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Health burden and costs attributable to the carbon footprint of the health sector in the European Union

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ABSTRACT

Background: The healthcare sector has an environmental impact of around 4.6% of global CO_2 emissions, contributing to aggravating the climate crisis. However, the impact of the health sector's emissions on human health is not regularly assessed. We aim to estimate the health burden and associated costs of the health sector's carbon footprint within the European Union (EU).
Methods: We calculated disability-adjusted life years (DALYs) and associated costs based on human health damage factors (DALYs/kg-CO_2e) by considering four scenarios. Three scenarios for shared socioeconomic pathways (S1 – high growth, S2 – baseline, and S3 – low growth) represented variations of global society, demographics, and economics until 2100. A fourth scenario (S4) considered the current EU's 55% reduction goal of greenhouse gas emissions. The healthcare sector's emissions per capita (in CO_2-equivalent) in 2019 were extracted from the Lancet Countdown, and population data were retrieved from Eurostat for the same year.
Results: In the EU, 365,047 DALYs (95%CI: 194,692–535,403) are expected to be caused by the health sector's emissions at baseline (S2). In an S1 scenario, the burden would slightly decrease to 316,374 DALYs (95%CI: 170,355–462,393), whereas a S3 scenario would increase 486,730 DALYs (95%CI: 243,365–681,422). If EU's carbon goals are met, the burden could be substantially reduced to 164,271 DALYs (95%CI: 87,611–240,931). Costs can amount to 25.6 billion euros, when considering DALYs monetisation.
Conclusion: CO_2 emissions from the health sector are expected to significantly impact human health. Therefore, it is important to ensure that EU climate policies for public buildings are in line with the Paris Agreement, increase funding for climate mitigation programs within the healthcare sector, and review clinical practices at the local level.

1. Introduction

Climate change is affecting the health sector, by increasingly overburdening healthcare services and the shortage of health workforce, compromising the sustainability of health systems and worsening health inequalities (Watts et al., 2019). As such, there is a need for health systems not only to adapt to the climate crisis, but also to have a role in mitigating climate change by limiting its contribution to global warming, as to reduce emissions and rethink practices.

According to the United Nations, buildings represent around 35 % of the global energy consumed, leading to almost 40 % of energy-related CO_2 emissions (Khasreen et al., 2009; UN Environment and International Energy Agency, 2017). In addition, buildings consume a large amount of water throughout their life cycle, in addition to the energy

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Abbreviations: CO_2, Carbon Dioxide; CO_2e, Carbon Dioxide-equivalent; CSDDD, Directive on Corporate Sustainability Due Diligence; DALY, Disability-Adjusted Life Year; EU, European Union; GHG, Greenhouse Gases; Kg, Kilogram; IPCC, Intergovernmental Panel on Climate Change; $PM_{2.5}$, Pollution from Fine Particulate; tCO_2e, tonnes of Carbon Dioxide-equivalent; UI, Uncertainty Interval; WTP, Willingness to Pay.

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y and use, which has increased in recent decades (Rothausen and Conway, 2011), leading to an increase in emissions and consequently, a greater negative environmental impact (Mannan and Al-Ghamdi, 2020).

Recent studies estimate that the health sector makes an important contribution to the climate crisis, with around 4.4 % of total greenhouse gas (GHG) emissions (Health Care Without Harm and ARUP, 2019a). A study reports the experience of the United States, whose use of resources leads to the production of about 7000 tons of hospital waste daily and an annual cost of 10 billion dollars in their management (Senay and Landrigan, 2018). In addition, in the same country, 85 % of the waste produced in a general hospital is not hazardous, often placed in the biological waste container, increasing waste management costs and the environmental impact due to inadequate waste treatment (Kaplan et al., 2012).

Actions developed in healthcare organizations that aim to improve the technical efficiency of basic provisioning systems (i.e. in the energy sector, building maintenance and transport) can contribute to better healthcare and reduce the environmental impact. Senay and Landrigan (2018) suggest that the application of energy saving measures and the reprocessing of single-use materials can originate a cost reduction of around ten billion dollars over ten years. Another study compares initiatives that contribute to the institution's resilience in the face of climate change, demonstrating their long-term cost-effectiveness (Balbus et al., 2016). Pisters et al. (2017). reinforce the importance and need for organizational commitment, combined with the reduction of energy consumption, as key elements for the success of the institution. A study suggests that these measures such as corporate culture, institutional commitment to climate goals and stakeholder engagement, as well as waste management, can reduce greenhouse gas emissions by 142 tons. As such, the health care sector can play an important role in sustainable transformation.

Despite the high burden on the environment, only a few studies have estimated the impact of the carbon footprint of health systems on human health. Eckelman and Sherman (2018) have estimated the disease burden of the United States' health care system, with expected 123 thousand to 381 thousand disability-adjusted life-years (DALYs) in future health damages. The Lancet Countdown presents a worldwide estimate of 4 million DALYs annually, basing estimates on particle pollution from fine particulates ($PM_{2.5}$) and ozone alone (Romanello et al., 2023).

Disaggregated data regarding the healthcare emissions in human health is essential for policymaking, especially in the European region, where European Union (EU) policies may play a significant role in tackling climate change mitigation and adaptation. Therefore, our study aims at estimating the burden and costs of the carbon footprint of the health sector in the EU, using health damage factors. The impact of climate change on health, especially with considerations of different scenarios, may be useful for evidence-informed policy making in the EU.

2. Methods

2.1. Burden of disease assessment and scenarios analysed

Burden of Disease studies aim to quantify the health impact of diseases and risk factors in composite metrics, such as the DALY. DALY is a widely used health metric, which was developed for and is used in the Global Burden of Disease study (Murray, 1996).

The healthcare sector's carbon emissions per capita were extracted from the Lancet Countdown (2019), and population data were retrieved from Eurostat for the respective year. We considered all countries that are part of the EU on the date of this study, which excludes the United Kingdom. The same calculations were carried out for 2020, available in the Supplementary Material.

The different GHGs extracted were expressed in carbon dioxide equivalents (CO_2e), which represent their ability to absorb and re-emit radiation back to the Earth's surface over their lifetimes, relative to that of CO_2.

We calculated the burden of disease for three different scenarios of shared socioeconomic pathways (S1 – high growth, S2 – baseline, and S3 – low growth) representing variations of global society, including demographics, economics, international cooperation, and energy technology development until 2100, combing with levels of climate mitigation, land use and air pollution control. (Calvin et al., 2023). These scenarios were designed to consider the range of challenges to climate change mitigation and adaptation.

A fourth scenario (S4) considered the current EU's 55 % reduction goal of GHG emissions (European Commission, 2020) over the 1990 values. A report from the European Environment Agency (2021) states that the EU has reached in 2019 a 24 % decrease over 1990 values.

We utilized health damage factors (in DALYs/kg CO_2e emitted), derived by Tang et al. (2019) from an integrated assessment of additional deaths per mass unit of GHG emissions attributable to climate change, as reported by the World Health Organization (2014), and from estimates for GHG emissions presented by the Intergovernmental Panel on Climate Change (IPCC) to the year 2100 (Field and Barros, 2014). The health damage factors considered relative risks for malaria, diarrhea, malnutrition, cardiovascular disease due to heat stress, and coastal floods (Tang et al., 2019). Additional details about the calculations of health damage factors are present in the Supplementary Material.

The final health damage factors, considering a customary 100-year global warming potential value, were:

- **S1 (high growth):** 1.3×10^{-6} (0.7×10^{-6}–1.9×10^{-6}) DALY/kg CO_2e
- **S2 (baseline):** 1.5×10^{-6} (0.8×10^{-6}–2.2×10^{-6}) DALY/kg CO_2e
- **S3 (low growth):** 2.0×10^{-6} (1.0×10^{-6}–2.8×10^{-6}) DALY/kg CO_2e
- **S4 (EU 55 % goal)**: 1.5×10^{-6} (0.8×10^{-6}–2.2×10^{-6}) DALY/kg CO_2e

S4 assumes the same health damage factors as the baseline, with a different endpoint on carbon emissions. All DALYs estimates were reported with uncertainty intervals (UI) of 95 %.

2.2. Monetisation of DALYs

For the estimation of costs attributable to carbon emissions of health systems, we applied two methodologies: costs per DALY and carbon offset costs.

For determining the cost per DALY, we defined the cost as equivalent to the value of a life year of 70,000 euros, with a range of 50,000 to 110,000 euros (de Bruyn et al., 2018).

Carbon offset costs are compensation of emissions by funding an equivalent CO2 saving elsewhere. The price of carbon offsets depends on a number of factors, including geographical region, provider, project type, certifying standard, among others, and remains largely unregulated (Groom and Venmans, 2023). On a global scale, the typical costs for carbon offsets present a variable range from 1 to 50 dollars, with certified offsets from reputable providers falling within the 9–15 dollars per tonne of CO_2-equivalent emissions (tCO_2), which is reflected in a price of around 12 euros (Kim and Pierce, 2018). The cost of consumer offsets has been reported through the willingness to pay (WTP) for CO_2, with a preferential threshold of 16 euros/tCO_2 for consumers, and an average hypothetical WTP of 200 euros/tCO_2 (Rodemeier, 2023).

On the other hand, carbon taxes have been emerging as a form of state regulation that determines a price on carbon emissions, as a way to promote the reduction of GHG emissions. The carbon tax within the European Union's Emissions Trading System is expected to reach 74 euros/tCO_2 in 2030 (Heflich and Saulnier, 2022). This value was considered as an alternative methodology for calculating the cost of GHG emissions in our study, as they attribute a monetary value to each tonne of GHG emitted into the atmosphere. To avoid this cost, economic operators might invest in cleaner technology, reduce waste, or find other ways to lower their emissions, serving as a proxy for the cost of GHG emissions.

3. Results

3.1. Burden of disease

In the EU, a total of 365,047 DALYs (95 % UI: 194,692–535,403) are expected to be caused by health sector's emissions at baseline (S2). Fig. 1 shows the geographical distribution of DALYs across EU countries: Germany, with an expected 101,716 DALYs (95 % UI: 54,249–149,184), Italy (40,945 DALYs, 95 % UI: 21,837–60,053) and France (32,540 DALYs, with 95 % UI: 17,355–47,725), which correspond to the countries with higher GHG emissions (67,810.8, 27,296.7 and 21,693.2 kton, respectively). On the other side, the countries presenting the lowest health burden are Malta, with 381 DALYs estimated (95 % UI: 203–559), and Luxembourg, with 654 DALYs (95 % UI: 349–960), which correspond to the countries with lower GHG emission (254.0 and 436.3 kton, respectively).

The distribution of DALYs considering the different health damage factors, according to outcomes considered in the WHO report, for different scenarios are available in Fig. 2. For the baseline S2 scenario, most of the disease burden is attributed to undernutrition (69.6 %), followed by malaria (14.9 %) and coastal floods (8.5 %). The low growth scenario (S3) would increase the burden attributable to malaria (20.1 %) and diarrhoea (7.2 %), whereas a high growth scenario would slightly increase malaria to 15.3 %.

Table 1 presents the distribution of the estimates for EU and different countries in each of the scenarios. The health sector estimates of DALYs associated with greenhouse gas emissions in the EU compared to the baseline scenario (S2) show that in S1 (high growth) the burden would decrease slightly to 316,374 DALYs (95 % UI: 170,355–462,393), whereas in S3 (low growth) the burden would increase to 486,730 DALYs (95 % UI: 243,365–681,422). If the EU's carbon goals are met (S4), the burden could substantially reduce to 221,988 DALYs (95 % UI: 118,394 – 325,583). The estimations of DALYs attributable to greenhouse gas emission of the health sector follow the decrease (S1) and increase (S3) of the burden trend observed for the EU estimations in different scenarios. Germany and Malta were the countries with highest and lowest burden-health care emissions estimation, respectively, for each scenario.

When comparing with 2020 values, available in the Supplementary Table S1, GHG emissions have generally decreased in the EU, with a variation of −20 %. However, four countries presented positive variations, including Cyprus, Estonia, Luxembourg, and Malta, with increases ranging from 54.0 % to 586.6 %.

3.2. Monetisation of costs

The estimations for the contribution of EU's health systems emissions to climate change translated to costs per DALY allowed us to analyse the economic impact associated with disease burden for each of the scenarios. The results of the estimations, when considering a cost of 70,000 euros per DALY, are presented in Table 2.

The baseline scenario (S2) showed that health costs associated with health sector's GHG emissions can amount to 25.6 billion euros (Range: 18.2–40.2 billion euros). To note that costs would decrease by around 39 % in an optimal scenario (S4), with a total cost of 15.5 billion euros (range: 11.1–24.4 billion euros).

The estimation of costs through carbon offsets was conducted using four different values, as mentioned in the Methods section. Considering a standard market price of carbon offset of 12 euros, the total cost would

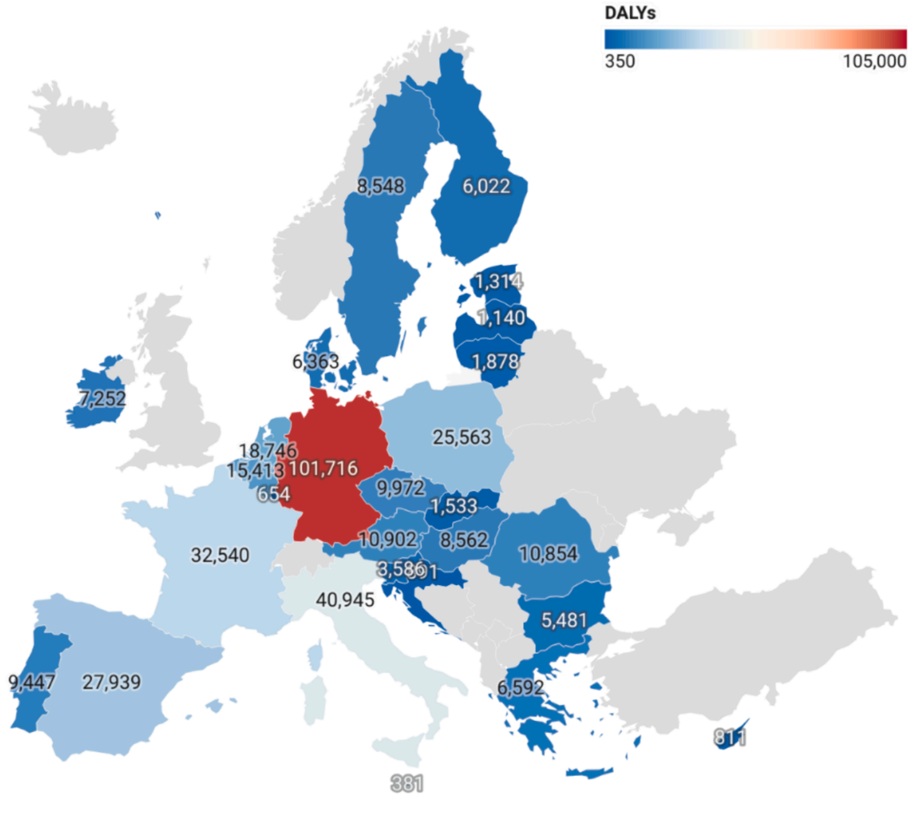

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Fig. 1. Geographical distribution of disability-adjusted life years (DALYs) in the European Union considering the baseline scenario.

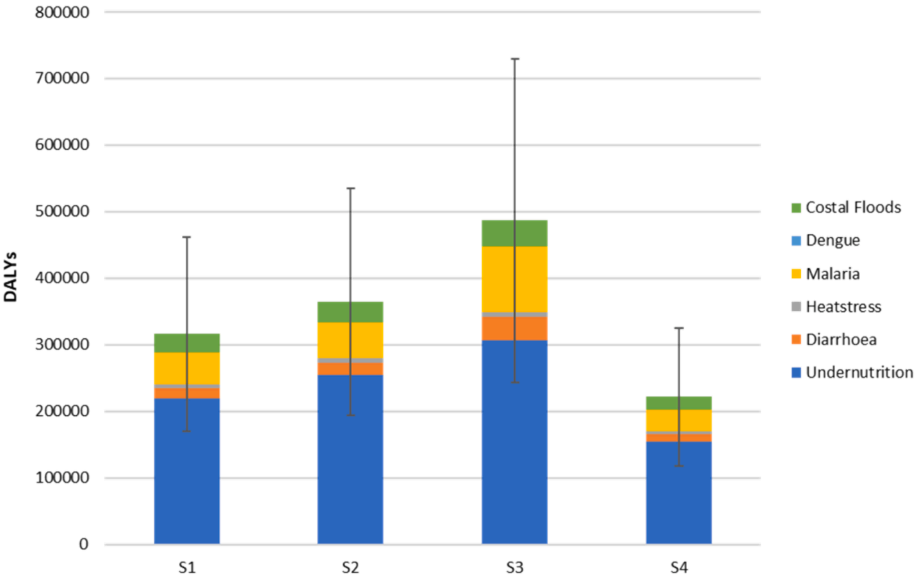

Fig. 2. Distribution of disability-adjusted life years (DALYs) across different scenarios (S) and by disease factor. S1: high growth; S2: baseline; S3: low growth; S4: EU's carbon goals are met.

Table 1
Estimations of health burden attributable to greenhouse gas emissions of the health sector in the European Union, by country.

Country	GHG emissions (kton)	S1		S2		S3		S4	
		DALYs	95 % UI	DALYs	95 % UI	DALYs	95 % UI	DALYs	95 % UI
Austria	7,267.9	9,448	5,088 – 13,809	10,902	5,814 – 15,989	14,536	7,268 – 20,350	6,630	3,536 – 9,723
Belgium	10,275.4	13,358	7,193 – 19,523	15,413	8,220 – 22,606	20,551	10,275 – 28,771	9,373	4,999 – 13,747
Bulgaria	3,654.3	4,751	2,558 – 6,943	5,481	2,923 – 8,039	7,309	3,654 – 10,232	3,333	1,778 – 4,889
Croatia	594.1	772	416 – 1,129	891	475 – 1,307	1,188	594 – 1,663	542	289 – 795
Cyprus	540.9	703	379 – 1,028	811	433 – 1,190	1,082	541 – 1,515	493	263 – 724
Czechia	6,647.9	8,642	4,654 – 12,631	9,972	5,318 – 14,625	13,296	6,648 – 18,614	6,064	3,234 – 8,894
Denmark	4,242.1	5,515	2,969 – 8,060	6,363	3,394 – 9,333	8,484	4,242 – 11,878	3,869	2,064 – 5,675
Estonia	876.2	1,139	613 – 1,665	1,314	701 – 1,928	1,752	876 – 2,453	799	426 – 1,172
Finland	4,014.7	5,219	2,810 – 7,628	6,022	3,212 – 8,832	8,029	4,015 – 11,241	3,662	1,953 – 5,371
France	21,693.2	28,201	15,185 – 41,217	32,540	17,355 – 47,725	43,386	21,693 – 60,741	19,788	10,553 – 29,022
Germany	67,810.8	**88,154**	47,468 – 128,841	**101,716**	54,249 – 149,184	**135,622**	67,811 – 189,870	**61,854**	32,989 – 90,720
Greece	4,394.5	5,713	3,076 – 8,350	6,592	3,516 – 9,668	8,789	4,395 – 12,305	4,009	2,138 – 5,879
Hungary	5,707.8	7,420	3,995 – 10,845	8,562	4,566 – 12,557	11,416	5,708 – 15,982	5,206	2,777 – 7,636
Ireland	4,835.0	6,285	3,384 – 9,186	7,252	3,868 – 10,637	9,670	4,835 – 13,538	4,410	2,352 – 6,468
Italy	27,296.7	35,486	19,108 – 51,864	40,945	21,837 – 60,053	54,593	27,297 – 76,431	24,899	13,279 – 36,519
Latvia	760.1	988	532 – 1,444	1,140	608 – 1,672	1,520	760 – 2,128	693	370 – 1,017
Lithuania	1,252.1	1,628	876 – 2,379	1,878	1,002 – 2,755	2,504	1,252 – 3,506	1,142	609 – 1,675
Luxembourg	436.3	567	305 – 829	654	349 – 960	873	436 – 1,222	398	212 – 584
Malta	254.0	**330**	178 – 483	**381**	203 – 559	**508**	254 – 711	**232**	124 – 340
Netherlands	12,497.4	16,247	8,748 – 23,745	18,746	9,998 – 27,494	24,995	12,497 – 34,993	11,400	6,080 – 16,720
Poland	17,042.1	22,155	11,929 – 32,380	25,563	13,634 – 37,493	34,084	17,042 – 47,718	15,545	8,291 – 22,800
Portugal	6,298.0	8,187	4,409 – 11,966	9,447	5,038 – 13,856	12,596	6,298 – 17,634	5,745	3,064 – 8,426
Romania	7,236.1	9,407	5,065 – 13,749	10,854	5,789 – 15,920	14,472	7,236 – 20,261	6,601	3,520 – 9,681
Slovakia	1,022.0	1,329	715 – 1,942	1,533	818 – 2,248	2,044	1,022 – 2,861	932	497 – 1,367
Slovenia	2,390.9	3,108	1,674 – 4,543	3,586	1,913 – 5,260	4,782	2,391 – 6,694	2,181	1,163 – 3,199
Spain	18,625.9	24,214	13,038 – 35,389	27,939	14,901 – 40,977	37,252	18,626 – 52,152	16,990	9,061 – 24,918
Sweden	5,698.6	7,408	3,989 – 10,827	8,548	4,559 – 12,537	11,397	5,699 – 15,956	5,198	2,772 – 7,624
EU	**243,364.8**	**316,374**	**170,355 – 462,393**	**365,047**	**194,692 – 535,403**	**486,730**	**243,365 – 681,422**	**221,988**	**118,394 – 325,583**

Legend: DALYs – Disability-adjusted life years; GHG – greenhouse gas; kton – kilotonne; S – Scenario; UI – Uncertainty interval.

Table 2
Overall health costs attributed to climate change due to EU's health systems emissions, for each scenario (in million euro).

Scenarios	Cost	Lower Limit	Upper Limit	Variation
S1	22,146.2	15,818.7	34,801.2	−13.3 %
S2	25,553.3	18,252.4	40,155.2	–
S3	34,071.1	24,336.5	53,540.3	33.3 %
S4	15,539.2	11,099.4	24,418.7	−39.2 %

Legend: S – Scenario.

sum up to 2.92 million euros, whereas this cost assumes a higher value with the hypothetical WTP of 200 euros (48.67 million euros). Considering extending the enterprise carbon tax price of 74 euros would result in a total cost of 18.0 million euros (Table 3).

When analysing the cost per DALY derived from carbon offsets, this would reflect on a baseline (S2) price of 8.00 euros per DALY, with the hypothetical WTP translating into a cost of 100.00 euros per DALY.

Table 3
Total cost and estimated cost per DALY for each scenario analysed, in euros.

Price of Carbon offset	Total cost	Cost per DALY			
		S1 (95 % UI)	S2 (95 % UI)	S3 (95 % UI)	S4 (95 % UI)
12	2,920,378	9.2 (6.3–17.1)	8.0 (5.5–15.0)	6.0 (4.3–12.0)	13.2 (9.00–24.7)
16	3,893,838	12.3 (8.4–22.9)	10.7 (7.3–20.0)	8.0 (5.7——16.0)	17.5 (12.0–32.9)
200	48,672,969	153.9 (105.3–285.7)	133.3 (90.9–250.0)	100.0 (71.4–200.0)	219.3 (149.5–411.1)
74	18,008,999	56.9 (39.0–105.7)	49.3 (33.6–92.5)	37.0 (26.4–74.0)	81.1 (55.3–152.1)

Legend: DALY – Disability-adjusted life years; S – Scenario.

4. Discussion

This study performed the estimation of the health burden and expected costs of the EU's health systems greenhouse gas emissions, considering the potential impact of different social economic pathways and EU's 55 % reduction goal of greenhouse gas emissions.

This analysis allowed us to understand the magnitude of the contribution of health systems to climate change, which is expected to contribute with 365,047 DALYs (95 % UI 194,692 – 535,403) in the baseline scenario. This is particularly relevant to inform decision-makers and to support and create targeted interventions to reduce the carbon footprint of health systems. Some interventions have been proposed in a recent systematic review, which recommends tackling six different sources of GHG emissions, including building design, operations and logistics, waste, energy, heating and cooling, and anesthetic gases (Blom et al., 2024).

Previous analyses in European countries have been reported the carbon footprint of health systems, including France (The Shift Project, 2023), Portugal (Central Administration of the Health System, 2022), Austria (Weisz et al., 2020), and the Netherlands (Steenmeijer et al., 2022), with a carbon footprint ranging from 5.8 % to 8.0 %. However, these have not estimated the disease burden attributable to health systems emissions nor the associated costs.

On the other hand, a few papers published in North America do translate their carbon footprint into DALYs, namely in Canada (Eckelman et al., 2018) and the United States (Eckelman and Sherman, 2016), with values ranging from 23,000 DALYs in Canada, and 405,000 DALYs in the United States, the latter presenting similar values of those calculated in this study for the European Union in the baseline (365,047 DALYs). However, these studies have selected the IMPACT2002 + method for the life-cycle assessment, with specific health expenditure categories. While this and other methods can be used in life-cycle assessment, as LIME2 and ReCiPe, these differ significantly from the results from our study, as these do not account for economy, population growth and different disease classifications, limiting comparability (Tang et al., 2018). Moreover, estimates may not be comparable due to the use of a US-specific input–output database (Eckelman et al., 2020), or different health damage factors from the one used in this study – either disaggregated by GHG (van Zelm et al., 2016) or a previous estimate by Tang et al. (2018).

Lancet Countdown has also presented disease burden (in DALYs) attributable to the carbon footprint for most countries in the world, considering the input–output database EXIOBASE v3.8.3 and Global Health Expenditure Database for 2020 (Romanello et al., 2023). Their estimates account for $PM_{2.5}$ and ozone, with estimates for the European Union lower than the ones reported in this study – 264 thousand DALYs vs. 365 thousand DALYs. These differences might be related to the health damage factors considered.

The monetisation through carbon offsets has been applied in other contexts, including medical conferences and meetings (Yakar and Kwee, 2020), together with health damage factors used in this study. The use of carbon offsetting opens the discussion on the responsibility of covering such costs: in this case, is it of the products and services providers (i.e. medical devices and pharmaceutical companies, electricity, and water providers, among others) or the health system itself, which utilises them. Depending on the health system organisation, this can either fall under the responsibility of private companies or the government, which may raise the discussion on differential carbon taxation.

Sectors as tourism have calculated their carbon footprint and quantified it through the conversion of consumption prices to basic prices, using EXIOBASE tables (Osorio et al., 2023). On the other hand, a Carbon Price Support was applied in the UK in 2013, which has been shown to decrease GHG emissions by the energy sector (Leroutier, 2022), demonstrating its usefulness of carbon taxes in lowering the environmental impact across sectors.

Carbon taxing requires a thorough analysis of the point of taxation in the production or consumption chain, and the subject of taxation, which may include direct users of fossil fuels or sectors which indirectly use it (Hájek et al., 2019). The EU Emission Trading System puts additional responsibility on the enterprises to reduce their carbon footprint (Heflich and Saulnier, 2022), which will increase the price of goods and ultimately impact consumers, affecting people with lower socio-economical status (Sager, 2019), consequently affecting their ability to afford healthy foods and housing. A study reported the application of a carbon tax downstream, to be paid by consumers (Rodemeier, 2023), which may impose a further economic burden on households, raising equity and fairness issues. A social cost has also been estimated for CO_2, with a proposal of setting it to 185 dollars per 1 tonne of CO_2 emitted (Rennert et al., 2022). Moreover, there is still no specific regulatory system for the pricing of consumer carbon taxing. A study proposes a global uniform carbon price of 30 USD/tonne CO_2e (Sager, 2019), which falls behind the estimated health costs in the present study. Carbon taxes for the industrial sector have been forecasted according to the energy consumption and GHG emissions, with the goal of achieving national determined contributions, which required a carbon tax of around 55 dollars in Korea (Oh et al., 2023).

Regardless of the methodology, all reports indicate that GHG emissions from the healthcare sector are expected to significantly impact human health. Therefore, it is important to ensure that EU climate policies for buildings, specifically health institutions, are in line with the Paris Agreement, while guaranteeing additional funding for climate mitigation programs within the healthcare sector.

Furthermore, clinical practices must be fully reflected on and reviewed at the institutional level to align with sustainability goals. In this context, Health Care Without Harm has developed several toolkits which assist health institutions in planning and implementing measures to improve their commitment on environmental sustainability (Health Care Without Harm and ARUP, 2019b). Nevertheless, specific environmental indicators for health institutions are still missing and these could be an important tool to measure environmental commitments and effectiveness of the actions taken.

At EU level, legislation is being progressively aligned with the Paris

Agreement, with the European Green Deal at the forefront of this change (European Commission, 2019). This can have an impact on national policies regarding environmental sustainability, including public hospital buildings. The Energy Efficiency Directive, recently revised, and the Energy Performance of Buildings Directive (European Union, 2010), currently under revision, are good examples of EU legislation that can impact buildings, including healthcare ones. The Corporate Sustainability Due Diligence Directive (CSDDD) aims to regulate companies across different sectors to ensure they perform due diligence regarding human rights and environmental impacts in their activities and supply chains. While the CSDDD does not directly affect the public healthcare sector, public healthcare providers are indirectly impacted when they procure goods or services from companies subject to the CSDDD (European Commission, 2024).

In addition, the NextGenerationEU aims at assisting countries in recovering from the Covid-19 pandemic, by providing additional funding directed to health and resilience (European Commission, 2021), which is a good opportunity for financing the health sector, as well as the digital and green transition. For example, the use of artificial intelligence can be implemented with caution to facilitate the assessment and modelling of energy consumption and carbon footprints, while telemedicine has the potential to reduce the associated carbon emissions arising from patients and workers transportation (Moyano-Fernández et al., 2024).

Moreover, green procurement is key in decreasing the footprint of health systems. The European Commission has developed a handbook (European Commission, Local Governments for Sustainability, 2016) which entails different specificities to be taken into account in the procurement process. The EU Directive on public procurement, recently updated (European Union, 2014), also presents life-cycle costing and the importance of eco-labels, stressing the importance of considering the potential impact of greenhouse emissions associated with products and services procured in the public sector, including the health sector. This has the potential to drive the green transition within the providers in the private sector.

Another aspect entails the increasing investment in public health services. As health promotion and disease prevention lay at the core of public health, efforts in creating healthier and more resilient populations prove to be cost-effective and highly decrease disease burden and contribute for health systems economical sustainability (Romanello et al., 2023).

4.1. Study limitations

Climate change impacts on health have not been specifically described by the Global Burden of Disease in recent years, which reports separate disease burdens without any disaggregation of attribution to climate change as a risk factor, which may be difficult to account for. As such, the most recent relative risks we have are the ones estimated by the World Health Organization (2014). The health damage factors estimated by Tang et al. (2019) consider these relative risks, as well as the results of the Fifth Assessment Report of the IPCC, which may underestimate the results. Moreover, the health damage factors utilized in the present study present a degree of uncertainty, due to the quantitative assumptions in the estimations, which may also influence our final estimations. Particularly, the relative risks considered in our study might be underestimated, as they are influenced by climate change and the geographic distribution of diseases. Moreover, the rise of temperature has been taking place earlier than predicted by IPCC, as shown by the Sixth Assessment Report (Calvin et al., 2023), which may additionally increase the health burden. This highlights the need for up-to-date relative risks for climate change and consequently, adjusted health damage factors.

Values retrieved for costs per DALY utilized are estimated for the European context, bound by the specific socioeconomic context that may influence the costs presented, which may underestimate the cost. Moreover, the costs per DALY only reflect the human health impacts, which may underestimate the true costs of GHG.

Values for carbon offsetting remain highly variable, which does not provide certainty in the estimates presented. However, the concept allows to encompass not only human health costs, but also socioeconomic and environmental impacts.

The selection of databases is also an important factor, as well as the multi-regional input–output database utilised. While there were also other estimates in the literature for the carbon footprint of health systems, with most reporting back to 2014 (Health Care Without Harm and ARUP, 2019a; Lenzen et al., 2020; Pichler et al., 2019), the ones presented by Lancet Countdown were the most updated ones, with estimations of GHG emissions for 2019. Data for 2020 was also available, but Covid-19 effects would highly influence carbon emissions, therefore we decided to use the 2019 values. In terms of the multi-regional input–output database, EXIOBASE v3.8.3 was utilized in this case, which presents methodological differences when compared to Eora or the World Input-Output Database (Moran and Wood, 2014), namely in the sectors and regions considered in the analysis, as well as the time series and environmental factors considered. For instance, EXIOBASE includes 163 industries and 200 products, accounting for the EU, 16 other major countries and the rest of the world, with a recent update of the time series, which considers 27 pollutants, including GHG, phosphate and nitrogen, compatible with the System of Environmental-Economic Accounting. Eora encompasses 26 to 500 industries and products for 190 countries, with a time series from 1990 to 2015, which includes 2720 environmental indicators (Giljum et al., 2019). Finally, the World Input-Output Database considers 56 sectors for EU, 15 major countries and the rest of the world, with a time series from 2000 to 2014, and considering the use of energy and its CO_2 emissions (Moran and Wood, 2014). The different databases would originate different estimates depending on the recency of the estimates and the environmental aspects considered.

5. Conclusion

CO_2 emissions from the health sector are expected to significantly impact human health, with originating 365,047 DALYs. Efforts set in place by the EU are expected to decrease this value by 39 % to 221,988 DALYs, with an avoidable burden of over 143 thousand DALYs. Costs can amount to 25.6 billion euros, when considering DALYs, and 2.9 million euros if considering a standard market price of carbon offset of 12 euros. The results from the study greatly contribute to strengthen evidence-informed environmental health policymaking.

Therefore, it is important to ensure that EU climate policies for buildings are in line with the Paris Agreement, with increased funding for climate mitigation programs within the healthcare sector and review clinical practices at the local level. The revision of Directives related to energy management of buildings, the improvement of green public and private procurement policies, and increasing funds towards digital and green transition, constitute opportunities for increased funding for health institutions and to boost emissions reduction. Moreover, promoting an integrated view of EU climate policies across different sectors will assist in accelerating the green transition.

Ultimately, investing in and strengthening public health services would greatly improve health outcomes and assist in creating healthier and more resilient populations, with relevant decreased disease burden. This further contributes for the health system economical sustainability.

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CRediT authorship contribution statement

José Chen-Xu: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mariana Corda:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Conceptualization. **Orsolya Varga:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology. **Susana Viegas:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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