The environmental impact of the Dutch health-care sector beyond climate change: an input–output analysis

Michelle A Steenmeijer, João F D Rodrigues, Michiel C Zijp, Susanne L Waaijers-van der Loop

Summary

Background Studies suggest that the Dutch health-care sector is responsible for 4–8% of the national carbon footprint, but the environmental footprint of this sector beyond climate change is not well understood. Therefore, we aimed to estimate the environmental footprint of the Dutch health-care sector for a range of environmental impact categories.

Methods In this input–output analysis, we used Exiobase (version 3), which contains data on global trade flows and their associated environmental impact, in combination with health-care expenditure data from Statistics Netherlands. We covered the impact categories: climate change, blue water consumption, abiotic material extraction, land use, and total waste generation. The calculated sectoral footprint was the sum of all impacts associated with the operational phase (direct impact) and impacts occurring in the value chain of purchased goods and services (indirect impact) given an expenditure vector. The expenditure vector was the sum of three elements of health-care expenditure: health-care services; pharmaceuticals and chemical products; and medical appliances. We calculated the impact share of health care on the total Dutch consumption footprint. We evaluated the contribution to the impact categories from the categories that composed the expenditure vector. We did a hotspot analysis in which the indirect impact was split according to where (sector, geography, or both) the impact physically occurred. These top-down results were complemented with bottom-up data on emissions from pressurised metered-dose inhalers, anaesthetic gases, and private travel.

Findings The health-care sector's share of the national footprint was highest for material extraction (13·0%), followed by blue water consumption (7·5%), climate change (7·3%), land use (7·2%), and waste generation (4·2%). Pharmaceuticals and other chemical products were the biggest contributors to all impacts. The sectors contributing to climate change were more evenly distributed than the sectors contributing to the other impact categories. The mining sector mostly contributed to material extraction and the agricultural sector contributed largely to blue water consumption and land use. The mining sector and the agricultural sector were the main contributors to waste generation. Climate change occurred mainly in the Netherlands, whereas the other impacts mainly occurred abroad.

Interpretation The Dutch health-care sector contributes to a broad set of environmental impact categories beyond climate change. Our results will help stakeholders involved in the health-care sector to pinpoint topics that need to be prioritised and to prevent trade-offs by addressing multiple environmental issues simultaneously.

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Center for Sustainability, Environment and Health, National Institute for Public Health and the Environment, Bilthoven, Netherlands (M A Steenmeijer MSc, S L Waaijers-van der Loop PhD, M C Zijp PhD); **2.-0 LCA consultants, Aalborg, Denmark** (J F D Rodrigues PhD)

Correspondence to: Michelle Steenmeijer, Center for Sustainability, Environment and Health, National Institute for Public Health and the Environment, Bilthoven 3721, Netherlands **michelle.steenmeijer@rivm.nl**

Introduction

The Dutch health-care sector is facing the effects of climate change on human health, including, but not limited to, increased heat stress, longer allergy seasons, and an increased number of extreme weather events.[1] At the same time, studies suggest that the Dutch health-care sector contributes 4–8% of the national carbon footprint.[2–5] The health-care sector can therefore make a considerable contribution towards achieving national climate targets and mitigating climate-change-induced risks for health in the near future. However, climate change is one of many threats to the Earth's natural ecosystems, which also include freshwater depletion, ocean acidification, and biodiversity loss.[6] These harmful changes to the environment pose serious risks to global human health.[7] In this context, the Dutch Government set in motion the Green Deal Sustainable Care initiative to improve the sustainability of the health-care sector.[8] The goals of this initiative are to reduce carbon emissions, stimulate circular practices, create a health-enhancing environment, and reduce medicine residues in surface water and groundwater.

Environmentally extended input–output analysis is a top-down method to estimate the overall environmental impact (eg, the carbon footprint) of a sector or region and can be used for scenario analyses.[9] In the past 3 years, several studies have investigated the carbon footprint of different national health-care sectors by use of environmentally extended input–output analysis as their primary method,[10–14] including a study specifically on the Netherlands.[4] Two other studies have presented global footprint methodology for calculating the carbon footprint of national health-care systems.[2,3] These studies focused on climate change as the only environmental impact

Research in context

Evidence before this study

We searched Scopus for articles published in English between database inception and May 6, 2021, on environmental footprints for the health-care sector using the search term "health care" in combination with "carbon footprint" or "environmental footprint". Studies have been published on the environmental footprint of national health-care sectors, including the footprint of the Netherlands' health-care sector. However, most studies have only focused on the carbon footprint, measuring the sector's contribution to climate change, and have not addressed other environmental impact categories. Although one global study did explore several different footprint indicators, it did not aim to provide the most accurate footprints for specific countries with the best available data or bottom-up information. Thus, we found no study exploring multiple environmental impact categories that also attempted to increase accuracy by integrating high-quality data, bottom-up data, or both. Existing footprint studies for the Netherlands refer to all previous studies with top-down environmental footprint analyses of national health-care sectors (individual countries or global analysis).

Added value of this study

To our knowledge, we present the first footprint study of the Dutch health-care sector assessing multiple environmental impact categories (climate change, abiotic material extraction, blue water consumption, land use, and waste generation). We combined the most up-to-date, publicly available data with additional health-care-specific data to produce a complete and current representation of the Dutch health-care sector. The health-care sector's share of the national footprint was the highest for material extraction (13·0%), followed by blue water consumption (7·5%), climate change (7·3%), land use (7·2%), and waste generation (4·2%). We also found that pharmaceuticals and chemical products were the biggest contributors to the impact categories, but that impacts occurred in different sectors. Carbon emissions occurred mainly domestically and operationally, whereas the other impacts occurred mostly abroad and upstream within the value chain of purchased products and services.

Implications of all the available evidence

In this study, we gained new insights for a better understanding of the environmental impact of the Dutch health-care sector. Our results will help stakeholders involved directly or indirectly in the health-care sector to pinpoint topics that need to be prioritised. Working on multiple Sustainable Development Goals simultaneously on a wide sectoral scale is crucial. For such, we have created a national overview of the environmental footprint of the Dutch health-care sector while keeping the results action-oriented. Our model can also be used for scenario modelling to estimate the effects of sustainability strategies. We have also discussed the challenges associated with integrating bottom-up data into top-down models.

category. The importance of addressing multiple environmental impacts is frequently shown by lifecycle assessments. Lifecycle assessments are footprint analyses on the product level based on bottom-up data.[15] Lifecycle assessment studies often cover multiple impact categories to make informed decisions, as trade-offs can occur between different environmental impact categories. For example, different types of inhalers score differently depending on the considered impact categories.[16]

Apart from studies of the US[17] and Canadian[18] health-care sectors, Lenzen and colleagues[5] were the first to include environmental impact categories additional to climate change, such as particulate matter, air pollutants, malaria risk, reactive nitrogen in water, and scarce water use, when assessing the global environmental footprint of national health care for 189 countries, including the Netherlands. Their global study created a generic overview per country or region of the environmental impact of health care to allow for comparisons across areas. However, to better understand environmental impacts in a particular sector of a country, it is necessary to improve data quality by use of national statistics[19] and by inclusion of health-care-relevant bottom-up categories, such as the impact of anaesthetic gases, the use of pressurised metered-dose inhalers, and private travel.[10,12] These impacts are not always accounted for in environmentally extended input–output analyses, but can considerably contribute to the carbon footprint of the health-care sector. In footprint studies of the health-care sector, private travel contributed to 10% of the environmental footprint in England,[12] 12% in Austria,[10] and 22% in the Netherlands,[4] the use of pressurised metered-dose inhalers contributed to 3–4% in England[12] and 0·35% in Austria,[10] and anaesthetic gases contributed to 2% in England[12] and 0·3% in Austria.[10]

We identified a knowledge gap between the existing footprint studies and the need to understand the environmental impact of Dutch health care beyond climate change to improve the sustainability of health care. Therefore, we aimed to estimate the environmental footprint of the Dutch health-care sector—not just climate change, but other environmental impact categories too. Carbon footprint results can be compared with the results of existing carbon footprint studies.

Methods

Study design

A sectoral footprint is the sum of all impacts associated with the operational phase (direct impact; eg, from exhaust gases from ambulances) and impacts occurring in the value chain of purchased goods and services (indirect impact) given an expenditure vector (expenditure on the required goods and services). We analysed the indirect impact footprint in two ways: first, in a contribution analysis, which is a split of the grand total impact by the categories that compose the expenditure vector; second, in a hotspot analysis, in which the indirect impact was split according to where (sector, geography, or both) the impact physically occurred. For example, when the carbon footprint contribution analysis shows that purchased electricity is the main contributor to a given footprint, the hotspot analysis might show that the carbon emissions physically occur at a domestic coal-fired power plant. In this input–output analysis, we used an environmentally extended multiregional input–output (EE-MRIO) dataset as the primary footprint data source to have the benefits of insights into the global trade flows of the EE-MRIO.[19] A short background on the EE-MRIO analysis and a full description of the calculation, including our calculation of environmental intensities, can be found in the appendix (pp 2–3). For Dutch health-care expenditure and the health-care sector's direct emissions, we instead used national statistics from Statistics Netherlands to ensure a more updated and accurate representation of the Dutch health-care sector. We used national health-care expenditure data to construct the expenditure vector and used the national accounts to update the sector's direct impact in the extension.

Previous studies on the carbon footprints of health-care sectors have highlighted that the top-down calculations in the EE-MRIO analysis need to be complemented with additional bottom-up estimations, otherwise considerable impacts can be missed.[4,10,12] In our analysis, we included the environmental impact from private travel of employees, patients, and visitors to health-care centres, as these impacts are not reported separately from the rest of private travel by households in national statistics. The environmental impacts of private travel were calculated by use of lifecycle assessment and therefore covered both direct impacts (use phase) and indirect impacts (production and waste disposal activities). The concepts and mathematical formulation of the lifecycle assessment can be mapped to the EE-MRIO analysis.[20] Similarly, carbon emissions from the propellant in pressurised metered-dose inhalers are not accounted for in a sectoral footprint using only EE-MRIO analysis because emissions occur in households (eg, during at-home use). The release of anaesthetic gases, which are operational emissions, is often estimated separately to the EE-MRIO analysis in studies due to an absence of emission data from medical gases in carbon reporting.[3] The contributions to the environmental footprint from both pressurised metered-dose inhalers and anaesthetic gases vary widely across studies,[10,12] so we made our own estimations for these impacts in the bottom-up calculation. To calculate the contribution of the Dutch health-care sector to the national consumption footprint, we used the total Dutch final demand from the original unaltered EE-MRIO for the Dutch consumption footprint calculation.

EE-MRIO data

For the EE-MRIO analysis, we used the Exiobase (version 3.7) industry-by-industry table.[21] Exiobase contains data on global trade flows, is a harmonised EE-MRIO database with a higher sectoral resolution (163 sectors for 49 countries or regions) than other harmonised EE-MRIO databases, and comes with many environmental extensions.[19] We covered the impact categories: climate change, blue water consumption, material extraction (used domestic extraction of abiotic materials), and land use. Additionally, we added total waste generation (the supply of waste and waste from stock) from the extension of the hybrid Exiobase (version 3) supply-use table.[22] Climate change, freshwater use, and land system change are part of nine planetary boundaries[6] and we used land use as a proxy for land system change. The circular economy will help to achieve planetary health by reducing the environmental pressures that occur in production–consumption systems, and we used waste generation and abiotic resource extraction to measure circularity on a macroeconomic scale.[23] The number of impacts we assessed could have been extended, but it was limited to a set of five for practical reasons. We chose impact categories that do not have an obvious link. At the time of building the model, the latest year for Exiobase (version 3) was 2016 and this year was therefore chosen as the baseline year for the analysis for all other impacts apart from waste generation. For the waste generation extension, we used the absolute values for the latest available year at the time: 2011. To allow for easier communication of results, we grouped sectors according to the classification table in the appendix (pp 33–37).

To estimate direct carbon emissions from the health-care sector, we used data from Statistics Netherlands' environmental accounts, which correspond directly with the Health and Social Work category from Exiobase. The emissions cover CO_2, CH_4, and N_2O but not medical gases. For the other impact categories, we did not replace direct impact values from their extensions in Exiobase with external data or national statistic data due to an absence of higher quality data.

For **Exiobase** see https://www.exiobase.eu/

See **Online** for appendix

For **national statistics from Statistics Netherlands** see https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83300NED/table?dl=67B3

Expenditure vector

To construct the expenditure vector from national health expenditure statistics, several steps were followed, and we provide a more detailed description in the appendix (pp 4–7). Due to the way we matched the classifications for Exiobase and the health-care expenditures, we could calculate the impact for three final demand expenditures: the consumption of pharmaceuticals and other medical non-durable goods; the consumption of therapeutic appliances and other medical durable goods; and the consumption of health-care services. However, for health-care services, we wanted to distinguish the impact associated with particular categories of goods and services used by the sector. So, instead of using total expenditure on its services, we used inter-industry flows for the use of goods and services for the Dutch Health and Social Work category from the

Exiobase transaction matrix. Furthermore, it was necessary to convert the health-care expenditure in purchaser prices to basic prices, as Exiobase reports in basic prices. The expenditure vector was the sum of these three elements of health-care expenditure: (1) expenditure on health-care services (the intermediate-use column for the Dutch Health and Social Work category from the Exiobase inter-industry table, scaled appropriately for the reported expenditure); (2) expenditure on pharmaceuticals and chemical products (otherwise known as pharmaceuticals and other medical non-durables; the expenditure was mapped onto the category in Exiobase called Chemicals Not Elsewhere Classified; the sourcing is distributed according to the regions providing chemicals not elsewhere classified in the Dutch total final demand); and (3) expenditure on medical appliances (otherwise known as therapeutic appliances and other medical durables; the expenditure was mapped onto Exiobase's Medical Precision and Optical Instruments, Watches and Clocks category; the sourcing is distributed according to the Exiobase category's providing regions in the Dutch total final demand).

Bottom-up data

A bottom-up inventory estimated that the use of anaesthetic gases in Dutch hospitals accounted for approximately 13·2 kilotonnes of CO_2 equivalent (ie, 4189 tonnes of CO_2 equivalent through the use of sevoflurane and desflurane and roughly 9000 tonnes of CO_2 equivalent through the use of nitrous oxide) in 2019.[24] We used these data despite the mismatch in reference year, as there are no data available for 2016. There are no direct impacts associated with anaesthetics for impact categories other than climate change. For pressurised metered-dose inhalers, carbon emissions during use were estimated to be 76·9 kilotonnes of CO_2 equivalent in 2016.[25] Again, we did not assign impacts for the use of at-home pressurised metered-dose inhalers to impact categories other than climate change. We adopted a similar approach to the English study[12] for calculating the total distance travelled per mode of transportation for employees, patients, and visitors. These values were linked to the corresponding activities in ecoinvent (version 3.7; a lifecycle inventory) to calculate the total impacts (more information provided in the appendix [pp 8–11]). The most suitable travel activities provided information in person-km up to and including the use phase. We broke down the impact of private travel into a direct component and an indirect component. The indirect component was appended to the hotspot analysis without further specification of sector or geography because bridging the Exiobase and ecoinvent classifications would have been too laborious.

For **ecoinvent** see https://ecoinvent.org/

Characterisation factors

Because we combined the EE-MRIO analysis footprint (based on Exiobase) with lifecycle assessment results (based on ecoinvent), we could not use the characterisation factors directly (ReCiPe 2016 [H][26] for ecoinvent and the DESIRE FP7[27] characterisation table for Exiobase) but needed to adjust them. Details of the approach we took can be found in the appendix (pp 12–18). The greenhouse gas emissions from the use of pressurised metered-dose inhalers are already characterised with ReCiPe 2016 (H).[25] For consistency, we converted estimations of carbon emissions from anaesthetic gases to ReCiPe 2016 (H), which resulted in 14·6 kilotonnes of CO_2 equivalent.

Uncertainty

For the top-down analysis, our data sources (Exiobase and Statistics Netherlands) did not report uncertainty ranges. Collecting the necessary data to conduct uncertainty propagation was outside the scope of this study. For the bottom-up data, there were not enough similar data sources to calculate uncertainty ranges for the sector-wide contribution of anaesthetics and pressurised metered-dose inhalers. Furthermore, the rough estimation of the number of total travelled distances per transport mode for private travel was likely to be more uncertain than the used lifecycle assessment data.

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.

Results

The results for the expenditure vector and the environmental intensities are provided in the appendix (pp 19–20). The expenditure on health-care services (93·1%) created roughly half of environmental impacts (43·5–61·4%) among the different impact categories (table). By contrast, the consumption of pharmaceuticals and chemical products had a high contribution to different environmental footprints (27·9–54·0%) but a small expenditure (4·1%). The share of environmental impact for consumed medical appliances among the categories was low (1·5–4·9%), as was its share of expenditure (2·9%). Of the total climate change footprint in health care, the release of anaesthetic gases accounted for 0·1% and the release of propellants from pressurised metered-dose inhalers accounted for 0·4%. The impact from private travel was higher on climate change (5·3%) than on all other footprints (<1·0%). Comparing our results with the Dutch consumption footprint, we found that health care was responsible for 7·3% of national climate change footprint (appendix p 21). Of the national Dutch consumption footprint, waste generation in health care accounted for 4·2%, material extraction accounted for 13·0%, blue water consumption accounted for 7·5%, and land use accounted for 7·2% (appendix p 21).

In our contribution analysis, contributions were more evenly distributed among the different product groups for climate change than for the other impact categories, contributions to which were mostly driven

	Basic price expenditure, million euros	Climate change, kilotonnes of CO_2 equivalent	Material extraction, kilotonnes	Blue water consumption, Mm³	Land use, km²	Waste generation, kilotonnes
Total	92 515 (100·0%)	17 575 (100·0%)	33 801 (100·0%)	394 (100·0%)	23 845 (100·0%)	4803 (100·0%)
Top-down						
Health-care services	86 096 (93·1%)	10 779 (61·3%)	14 714 (43·5%)	218 (55·3%)	13 748 (57·7%)	2811 (58·5%)
Pharmaceuticals and chemical products	3778 (4·1%)	4909 (27·9%)	18 261 (54·0%)	169 (42·9%)	9744 (40·9%)	1780 (37·1%)
Medical appliances	2641 (2·9%)	864 (4·9%)	783 (2·3%)	7 (1·8%)	351 (1·5%)	212 (4·4%)
Bottom-up						
Release of anaesthetic gases	NA	14 (0·1%)	..	..	..	..
Release of propellants from pressurised metered-dose inhalers	NA	77 (0·4%)	..	..	..	..
Private travel	NA	932 (5·3%)	42 (0·1%)	0·29 (0·1%)	3 (<0·1%)	..

Column data might not add up to totals due to rounding errors. NA=not applicable.

***Table:* Environmental footprints by top-down and bottom-up categories**

by pharmaceuticals and chemical products and food and food services (figure 1; underlying data in appendix pp 22–23). Operational impacts and heat and electricity had a larger impact on climate change than on the other impact categories. The main similarity among impact categories in our contribution analysis was that pharmaceutical and chemical products were the biggest contributors to their environmental footprint.

The hotspot analysis of the environmental footprints shows the sectors in which the impact occurred (figure 2; appendix pp 24–25). Again, the sectors were more evenly distributed for climate change than for the other impact categories. As expected, the mining sector contributed predominantly to the impact of material extraction and the agricultural sector contributed largely to blue water consumption and land use. Furthermore, both the mining sector and the agricultural sector were the main contributors to waste generation. By contrast, the mining sector accounted for only 2·6% of climate change and the agricultural sector accounted for only 11·8% (appendix pp 24–25).

Climate change due to the Dutch health-care sector occurred mainly in the Netherlands (6009 [34·2%] of 17 575 kilotonnes of CO_2 equivalent), whereas material extraction occurred predominantly in the Asia-Pacific (25 243 [74·7%] of 33 801 kilotonnes; figure 3; appendix pp 26–28). Land use and waste generation mainly occurred in the Americas, Europe (excluding the Netherlands), and the Asia-Pacific. Furthermore, both the Asia-Pacific and the Middle East had a considerable role in blue water consumption.

Discussion

To our knowledge, this work represents the first footprint study of the Dutch health-care sector in which multiple environmental impact categories were assessed. Societal challenges, such as climate change, biodiversity loss, and the transition towards a circular economy, are closely connected.[29] Therefore, measures to deal with one of these challenges are likely to influence the others. For example, the transition to bio-based products as a measure to mitigate climate change and move to a circular economy can require more land and, as such, negatively affect biodiversity.[30] Our study reveals that the use of pharmaceutical and chemical products in the Dutch health-care sector contributed largely to all the environmental impact footprints we considered. Hence, further to the focus of Dutch national or local climate action programmes on buildings and transport, additional actions are needed to mitigate and reduce the environmental effects of pharmaceutical and chemical products. Our results provide actionable perspectives for both policy makers and health-care professionals and organisations. For instance, these product groups can now be prioritised within sustainable procurement and additional focus can be put towards encouraging frugal or targeted use. Furthermore, our study showed that the environmental footprint of food and food services in health care is important to mitigate from a holistic perspective, but the requirement for action is less clear from a perspective solely focused on climate change. The results also show that the impacts upstream of supply chains dominate (eg, scope 3) for all impact categories. Therefore, international policies and sustainability strategies, such as the European Commission's Circular Economy Action Plan and the Zero Pollution Action Plan, are important to alleviate global, societal, and environmental problems and need to be incorporated in sustainable health-care strategies and ambitions. For true green and circular procurement, collaboration along the value chain and international policy interaction are required.[8] First and crucial initiatives are on the way in the Netherlands,[31,32] but they would benefit from widening international

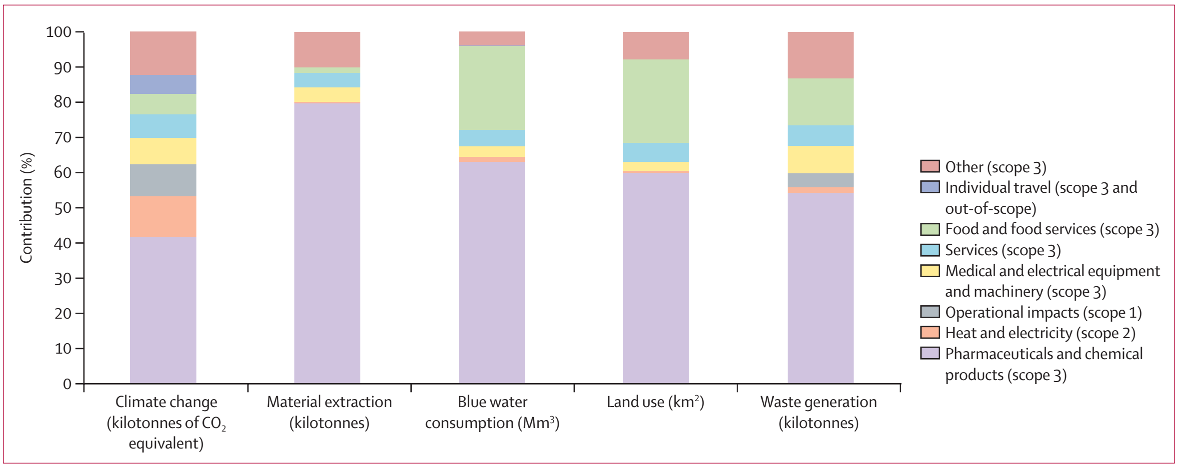

Figure 1: **Contribution analysis of health-care impact footprints by product group sectors**
Scopes are according to the Greenhouse Gas Protocol.[28] The sectors are grouped according to the classification table provided in the appendix (pp 33–37). The seven named groups cover at least 85% of all impact categories, with the remaining sectors combined in the group labelled other.

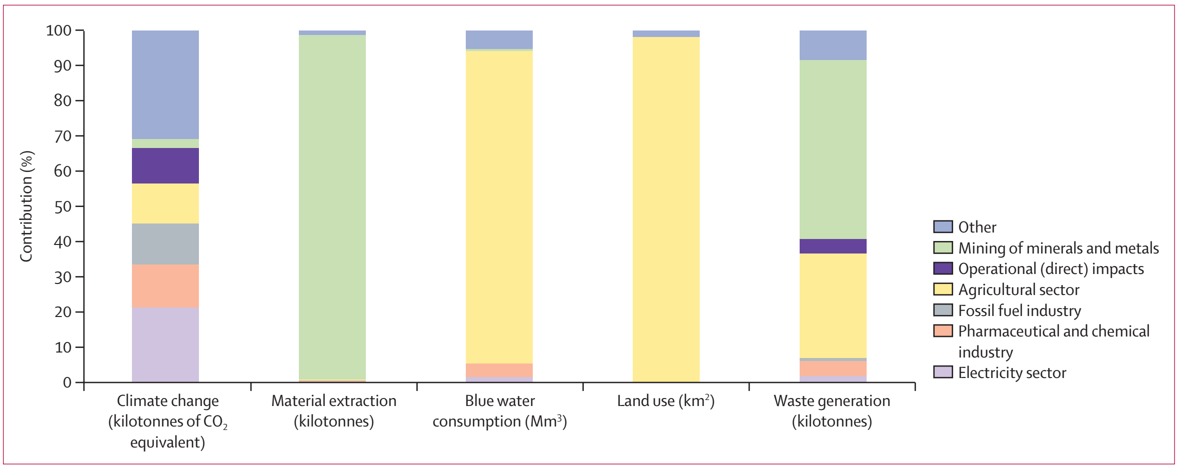

Figure 2: **Sector hotspot analysis of the health-care impact footprints**
The results are aggregated into six main groups that contribute to at least 9% of any of the impact categories, with the remainder combined in the group labelled other. The sectors were grouped according to the classification table in the appendix (pp 33–37). The indirect impact from private travel was proportionally distributed among all groups.

collaboration, such as the further inclusion of pharmaceutical-producing countries, and expanding scope from only the climate change footprint to a wider environmental footprint.

We found that health care contributed more to the national footprint of abiotic material extraction than it did to the national climate change footprint. Further research should investigate whether this result is caused by the single-use culture in Dutch health care or by any model uncertainties. Conversely, the share of the national footprint was smaller for waste generation than for all other impact categories. For waste production specifically, there was a temporal mismatch between the baseline year and the year of data for waste generation, but uncertainty can also be caused by classification mismatches, aggregation biases, and uncertainty in the EE-MRIO data. A more accurate Exiobase version than the one we used is available for the Netherlands in the form of a system of national accounts;[33] however, these satellite accounts are limited to carbon emissions and material extraction. Future studies should examine how to analyse the uncertainty of the results, especially for impact categories that are rarely analysed in the published literature, such as waste generation.

Previously published studies[2–5] calculating the carbon footprint of the Dutch health-care sector differ in their use of EE-MRIO data, their environmental extensions, their definitions of health care, and the reference year used (appendix pp 29–31). These variabilities make comparing these studies difficult, not only for the Netherlands but for other countries too. However, the presented approach combined the most up-to-date, publicly available data with additional health-care-specific data to produce a complete and current representation of

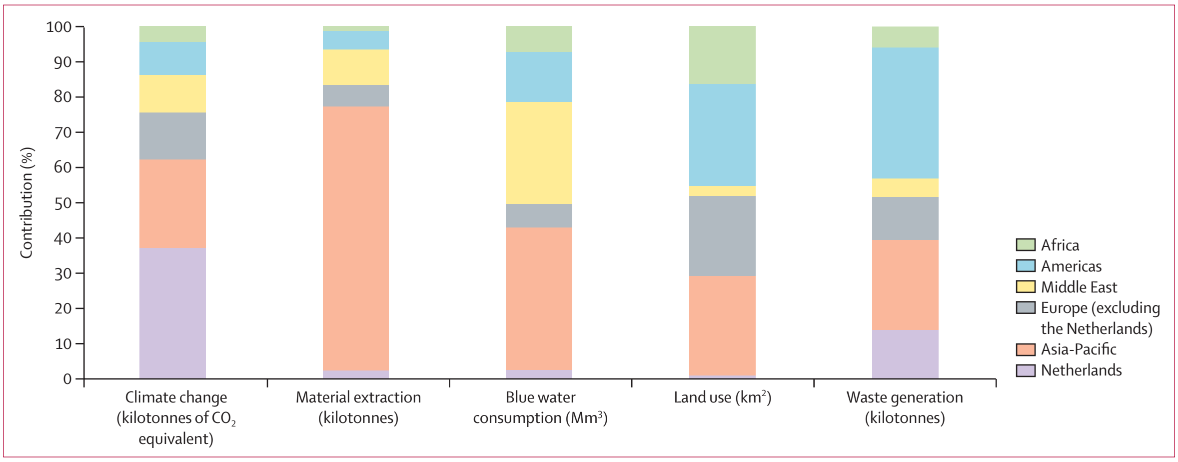

Figure 3: **Geography hotspot analysis of the health-care impact footprints**
Results were aggregated into six global regions according to the classification presented in the appendix (pp 26–28). The indirect impact from private travel was proportionally distributed among all regions.

the Dutch health-care sector. The contribution of the health-care sector to the national climate change footprint that we calculated in this study (7·3%) is in the range of previously published contributions (4–8%).[2–5] Furthermore, we found that pharmaceutical and chemical products were the biggest contributors to the climate change environmental footprint of the health-care sector. This result aligns with the contribution analysis findings[2,10–14,18] for other countries' health-care sectors (appendix p 32).

The primary method used in this study, EE-MRIO analysis, is useful to calculate the overall complete environmental footprint, revealing sectoral hotspots and allowing consistent comparison between different environmental impact categories. However, Exiobase aggregates all health-care and welfare services into one category (Health and Social Work), providing only general insights for the entire sector, whereas other EE-MRIOs can provide more detail, even including several different health-care functions for some countries.[5] Similarly, the expenditure on pharmaceutical products and other medical non-durables is covered by Exiobase's Chemicals Not Elsewhere Classified category. This category is a heterogeneous group that contains products with different prices and supplied volumes (eg, simple soap *vs* pharmaceuticals), making it unclear how representative the calculated impact is for this expenditure category. The Health and Social Work category should be disaggregated on the basis of spend data from different types of health-care providers. For the Chemicals Not Elsewhere Classified category, we need to investigate how to split this category into more specific subcategories, with at least one category for pharmaceuticals. A 2022 thesis reports that the impact per euro of basic pharmaceuticals and pharmaceutical preparations sourced from the Netherlands is three-times smaller than that of chemicals and chemical products produced in the Netherlands for the climate change footprint and seven-times smaller than that of chemicals and chemical products produced in the Netherlands for the abiotic material extraction footprint.[34] When these numbers are known for other supplying countries, a more detailed analysis can be done. The disaggregation of product group categories will then help to provide insight into what action can be taken for different subsectors in health care and for more detailed product groups.

Our study has several limitations. First, the use of EE-MRIO analysis for calculating the sectoral footprint comes with a limitation regarding scope. The sectoral footprint calculation does not include any impact related to at-home consumption of health-care products by households. In the EE-MRIO dataset, the environmental extensions for households are aggregated, so the exact source of the stressor cannot be identified. We added one source of impact from at-home consumption to our analyses, namely the release of propellants from pressurised metered-dose inhalers, and further researching any other impacts that are not yet captured would be valuable. Second, we did not include impacts from capital investments by the health-care sector in our analyses because Exiobase combines the gross fixed capital formation of all sectors into one account. As sustainability strategies also include investments for long-term effects, future work should examine whether impacts associated with health-care investments (eg, building care facilities) can be added to the footprint analysis for completeness. Finally, collecting the necessary data to conduct uncertainty propagation was outside the scope of this study. Among the major publicly available EE-MRIO datasets, only Eora reports uncertainty ranges.[5] One study, by use of estimated uncertainties from another EE-MRIO dataset, GTAP, found low uncertainty for the Dutch carbon consumption footprint; however, the uncertainty increased when zooming in on one sector (uncertainty was not explored for the health-care sector specifically).[35] Among different EE-MRIO datasets, there can be considerable differences between results for the national climate change[36,37] and material[38] footprints, but these differences have not been investigated for the health-care sector specifically or for other impact categories.

Bottom-up data, specifically lifecycle assessment results, are used to complement and further improve environmental footprint analyses, but also require additional effort to integrate with top-down results. Available bottom-up impact data do not always include the same lifecycle stages as in the EE-MRIO analysis, nor are they always calculated for the same impact categories. Impact categories that are less standardised than others, such as material extraction, require considerable effort to ensure that the data fit the EE-MRIO impact categories, with waste flows not being accounted for at all in the lifecycle assessment. Therefore, this top-down study provides a good basis to harmonise future sustainability assessments in the health-care sector. If new bottom-up estimates use the impact categories and the characterisation factors that we selected in this study, as well as account for similar lifecycle stages, then they can be more easily integrated into the top-down footprint, thereby contributing to an improved overview of the national environmental footprint, which is useful for groups of stakeholders, such as policy makers.

Overall, this state-of-the-art study reveals the environmental footprint of the Dutch health-care sector, what product groups contribute to this footprint, where the impacts occur, and how contributions differ among impact categories. Our results will support all stakeholders who are directly or indirectly involved in the health-care sector in pinpointing topics that need to be prioritised. This model serves as a starting point in the evolution of calculating environmental footprints, with the use of disaggregation and additional bottom-up data suggested for the future, and it can be used in scenario modelling to estimate the effects of sustainability strategies on different impact categories. This model can also be used for monitoring and evaluation purposes, which are crucial in sustainability strategies.[39] With this tailored environmental footprint model, we have created a national overview of the environmental footprint of the Dutch health-care sector while keeping the results action-oriented. This approach can initiate needed collaboration in the international value chain for systemic change and creates the opportunity to prevent trade-offs by addressing multiple environmental issues simultaneously. Sustainability is an integrated challenge, and holistic methodologies will help to save the limited time and resources we have for a healthy future for all.

Contributors

SLW-vdL and MCZ were involved with study conceptualisation and assisted the research to completion. JFDR and MAS designed the study and did the data analysis. MAS wrote the first draft of the manuscript. MCZ, JFDR, and SLW-vdL edited and reviewed the manuscript. All authors had full access to all the data in the study, had final responsibility for the decision to submit for publication, and accessed and verified the data.

Declaration of interests

We declare no competing interests.

Data sharing

The model and data are publicly available in the Github repository at https://github.com/rivm-syso/envr-footprint-healthcare.

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