reduce demand for health services, to ensure appropriate care and avoid unnecessary investigations and treatments, and to reduce impacts from the supply of health services.<sup>57</sup> If these strategies combined are not enough to reduce health-care's footprint to a sustainable level, an option would be to shift the remaining burden from health care to other sectors. However, that would require planning and explicit prioritisation of health care over other economic sectors.

Health-care systems have a duty to set an example and act as ambassadors. Health-care professionals would therefore have to be trained to respond to these issues properly. According to a recent study carried out in France among 3384 health students, only 60 (31%) of their 193 institutions integrated training on environmental issues.<sup>58</sup> When provided, these programmes represent on average only 0.4% of the total training duration and a systematic approach and general strategy are often missing.<sup>59</sup> Moreover, courses on the environment are often optional, with no direct link to the management of institutions, financial profitability, or resilience in the event of crises.

The main limitations of this study are those inherent to input-output modelling, in particular to the raw data used to build environmental extensions. EXIOBASE3 does not provide measurement errors so it was not possible to propagate the uncertainties as can be done with other input-output databases. However, a previous

study on the environmental footprints of health-care systems<sup>1</sup> used Monte-Carlo techniques to assess the uncertainty of their results from the SDs provided by the Eora database. They found final SDs of less than 5%.<sup>1</sup>

When comparing regions, we found that exponential amounts of resources were required to support the development of health access and quality systems. As the environmental impacts associated with these resources are responsible for an increase in some non-communicable diseases, health systems find themselves in the midst of a vicious cycle. To navigate back inside planetary boundaries, health-care environmental strategies must be broader than greenhouse gases and include objectives in terms of resource use. As an exponential relationship exists between regions but not within regions, breaking the trend seems possible. We therefore call for the creation of a health-care access, quality, and efficiency index that would include both access and quality and resource and energy footprints in its calculation. This would encourage policy makers to act promptly to limit the environmental damage caused by health-care systems.

#### Contributors

BA was responsible for conceptualisation. All authors contributed to the literature search. BA and OV were responsible for data curation. All authors contributed to data analysis and interpretation of results. BA, GF, and LM wrote the original draft. All authors were responsible for writing, reviewing, and editing the manuscript. All authors had access to all data in the study, BA and OV verified the data and the corresponding author had final responsibility for the decision to submit for publication.

#### Declaration of interests

ME is a consultant to P4H Network-WHO. He has an employment contract with The Shift Project and has received payment from Roche for a presentation. All other authors declare no competing interests.

#### Data sharing

1239 socio-environmental impacts of 49 health-care systems during the period 1995–2015 have been calculated. The dataset has been submitted along with the manuscript (appendix 2) and will be made publicly available online upon publication. The code to reproduce the study is also available online.

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See Online for appendix 2

For the code to reproduce the study see <https://github.com/baptiste-an/Energy-and-HAQ>

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