Inequalities in health-care carbon footprints and implications for demand-side interventions: a global assessment across population groups

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Summary

Background Reducing emissions from health care is now recognised as an urgent priority on the climate–health agenda. Although studies have quantified the environmental impacts of health systems at national and global scales, inequalities in health-care carbon footprints (HCFs) across population groups (both between and within countries) and their trajectories remain unexplored. This study quantified these disparities and evaluated the potential of targeted demand-side interventions to achieve equitable, low-carbon health care while expanding delivery of care.

Methods We estimated the HCFs of different income groups within 121 countries from 2005 to 2017 by integrating consumer expenditure surveys, national health expenditure data, and a global multiregional input–output model. Our approach enabled the disaggregation of emission patterns by income groups, health expenditure groups, health-care expenditure category, as well as health-care products and services. Scenario analyses were then carried out to evaluate the potential of demand-side interventions in reducing health care-related carbon emissions under different strategies.

Findings Our analysis revealed disparities in HCFs both between countries and among population groups within them. By 2017, the top 10% of high-spending health-care consumers contributed 48% (1128 Mt CO_2 equivalents [CO_2e]) of the total HCFs, in comparison to the less than 10% of the total HCFs contributed by the bottom 50%. In addition, the top 1% contributed 2857 kg CO_2e per capita, more than eight-times the global per-capita average and nearly 66-times that of the bottom 50%. In addition to high-income countries, which maintained consistently high levels of HCFs over time, upper-middle-income countries also contributed to a substantial rise, with total HCF increasing from 181 Mt CO_2e in 2005 to 760 Mt CO_2e in 2017, representing more than a three-fold increase. By estimating the health expenditure–carbon elasticity, we found that health-care spending embodies higher marginal emissions among high-spending groups than that among low-spending groups. Scenario analyses indicated that without compromising on health outcomes, demand-side controls targeting carbon-intensive overuse of health care among the top 10–20% while simultaneously advancing ambitious universal health coverage could deliver a 25–40% reduction in carbon footprints and even ease costs.

Interpretation Our study moves beyond cross-country comparisons based on national averages or totals by examining HCFs across different population groups within countries. The highest-spending populations were found to contribute disproportionately to health-care carbon emissions, thus highlighting that achieving equitable, low-carbon health-care transitions requires attention to within-country population disparities to target interventions. Our findings provide quantitative evidence for pathways to meet fair health-care emission-reduction targets while maintaining care quality. Expanding access to essential health care, combined with addressing carbon-intensive overuse among high-spending populations, could achieve substantial reductions in emissions.

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Introduction

Sustainable health systems are crucial components of the broader climate and health agenda.[1,2] Globally, health systems contribute more than 2·2 billion tonnes of CO_2 equivalents (CO_2e) annually; if counted as a country, then the sector would rank among the top five emitters worldwide.[3] To be truly sustainable, health-care systems should not only be effective, affordable, and equitable at present but also be capable of safeguarding the health and well-being of future generations within planetary boundaries.[4,5] In response, more than 90 countries have committed to developing sustainable health systems since the launch of the 26th UN Climate Change Conference (COP26) Health Programme, in an effort to accelerate the health-care

Research in context

Evidence before this study

Building sustainable, low-carbon health systems has become a central priority on the global climate and health agenda. Previous research has estimated health-care emissions at national or global levels, but most analyses remain at the total or average level, rarely examining the disparities between different income or expenditure groups within countries. Although some works have discussed equity implications conceptually, few studies have linked health-care payers and consumption categories to carbon emissions or quantitatively integrated these analyses into health-care decarbonisation strategies. Without such insights into how different populations contribute to health-care carbon footprints (HCFs), mitigation efforts risk unintentionally exacerbating health inequities.

Added value of this study

Here, we use integrated household expenditure surveys, national health expenditure data, and multiregional input–output models to quantify global inequalities in HCFs. The framework enables disaggregation of health-care emissions by income groups, spending percentiles, payer categories, and consumption categories, thereby revealing how populations disproportionately contribute to health-care emissions, both between and within countries. The framework also supports scenario analysis under varying demand-side intervention priorities, allowing comparison of emission reductions from targeted interventions while safeguarding care delivery. The results indicate pathways that enable synergies between equitable health-care decarbonisation and the expansion of essential health care.

Implications of all the available evidence

HCFs are unevenly distributed between and within countries. Within countries, we find that different income-level population groups contribute through distinct health-care service categories. The top 10% of global health-care consumers are responsible for about half of total HCFs, and higher health-care expenditure groups are associated with higher marginal HCFs. By addressing carbon-intensive overuse among high-spending groups, substantial emission reductions can be achieved while ensuring equitable access to necessary services, with reductions far exceeding the additional carbon associated with expanding essential health care. Effective demand-side strategies should facilitate a shift from national averages to precise, within-country targeted actions, ensuring broad and equitable decarbonisation.

sector's progress towards achieving net-zero emissions by 2050, in line with the Paris Agreement.[6]

However, meeting the low-carbon target in health-care systems presents a unique challenge: reducing carbon footprints equitably while ensuring access to essential health care for all. Universal health coverage (UHC) remains a central objective under Sustainable Development Goal (SDG) 3, particularly for low-income countries (LICs).[7,8] Scaling up health-care services in these settings is essential to safeguard basic rights and population health, but could also lead to further carbon emissions.[9,10] Addressing this tension requires both supply-side and demand-side efforts.[11] Since the late 2000s, low-carbon technologies on the supply side have been widely explored.[12,13] In contrast, although studies have begun to examine variations in health-care carbon footprints (HCFs) on the demand side, most estimates remain focused on national or regional totals or averages.[14–16] Although these estimates are valuable for broad monitoring, the underlying disparities across income groups, consumption categories, and financing mechanisms remain insufficiently characterised.

Evidence from global carbon-inequality studies shows that emissions tend to be concentrated among the wealthiest,[17–19] and this carbon inequality appears to apply to health care as well.[20] In high-income settings, increasing research evidence on the overuse of health-care services,[21,22] which can lead to rising social and environmental costs that outweigh the benefits, has raised concern.[23] In sharp contrast, per-capita health spending in LICs remained less than US$50 in 2021, whereas the same was more than $4000 in high-income countries (HICs).[24] Owing to their low ability to pay for health care, as compared with their richer counterparts, poorer populations often struggle to access even basic health care and have a paucity of lower-carbon options for the same goods and services, which often require additional inputs. Although the choice and engagement of the individual care recipient are increasingly being recognised as crucial components of modern health care,[25] disadvantaged populations often face limitations and disparities in health-care access that constrain their ability to support sustainable change. At present, climate responsibility in health care is increasingly being viewed as influenced by the capacity to pay.[26,27] However, low knowledge of how different population groups contribute to HCFs remains a barrier to integrating low-carbon health-care targets with health equity in policy making. Without such insight, mitigation efforts risk unintentionally shifting burdens onto the most vulnerable populations.

We aimed to identify how different population groups across countries contribute to HCFs disproportionately and to reveal the associated mitigation opportunities. We constructed an integrated framework that combines household and consumer expenditure surveys (CESs), national health expenditure data, and environmentally extended multiregional input–output (EE-MRIO) analysis models to estimate HCFs for 121 countries from 2005 to 2017, covering more than 90% of the global population. We then disaggregated HCFs by spending percentiles, payer categories, and consumption categories and conducted scenario analyses to evaluate the mitigation potential of alternative demand-side interventions.

Methods

Data processing

Bottom-up data from households or CESs can be used to estimate the carbon footprints embodied in health expenditure across population segments (e.g., income quintiles), particularly in the analyses of carbon inequity.[28,29] For LICs, LMICs, and UMICs, we used the World Bank's Global Consumption Database.[30] Since this dataset has low representativeness for HICs, the CES data of European countries were taken from the Eurostat Household Budget Survey.[31] Data for the USA, Japan, Switzerland, Canada, South Korea, and Australia were obtained from each country's official household expenditure survey (appendix pp 3–5). Then, based on data availability, we constructed a complete time series of CES data for each economy from 2005 to 2017, in stages. First, for countries with any available quintile-level health-care expenditure data, we interpolated missing values linearly when at least two non-missing observations existed across years. If fewer than two non-missing observations were available, then we imputed missing values using the average change observed in neighbouring countries within the same region. For countries with no time-series data available at all, and with no neighbouring-country data available, we assumed that inequality trends in household health expenditure followed those of overall household inequality. Missing values were inferred for a specific year on the basis of the discrepancies between the World Bank's Poverty and Inequality Platform[32] inequality data (aggregated to five quintiles) and the country's observed distribution in the same year for which data existed (appendix pp 6).

The value of national health expenditure for a given country and year was sourced from WHO Global Health Expenditure Database[33] (GHED, in purchasing power parity-adjusted international dollars [PPP$]), which compiles internationally comparable data reported by national authorities. Then, we applied linear interpolation to address missing data for some years. To enhance policy relevance, we aggregated health expenditures into four payer categories for each country and year: household out-of-pocket spending (OOPS), voluntary health payments, compulsory health insurance spending, and government health schemes, in addition to four health-care consumption categories: pharmaceuticals (including prescribed medicines and over-the-counter medicines), medical devices, health-care administration, and health-care services (appendix p 11). Household health-care expenditures were anchored to GHED-reported OOPS and allocated across health-care consumption categories on the basis of proportional breakdowns observed in national CESs. Although CES data follow the Classification of Individual Consumption According to Purpose, classification schemes vary across countries. Therefore, we mapped different Classification of Individual Consumption According to Purpose categories to a unified set of health-care consumption categories to ensure cross-country consistency (appendix pp 12–14). To reconcile CES and GHED data across countries and to align them with health-care products and services in the EE-MRIO model, we developed a weighted goal programming approach (appendix pp 14–15). This method ensures consistency among different health expenditure types and allows for the allocation of all the payer categories across health-care consumption categories.

Finally, we estimated the HCF associated with each payer category separately and summed them to obtain the total HCF, as detailed in the next section. This study covers 121 countries and regions (appendix pp 7–11), capturing the distribution of HCFs across different population segments from 2005 to 2017, encompassing more than 90% of the global population.

See Online for appendix

HCFs across population groups

Acknowledging that the health-care market differs fundamentally from typical consumer markets, consumers of health-care products and services (ie, care recipients) face multiple constraints in their choices, including information asymmetry, the highly specialised nature of health care, and the structure of health-care financing systems. There is also considerable cross-country variation in health-care policies and regulatory frameworks (appendix p 17). In this study, we consider the institutional and policy structures of national health systems as contextual factors shaping health-care consumption patterns. Ultimately, the allocation of health-related carbon emissions is based on consumption-based carbon footprint accounting,[34] attributing emissions to the socioeconomic activities that are based on the demand of health-care spending. This approach ensures the feasibility of carbon footprint accounting and maintains comparability across regions with diverse health systems.

We used an EE-MRIO method based on the EXIOBASE 3 (version 3.9.5) dataset[35] to calculate the embodied carbon footprint, with health expenditure treated as the driving force (appendix pp 15–16). We followed previous approaches and resolved the model into 189 countries and regions.[36] We selected EXIOBASE 3 over other multiregional input–output analysis models (eg, Global Trade Analysis Project [GTAP]) because of its extensive product sector coverage, comprehensive coverage of impact factors, and broader environmental accounting data.[37] The specific greenhouse gas emissions and global warming potential characterisation factors used in our analysis are summarised in the appendix (p 16).

Then, HCFs across population groups were estimated using a hybrid approach. First, we combined bottom–up CES data with the EE-MRIO model to calculate the embodied HCFs from household health expenditures (OOPS) for different population groups. Second, this analysis was complemented by a top–down method to account for emissions associated with other payer categories, such as voluntary health payments, compulsory health insurance spending, and government health schemes. In this step, we assumed that spending from these other payers generally followed the same distribution across population groups as out-of-pocket expenditures, with adjustments to reflect characteristics of some financing schemes. Finally, per-capita HCF sums emissions from all payer categories. In addition, to more easily assess HCF patterns by spending across different population groups, we applied a flexible re-ranking method to re-slice and aggregate population groups by per-capita expenditure. Further technical details are provided in the appendix (pp 17–21).

Scenario design

We constructed a series of scenarios along three dimensions: expanding health coverage, controlling health-care overuse, and reducing emission intensity. Such scenario-based assessments have been widely applied in previous studies to evaluate the mitigation potential of demand-side emissions.[38,39] Our framework includes one business-as-usual scenario and 12 intervention scenarios (table and appendix p 22). For clarity, the business-as-usual scenario reflects the actual distribution of health expenditures (in PPP$) and associated HCF based on data from 2015 (adjusted to 2015 prices), serving as the reference for evaluating other scenarios. The health-care coverage benchmark aligns with the UHC target, estimating the carbon footprints embodied in the more ambitious health-care cost benchmarks required for countries to reach this goal. We adopted the incremental per-capita spending for different income groups estimated by Stenberg and colleagues[40] to achieve the ambitious benchmark: PPP$76 (range 46–141) for LICs, PPP$58 (22–167) for lower-middle-income countries (LMICs), and PPP$51 (36–118) for upper-middle-income countries (UMICs; appendix pp 21–23).

Uncertainty analysis

To test the uncertainties of our findings when allocating HCFs across population groups, we applied a set of parameter assumptions. Specifically, we introduced variations in the parameter ε, which adjusts the distribution of emissions across income groups. Results showed that changes in ε have a more pronounced effect on top-income groups; when $\varepsilon=0$ (ie, equal per-capita distribution within groups), the top 10% of the population accounted for 1% less of the total HCF; conversely, when $\varepsilon=1$, their share increased by 1% (appendix p 25). Despite this variation, the overall trends and key conclusions of our study remain reliable. Then, we applied the minimum and maximum estimates per person for different income groups[40] in our scenario analysis to obtain the uncertainty range of estimates.

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.

	A1	A2	B1	B2	C1	C2	C3	D1	D2	D3	D4	D5
Controlling health-care overuse	Increase per-capita health spending across income groups to the ambitious health-care coverage benchmark[40]	··	Reduce health-care overuse by top 10% groups to the lowest level within their segment	Reduce health-care overuse by top 20% groups to the lowest level within their segment	··	··	··	A1 + B1	A1 + B2	A1 + B1	A1 + B2	A1 + B2
Reducing emission intensity	··	··	··	··	Reduce emission intensity for top 10% groups to the segment's lowest level	Reduce emission intensity for top 20% groups to the segment's lowest level	Reduce emission intensity for the 10–30% group to the segment's lowest level	··	··	C1	C2	C3
Expanding health coverage	··	Narrow the gap for segments below the median by raising their spending to the median within each country	··	··	··	··	··	A2	A2	A2	A2	A2

A1–D5 are 12 scenario designs.

***Table:* Overview of scenario designs**

Results

The global distribution of HCFs shows inequality patterns similar to those of the overall global carbon footprint, and we tested this hypothesis using a large sample of population segments. The highest-spending 10% of all health-care consumers accounted for 48% of the total HCFs in 2017, down by 8% from 2007 (figure 1A). This finding partly reflects the expansion of UHC and increased health-care spending among the middle groups, which contributes to a reduction in disparities in the associated carbon footprints. In contrast, the bottom 50% of consumers contributed only around 6% of the total HCF. In 2017, the top 1% of health-care consumers had an HCF of approximately 2857 kg CO_2e per capita, more than eight-times the global population-weighted average (340 kg CO_2e per capita) and nearly 66-times that of the bottom 50% (43 kg CO_2e per capita), with no notable change over time (figure 1B). There is regional inequality in HCFs across income quintiles, particularly when comparing HICs, such as those in North America and Europe, with LICs in sub-Saharan Africa (figure 1C). The USA in particular stood out because of its high total HCF and per-capita HCF, in addition to elevated health-care expenditure. Among its population, the richest quintile was responsible for more than 186 Mt CO_2e, approximately 1·7 times that of the poorest quintile (109 Mt). In contrast, even the richest quintile in countries within sub-Saharan Africa and the Middle East and north Africa had HCF levels of less than 10 Mt CO_2e (appendix p 29).

There was persistent spatial heterogeneity in within-country HCF inequality (figure 1D). The highest within-country HCF Gini coefficients reached approximately 0·3 in 2017, which is lower than the level of global HCF inequality observed between countries (Gini=0·69, appendix p 27). By 2017, although modest reductions in HCF inequality occurred in some regions, particularly parts of eastern Europe and continental America, HCF inequality remained high or even worsened in several countries in sub-Saharan Africa and south Asia and east Asia–Pacific (appendix p 28). These patterns are closely associated with differences in national health financing structures. In many LICs, low public financing and underdeveloped health-care insurance systems have resulted in a greater reliance on household OOPS, making household HCF more directly linked to individual financial capacity (figure 2A). In contrast, although HICs generally have more comprehensive health systems, disparities in HCFs persist within countries.

HICs maintained consistently high levels of HCFs over time. In contrast, UMICs showed a substantial rise, with total HCF increasing from about 181 Mt CO_2e in 2005 to 760 Mt CO_2e in 2017, representing more than a three-fold increase. Meanwhile, LMICs and LICs remained at the lowest levels, with total HCF in LICs declining from about 95 Mt CO_2e to 24 Mt CO_2e over the same period (a 75% decrease) (figure 2A). Government health scheme spending (green) and compulsory health insurance spending (yellow) were the main contributors to HCFs in HICs. In LMICs and LICs, OOPS (red) accounted for a larger share of HCF than HICs and HMICs, which reflects the structure of national health systems: in HICs, public health-care mechanisms support access to health goods and services, whereas in LICs, health-care consumers shoulder more of the costs themselves. In 2017, OOPS-based HCFs accounted for more than half of the national HCFs in non-HICs (64% [15 Mt CO_2e] in LICs, 53% [65 Mt CO_2e] in LMICs, and 46% [340 Mt CO_2e] in UMICs), compared with just 23% (336 Mt CO_2e) in HICs (appendix pp 29–30).

Across all countries, the richest quintile (Q5) consistently accounted for the largest share of HCFs, typically exceeding 25% of the total in 2017 (figure 2B). This disparity was more pronounced in LICs, where Q5 contributed more than a third of the total. In contrast, the poorest quintile (Q1) contributed only around 10%. In terms of health-care consumption categories, in HICs, Q5 generated the highest HCF through health services, mainly driven by differences in their access and options, including resource-intensive health-care services (figure 2C). In UMICs and LMICs, the share of HCFs from pharmaceuticals increased with income. In LICs, more than half of total HCFs came from pharmaceuticals and medical devices across all income quintiles, highlighting low access to formal health-care services and a reliance on self-medication. Among these populations, richer individuals with greater purchasing power contributed to higher pharmaceutical and services-related carbon footprints than poorer individuals (appendix p 30).

Then, all population groups were reranked by per-capita health-care spending and aggregated into population quintiles (Q1–Q5), with per-capita spending ranging from the lowest (Q1) to the highest (Q5), to better illustrate HCF patterns driven by health-care consumption categories. The quintile with highest per-capita health-care expenditure (Q5) of the population consistently had the highest per-capita HCF across all health-care consumption categories in 2017, exceeding the global per-capita average (dashed line; figure 3A). Although Q5 presented lower carbon intensity than the other quintiles, namely lower HCFs per unit of expenditure (figure 3B), their greater carbon efficiency still did not offset the emissions associated with their much higher health consumption.

The spending–emission elasticity quantifies the change in HCF resulting from a change in expenditure (figure 3C). Values more than 1 indicate that HCF increases faster than spending, identifying which expenditure growth drives larger emission increases (appendix p 21). Except for medical devices, Q1 showed a downward trend in the spending–emission elasticity across categories by 2017 (appendix p 33), whereas Q5 displayed higher elasticity than Q1 in all categories except administration. This spending-emissions elasticity pattern suggests that marginal emissions of health-care expenditure are disproportionately higher among high-spending groups than among low-spending groups. Particularly for medical

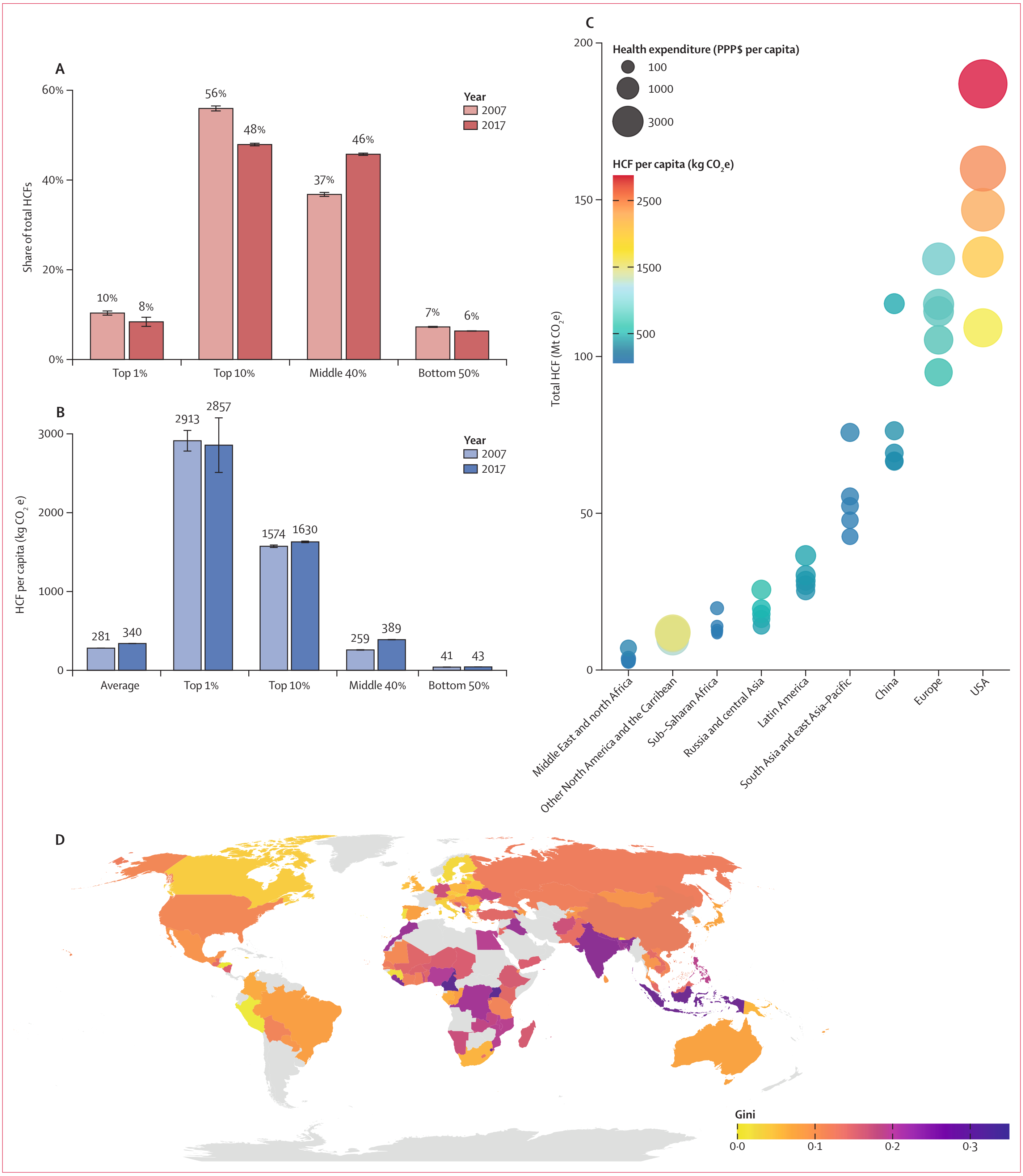

Figure 1: **Inequality in global HCFs**

Share of total HCFs (A) and per-capita HCF (B) of the highest-spending top 1%, top 10%, middle 40%, and bottom 50% health-care consumer groups. (C) The distribution of total HCFs by income quintiles across regions in 2017. Total HCF represents the sum of all countries or territories within the region. Bubble sizes indicate the per-capita health expenditure of each income quintile within the region group, and colour represents its per-capita HCF. (D) Distribution of within-country HCF inequality, measured by the Gini coefficient across income quintiles within each country in 2017. The results shown are based on the benchmark parameters (β=0, δ=1, and ε=0·5), and error bars reflect estimates under extreme parameters. Details are provided in the appendix (pp 17–20). CO_2e=CO_2 equivalent. HCF=health-care carbon footprint.

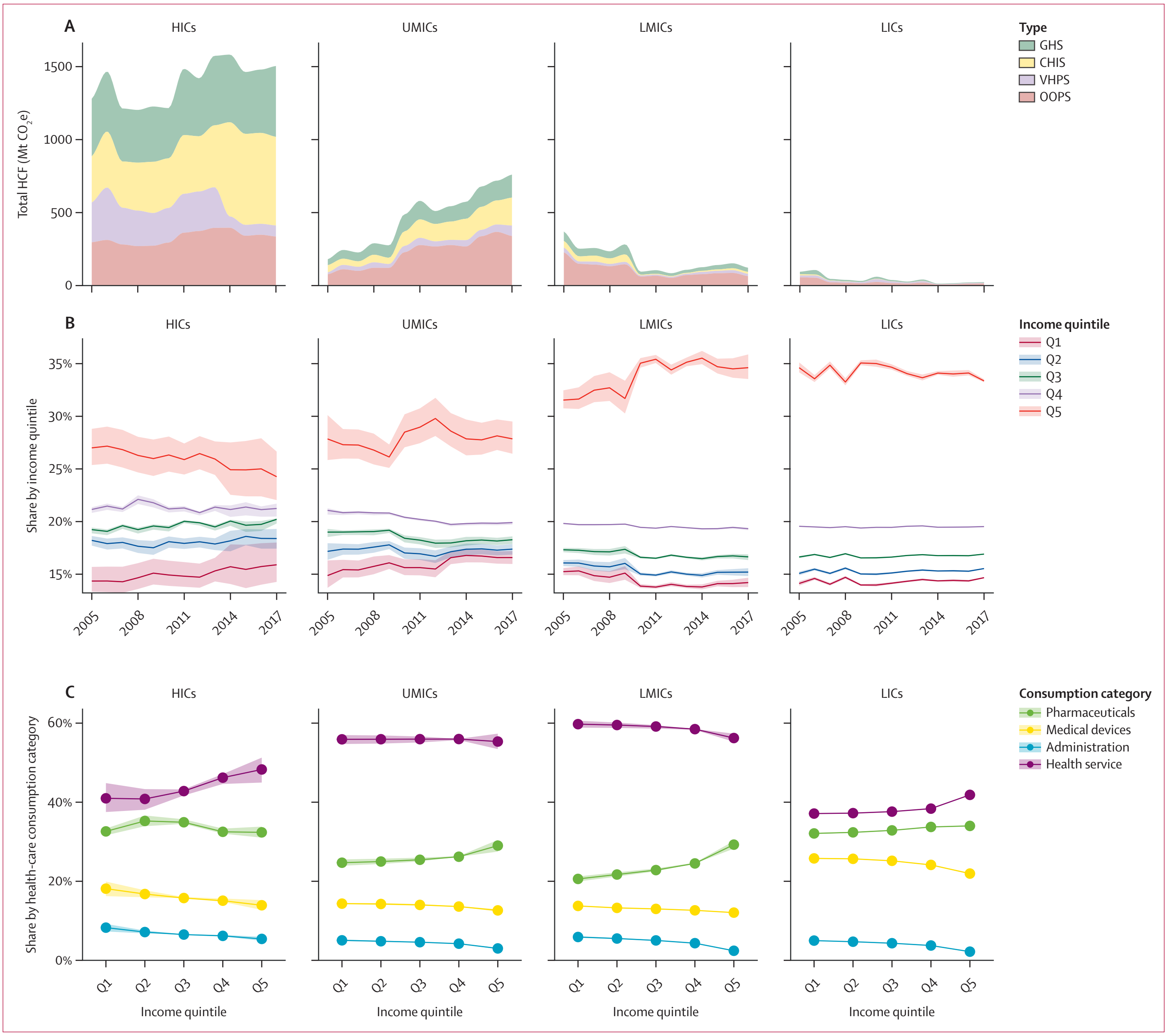

Figure 2: **Heterogeneity of HCF across payer categories, income quintiles, and consumption categories**

The panels are arranged by country income classifications: HICs, UMICs, LMICs, and LICs. (A) The distribution of HCFs by four payer categories, namely, GHS, CHIS, VHP, and household OOPS. Share of HCFs across income quintiles from 2005 to 2017 (B) and health-care consumption categories by income quintiles in 2017 (C). CHIS=compulsory health insurances. CO_2e=CO_2 equivalent. GHS=government health schemes. HCF=health-care carbon footprint. HIC=high-income country. LIC=low-income country. LMIC=lower-middle-income country. OOPS=out-of-pocket payments. UMIC=upper-middle-income country. VHP=voluntary health payments.

devices and health administration within Q5, the health spending–emission elasticity exceeded 1 (dashed line), indicating that the growth in their HCF exceeded the growth in health expenditure.

Appropriate or inappropriate health care and its implications for sustainability are well recognised issues that require attention,[41] with previous studies showing that countries with similar Healthcare Access and Quality scores can have widely different per-capita health-care emissions.[42] Our results further indicate that for some affluent high-spending groups, their additional expenditure drives higher carbon footprints without evidence of further improving health outcomes, consistent with low-value care.[21–23] Building on multiple aspects of sustainable health care discussed in previous studies, we evaluated one baseline and 12 scenarios to compare the potential for global health-care emission reductions while promoting the UHC target (SDG3). These scenarios reflect

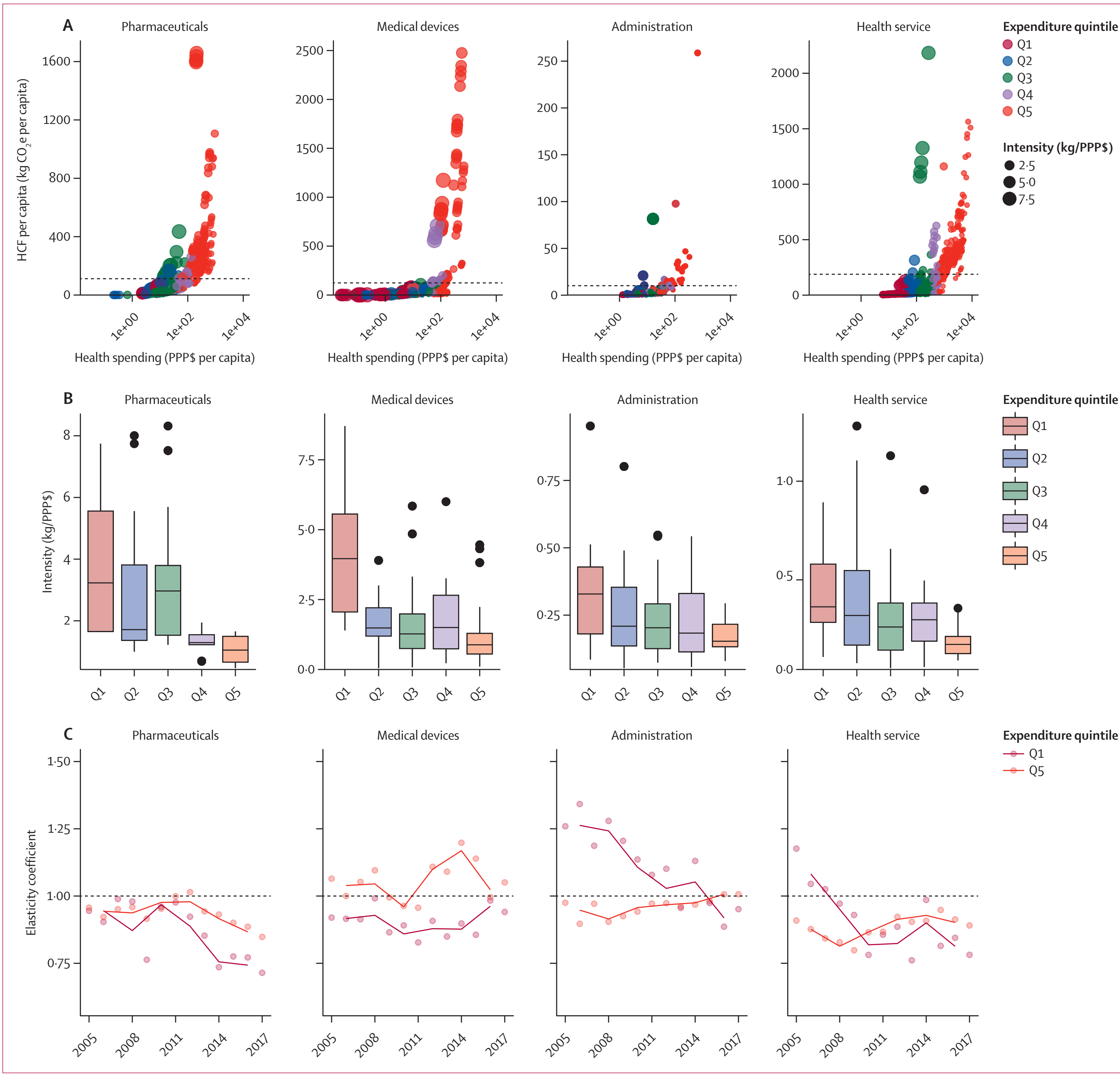

Figure 3: **Disparities in HCF across health-care consumption categories**

(A) The evolution of per-capita HCF with rising per-capita health expenditure of population segments in 2017. (B) Changes in health-care carbon intensity across five quintiles in 2017, wherein carbon intensity is emissions per unit of expenditure (unit in kg CO_2e per PPP$). (C) Trends in the expenditure–carbon elasticity for the spending quintile Q1–Q5, from 2005 to 2017. CO_2e=CO_2 equivalent. HCF=health-care carbon footprint. PPP$=purchasing power parity-adjusted international dollars.

three main dimensions: increasing health-care costs to meet ambitious benchmarks[40] for achieving UHC while enhancing within-country equity; reducing emissions from health-care overuse among some top health-care consumers without compromising on essential health outcomes; and lowering the carbon intensity of expenditure (expanding and shifting towards lower-carbon options) within some consumer groups.

Based on the sample of this study, increasing investment to reach more ambitious health-care benchmarks (A1) would increase global HCF by 5% (98 Mt CO_2e, range 55–242), and improving expenditure for lower-

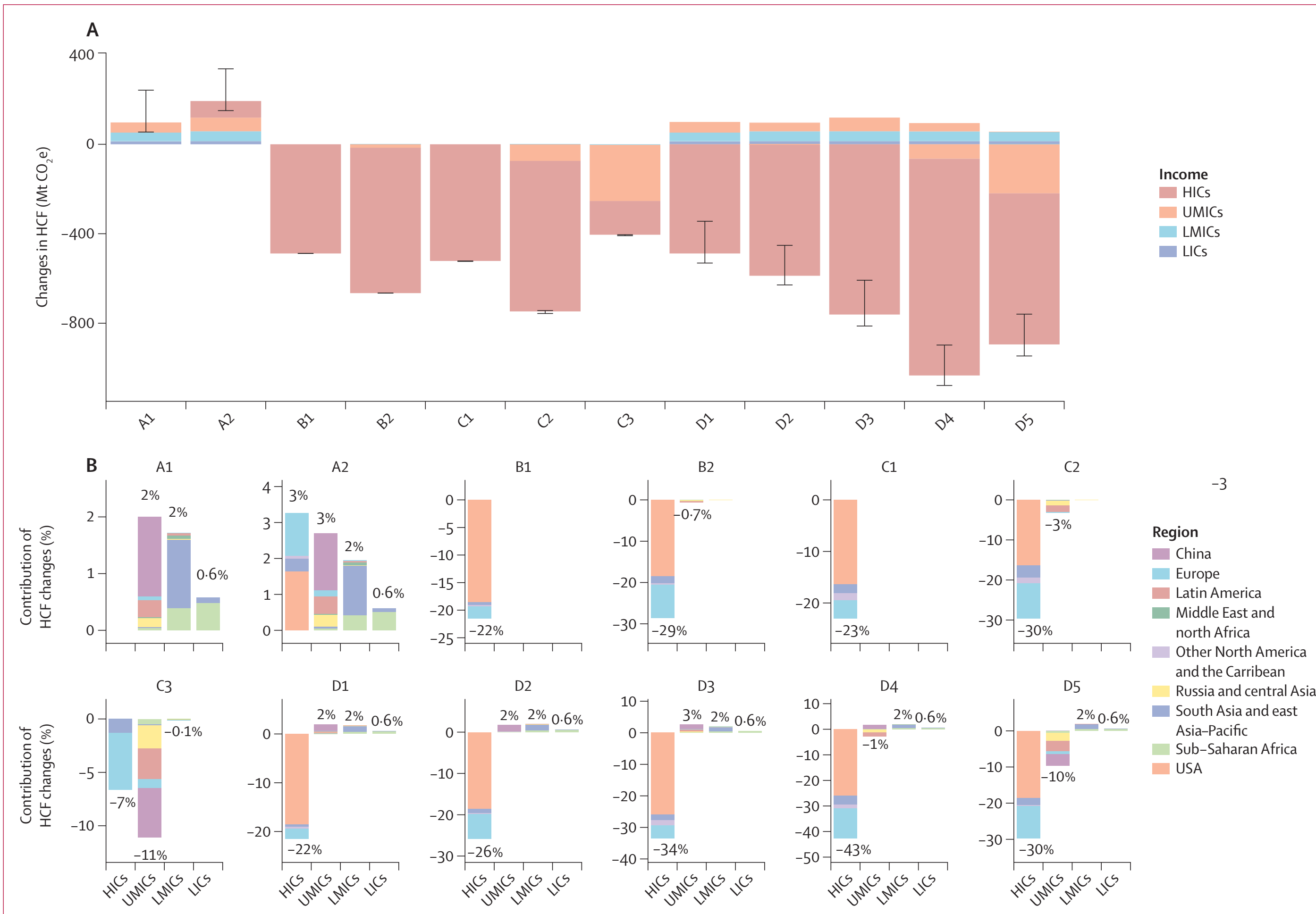

Figure 4: **Changes in total HCFs under different demand-side intervention scenarios: 12 scenarios (A1–D5) are considered, based on data from 2015**
(A) Upper panel shows the total HCF change under different interventions, as compared with the BAU scenario (Mt CO_2e), with colours used to distinguish the contribution of country groups classified by different income levels. (B) The lower faceted panels detail the contribution shares of different regions within country groups classified by income level under each scenario (%). BAU=business-as-usual. CO_2e=CO_2 equivalent. HCF=health-care carbon footprint. HIC=high-income country. LIC=low-income country. LMIC=lower-middle-income country. UMIC=upper-middle-income country.

income population groups in non-HICs simultaneously (A2) would do so by 9% (193 Mt CO_2e, 150–337) (figure 4). In contrast, reducing health-care overuse among the top 10% (B1) of health-care consumers would reduce HCFs by approximately 22% (–488 Mt CO_2e) and that in the top 20% (B2) by approximately 29% (–666 Mt CO_2e). If the carbon intensity of expenditure among the top 10% of health-care consumers was reduced to the lowest level within each group (C1 to C3), then HCFs would decline by 23% (–522 Mt CO_2e, –524 to –522); if among the top 20%, then by 33% (–746 Mt CO_2e, –757 to –744); and if among the top 10–30%, then by 18% (–404 Mt CO_2e, –409 to –404). Overall, expanding health-care coverages results in modest increases in HCFs as compared with the substantial reductions achievable by reducing overconsumption among high-expenditure groups. Combining A2 with B1 (corresponding to D1) can reduce the total HCF by approximately 17% (–391 Mt CO_2e, –434 to –247) and combining A2 with B2 (corresponding to D2) by approximately 22% (–491 Mt CO_2e, –532 to –355). Even when accounting for the additional HCFs associated with the extra health-care costs required to achieve ambitious UHC targets and enhance within-country health-care equity (D3 to D5), a combined strategy targeting both overuse and high-carbon health-care practices among the top health-care consumer quintile could reduce total HCFs by up to about 41% (–939 Mt CO_2e, –984 to –803).

Discussion

This study reveals clear spatiotemporal patterns of inequality in HCFs between and within countries by integrating multiple sources of bottom–up detailed expenditure data with top–down carbon measurement approaches across diverse population groups. Within countries, wealthier groups generally have higher per-capita HCFs than poorer groups. At the same time, the fact that health-care systems are not fully market-driven in most countries leads to larger disparities in HCFs between countries than within them (figure 1). HICs contribute disproportionately to global HCFs, whereas LICs contribute less (figure 2A). The observed reduction in total HCF in LICs might reflect their fluctuating domestic health-care expenditures or decreased carbon emissions per unit of health-care service during the study period. However, despite their much lower contributions, LICs are well known to face a heavier health burden.[1,15,43] In some countries, care recipient preferences for imported equipment or frequent consultations often stem from deep-rooted distrust in medical institutions, asymmetrical information, and fragmented care pathways.[44] Expanding insurance coverage improves access and also reduces cost sensitivity, which encourages the overuse of treatments and procedures (such as repeated imaging, unnecessary hospital admissions, and pharmaceuticals) that frequently provide little additional health benefit.[45–48] In contrast, the high proportion of OOPS in LICs compels residents to restrict health-care use. Although this practice constrains overuse, it does so at the cost of access to essential services, including low-carbon options.

Generally, high-spending populations are positioned at lower levels of carbon intensity than low-spending populations, reflecting differences in efficiency and technology, in addition to the greater opportunity that wealthier consumers generally have to adopt low-carbon technologies than their poorer counterparts.[17,42] Nevertheless, the additional health-care spending of high-spending populations tends towards goods and services with high marginal emissions, making these groups important targets for emission-reduction strategies.

The insights from this study support considering health-care decarbonisation as a mechanism for achieving health equity. High marginal emissions associated with some categories of expenditure among high-income populations are crucial. These carbon-intensive goods and services (eg, categories with elasticity>1; figure 3C), which provide little health gain, can unlock substantial emission-reduction potential through targeted interventions. Conversely, expanding basic health-care coverage for low-income populations would result in modest emission increases, but with the potential to substantially improve health outcomes. Finally, technological and process improvements to reduce carbon intensity can complement the efforts described: lower-income groups can reduce the carbon costs of expanding health-care coverage, whereas higher-income groups can use the saved emissions budget to help poorer groups to expand services. Ultimately, this approach achieves the dual benefit of reducing overall emissions while narrowing health inequalities.

These findings indicate that meaningful decarbonisation can be achieved without compromising on essential health services or health-care equity, by reducing overuse and carbon-intensive health-care consumption among a small but disproportionately impactful segment of the population.

Specifically, policy makers need to strengthen demand-side actions, including clarifying the environmental costs of health care (eg, carbon labelling)[49] to support evidence-based decision making, promoting alternative low-carbon technologies or services, and reforming payment and incentive mechanisms to guide sustainable demand. Moreover, with prioritisation of equitable health care, low-carbon strategies need to be tailored for different population groups. For wealthier, high-spending groups, identifying and reducing public funding for low-value care can reduce marginal emissions without compromising health-care quality. For low-income populations and middle-income populations, low-carbon targets should be established on the basis of ensuring and expanding health-care coverage. International support for technology transfer and financing can help these consumers to bypass carbon-intensive stages. In general, the green transition of health-care systems requires coordinated multistakeholder efforts, including a systematic understanding of market characteristics, national health policies and financing, and the incentives and decision-making models of providers.[50] Future research should further integrate health-care policy, market structures, and beneficiary characteristics into low-carbon health-care analysis. Developing decision-support tools (including artificial intelligence-assisted diagnostics) to guide providers towards evidence-based, rational, and sustainable decisions is essential. Ideally, a health system based on rational demand enables individuals to naturally achieve the health benefits of avoiding overuse within default treatment, including less waste, lower costs, and climate adaptation.

The limitations of this study stem from the particularity of the medical market and the inherent characteristics of the EE-MRIOs. As noted earlier, health-care products and services differ from general consumer goods in both complexity and essentiality. This study allocates HCFs on the basis of the final demand-based principle, which ensures accounting feasibility and supports cross-country comparability. In terms of model and data, carbon intensities at the sector level are fixed in the EE-MRIO for each country. This treatment assumes that health-care expenditure is linearly related to carbon emissions, which can lead to over-estimations of emissions among the highest spenders and underestimations among the lowest. This limitation has been widely recognised in previous literature.[17,51,52] In addition, the CES and GHED datasets present heterogeneity within and across countries. Despite this heterogeneity, these datasets remain the best available choice because of their wide coverage and detailed classification (appendix p 23). Nevertheless, this study identifies emission-reduction opportunities and priority areas rather than evaluating the feasibility of specific measures. As highlighted in previous studies, such findings should be interpreted with caution. Estimates of mitigation potential for top groups represent theoretical upper bounds rather than guaranteed or readily achievable targets.

Contributors
HZ and WC designed the study. HZ developed the modelling framework and wrote the original draft, with contributions from ShaZ and ML. ShiZ and WC provided constructive comments to improve the original draft. All authors were responsible for reviewing and editing the manuscript. HZ and WC verified the data. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests
We declare no competing interests.

Data sharing
The original data and code for the figures are available at public sources.

For more on the **original data and code** see https://doi.org/10.5281/zenodo.15767424

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