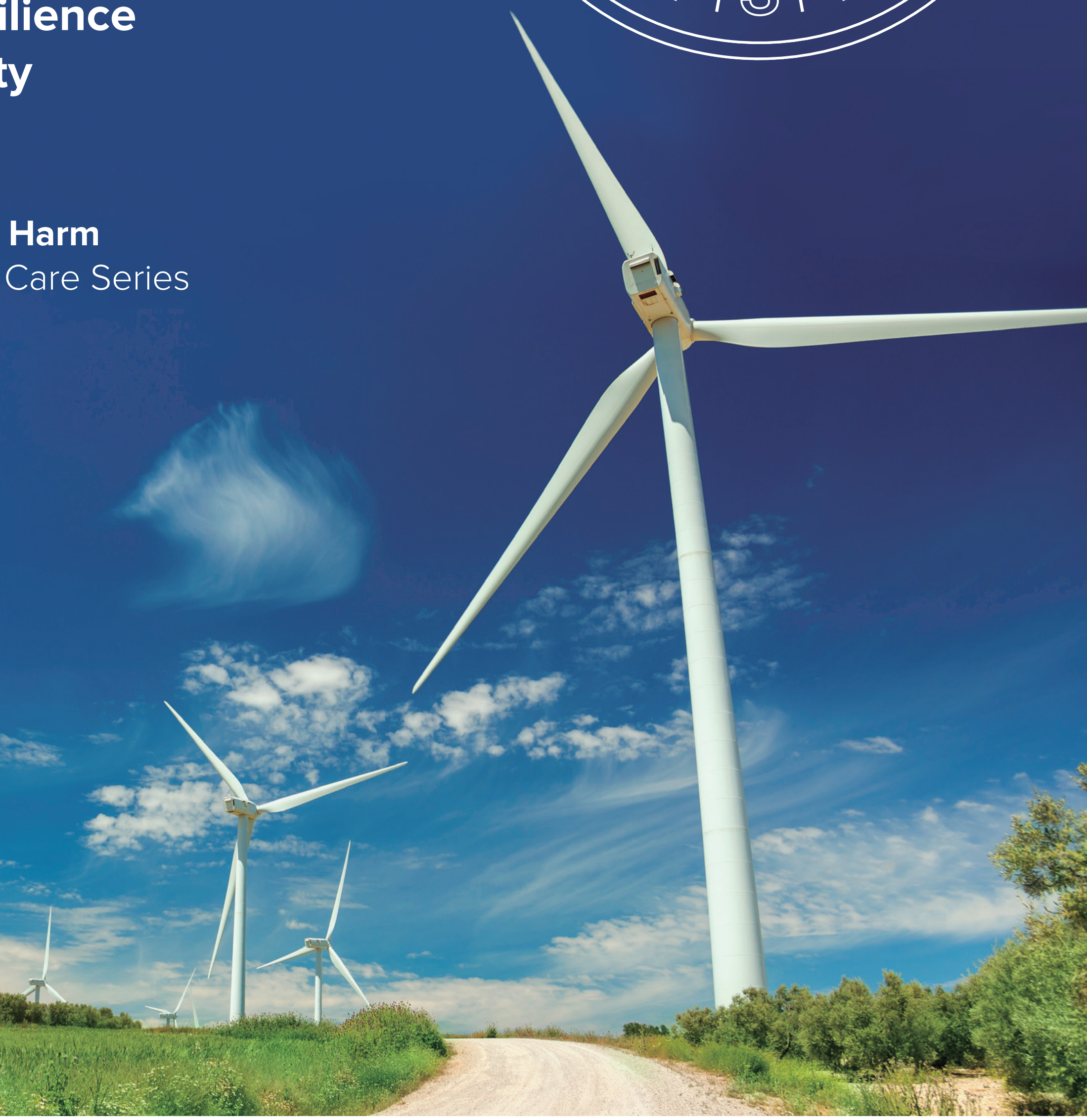
Global Road Map for Health Care Decarbonization

A navigational tool for achieving zero emissions with climate resilience and health equity

Health Care Without Harm
Climate-Smart Health Care Series

Annex A



Green Paper
Number Two

Health Care Without Harm

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Annex A: Technical report

Contents

Introduction

This technical report details the analytical methods used to prepare the *Global Road Map for Health Care Decarbonization*.

The methodology for the following components is presented by the following:

- Modelling of the baseline
- Derivation and distribution of a global health sector emissions budget
- Projecting growth and decarbonization trends to predict future emissions
- Modelling the impact of key decarbonization actions

Additionally, there is a section highlighting the key assumptions and limitations used throughout the study.

Deriving an emissions baseline for 2014

Introduction

The goal of this aspect of the study was to gain insights into the Greenhouse Gas Protocol (GHGP) Scope 3 emissions of the global health care sector beyond the findings contained in Green Paper One (hereafter referred to as the Green Paper)[1]. The method chosen was structural path analysis, an advanced input-output (IO) modelling approach. This section covers the methodology employed to conduct this analysis, a detailed validation of outputs against a peer-reviewed assessment of the United Kingdom health sector footprint, and discussion of the wider results with reference to further published national footprints.

Findings

Health care's global emissions footprint is presented in terms of supply chain categories devised for this study and by GHGP Scope 3 categories and sub-categories as defined in Section A.1.4.2, Figure A.1, and Table A.3 respectively.

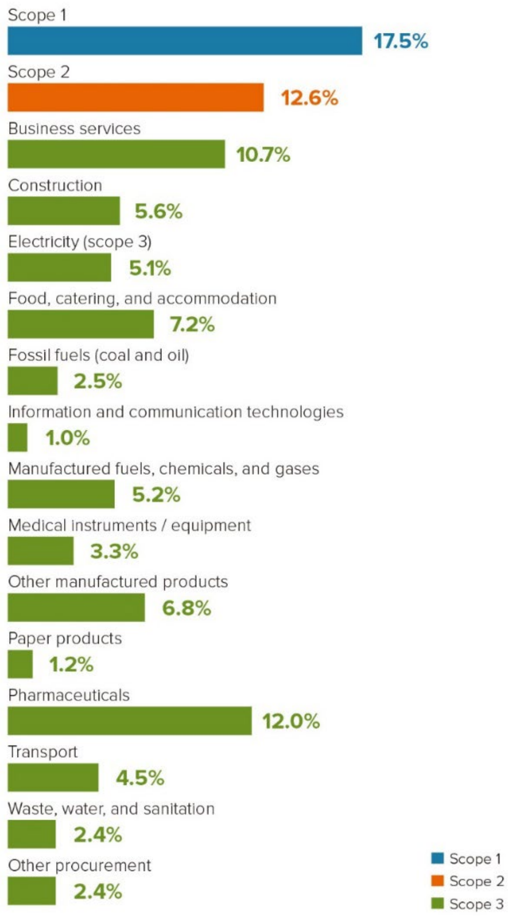

Figure A.1. Health care's global emissions footprint by supply chain categories devised for this study.

Figure A.2. Health care's global emissions footprint by GHGP supply chain categories and sub-categories.

Purchased health care: Second tier added to Scope 1, third tier electricity added to Scope 2, all other impacts Scope 3

Where health care organizations buy health care services from each other, these transactions are captured in the IO model as flows from the health and social work sector to the health and social work sector. This means health care services appear in the supply chain for health care. A limitation of the methodology used in Green Paper 1 is that Scope 1 emissions could only be estimated through the IO model using the tier 1 emissions from the health and social work sector as a proxy. This estimate therefore considers emissions from health care organizations in the supply chain, as Scope 3, as they would be for a health care provider procuring those services (e.g., the “other purchased health care” category in the NHS footprint). When footprinting the entire health care system, all emissions from health care organizations should be considered as Scope 1. The SPA allows us to transfer these emissions from Scope 3 to Scope 1, changing slightly the estimate for Scope 1 health care emissions (for the United Kingdom, Scope 1 changes from 12.3% to 13.8%, with Scope 3 reducing by the same amount).

Inhalational anaesthetics and meter-dose inhalers

The gases used for anaesthesia are potent greenhouse gases. Commonly used anaesthetics include nitrous oxide and the fluorinated gases sevoflurane, isoflurane, and desflurane. Global Warming Potentials (GWPs) range between 130 kgCO_2e/kg (sevoflurane) and 2540 kgCO_2e/kg (desflurane). At present, the majority of these gases enter the atmosphere after use. Similarly, metered-dose inhalers (MDIs) use hydrofluorocarbons as propellants. These gases have warming potentials between 1,480-2,900 times that of carbon dioxide.

These direct emissions are not included in World Input Output Database (WIOD), and there is limited data available on the scale of the footprint associated with them. However, it is important to attempt to represent the magnitude of these additional emissions in this study at a global scale and explore the potential to mitigate these contributions to the climate emergency.

For anaesthetic gases, the following datasets were used:

- Nitrous Oxide: UNFCCC Annex 1 nations report emissions data for the use of nitrous oxide in the health setting,[2] which totalled 7.0 MtCO_2e. Together, these nations accounted for 15% of the global population, 57% of the global GDP, and 73% of global health expenditure in 2014.
- Fluorinated gases: A study by Vollmer et al.[3] found global emissions from these types of anaesthetics to atmosphere in 2014 to be 3.1±0.6MtCO_2e. This study did not differentiate between emissions from human health care and veterinary uses, and it has not been possible to gather sufficient evidence to establish the proportions of these emissions associated with each. It has therefore been decided to report the full emissions footprint for these gases.

For MDIs, the following data is available:

- UNFCCC Annex 1 nations report emissions data for the use of MDIs,[2] totalling 6.9MtCO_2e.

From this data, covering the wealthiest and largest global health systems, a combined, order-of-magnitude estimate of the global footprint has been established. Given that global data for nitrous oxide use and MDIs was not available, this value is an underestimate.

Results review

Once the SPA was conducted for the 44 nations and regions in WIOD, a multi-step validation process was followed. Initially, results were checked against the findings of the previous assessment to ensure consistency with our previous work using the WIOD database.

Following this, a national comparison was conducted to benchmark the categorization of emissions returned by the SPA against national results for the United Kingdom published by the NHS Sustainable Development Unit. The aim of this was to assess the distribution of supply chain emissions against previously observed results. The United Kingdom was chosen due to the pioneering work of the NHS, which has characterized and reported emissions in detail. Additionally, the reporting categories used by the NHS provided the starting point for the categories used for this study.

It is noted from discussions with the leading academics in this field that making meaningful comparisons between economic sector totals calculated by IO methods is difficult. The data behind the IO model are calibrated to ensure the total model balances with expected values from third parties; little is done to ensure agreement at the level of individual economic sectors. This validation exercise therefore takes approximately +/-40% at the sector level as good agreement. Any sectors that do not achieve good agreement are highlighted for further investigation.

In addition to the assessment for the United Kingdom, some more general checks and comparisons of the per capita emissions breakdown across model nations was performed. Countries where per capita emissions differed from the wider dataset were highlighted, and where possible, checked against external data points.

United Kingdom comparison with results published by the NHS

Our modeling covers health care emissions in the United Kingdom for 2014. To derive comparable results from the NHS data for the health and social care sector in the United Kingdom, results for health care provision and public health were scaled up by population to represent the whole country. Additionally, expenditure data confirms private health care represented 20% of the United Kingdom health sector in 2014, and so results were further scaled to account for this. Based on the NHS analysis, and following this scaling process, the United Kingdom health sector footprint was found to be 38.9 MtCO_2e in 2014. Our modelling found the United Kingdom health sector climate footprint to be 42.5 MtCO_2e, meaning there was a percentage difference of 9% between overall model totals.

The NHS methodology employed a mixture of bottom-up emissions and top-down assessment using an IO model focused on the United Kingdom economy developed by the University of Leeds.[4] This allowed for greater sectoral resolution in its modelling of the United Kingdom economy than WIOD, which provides a global model structured using 56 sectors. One further difference worth mentioning is that the IO used for the NHS had a single category for health care, while WIOD has a combined category for health care and social work. The method ensures the footprint reported by WIOD is for health care, and for many categories their distribution will be the same. Yet in others, for example medical equipment and procured same-sector services, it is possible that category-by-category breakdowns will not agree. Given the agreement between overall model totals, and close alignment for many of the key procurement categories, this difference is judged to be acceptable when considering differing modelling approaches and the compromise between sectoral resolution and geographical coverage reached when WIOD was selected for this study.

The NHS provide a detailed breakdown of their operational and supply chain emissions. Their categorization and reporting style is widely recognized as sector-leading and has informed the categorization system chosen for reporting the outputs of this study. Using the latest NHS footprint update,[5] SPA outputs were aggregated to correspond with the NHS classification system. The resulting comparison is shown in Figure A.3 and commentary is provided for each category in the following pages. Overall, the models present a similar breakdown with emissions focused in key procurement categories, like business services and pharmaceuticals. Taken in combination with the close agreement in totals, the findings give confidence regarding the accuracy of the SPA assessment as applied to the United Kingdom.

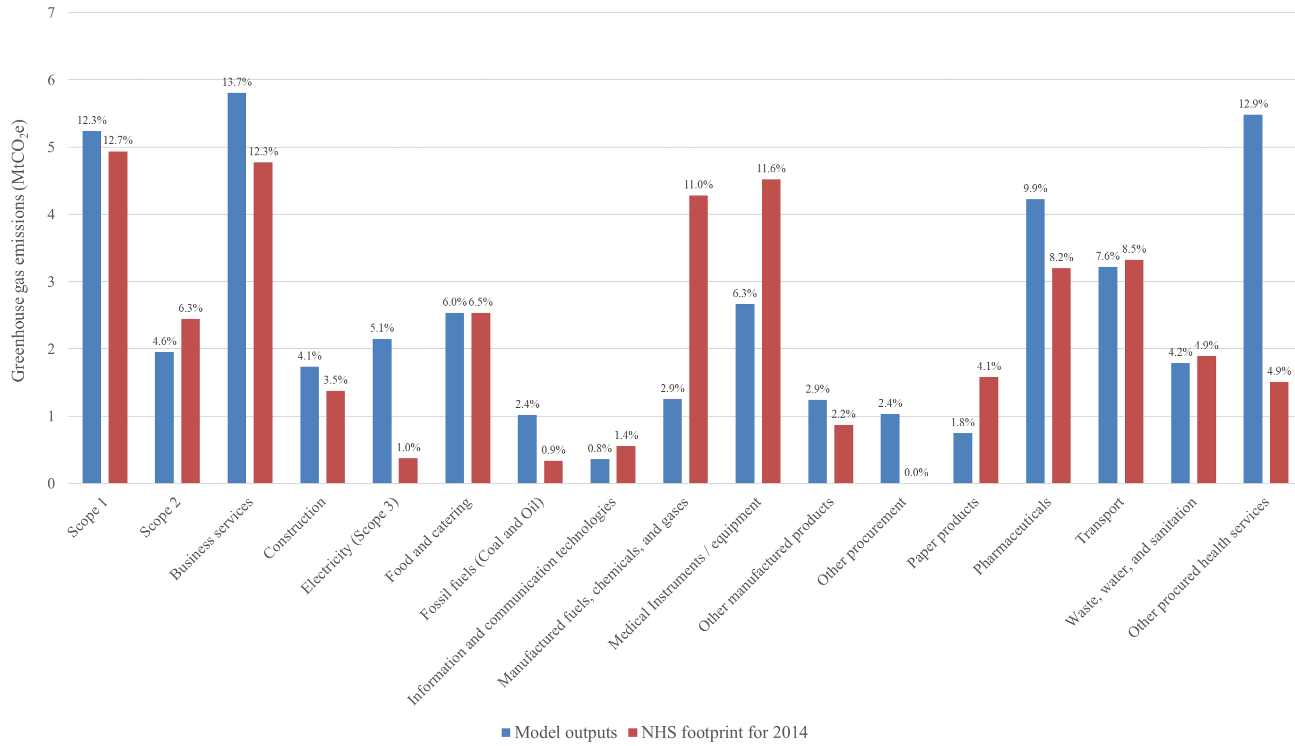

Figure A.3. Comparison between the United Kingdom's health care emissions from the modelling and breakdowns reported by the NHS for 2014. Emissions shown in $MtCO_2e$, with the percentage contribution of each category to the overall footprint also shown.

Scope 1 emissions

Model	Emissions ($ktCO_2e$)	Proportion (%)
SPA	5236	12.3
NHS SDU	4937	12.7

The two models match closely in their reporting for Scope 1 emissions. The NHS model is based upon bottom-up data for energy use and transport, while our assessment uses top-down estimates. Thus, agreement provides a high degree of confidence in this value from the SPA.

Scope 2 emissions

Model	Emissions ($ktCO_2e$)	Proportion (%)
SPA	1953	4.6
NHS SDU	2444	6.3

Our modelling predicts a lower value for Scope 2 emissions than that reported by the NHS using bottom-up data. It is good that WIOD gives a value within our range of expected agreement between IO methods (percentage difference: -20%) in a comparison with bottom-up data.

Business services

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	5808	13.7
NHS SDU	4770	12.3

The models provide a good agreement for the business services category (percentage difference: +22%), the largest supply chain category in both models. When combining WIOD categories to match the NHS categorization, the “accommodation services” and “food services” categories in the NHS IO model are within the same category in WIOD, “accommodation and food services.” This sector was mapped to the business services sector, whereas the NHS model maps the “food services” component to its “food and catering category” which will lead to a slight inflation of the business services category in our modelling and may account for the difference seen in the figure.

Construction

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	1738	4.1
NHS SDU	1374	3.5

There is agreement between the models in this category (percentage difference: +26%).

Electricity

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	2148	5.1
NHS SDU	372	1.0

There is divergence between the models for this category. The WIOD model includes full supply chain emissions for electricity production in this value for Scope 3 emissions from electricity generation. This includes emissions from high-intensity activities such as fossil fuel extraction and processing. This is in contrast with the bottom-up data in the NHS reporting, which only covers transmission and distribution losses in its Scope 3 electricity reporting. Transmission and distribution losses cannot be considered on their own in the WIOD model, meaning a direct comparison is not possible. For this reason, it is expected that the WIOD model will return a higher value for this category.

Food and catering

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	2534	6.0
NHS SDU	2537	6.5

There is good agreement between the models in this category (percentage difference: -0.2%). The WIOD value excludes emissions for food services, which due to aggregation within WIOD are included in business services. In the NHS model, the food services sector has a value of 0.7 MtCO_2e, meaning if it had been possible to directly align the WIOD and NHS categorizations, good agreement would still be achieved.

Fossil fuels (coal and oil)

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	1019	2.4
NHS SDU	338	0.9

The two models differed in methodology with the NHS reporting bottom-up data on recorded consumption. This suggests that WIOD is providing an overestimate in this category for the United Kingdom. Due to the low magnitude of emissions from this sector, it is considered to have a minor impact on model validity.

Information and communication technologies

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	357	0.8%
NHS SDU	552	1.4%

There is a good agreement between the two models for this low-emission category (percentage difference: -35%).

Manufactured fuels, chemicals, and gases

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	1247	2.9

NHS SDU	4277	11.0

There is a significant disparity between the two models for this category. WIOD provides less sectoral resolution in this category than the NHS model, which combines eight IO model sectors to WIOD's one. This increases the likelihood that the two IO models are considering different sector boundaries and therefore accounting for activities in different ways.

Medical instruments/equipment

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	2664	6.3
NHS SDU	4520	11.6

The WIOD model provides a lower estimate for the emissions from the purchasing of medical instruments and equipment than the NHS model. This may in part be due to the expenditure profile within WIOD being for "health and social work activities," whereas the NHS model is built using an IO profile, which separates the demand from health and social care. Social care has a lower proportion of capital expenditure on medical equipment than health care in the IO model used by the NHS. The combination of these sectors in WIOD may reduce the expenditure modelled in this procurement category and therefore the emissions returned.

Other manufactured products

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	1246	2.9
NHS SDU	872	2.2

There is reasonable agreement between the models for this low-emission category (percentage difference: +43%).

Paper products

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	747	1.8
NHS SDU	1583	4.1

WIOD provides a lower estimate of the emissions from this category than the NHS estimate. However, as this is a low-emission category, this is considered to have a minor impact on model validity.

Pharmaceuticals

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	4224	9.9
NHS SDU	3195	8.2

There is a good agreement between the models for this high-emission category, with WIOD showing a slightly raised contribution relative to the NHS value (percentage difference: +32%).

Transport

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	3217	7.6
NHS SDU	3321	8.5

There is a good agreement between the models for this category with WIOD showing a slightly lowered contribution relative to the NHS value (percentage difference: -3%).

Waste, water, and sanitation

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	1790	4.2
NHS SDU	1887	4.9

Due to sewerage falling in a different category in WIOD, it was necessary to aggregate the “waste products and recycling” and “water and sanitation” categories used by the NHS to draw a true comparison between models. For this aggregated category, close agreement between the two models was observed (percentage difference: -5%).

Other procurement

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	1068	2.4
NHS SDU	0	0.0

The expenditure profile within the NHS model returns zero expenditures within the sectors included in this category (covering wholesale trade and including vehicles), which merits further investigation. The WIOD model indicates that there is a small contribution to the emissions profile from these sectors.

Other procured health services

Model	Emissions (ktCO_2e)	Proportion (%)
SPA	5507	13.0
NHS SDU	1886	4.9

There is significant divergence between the models for this sector, which represents spending by health sector organizations on goods and services from other areas of the health sector. This difference is driven by the aggregation of the health and social work sectors within the WIOD expenditure profile. In the IO model used by the NHS, 11% of health sector spending in 2014 was on other areas of the health sector, whereas in WIOD the human health and social work sector spends 30% of its own category. For this sector, the aggregation of health and social work within WIOD means a greater proportion of total spending falls into this category when compared to the NHS model.

United States and Eckelman et al. study

An in-depth comparison between the results of this study and a previously published study for the United States[6] was undertaken following the completion of these results. This review highlighted some disparities between the results of our modelling and the published results, which appeared to be related to the scaling of emissions intensity from a 2008 base year in the previous study. Since this review was completed, an update to this study has been published by Eckelman et al.,[7] superseding the study that our model was originally compared against.

This update showed much closer alignment with the results of our modelling. The overall footprint for 2014 was reported to be 518.6 MtCO_2e, which is within 5% of the value returned by our model of 546.5 MtCO_2e. The update to the study also separates emissions by scopes.

Scope	Unit	Our study	National paper	% difference	Overall sector footprint shows good agreement between studies
Scope 1 emissions	Mt	118.3	35.3	-70%	There is a large discrepancy between the Scope 1 footprints for the two studies. Differing data sources and system boundaries may contribute to this.
Scope 2 emissions	Mt	81.8	62.4	-24%	Scope 2 makes up a similar proportion of the footprint for both studies (12% and 15%)
Scope 3 emissions	Mt	346.3	420.9	22%	Our study has a lower Scope 3. It may be that the imbalance between Scope 1 and 3 is related to the differing methods and data sources resulting in different allocation of emissions between scopes.

Table A.1. Comparison between scope breakdowns of the U.S. footprint produced by our modelling and provided in the updated U.S. national footprint study.

Further checks on national results

In addition to the reviews detailed in the previous sections, the wider body of results was interrogated to identify trends and potential areas of divergence. Emissions per capita for each of the SPA categories was investigated for the model nations. Histograms visualizing the range in per capita values were produced for each sector, examples of which for “business services” and “pharmaceuticals” are shown in Figure A.4 and Figure A.5 respectively.

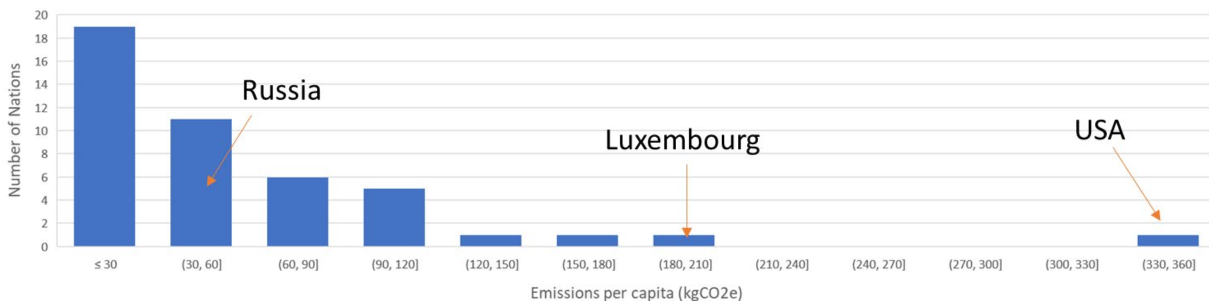

Figure A.4. Distribution of per capita emissions associated with business services procured by the national health system. The positions of Russia, Luxembourg, and the United States are shown as examples.

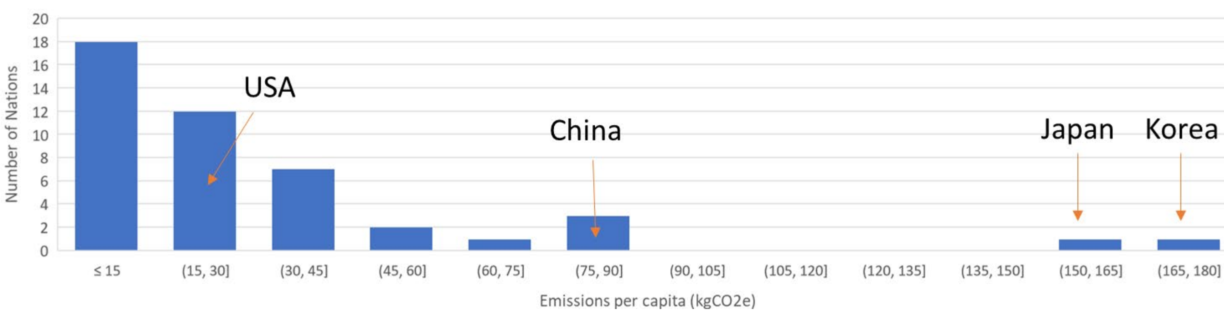

Figure A.5. Distribution of per capita emissions associated with pharmaceuticals procured by the national health system. The positions of the United States, China, Japan, and Korea are shown as examples.

Following the plotting of these distributions on a category by category basis, a heatmap (Figure A.6) was used to assess, by inspection, the overall variation in values seen across the model. If the emissions per capita showed a significant difference in magnitude to those seen for other nations they were marked in orange for further investigation. Efforts were made to identify the causes and explanations for these differences from available data. For Russia and Turkey, the WIOD team have identified a lack of reliable national accounts in their construction of input-output tables,[8] which may cause some divergence in model results. For nations where national footprints were available in the literature, further comparisons were made and these values are shown with an orange box surrounding them. These comparison points are displayed in Table A.2.

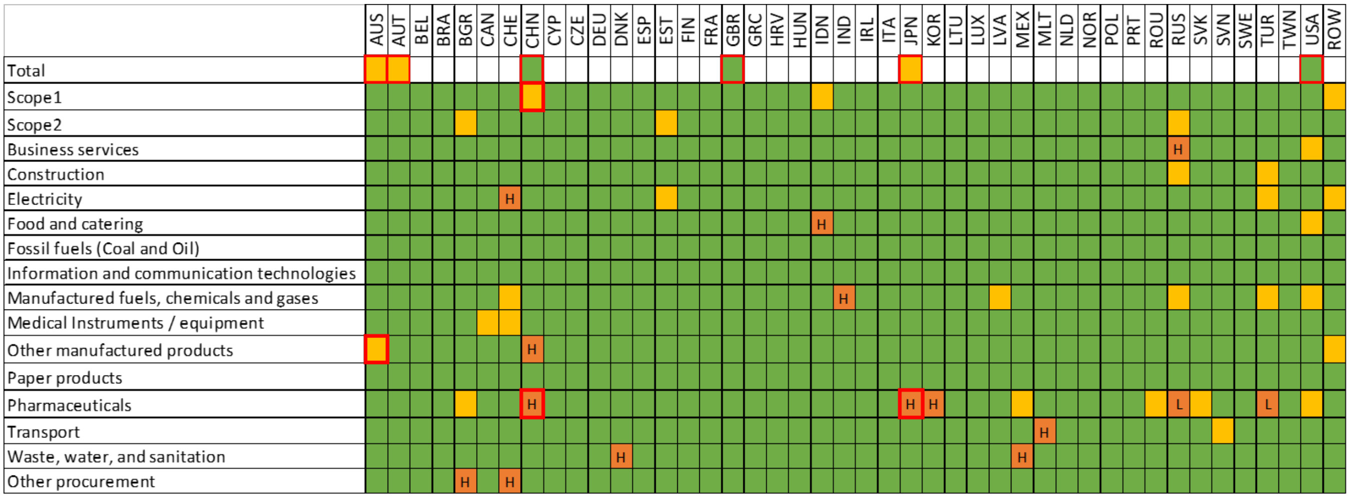

Figure A.6. The heatmap is used to categorize the degree of variation in per capita emissions by category across the WIOD nations. Green denotes nations where values correspond to behaviour observed across the model nations, yellow is used for nations with emissions a short distance from levels seen more widely across the model nations, and orange is used where emissions are substantially higher/lower than levels seen elsewhere. It is also indicated when emissions are higher (H) or lower (L) than the observed distribution.

From this analysis, it was concluded that the results of this analysis for the 2014 baseline are broadly consistent with the preceding work in this literature. Comparisons of studies in this field are fundamentally a comparison of estimates provided by models building on differing datasets, definitions of the health system, and modelling scope. The level of consistency found between detailed, national studies and the global modelling approach employed in this study has provided confidence in its suitability for our modelling of global health care sector emissions.

	Points examined	Unit	This study	Other study	Difference	Comment
Japan[9]	Total health care emissions	Mt	104	70	-32%	Other study does not include medical retailers.
	Pharmaceuticals	Mt	20	13	-36%	Exclusion of medical retailers could explain lower pharmaceutical footprint, proportion is consistent.
China[10]	Total health care emissions	Mt	342	315	-8%	Other study excludes imports, estimated at 6%. Good agreement at total footprint level.
	Pharmaceuticals	Mt	113	173	54%	Significantly higher pharma footprint in other study, out-of-pocket seems to play a significant role, recommend further study to investigate pharmaceutical emissions in China.

	Points examined	Unit	This study	Other study	Difference	Comment
	Scope 1	Mt	41.0	50.4	23%	Our Scope 1 is smaller despite a larger total footprint.
Australia[11]	Total health care emissions	Mt	30.2	35.8	19%	Our value falls within the quoted uncertainty range; assessments used different IO models and expenditure datasets.
	Other manufactured products	kt	2.2	-	N/A	Other study does not give supply chain results.
Austria[12]	Total health care emissions	Mt	5.0	6.8	36%	Other study is CO_2 only, more variability is often seen for IO models of smaller, wealthy nations.

Table A.2. Further comparison of model outputs against results reported in the literature.

Methodology for supply chain analysis

The following pages detail the approach taken to quantifying emissions from health sector supply chains through structural path analysis (SPA). Following this, the approach taken to processing SPA outputs into reporting categorization is detailed, with the logic behind the chosen categories presented.

Structural path analysis

When analyzing the structure and associated emissions for an economic unit using input-output (IO) modelling, SPA presents an advanced method for the direct quantification of the individual components of a global, high-complexity supply chain.

Figure A.7 provides an illustrative example of a health sector supply chain. It is focused on the direct provision of transport services, electricity, and catering services to the health care provider at tier 1 of the structure. Also shown is a section of the catering provider's supply chain, showing the sectors involved indirectly in the servicing of health care's demand for catering services.

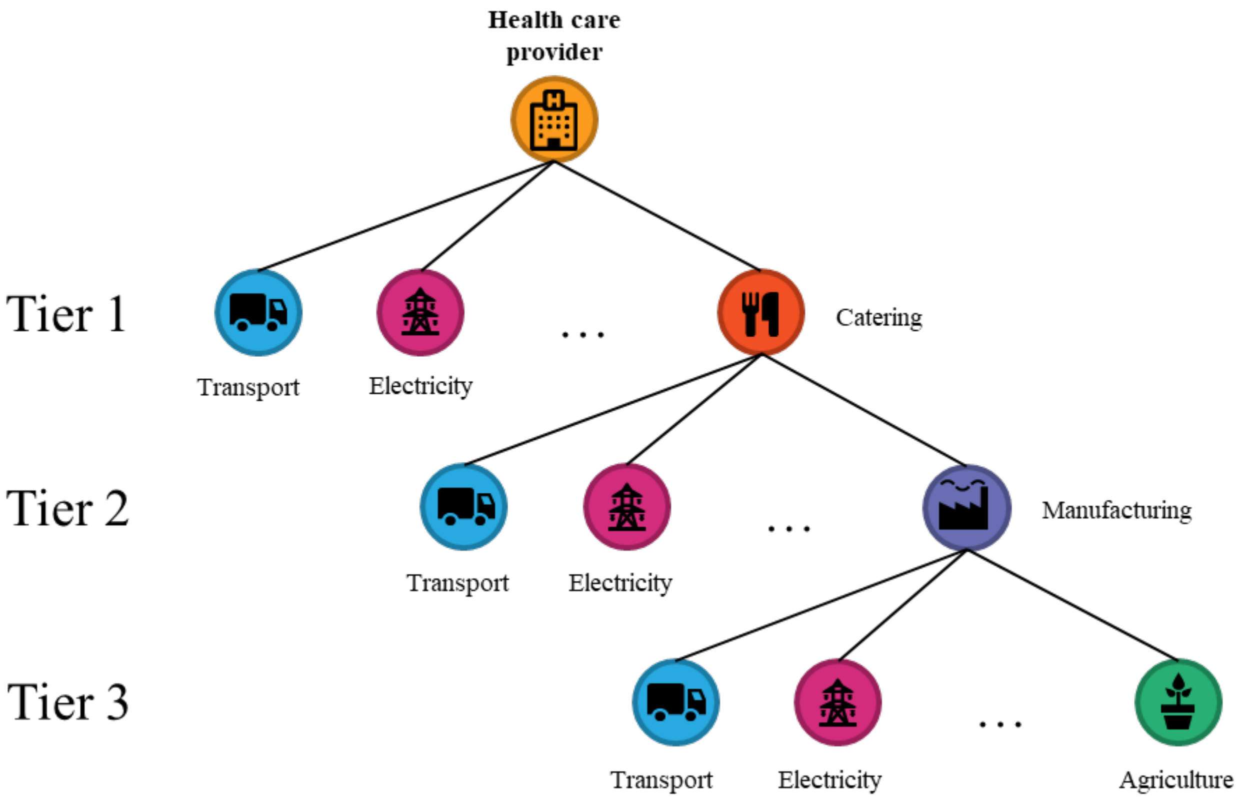

Figure A.7. A simplified representation of a section of a health care provider's supply chain.

The purpose of SPA is to break this supply chain tree structure into its component branches, or paths, quantify the capital through each path, and derive the emissions associated. Examples of paths in the example supply chain are shown in Figure A.8. Once the paths, and their emissions, for a supply chain structure are known, then individual paths can be grouped based on the sectors through which they flow. This allows for a wide range of insights to be gained into the capital and emission flows through the supply chain, the tiers at which emissions occur, and the goods and services with the greatest quantities of associated GHGs.

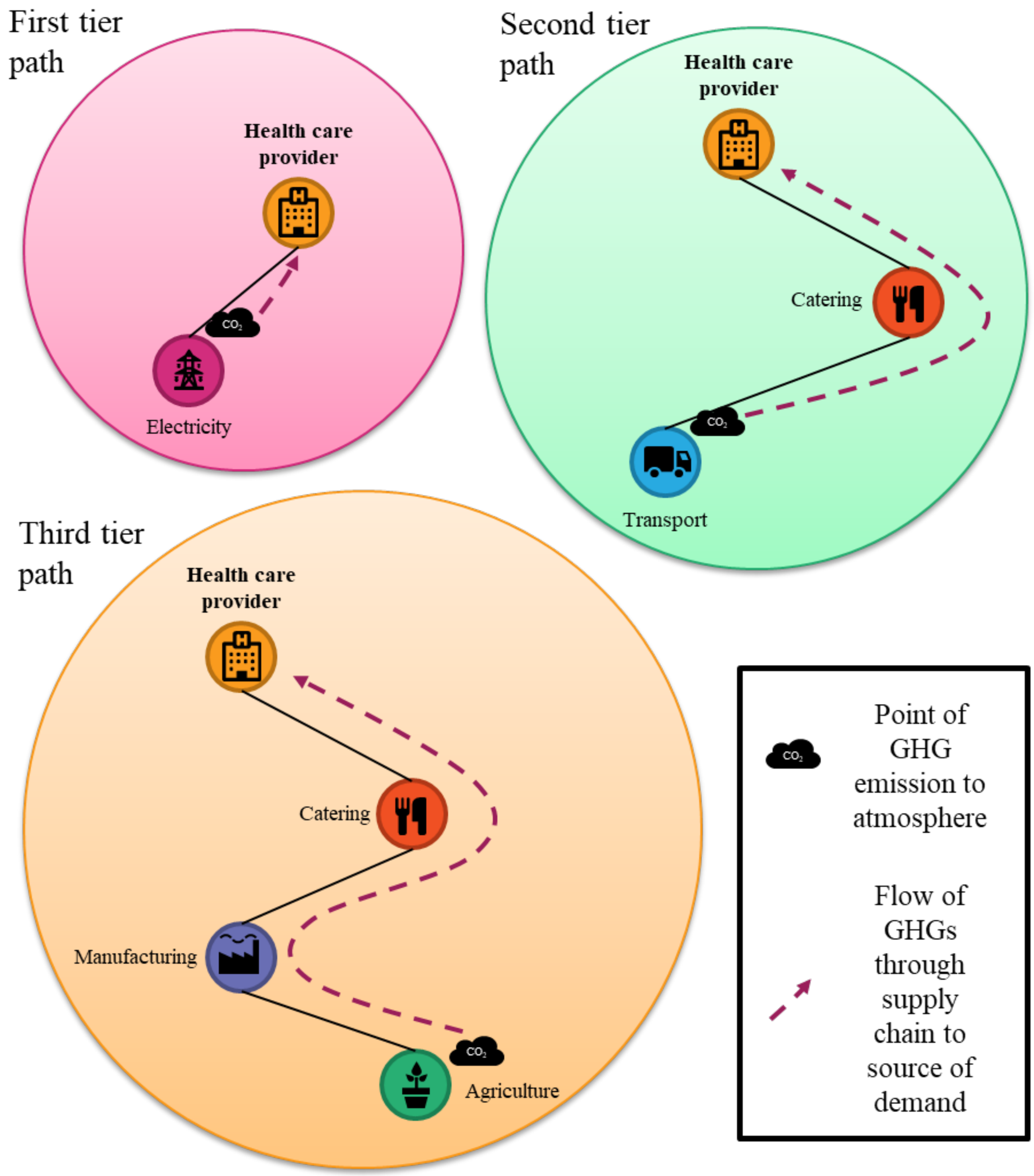

Figure A.8. Illustrative supply chain paths in the first, second, and third tiers. Also shown are how emissions associated with each path are attributed to the sector driving demand for the supply chain path (in this case the health care provider).

The mathematics behind SPA are relatively straightforward, covered in detail in Lenzen.34 To calculate a path contribution, the capital flow associated with the path is first calculated from the final demand profile of the health care sector (derived during the modelling for Green Paper 1) and scaled according to the proportion of this expenditure associated with the path. This proportion is found from the technical coefficients within WIOD that describe the relative scale of financial flows between sectors of the global economy. Once the capital flow is found, it is multiplied by the direct emissions intensity for the sector producing the emissions associated with the path (which is the final sector of the path).

The complexity in performing a SPA comes through the sheer number of calculations required to quantify all paths responsible for emissions in the supply chain. This is a computationally exhaustive process. The number of paths to be calculated was managed using pruning techniques as described by Lenzen and discussed in the “Limitations and assumptions” section of this report.

Categorization and reporting of emissions

Following the execution of a SPA for all 44 nations and regions within WIOD, the presentation of results and overall framing was undertaken using two categorization approaches:

- **Health care provision perspective**: Building upon the reporting employed by the NHS SDU, this categorization groups emissions from the supply chain according to procurement categories used by health care provider purchasers, like pharmaceuticals and medical equipment.
- **Greenhouse Gas Protocol perspective**: Emissions are grouped in a manner consistent with the terminology and methods presents in the GHGP corporate reporting standard.

Table A.3 shows the categorizations used for each of the above perspectives, while Table A.4 details the types of emissions covered in each category. When compiling emissions from individual paths into both of these categorization schemes, the WIOD sectoral classification, which is based upon the International Standard Industrial Categorization, was aligned with the target lists of categories. The mapping of WIOD categories to the lists of categories below is shown in Table A.5 and Table A.6.

Emission type	Health provision categorization	GHGP categorization
Scope 1	Direct emissions from health care facilities and the operation of fleet vehicles	Direct emissions from health care facilities and the operation of fleet vehicles
Scope 2	Emissions from the generation of electricity purchased by the health sector	Emissions from the generation of electricity purchased by the health sector
Scope 3 sub-categories:	Business services	Purchased goods and services
	Construction	Capital goods

Emission type	Health provision categorization	GHGP categorization
	Electricity: Supply chain emissions for the electricity sector and transmission and distribution losses	Fuel- and energy-related activities not included in Scope 1 or Scope 2
	Food, catering, and accommodation	Transportation, distribution, business travel
	Fossil fuels (coal and oil)	Waste generated in operations
	Information and communication technologies	
	Manufactured fuels, chemicals, and gases	
	Medical instruments/equipment	
	Other manufactured products	
	Paper products	
	Pharmaceuticals	
	Transport including freight and business travel	
	Waste, water, and sanitation	
	Other procurement	

Table A.3. Categorization schemes used to present findings of the SPA analysis.

SPA categories	Definition of category coverage
Scope 1: Operation of buildings	Direct emissions from the operation of buildings, predominantly from boilers and incinerators
Scope 1: Transport	Direct emissions from health sector-owned vehicle fleets as well as health care professionals travelling for work (excluding regular commuting)

SPA categories	Definition of category coverage
Scope 2	Emissions from the generation of electricity purchased by the health sector, largely from the combustion of fossil fuels
Scope 3: Business services	Emissions associated with professional services procured by the health sector, like legal, accountancy, and consultancy services
Scope 3: Construction	Emissions associated with the construction of buildings and infrastructure, including the supply and manufacture of construction materials
Scope 3: Electricity	Emissions associated with the transmission and distribution of electricity purchased by the health sector, as well as the electricity generated within the sector's own supply chain
Scope 3: Food, catering, and accommodation	Emissions associated with the food products and catering services provided by the health system and accommodation required by health workers
Scope 3: Fossil fuels (coal and oil)	Emissions associated with the production of fossil fuel products procured by the health sector for uses including boilers, generators, and vehicles. These emissions are those generated in the production of these fuels, and does not include emissions from burning these fuels, which are included in Scope 1
Scope 3: Information and communication technologies	Emissions associated with IT and communication services procured by the health sector, including computer systems, telecoms, and publishing activities
Scope 3: Manufactured fuels, chemicals, and gases	Emissions associated with the production of purchased chemicals, like soap and detergents, and gases used in the health setting
Scope 3: Medical Instruments/equipment	Emissions associated with purchased medical instruments and equipment, including computers, electronics, and optical products
Scope 3: Other manufactured products	Emissions associated with purchased products including plastics, textiles, machinery, vehicles, and electrical equipment
Scope 3: Other procurement	Emissions associated with goods purchased in bulk through wholesalers and intermediaries
Scope 3: Paper products	Emissions associated with the production of paper and cardboard products procured by the health sector
Scope 3: Pharmaceuticals	Emissions associated with the production of pharmaceuticals procured by the health sector, encompassing the emissions associated with the energy, materials, and transportation of pharmaceuticals
Scope 3: Transport	Emissions from transport services purchased by the health sector, covering freight and passenger transport
Scope 3: Waste, water, and sanitation	Emissions associated with water collection, treatment, supply, and sewerage and with waste disposal and recycling

Table A.4. Health sector emissions sources covered by the categorization scheme used in this study.

Arup categories	WIOD categories
Business services	Warehousing and support activities for transportation
	Postal and courier activities
	Financial service activities, except insurance and pension funding
	Insurance, reinsurance, and pension funding, except compulsory social security
	Activities auxiliary to financial services and insurance activities
	Real estate activities
	Legal and accounting activities, activities of head offices, and management consultancy activities
	Scientific research and development
	Advertising and market research
	Other professional, scientific, technical, and veterinary activities
	Administrative and support service activities
	Public administration and defence and compulsory social security
	Education
	Other service activities
	Activities of households as employers, undifferentiated goods- and services-producing activities of households for own use
	Architectural and engineering activities, technical testing, and analysis
	Activities of extraterritorial organizations and bodies
	Human health and social work activities
Construction	Construction
	Repair and installation of machinery and equipment
	Manufacture of other non-metallic mineral products
	Manufacture of basic metals
	Manufacture of wood and of products of wood and cork, except furniture, and manufacture of articles of straw and plaiting materials
	Manufacture of fabricated metal products, except machinery and equipment
Electricity	Electricity, gas, steam, and air conditioning supply
Food and Catering	Crop and animal production, hunting, and related service activities
	Fishing and aquaculture

Arup categories	WIOD categories
	Manufacture of food products, beverages, and tobacco products
	Accommodation and food service activities
Fossil fuels (coal and oil)	Manufacture of coke and refined petroleum products
Information and communication technologies	Publishing activities
	Motion picture, video, and television program production, sound recording and music publishing activities, and programming and broadcasting activities
	Telecommunications
	Computer programming, consultancy, and related activities, information service activities
Manufactured fuels, chemicals, and gases	Manufacture of chemicals and chemical products
	Mining and quarrying
Medical instruments/equipment	Manufacture of computer, electronic, and optical products
	Manufacture of furniture and other manufacturing
Other manufactured products	Forestry and logging
	Manufacture of textiles, wearing apparel, and leather products
	Manufacture of rubber and plastic products
	Manufacture of motor vehicles, trailers, and semi-trailers
	Manufacture of other transport equipment
	Manufacture of machinery and equipment n.e.c.
	Manufacture of electrical equipment
	Retail trade, except of motor vehicles and motorcycles
Paper products	Manufacture of paper and paper products
	Printing and reproduction of recorded media
Pharmaceuticals	Manufacture of basic pharmaceutical products and pharmaceutical preparations
Transport	Land transport and transport via pipelines
	Water transport
	Air transport
Waste, water, and sanitation	Sewerage, waste collection, treatment and disposal activities, materials recovery, remediation activities, and other waste management services
	Water collection, treatment, and supply
Other procurement	Wholesale and retail trade and repair of motor vehicles and motorcycles

Arup categories	WIOD categories
	Wholesale trade, except of motor vehicles and motorcycles

Table A.5. Allocation of WIOD categories to the health procurement sectors presented in this study.

GHGP category	GHGP sub-category	WIOD category
Scope 1		Health care sector emissions
Scope 2		Electricity, gas, steam, and air conditioning supply
Scope 3	Purchased goods and services	Postal and courier activities
		Accommodation and food service activities
		Financial service activities, except insurance and pension funding
		Insurance, reinsurance, and pension funding, except compulsory social security
		Activities auxiliary to financial services and insurance activities
		Real estate activities
		Legal and accounting activities, activities of head offices, and management consultancy activities
		Scientific research and development
		Advertising and market research
		Other professional, scientific, and technical activities, including veterinary activities
		Administrative and support service activities
		Public administration and defence and compulsory social security
		Education
		Other service activities
		Activities of households as employers and undifferentiated goods- and services-producing activities of households for own use
		Activities of extraterritorial organizations and bodies
		Architectural and engineering activities, technical testing, and analysis
		Crop and animal production, hunting, and related service activities
		Fishing and aquaculture
		Manufacture of food products, beverages, and tobacco products

GHGP category	GHGP sub-category	WIOD category
		Publishing activities
		Motion picture, video, and television program production, sound recording and music publishing activities, and programming and broadcasting activities
		Telecommunications
		Computer programming, consultancy and related activities, and information service activities
		Manufacture of chemicals and chemical products
		Manufacture of textiles, wearing apparel, and leather products
		Manufacture of rubber and plastic products
		Retail trade, except of motor vehicles and motorcycles
		Manufacture of paper and paper products
		Printing and reproduction of recorded media
		Manufacture of basic pharmaceutical products and pharmaceutical preparations
		Water collection, treatment, and supply
		Wholesale trade, except of motor vehicles and motorcycles
		Water transport
	Capital Goods	Construction
		Repair and installation of machinery and equipment
		Manufacture of other non-metallic mineral products
		Manufacture of basic metals
		Manufacture of wood and of products of wood and cork, except furniture and manufacture of articles of straw and plaiting materials
		Manufacture of fabricated metal products, except machinery and equipment
		Mining and quarrying
		Manufacture of computer, electronic, and optical products
		Manufacture of machinery and equipment n.e.c.
		Manufacture of electrical equipment
		Forestry and logging
		Manufacture of motor vehicles, trailers, and semi-trailers
		Manufacture of other transport equipment

GHGP category	GHGP sub-category	WIOD category
		Manufacture of furniture and other manufacturing
		Wholesale and retail trade and repair of motor vehicles and motorcycles
	Fuel- and energy-related activities	Electricity, gas, steam, and air conditioning supply
		Manufacture of coke and refined petroleum products
	Transportation, distribution, and business travel	Warehousing and support activities for transportation
		Air transport
		Land transport and transport via pipelines
	Waste generated in operations	Sewerage, waste collection, treatment and disposal activities, materials recovery, remediation activities, and other waste management services

Table A.6. Allocation of WIOD categories to GHGP based break down.

Expanding country coverage

The 43 nations covered in detail in the WIOD input-output model skew toward higher income nations. Other studies, making use of differing data sources and methodologies, have provided estimates for other nations. One such study, from Lenzen et al.,[13] has produced a global health sector footprint based on Eora, a different input-output model, and provides the health sector footprint for 25 nations not considered in detail in WIOD.

The additional nations are shown in Table A.10 and profiles are given in the country factsheets that accompany this report. Integrating these published footprints for an additional 25 nations has allowed the Road Map to be more expansive than Green Paper One.

Since these footprints were determined through a different methodology (Eora), taking a different source for health sector expenditure, the sector definitions and activities covered have different boundaries from those in the WIOD-based model. Additionally, the structure of the health care sector footprint for these nations was not available. National health care emission reduction trajectories and expenditure projections are available for all countries, allowing estimation of the reference case scenario (BAU) and target trajectories for the additional national footprints. The potential scale of emissions reduction for these nations is instead estimated using the global mean reductions derived from the WIOD model. These estimates are shown to highlight the potential savings if these health systems decarbonize in line with the global average and therefore do not capture the expected variability associated with the national context. It is recommended that these nations further investigate their national health system footprint and potential to decarbonize to capture the national context in greater detail.

Health sector emissions budgets

Introduction

This section describes the approach followed to estimate the global health care sector emissions budget and national emissions trajectories. The carbon budget for the health care sector is based on a customized contraction and convergence method.[i] This method was tailored to fit the analysis of the health care sector's contribution to global emissions and the Paris Agreement. The emissions trajectory for each country has been estimated based on four trajectory types.

This section is structured based on the following components:

- Section A.2.2.1 describes the approach followed to calculate the global emissions budget and the calculated budget for the global health care sector.
- Section A.2.2.3 describes the approach followed to estimate the nations' trajectories based on the emissions budget.
- Section A.2.2.3 provides summary graphs for each trajectory type.

The emissions budget and trajectories have been estimated for greenhouse gas (GHG) emissions (hereon referred to as emissions). The six main GHGs covered by the United Nations Framework Convention on Climate Change (UNFCCC) / Kyoto Protocol have been considered. These are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6).[14] The results are expressed in carbon dioxide equivalent (CO_2e), which signifies the amount of CO_2 which would have the equivalent warming impact over 100 years.[14]

Methodology

Emissions budget

This section describes the approach followed to calculate the health care sector's portion of the global emissions budget. It is divided into two subsections. The first subsection focuses on the approach followed to determine the global emissions budget. The second subsection describes the steps followed to allocate a portion of the global emissions budget to the health care sector, splitting this across model nations.

[i] A similar method was used in for the C40 Deadline 2020 project. Available at: https://www.c40.org/other/deadline_2020

Global emissions budget

For the purposes of this study, the global emissions budget was set to achieve the aspirational aim of the Paris Agreement. This is to limit global average temperature rise to no more than 1.5 °C above pre-industrial levels.

The emissions budget considered in this study is the remaining cumulative GHG emissions from 2014 for a warming of 1.5 °C. In line with the IPCC Special Report Global Warming of 1.5 °C (SR15) report, this has been estimated using the emissions scenarios developed as part of the Integrated Assessment Modelling Consortium (IAMC).[15] Data was extracted for 36 scenarios corresponding to 1.5 °C with no or limited overshoot[ii] reporting Kyoto GHG emissions.

The yearly[iii] emissions used to derive the emissions budget were estimated as the median from all scenarios. The result is in line with the emissions reported in IPCC SR15 (see Table 2.4 in Chapter 2 of the IPCC SR15). In these modelled scenarios, global net anthropogenic CO_2 (note that this does not include non-CO_2 emissions) emissions decline by about 45% from 2010 levels by 2030, reaching net zero around 2050.

Table A.7 shows the global emissions budget from 2014 obtained using this approach.

	1.5 °C scenario
Remaining emissions budget including CO_2 and non-CO_2 emissions from January 2014 ($GtCO_2e$)	995

Table A.7. Remaining emissions budget (including CO2 and non-CO2 emissions) from January 2014 for the 1.5 °C scenario.

Global emissions pathway

The global pathway was modelled using, as a reference, the median of the IAMC scenarios representing a 1.5 °C with no or limited overshoot. Figure A.9 shows the modelled global emissions pathway to achieve the emissions budget described above. The median of the IPCC SR15 scenarios is shown for illustration purposes.

[ii] Pathways with overshoot are those where warming temporarily exceeds ('overshoots') 1.5°C and returns to 1.5°C either before or soon after 2100. See also https://www.ipcc.ch/site/assets/uploads/sites/2/2018/11/SR15_Chapter 1_Low_Res.pdf page 60.
[iii] Note: The five yearly values obtained from the IAMC database were interpolated to yearly values in order to estimate cumulative emissions.

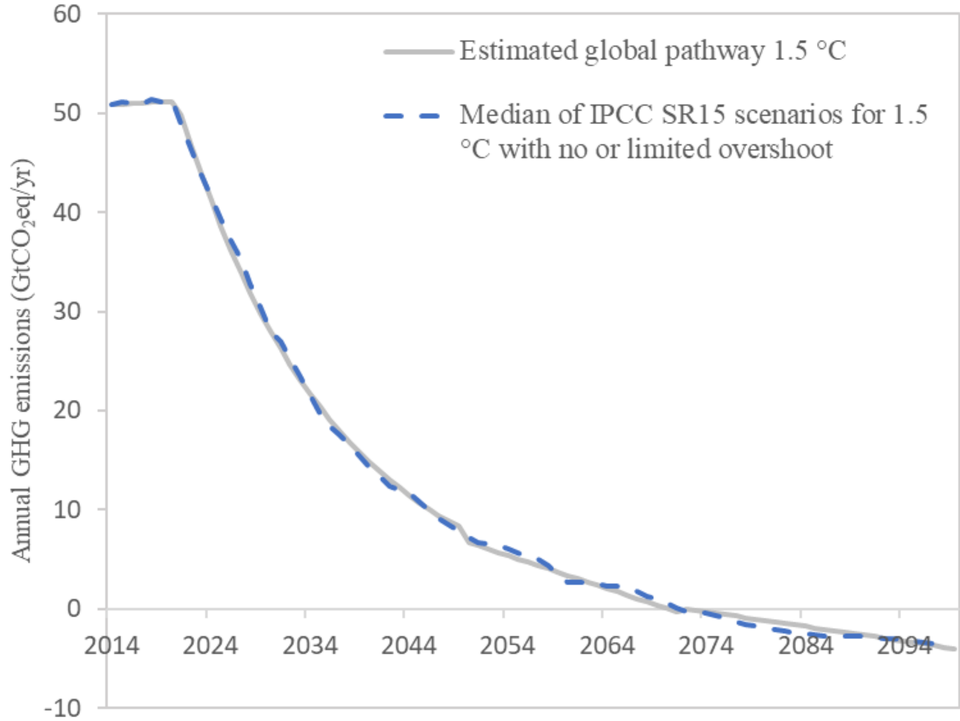

Figure A.9. Estimated global emission pathway to limit global temperature to 1.5 °C and median of the IPCC SR15 IAMC emissions scenarios.

A modelled pathway was fitted to the IAMC scenarios instead of directly using the scenario data with the purpose of obtaining a more realistic curve. In some years, the median obtained from the IAMC scenarios leads to possibly unrealistic changes in emissions. This is due to the fact that the curve has been estimated empirically from a number of scenarios (see for example around year 2060 in the curve for median of IAMC scenarios in Figure A.9). Still, it should be noted that both curves lead to the same emissions budget.

Global emissions budget for the health care sector

Approach to allocating the global health care sector emissions budget

Using the global health care budget and pathway calculated we then applied a contraction and convergence approach. This approach is a two-phase process developed by the Global Commons Institute.[16] The convergence phase is an "adaptation" period during which regional emissions per capita can linearly increase up or decrease down to the global average in the convergence year (e.g., 2040). In the contraction phase, all regional emissions per capita decrease to equal global per capita emissions for a specified year (e.g., 2100). The reader is referred to Global Commons Institute for more information on the contraction and convergence approach.[16]

In this study, we have tailored the method to reflect sectorial emissions rather than regional emissions. For this purpose, we have used global domestic product (GDP) and total expenditure in the health sector as a reference.[16] In 2017, for example, we understand that the health care sector represented 10% of total GDP.[17] The percentage of GDP that the health sector represents from now to 2100 was used to scale the global pathway (shown in Figure A.9), leading to target emissions of 0.11tCO_2e by the convergence year (2040). The convergence year of 2040 was selected because the starting point of health care emissions per GDP is lower than the global average. Hence, a relatively late convergence year was selected which leads to a steady decrease of emissions up to global average (an early convergence year would lead to a very small or no reduction in emissions up to convergence year).

Results from allocating an emissions budget to the global health care sector

The contraction and convergence approach was applied to the emissions projected from the year 2014 to 2050 for the global health care sector. Data from Health care Without Harm's Climate footprint report was used as the baseline for this study.[iv]

Table A.8 summarizes the results of allocating a portion of the global emissions budget to the global health care sector using the contraction and convergence approach. Emissions per capita from health care are estimated to have to reduce by 39% up to convergence year and a further 45% by 2050 to reach almost near zero.

	Value consistent with 1.5 °C
Global health care sector emissions budget for 2014 – 2050 (GtCO_2e)	50.3
Global health care sector emissions per capita in 2014 (tCO_2e/capita)	0.28
Global health care sector emissions per capita in 2040 (tCO_2e/capita)	0.11
Global health care sector emissions per capita in 2050 (tCO_2e/capita)	0.05

Table A.8. Summary results of global health care sector emissions budgets and required emissions per capita in 2014 (baseline year), 2040 (convergence year), and 2050 for the 1.5 °C scenario.

Emissions trajectories

This section presents the emissions trajectories developed for each national health care sector based on the emissions budget from 2014 to 2050 for the 1.5 °C scenario with no or limited overshoot. This section is divided into two subsections, which briefly describe the approach used to assign trajectories to each country and the model used to develop the trajectory curves.

[iv] Appendix A tabulated national health care emissions for the 43 WIOD nations available at: www.noharm.org/ClimateFootprintReport

Approach to allocating trajectories

A country's trajectory is defined as a plausible emissions pathway a country must follow to remain within the global emissions health care sector budget. The approach involves two main steps: 1) definition of trajectory types and 2) identification of criteria for trajectory allocation to nations.

Definition of trajectory types

Table A.9 describes the four trajectories used in this study. The trajectory types used here are based on those used in the C40 work to define city trajectories and developed as part of Deadline 2020.[18]

Trajectory	Description	Peak year	Trend up to peak year	Rate of emission decrease
Steep decline	Nations are required to immediately begin a steep decrease in emissions per capita	-		Steep
Steady Decline	Nations are required to immediately follow a steadier decline in emissions per capita than the steep decliners	-		Steady
Early Peak	Nations are allowed to increase emissions up to a peak year of 2022 before steadily declining	2022	Linear	Steady, as per steady decline
Late Peak	Nations are allowed to increase emissions up to peak year of 2026 before steadily declining	2026	Linear	Steady, as per steady decline

Table A.9. Description and main characteristics of the four trajectories.

Trajectory curve modelling

The trajectory curves were calculated using a mathematical function that governs the overall shape of the trajectory, namely:

Steep and steady decline: The trajectory follows a logistic negative growth function (S-curve).

Early and late peak: The trajectory follows a period of linear growth up the peak year, after which it is modelled using a logistic negative growth function to meet the target emissions level.

The process to develop the final trajectories was iterative whereby the parameters of the curves were adjusted to respond to requirements of the trajectory description (e.g., steepness was realistic) while ensuring that the sum of the trajectories was within the global health care sector emissions budget.

Identification of criteria and thresholds

For this study, per capita GDP was identified as the key criteria to assign trajectories as it offers a proxy for each country's capacity to reduce emissions and is also a proxy for nations' current contribution to total health care emissions. The findings show a strong linear relationship between nations' GDP and emissions per capita. Figure A.10 shows this correlation. Three nations (United States, Norway, and Luxembourg) stand out as outliers as they have considerably higher (United States) or lower (Norway, Luxembourg) emissions than expected based on their GDP.

Thresholds were defined to group nations into the different trajectories. These thresholds were selected based on the range of GDP per capita across nations and their typology. Four GDP levels were defined: up to US $5,000, $5,000 – $20,000, $20,000 – $43,000, and higher than $43,000.

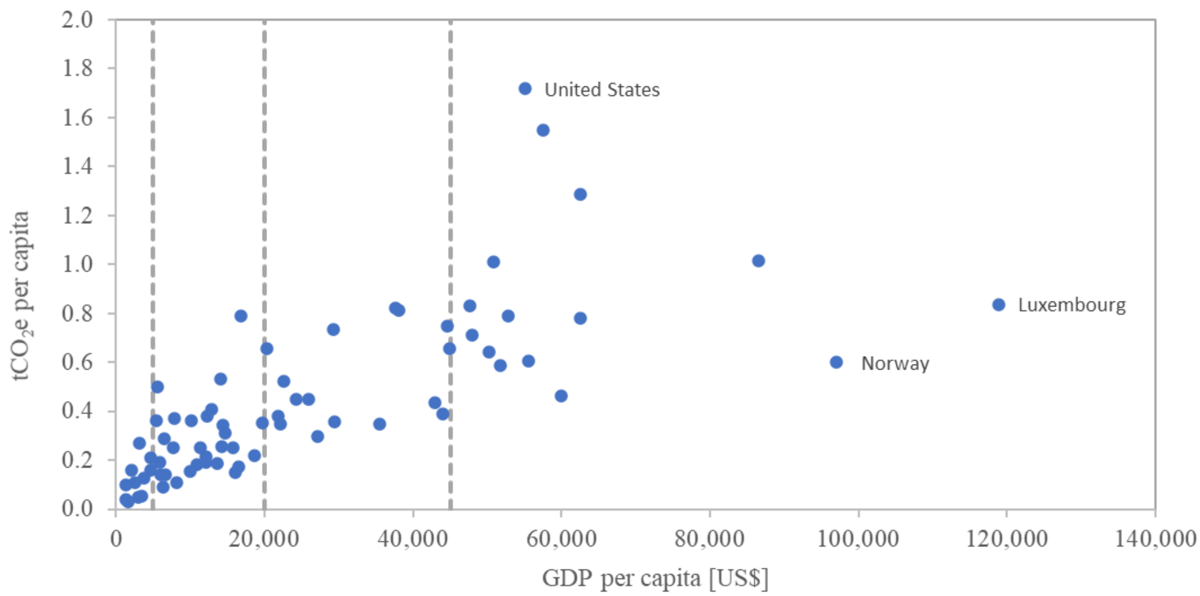

Figure A.10. Emissions per capita compared to their GDP for the nations covered in this study according to their typology and threshold used to allocate the four trajectories to nations (dashed gray line).

Table A.10 presents the trajectory types assigned to nations.

Steep decrease	Steady decrease	Early peak	Late peak
Australia	Cyprus	Brazil	India
Austria	Czech Republic	Bulgaria	Indonesia
Belgium	Estonia	China	*Georgia*
Canada	Greece	Croatia	*Kenya*
Denmark	Korea	Hungary	*Kyrgyzstan*

Steep decrease	Steady decrease	Early peak	Late peak
Finland	Latvia	Mexico	*Philippines*
France	Lithuania	Poland	*Rest-of-World*
Germany	Malta	Romania	*Ukraine*
Ireland	Portugal	Russia	*Uzbekistan*
Italy	Slovak Republic	Turkey	*Vietnam*
Japan	Slovenia	*Argentina*	
Luxembourg	Spain	*Chile*	
Netherlands	Taiwan	*Colombia*	
Norway	*Israel*	*Ecuador*	
Sweden		*Iran*	
Switzerland		*Kazakhstan*	
United Kingdom		*Malaysia*	
USA		*Mauritius*	
New Zealand		*North Macedonia*	
Kuwait		*Paraguay*	
Singapore		*Peru*	
		South Africa	
		Thailand	
		Uruguay	

Table A.10. Trajectories assigned to nations. Nations added from the work of Lenzen et al.13 are shown in italics.

Results for nations grouped according to their trajectory

Figure A.11 shows the annual emissions per capita according to their trajectories. Steep decline nations decline up to 2030, after which the decrease rate slows down to gradually converge to zero emissions. The steady decline nations follow a slightly less steep trajectory than steep decline nations. The emissions from steep decline and steady decline nations follow a similar path from around 2030.

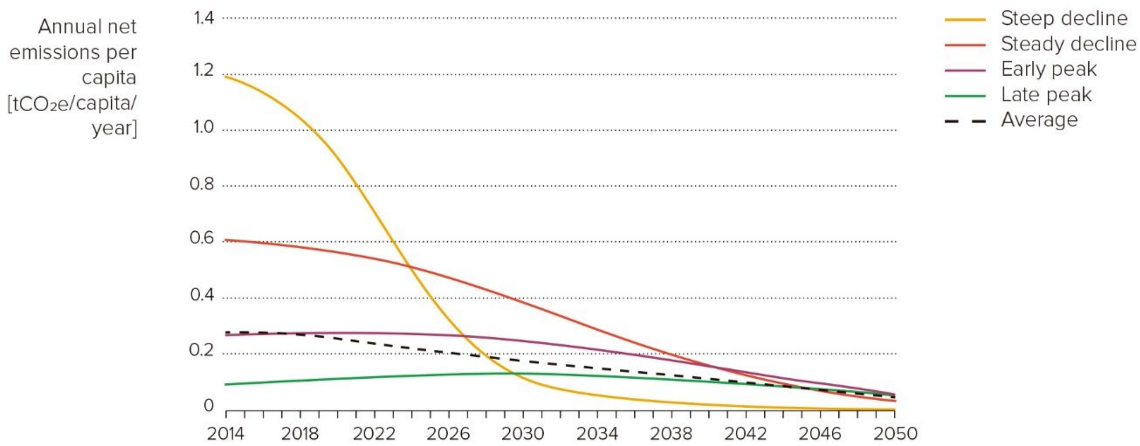

Figure A.11. Annual net emissions per capita for the global health care sector categorized by emissions profile as well as the global average.

For the peaking trajectories, the peaks in per capita emissions for the early peak and late peak trajectories are in 2022 and 2026 respectively, although the emissions growth is fairly minimal to those peaks. From there, the emissions per capita were modelled to decline gradually as per the steady decline trajectory.

Figure A.12 shows the annual emissions for the four trajectory types (i.e., emissions per capita multiplied by the population sum within each trajectory).

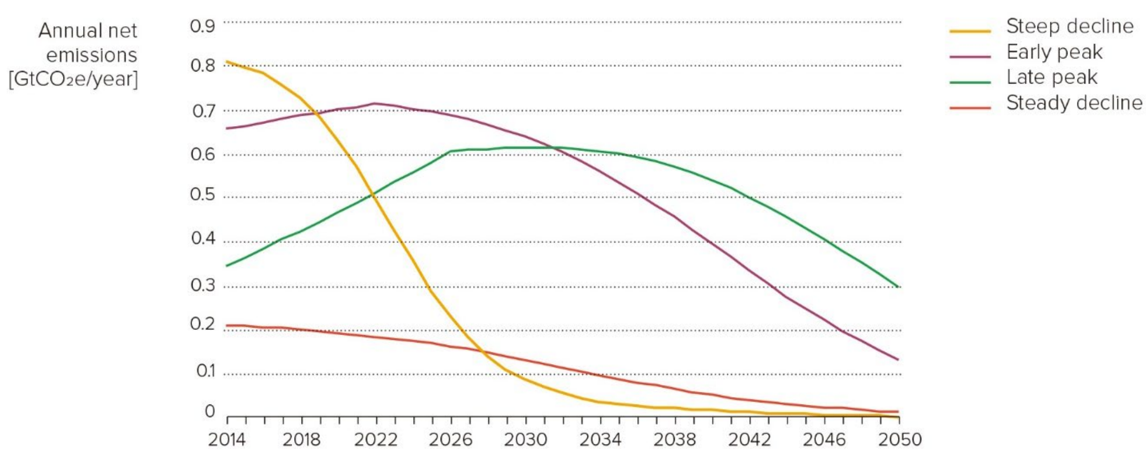

Figure A.12. Annual net emissions trajectories for the global health care sector categorized by emissions profile.

Late peak nations have the highest annual emissions throughout the period modelled, followed by steep decline nations. After 2035, early peak, late peak, and steep decline nations have similar annual emissions. The late peak nations' curve displays discontinuity of the curve at the peak year. It is important to note that in reality, the step change in emissions is likely to be smoother than portrayed by the model, which is a simplified representation of how emissions can be allocated within the available budget.

Future health sector growth

Data sources

Institute of Health Metrics and Evaluation (IHME) have produced projections for health sector expenditure.[19] This dataset has informed projections for sector growth in the Road Map modelling. IHME's projections are based on methods published in leading peer reviewed journals, including The Lancet[20] and Population Health Metrics.[21]

The IHME datasets used to project future health care demand in the Road Map cover recorded expenditure data for the years up until 2018 and project future expenditure through to 2050. The projections for total health spending (in 2019 in U.S. dollars) were used for this study, taking the mean projection profile. More information on the dataset and methods used in generating projections can be found in the accompanying report to the dataset.[19]

Method

Modelling changes in health sector demand through to 2050 have been undertaken through using health care expenditure change for the scaling of size of the health sector in each nation over time. The link between emissions and expenditure is central to the I/O method for estimating emissions adopted for the Road Map, meaning using expenditure projections to consider health system growth makes most sense for predicting concurrent emissions growth.

Conclusions

Based on the standing of the method and source data in the literature, dialogue with those responsible, and the outcomes of our assessment of the trends involved, we believe these projections provide a robust basis for the production of a global health care sector Road Map.

Figure A.13 to Figure A.17 show the growth trajectories for 43 WIOD nations and RoW, initially on one plot, then broken down into bands based on emissions per capita of the health system in subsequent figures.

The IHME predict that three WIOD nations will see their health systems grow by over 400% between 2014 and 2050: China (692%), India (521%), and Indonesia (471%). Most other nations are forecasted to grow between 150-300%, and three nations are predicted to remain close to their 2014 size: Greece, Italy, and Portugal.

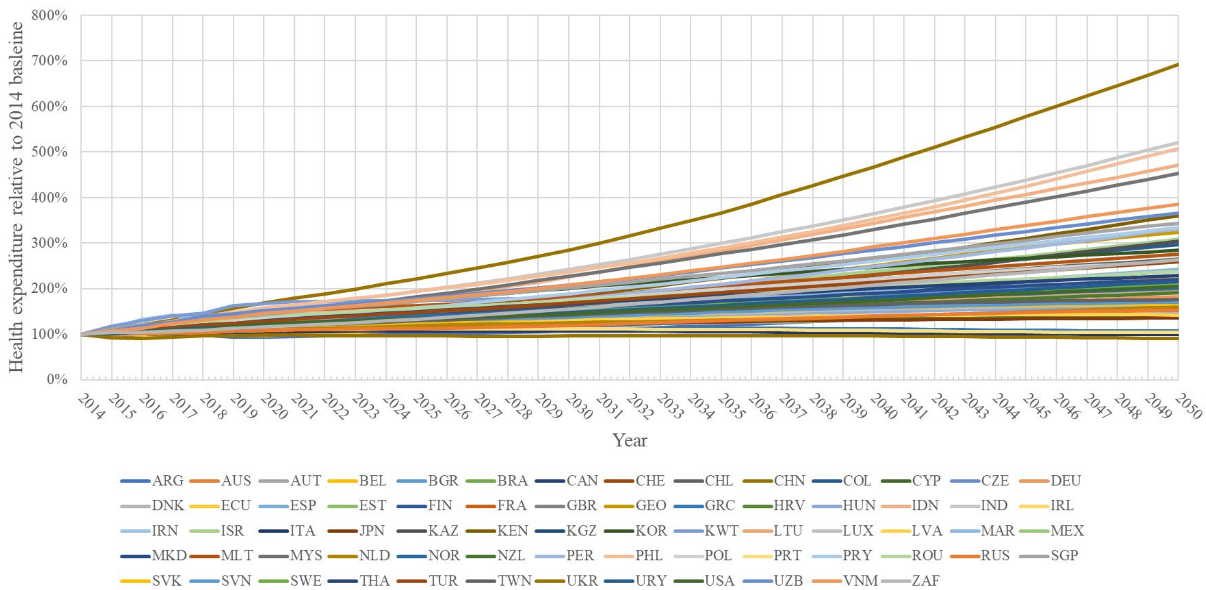

Figure A.13. Projected growth in health care expenditure for national footprints used in this assessment, based on IHME projections.

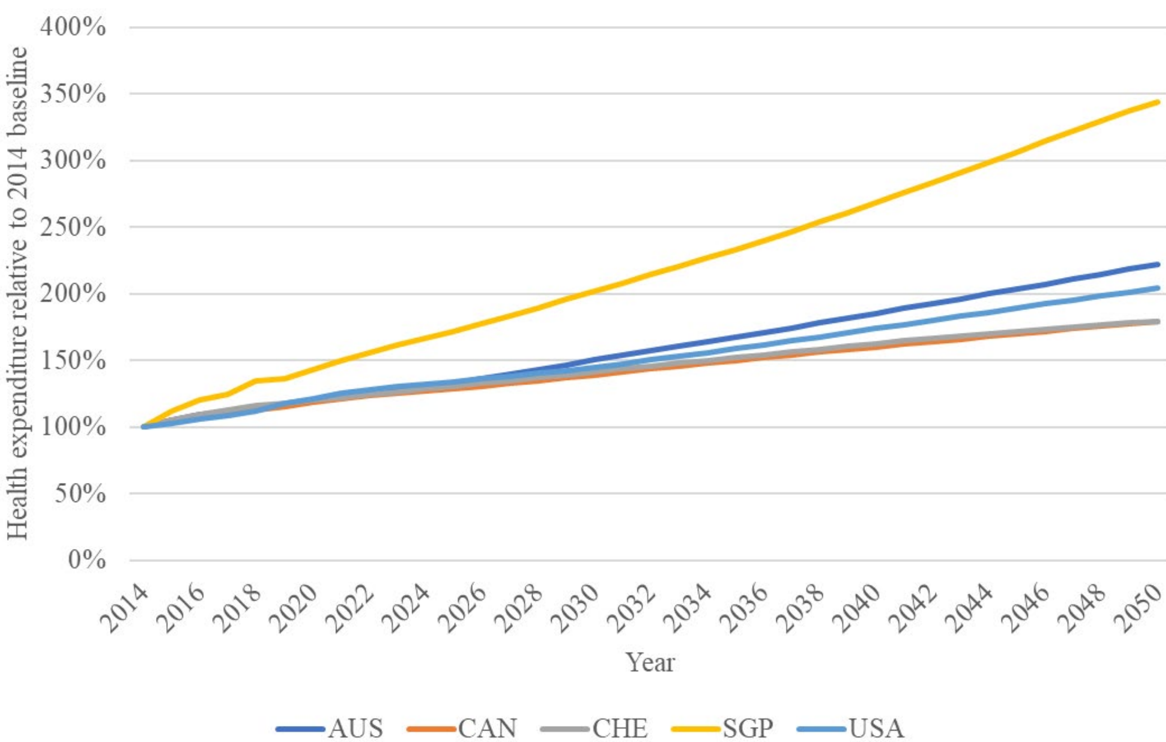

Figure A.14. Projected growth in expenditure for health systems found to be “top emitters” (over 1.0tCO_2e per capita) in Green Paper One,[1] based on IHME projections.

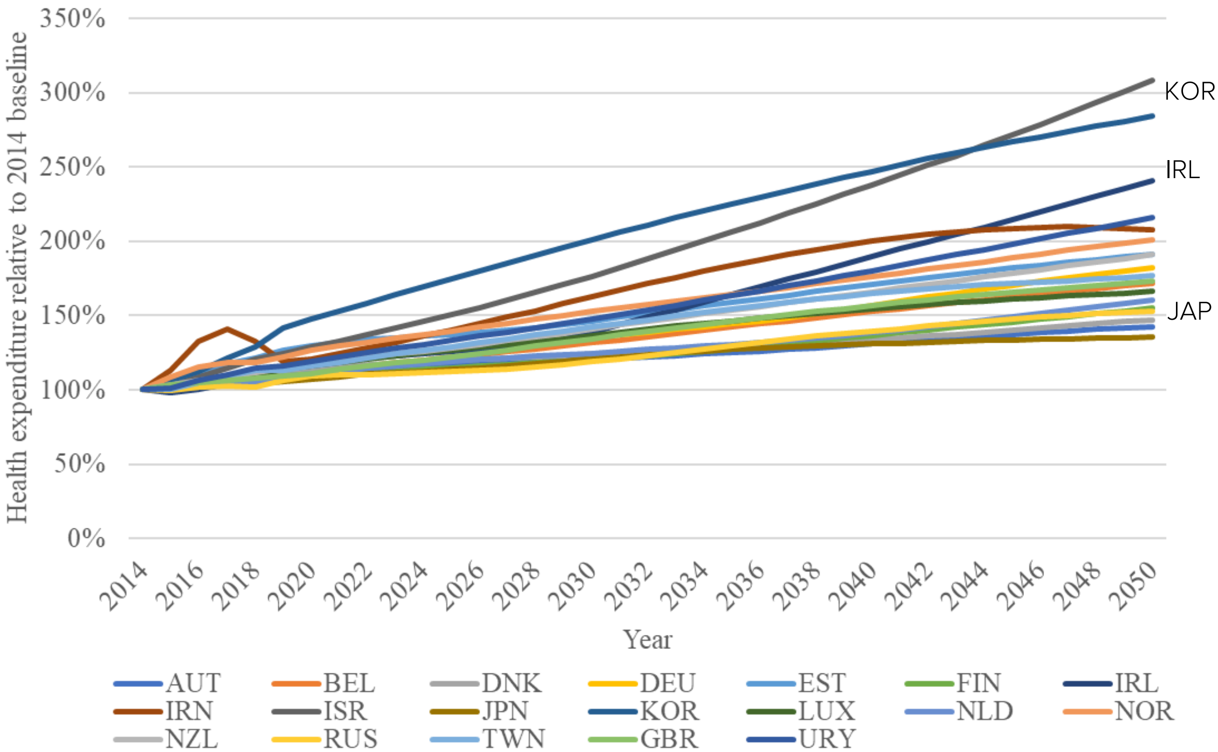

Figure A.15. Projected growth in expenditure for health systems found to be "major emitters" (0.5-1tCO_2e per capita) in Green Paper One, based on IHME projections.

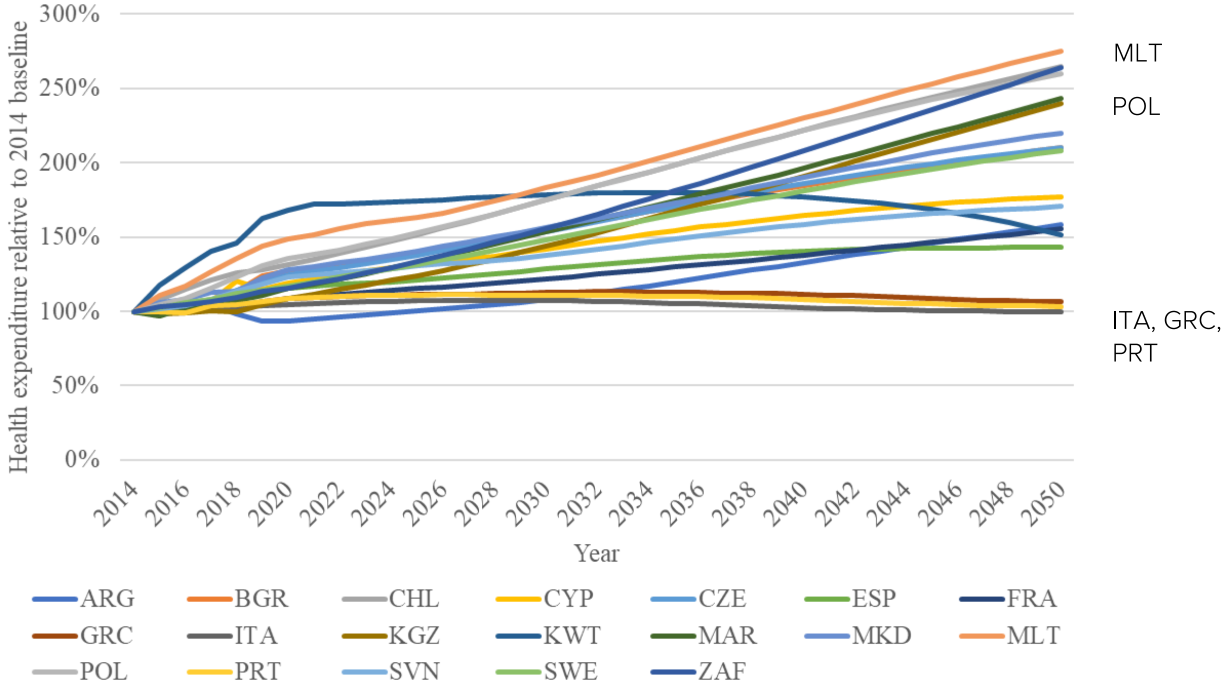

Figure A.16. Projected growth in expenditure for health systems found to be "higher than average emitters" (between global average 0.28tCO_2e and 0.50tCO_2e per capita) in Green Paper One, based on IHME projections.

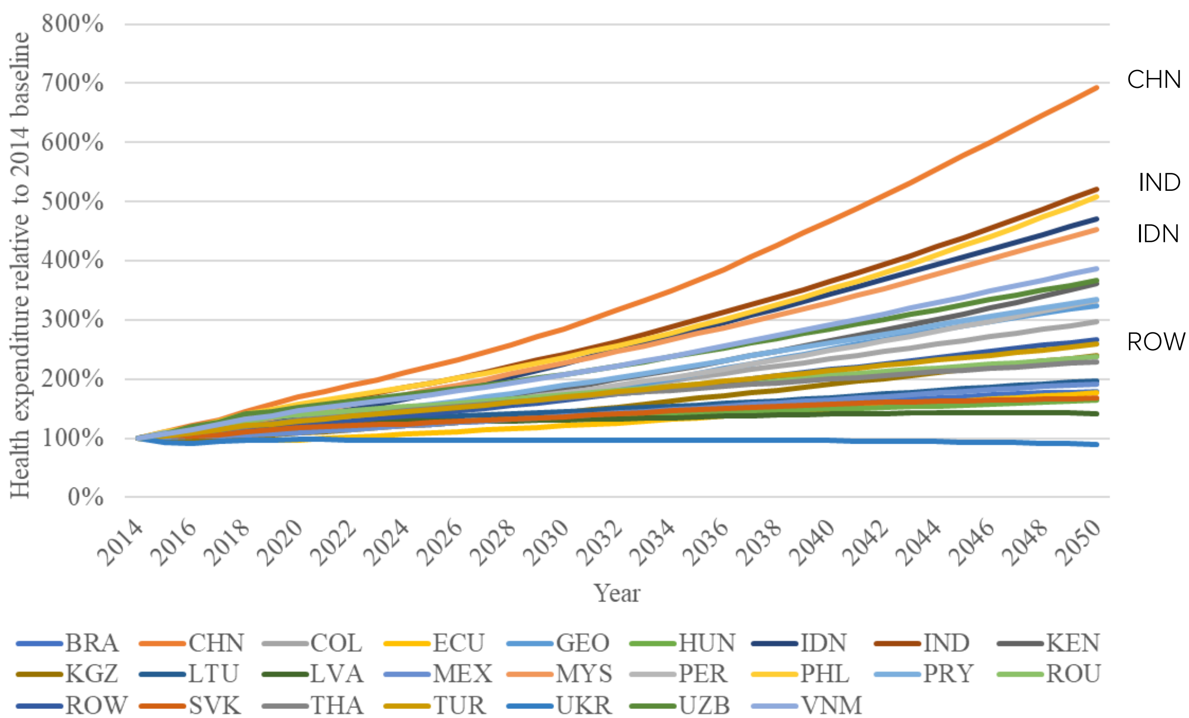

Figure A.17. Projected growth in expenditure for health systems found to be "lower than average emitters" (below the global average 0.28tCO_2e per capita) in Green Paper One, based on IHME projections.

Decarbonization trajectories across the global economy

Overview

To establish the impact of uptake in low-carbon technologies on emissions intensities across the global economy, a review of the literature was conducted. This review highlighted the work of the International Energy Agency (IEA)[22] and for agriculture, Popp et al.,[Error! Bookmark not defined.] which provide decarbonization forecasts for the major emitters in the global economy up to 2050.

The IEA's Energy Technology Perspectives (ETP) 2017 report provided the basis for all emissions pathways included in this modelling other than agriculture. This assessment considered a number of future scenarios for the rate and extent of transitions to low-carbon approaches and technologies.

Importance of health sector advocacy leading to action by all

In this work, the IEA's Beyond-2-Degrees-Scenario (B2DS) is used. This is a highly ambitious scenario, with a rapid uptake of low-carbon alternatives across the global economy. Such is the scale of the challenge to decarbonize our health sector and the wider economy that this rate of decarbonization is needed. Achieving this rate of decarbonization is contingent on advocacy that leads to action by all to curb emissions and the climate emergency they drive. An alternative scenario is the Reference Technology Scenario (RTS), which represents a lower level of ambition for climate action in the wider economy.

Decarbonization of agriculture was modelled using research by Popp et al.[Error! Bookmark not defined.] These trajectories were applied to the WIOD model in the same manner as the trajectories provided by the IEA.

Emissions trajectories were mapped to the corresponding WIOD sectors and regions, ensuring that decarbonization trends were appropriate for the causes of emissions from each WIOD sector and the region the nation fell. This modelling therefore incorporated the IEA ETP assumptions for transition of emissions intensity of the corresponding industry.

Once this was completed, decarbonization pathways were used in conjunction with the demand-side forecasts derived for future heath sector growth (Section 0) to develop a projection for global health care emissions in which changes in demand and the decarbonization of the global economy are both considered.

Application of global trends to the health sector emissions model

Taking outputs of the SPA for each nation, applying scaling factors for growth, and decarbonization pathways for key industries required the processing of large amounts of data. Acknowledging that SPA methods have not been used with WIOD before for this purpose (to our knowledge), the team implemented customized automation scripts in python which takes 2014 data, scales to each target year, and outputs findings in database formats and yearly reports.

Data sources

IEA Energy Technology Perspectives

Data used for modelling the decarbonization trends for major technologies and industries originates from analysis by the IEA. The IEA modelled several scenarios for how sectoral energy-related CO_2 emissions may develop in the future.

The ETP's focus was on modelling changes in energy consumption and primary sources of energy (e.g., coal, oil, and natural gas to lower carbon alternatives) and covers projections for energy CO_2 emissions only. The total emissions of key sectors (buildings, transport, and industry) were estimated for the years 2014 and 2025 and then five-year intervals between 2025 and 2050. The ETP also included regional and some country-specific sectoral decarbonization pathways, but these were less detailed at the country level. For integration into the Road Map, linear interpolation was used to achieve decarbonization pathways expressed for each year until 2050.

A key omission of the IEA ETP modelling is non-CO_2 emissions.[v] According to the United States Environmental Protection Agency (U.S. EPA), 22% of non-CO_2 emissions are energy related and the remainder associated with agriculture (31%), refrigeration gases (12%), or waste processes (12%). Additionally, according to the IPCC AR4, 99.7% of agricultural emissions arise from non-CO_2 emissions.

Although waste and refrigeration sources of non-CO_2 emissions are not insignificant, the dominant GHG emitted is CO_2. It could also be argued that waste and refrigeration emissions are strongly linked to emissions reduction of energy CO_2 emissions given that refrigerant leakage is associated with energy systems, like chillers, and that waste emissions can be treated through the adoption of energy-from-waste systems (which are considered within the IEA scenario). For these reasons the energy, refrigerant, and waste related non-CO_2 emissions were assumed to follow the same projections as CO_2 emissions from IEA modelling. The exception in terms of non-CO_2

[v] Methane, nitrous oxide, and fluorinated gases

emissions are those arising from agricultural activities for which a separate approach was developed.

Emissions from agriculture

According to the trajectory of interest[23], global methane and nitrous oxide emissions intensity (tCO2e/calorie consumed) were modelled to change by 20% and -9% respectively between 2011 and 2050, with this trajectory presenting a reduction in emissions intensity versus a scenario where no climate action is taken. According to the authors, the emission intensities' decrease is due to improvements in agricultural practices and dietary shift when compared to current practice.

Decarbonization pathways

The IEA datasets and model for agriculture provided future emissions intensity projections relative to 2014 levels for the key industries and activities that drive global emissions. By way of example, three of the 15 key sectors are shown below: Figure A.18, Figure A.19, and Figure A.20. They present the predicted decarbonization of electricity generation, operation of serviced buildings, chemicals, and petrochemicals for the IEA regions.

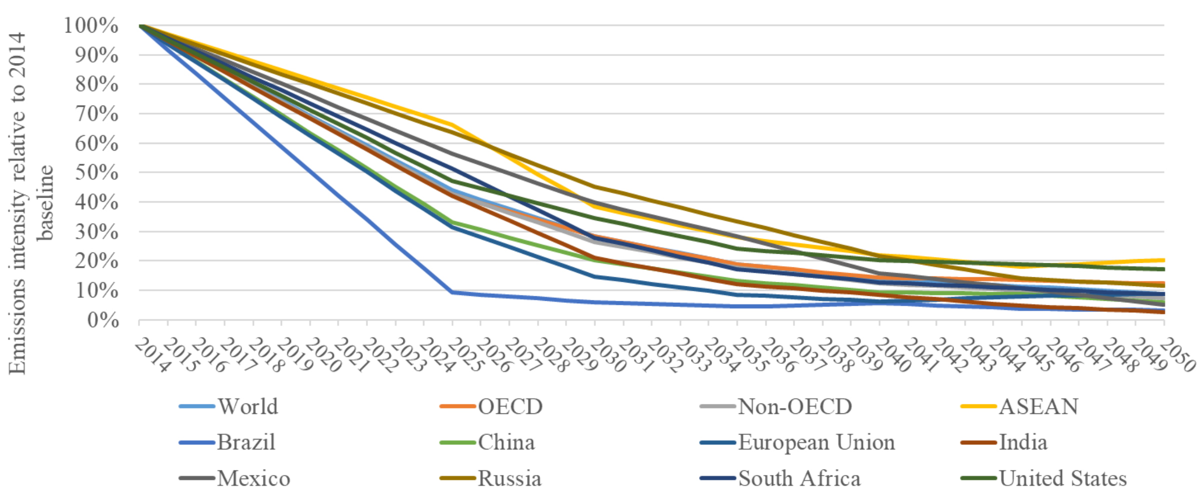

Figure A.18. Projected decarbonization of electricity generation relative to 2014 for the regions covered in the IEA projections.

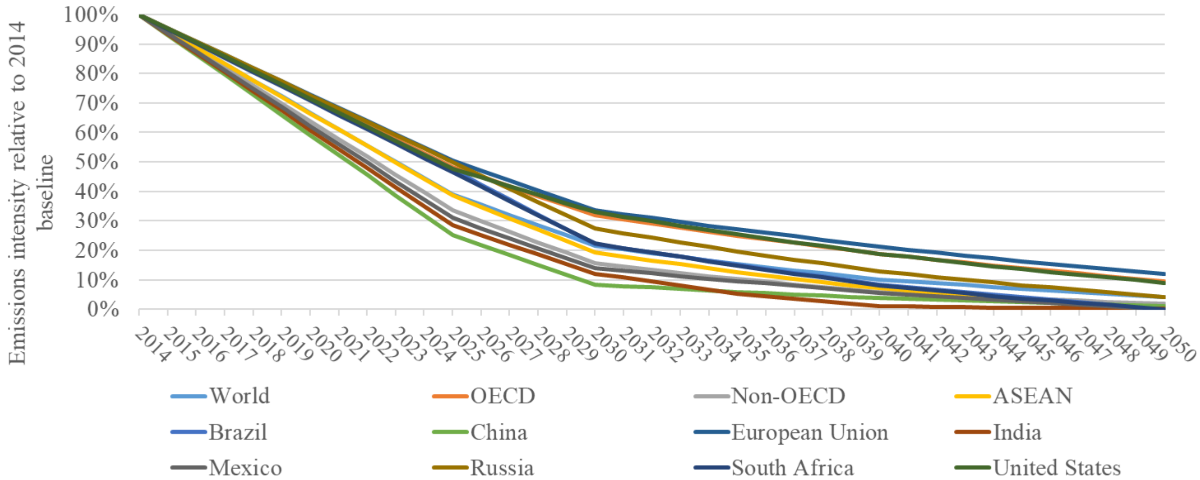

Figure A.19. Projected decarbonization for the operation of serviced buildings relative to 2014 for the regions covered in the IEA projections.

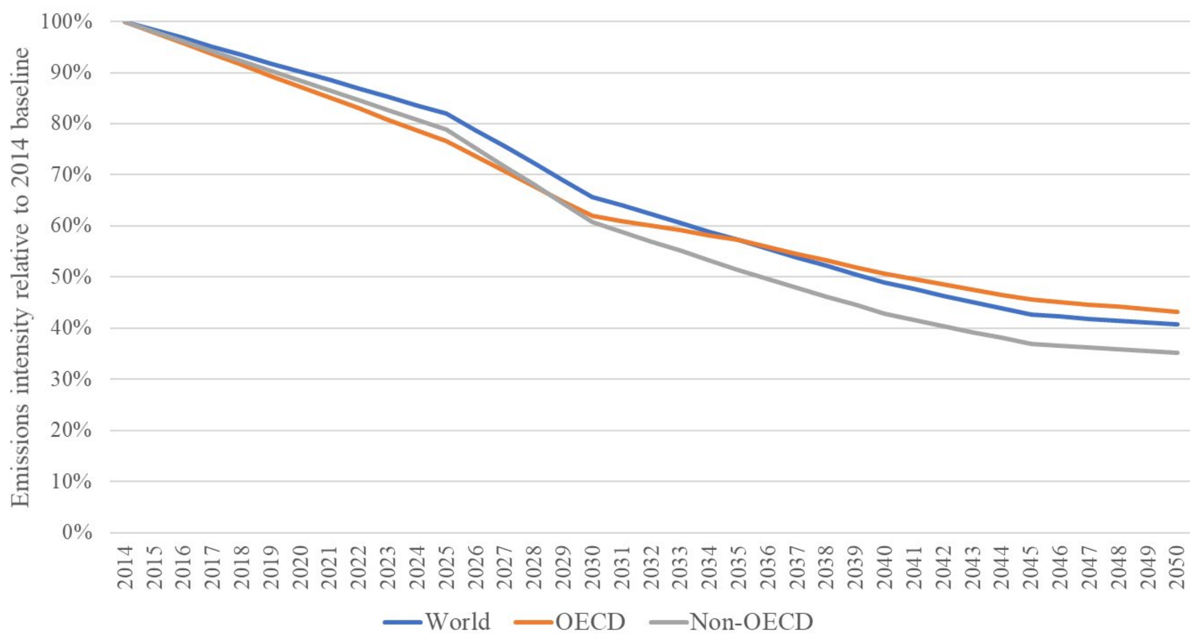

Figure A.20. Projected decarbonization of chemicals and petrochemicals relative to 2014 for the regions covered in the IEA projections.

In assigning the decarbonization trends, WIOD sectors were given the trajectory most closely aligned with their principle emissions mechanism. For example, for largely office-based sectors, like "legal and accounting activities, activities of head offices, and management consultancy activities," the primary source of direct emissions is from serviced offices, and so the IEA projection for the decarbonization of serviced buildings is applied. In the same manner, the WIOD category, which covers the manufacture of pharmaceuticals, is assigned the decarbonization trend for chemicals and petrochemical production produced by the IEA.

The decarbonization projections used to inform the modelling have levels of geographical granularity, which vary across sectors, and do not therefore provide individual trajectories for the 44 nations and regions in WIOD.

Table A.11 shows the geographical breakdown provided for each decarbonization trend incorporated in the Road Map modelling.

For each nation, decarbonization trends for the highest granularity region available was applied. For example, the United Kingdom model uses the European Union trajectory as both WIOD and the decarbonization trends used consider data before Brexit. The rest-of-world region is assumed to follow the non-OECD trend in the modelling. Although there are nations within RoW that are OECD members, the population-averaged profile of this region is better aligned with the non-OECD grouping.

Decarbonization trend	Data source	Geographical breakdown in projections
Agriculture	Popp et al.	World
Aluminium	IEA	OECD, non-OECD
Cement	IEA	OECD, non-OECD
Chemicals and petrochemicals	IEA	OECD, non-OECD
Commercial buildings (mix of serviced and un-serviced)	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States
Electricity generation	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States
Freight: Heavy road	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States
Freight: Light road	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States
Freight: Shipping	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States
Iron and steel	IEA	OECD, non-OECD
Passengers: Air	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States
Passengers: Heavy road	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States

Decarbonization trend	Data source	Geographical breakdown in projections
Passengers: Light road	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States
Pulp and paper	IEA	OECD, non-OECD
Rest of industry	IEA	OECD, non-OECD
Serviced buildings	IEA	OECD, non-OECD, ASEAN, Brazil, China, European Union, India, Mexico, Russia, South Africa, United States

Table A.11. Geographical resolution of decarbonization trends used in modelling.

The sectors used by IEA are incorporated into the WIOD model via a mapping described in Table A.12.

WIOD sector	Decarbonization trend
Crop and animal production, hunting, and related service activities	IPCC non-CO2 (based on Popp et al.)
Forestry and logging	IPCC non-CO2 (based on Popp et al.)
Fishing and aquaculture	IPCC non-CO2 (based on Popp et al.)
Mining and quarrying	Rest of industry
Manufacture of food products, beverages, and tobacco products	Rest of industry
Manufacture of textiles, wearing apparel, and leather products	Rest of industry
Manufacture of wood and of products of wood and cork, except furniture, and manufacture of articles of straw and plaiting materials	Rest of industry
Manufacture of paper and paper products	Pulp and paper
Printing and reproduction of recorded media	Pulp and paper
Manufacture of coke and refined petroleum products	No change
Manufacture of chemicals and chemical products	Chemicals and petrochemicals
Manufacture of basic pharmaceutical products and pharmaceutical preparations	Chemicals and petrochemicals
Manufacture of rubber and plastic products	Chemicals and petrochemicals
Manufacture of other non-metallic mineral products	Cement
Manufacture of basic metals	Combination of iron, steel, and aluminium

WIOD sector	Decarbonization trend
Manufacture of fabricated metal products, except machinery and equipment	Combination of iron, steel, and aluminium
Manufacture of computer, electronic, and optical products	Rest of industry
Manufacture of electrical equipment	Rest of industry
Manufacture of machinery and equipment n.e.c.	Rest of industry
Manufacture of motor vehicles, trailers, and semi-trailers	Rest of industry
Manufacture of other transport equipment	Rest of industry
Manufacture of furniture and other manufacturing	Rest of industry
Repair and installation of machinery and equipment	Rest of industry
Electricity, gas, steam, and air conditioning supply	Electricity
Water collection, treatment, and supply	No change
Sewerage, waste collection, treatment, and disposal activities, materials recovery, remediation activities, and other waste management services	No change
Construction	Cement
Wholesale and retail trade and repair of motor vehicles and motorcycles	Service buildings
Wholesale trade, except of motor vehicles and motorcycles	Service buildings
Retail trade, except of motor vehicles and motorcycles	Service buildings
Land transport and transport via pipelines	Passengers: Light road
Water transport	Freight: Shipping
Air transport	Passengers: Air
Warehousing and support activities for transportation	All buildings
Postal and courier activities	Freight: Light road
Accommodation and food service activities	Service buildings
Publishing activities	Service buildings
Motion picture, video, and television program production, sound recording and music publishing activities, and programming and broadcasting activities	Service buildings
Telecommunications	Service buildings
Computer programming, consultancy and related activities, and information service activities	Service buildings
Financial service activities, except insurance and pension funding	Service buildings

WIOD sector	Decarbonization trend
Insurance, reinsurance, and pension funding, except compulsory social security	Service buildings
Activities auxiliary to financial services and insurance activities	Service buildings
Real estate activities	Service buildings
Legal and accounting activities, activities of head offices, and management consultancy activities	Service buildings
Architectural and engineering activities, technical testing, and analysis	Service buildings
Scientific research and development	Service buildings
Advertising and market research	Service buildings
Other professional, scientific, and technical and veterinary activities	Service buildings
Administrative and support service activities	Service buildings
Public administration and defence and compulsory social security	Service buildings
Education	Service buildings
Human health and social work activities	Service buildings
Other service activities	Service buildings
Activities of households as employers and undifferentiated goods- and services-producing activities of households for own use	All buildings
Activities of extraterritorial organizations and bodies	Service buildings

Table A.12. Mapping of decarbonization trends to WIOD categories used in projections.

The future of health sector emissions

Combining projected growth and decarbonization trends

Once the national growth projection from the IHME and the decarbonization trajectories from the IEA were established for all model nations, these trajectories were mapped onto the baseline emissions model for 2014 to explore future behaviour and trends.

The baseline model broke down the total footprint into a list of supply chain paths and their associated emissions value. To compute the emissions associated with the path in a future year, the emissions value was first scaled by the ratio of health expenditure between the future year and the baseline year of 2014. Following this step, the decarbonization trends were applied. If the emissions from the supply chain path were from a sector, like electricity generation, where the IEA projected a decarbonization of the sector, then the emissions value is scaled by the reduction in carbon intensity projected for the future year relative to the base year.

This approach was used to scale emissions for all paths in the WIOD model, projecting how the baseline health sector footprint is likely to respond to forecasted growth in health sector spending and decarbonization of key industries.

Modelling emissions interventions

Once the impacts of health sector growth and the decarbonization of major industries was incorporated into the model, giving projected emissions across the period between 2014 and 2050, the impact of emissions mitigation actions were investigated using this model.

The following sections describe how interventions in the health sector supply chain, related to the use of anaesthetic gases, MDIs, and system effectiveness, were tested using this model.

Interventions

Table A.13 details the supply chain interventions tested as emissions mitigation options. The action is documented in the description column and the resulting emissions reduction potential of the action is provided in the threshold column. Unless otherwise indicated, the threshold value is derived from the evidence base established for the “the future of urban consumption in a 1.5°C world” published through a collaboration between Arup, C40 Cities, and the University of Leeds.[24]

Intervention area	Description	Threshold
Food	Increase the material efficiency of food packaging. A 19% efficiency target has been adopted for this study.	19% reduction in annual emissions from food packaging by 2050
	Increase proportion of recycled materials in packaging to 50% recycled by 2050. This equates to a 29% reduction in emissions from food packaging.	29% reduction in annual emissions from food packaging by 2050
	Reduce food waste in health sector facilities (plate waste). Plate waste has been estimated to be 30% in hospitals,[25] and a 50% reduction in this rate has been chosen as a target by 2050.	15% reduction in food related emissions by 2050
	Reduce food waste in supply chain, reducing supply chain waste across all levels of food production by 50% has been found to equate to a reduction in emissions of 10.4%.	10.4% reduction in food related emissions by 2050
Construction	Wider adoption of structural timber in health facilities	20% reduction in emissions from steel in construction by 2050, 14% reduction in emissions from concrete in construction by 2050
	Switch to low-carbon cement.	35% reduction in emissions from concrete in construction by 2050
	Improve material efficiency through optimizing the structural design.	20% reduction in emissions from steel in construction by 2050, 32% reduction in emissions from concrete in construction by 2050
	Reuse of structural steel components in construction	11% reduction in emissions from steel in construction by 2050
	Reduce demand for new construction through enhanced building utilization, leading to a 10% reduction in demand for new floor area by 2050.	10% reduction in emissions from construction by 2050
Transport	Increase material efficiency in health care fleet vehicles, resulting in 50% reduction in steel and plastic by 2050.	50% reduction in emissions from steel and plastic in vehicle manufacturing by 2050
	Optimize fleet lifetime, increase longevity through active maintenance, and prioritize the lifespan of vehicles at procurement.	10% increase in fleet operational lifespan by 2050
	Reduce air travel by health sector professionals.	75% reduction in air travel by 2050

Intervention area	Description	Threshold
	Encourage transition to more sustainable aviation fuel.	80% further decarbonization of aviation through efficiency and use of biofuels by 2050
Textiles	Reduce waste in the supply chain by 50% by 2050.	12.5% reduction in emissions from textiles by 2050
	Increase the lifespan of textile goods used in health setting by 33%.	25% reduction in emissions from textiles by 2050
Medical equipment	33% life extension for medical equipment	25% reduction in emissions associated with new medical equipment by 2050
IT equipment	20% life extension for IT equipment used in health care	17% reduction in emissions associated with new IT equipment by 2050

Table A.13. Supply chain interventions and thresholds implemented in model

The mechanism for projecting adoption rates was based on “S-curve adoption” profiles on the principle that adoption of new social behaviors or technologies typically follow an S-curve rather than a linear curve or other function.[26] The profile used to model uptake of interventions is shown in Figure A.21.

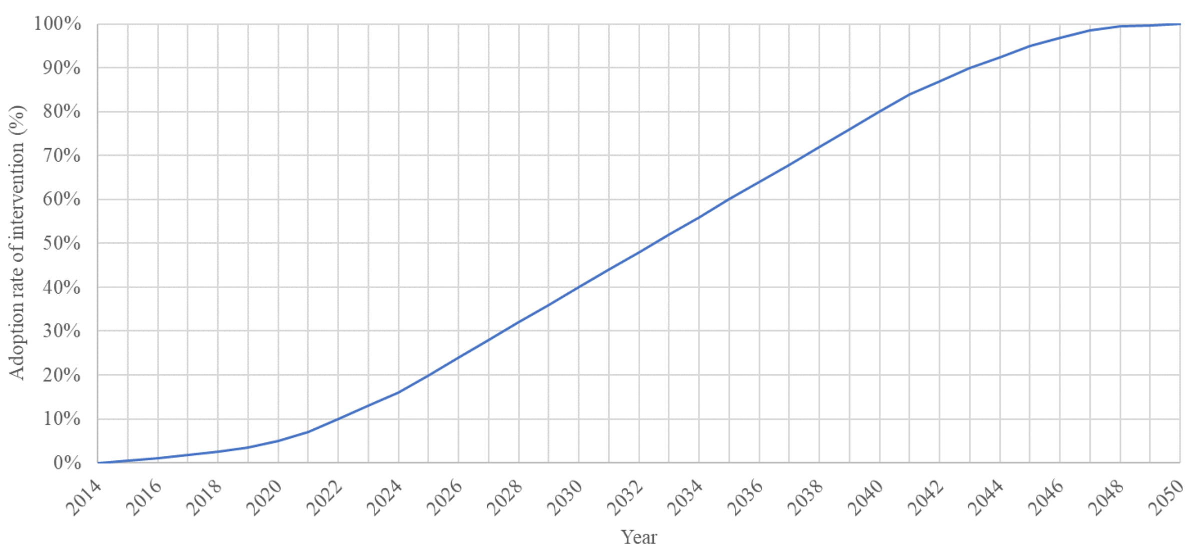

Figure A.21. Adoption curve used to model uptake of interventions between 2014 and 2050.

Reducing emissions from anaesthetic gases and MDIs

The emissions reduction targets applied to global emissions from anaesthetics and MDIs aims for a 50% reduction in emissions relative to 2014 levels by 2030 and 80% by 2050.

This has been modelled using the data available for UNFCCC Annex 1 nations and global emissions of fluorinated gases. As such, the majority of the emissions covered in this study are from more affluent health systems in developed nations, and therefore mitigation actions, including capture of exhaust gases and transition to powder based inhalers, should allow for a reduction in emissions without cutting access to essential medicine.

For developing nations outside the UNFCCC Annex 1 classification, emissions will be expected to increase in this time without action taken to reduce emission to atmosphere.

Health system effectiveness

There is significant variation between health systems' effectiveness in ensuring quality health outcomes and delivering universal health coverage (UHC).

As previously described, health care's climate emissions are linked to health care expenditure. Excess spending can lead to excess emissions. Determining excess spending requires a measure of health system effectiveness. For instance, it requires determining how each dollar spent leads to improved health outcomes or greater health coverage. This can be estimated by examining the relationship between expenditure and effective universal health coverage. The Institute for Health Metrics and Evaluation has published a paper that plots such a relationship.[27]

Figure A.22 illustrates this point by comparing the parity cost per capita spent on health care to 17 UHC indicators. It suggests that the effectiveness of additional dollars spent varies greatly between countries and has diminishing returns as health care spending per capita increases.

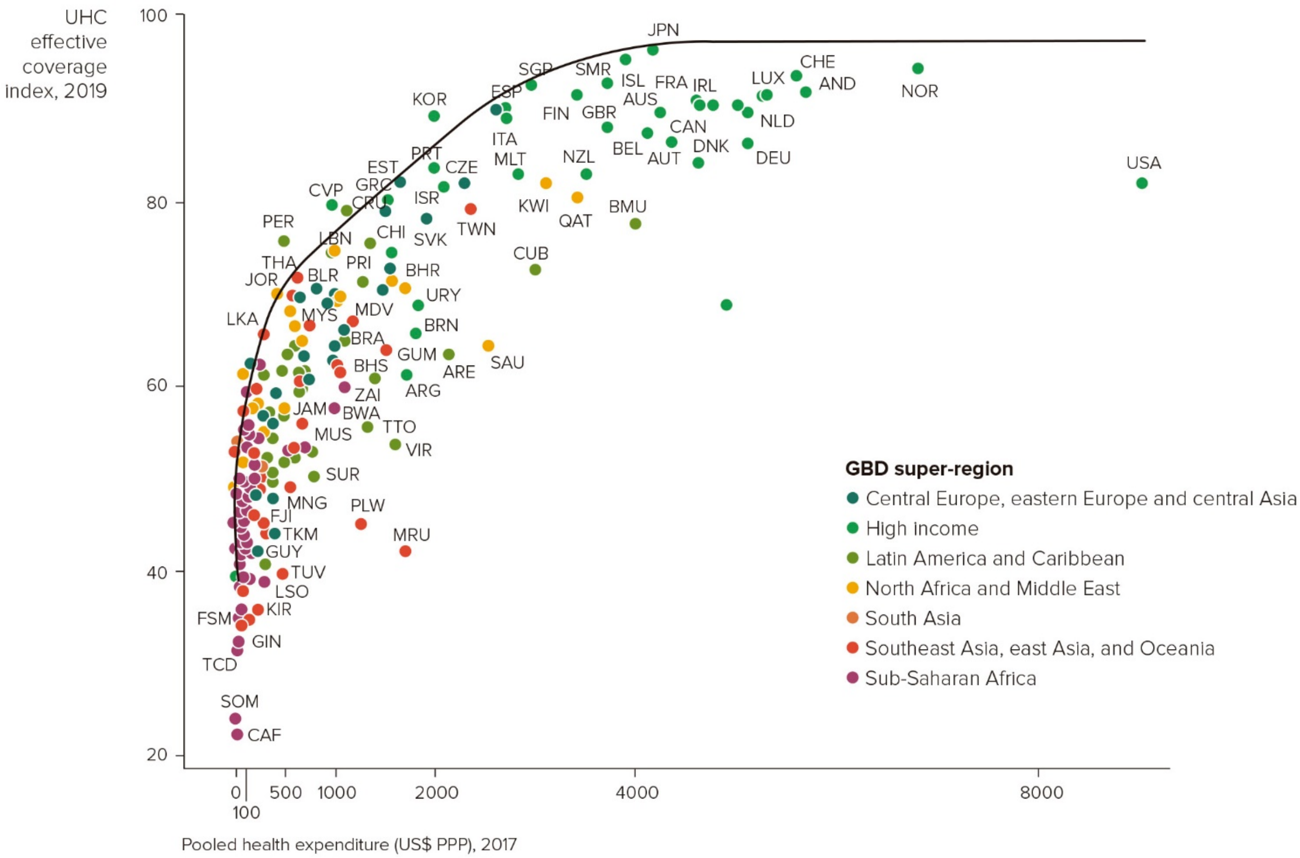

Figure A.22. UHC effective coverage index frontier relative to pooled health spending per capita. Source: IHME

Wealthier countries in particular can achieve more effective health coverage by reducing their spending and becoming more efficient. These expenditure reductions can also lead to a reduction in carbon emissions.

Figure A.23, quadrant C identifies countries where, by improving health systems effectiveness, expenditure reductions can be achieved without reducing the level of UHC. The model developed shifts these countries toward the curve of best performance by 20% of the difference between the country's expenditure in 2017 and the corresponding position, at that level of UHC provision, on the curve of best performance.

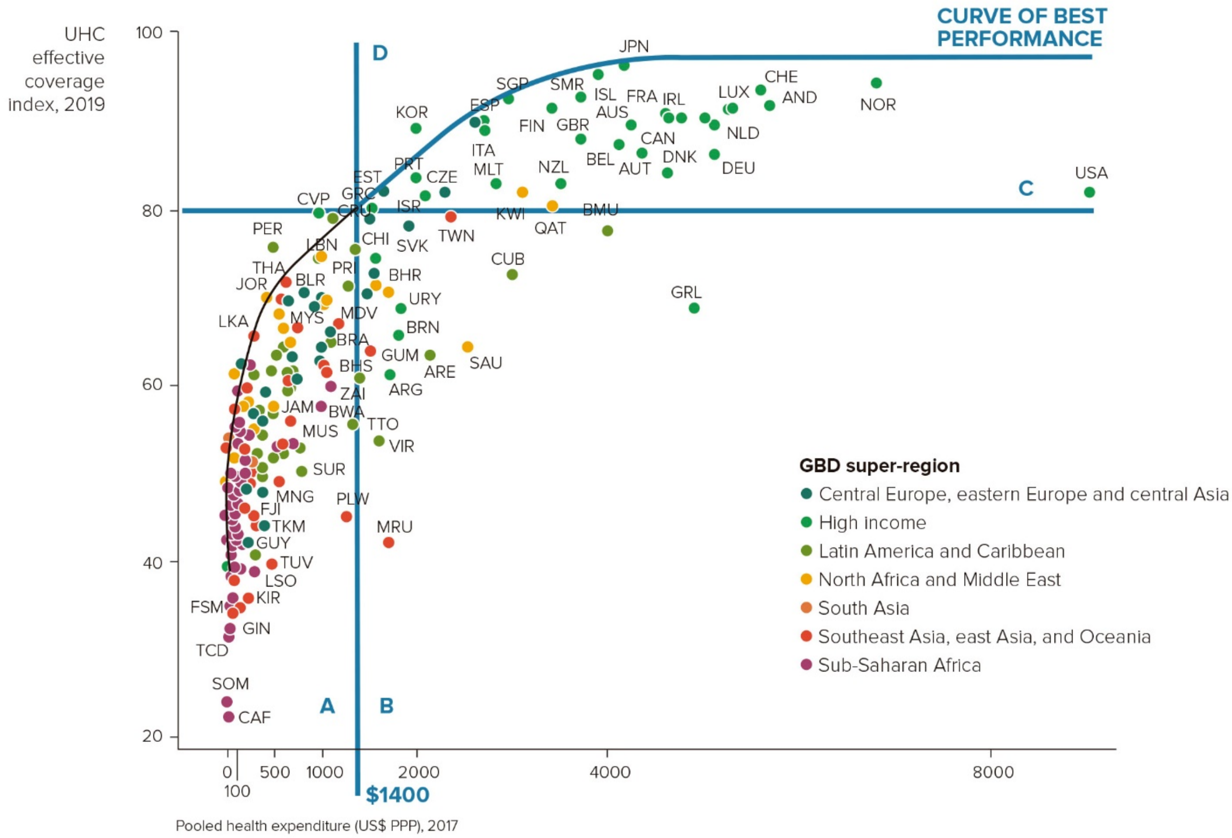

Figure A.23. Allocating countries to one of four groups delineated by a chosen threshold of UHC coverage of 80, with a health expenditure of $1400 per person per year.

Assigning emissions reduction to pathways and actions

In categorizing, grouping, and analyzing the emissions mitigation potential of differing interventions around health care emissions, two lenses have been used to identify the areas of highest potential impact: pathways and actions. The projected emissions from health care after mitigating actions were modelled was also calculated and expressed in terms of the SPA categories defined in Figure A.7.

Calculating emissions reduction potential of pathways

Three interrelated, overlapping decarbonization pathways have been identified:

- Pathway 1: Facilities and operations

  Direct action on emissions from health facilities and operations.

- Pathway 2: Supply chain

  Decarbonization potential of actions taken by direct suppliers to the health sector to reduce their emissions, driven by targeted action and incentives by the health sector leveraging its buying power.

- Pathway 3: Wider economy and society

  As well as acting to curb the emissions more directly under its influence (pathways 1 and 2), the health sector needs to advocate for wider society to move with it in aggressively pursuing opportunities to decarbonize.

Modelled interventions were mapped to one of the three pathways, as shown in Table A.14. The wedges were calculated by summing the reduction potential of the intervention attributed to each pathway.

Pathway	Decarbonization trend within pathway
Pathway 1	• Buildings and infrastructure • Transport and travel • Anaesthetics and MDIs • System effectiveness • Reduced food (plate) waste
Pathway 2	• Scope 2 purchased electricity • Modelled efficiency gains in the production of food and textile products consumed by the health system
Pathway 3	• Further decarbonization in wider economy, in line with B2DS trajectory, including decarbonization in the following sectors covered by the IEA: o Operation of buildings o Electricity use in supply chain o Transport and freight o Cement production o Metal production o Chemicals and petrochemicals o Pulp and paper o Rest of Industry

Table A.14. Allocation of decarbonization trends to the three pathways

The scaled values described in Section A.5.1 were aggregated into the reduction wedges for each SPA category, and the remaining emissions were outputted. These values were then combined to frame the results by pathway and action area.

Calculating emissions reduction potential of actions

Cutting across the pathways are a series of seven high-impact actions that must be achieved to transform health care into a decarbonized, climate-resilient sector. These actions focus on the steps that can be taken to act on the full supply chain emissions contributed by key areas of health sector procurement. These action areas are further detailed in the discussion paper. Table A.15 shows how procurement and operational aspects of the health sector correspond to the actions. Emissions reduction wedges were quantified through identifying the reduction for each SPA category and summing contributions against each action as shown in the table. Definitions and examples of the activities falling into each of these categories is provided in Figure A.7.

Action area	SPA categories
1. Electricity direct to health	• Scope 2: Purchased electricity • Electricity generation supply chain
2. Buildings and infrastructure	• Scope 1: Operation of buildings (including onsite combustion) • Construction
3. Travel	• Scope 1: Transport • Scope 3: Transport
4. Food	• Food, catering, and accommodation
5. Pharmaceuticals	• Pharmaceuticals
6. Circular health	• Manufacture and distribution of fossil fuels • Manufactured fuels, chemicals, and gases • Medical Instruments/equipment • Other manufactured products • Paper products • Waste, water, and sanitation • Other procurement
7. Effectiveness	• Business services • Information and communication technologies • System effectiveness

Table A.15. Attribution of procurement categories to action areas identified

Characterizing the emissions gap

Following the emissions mitigation actions highlighted in this study, there remains a substantial emissions footprint from the global health sector. These residual emissions are referred to in the

Road Map as "uncharted territory." This projected footprint was split into the categories in Figure A.7. Each SPA path was scaled using the projected health care expenditure growth, Section A.3, then scaled again to account for sector decarbonization, Section A.4, with the appropriate decarbonization factor selected using the mapping of categories to WIOD sectors in Table A.12. This provided a time series of predicted health sector emissions to 2050 in terms of the categories presented previously scheme, used to produce Figure A.21 in the Road Map.

Highlighting emissions resulting from fossil fuels

The estimate of the component of emissions resulting from the combustion of fossil fuels used the component of emissions by greenhouse gas associated with energy in 2014 from the PRIMAP-hist dataset.[28] This proportion was applied to the health sector footprint by gas (carbon dioxide, nitrous oxide, methane) to approximate the proportion of the footprint originating from the combustion of fossil fuels.

Health interventions

In addition to the supply chain interventions detailed above, four health focused interventions have been explored at a high level using the model. The purpose of this exploration was to provoke debate around the climate benefits to be gained through reducing the burden of disease associated with the following four societal risk factors:

- Tobacco use,
- Air pollution,
- Meat consumption,
- Obesity.

Each intervention explores the reduction in health expenditure and in turn GHG emissions that could be achieved through significant reduction in the burden of disease associated with tobacco use, air pollution, meat consumption and obesity. The evidence base underpinning these public health interventions are detailed in the four health intervention papers. Taking the findings of these papers, the potential emissions reduction associated with reducing demand for health care from diseases linked to these risk factors was modelled using the interventions described in Table 2. These interventions are broad estimates highlighting the scale of opportunity to reduce health system emissions through reducing demand. Emissions reductions are modelled through shrinking expenditure on the health system, and therefore do not consider rebound effects.

Health intervention	Assessment method and key thresholds	Rationale	Main data sources
Curbing tobacco use	60% reduction in health care expenditure on conditions lined to tobacco use by 2050, relative to 2010 levels.	The WHO Global Monitoring Framework for Noncommunicable Diseases (NCDs) has set a global target of a 30% reduction in tobacco use prevalence by 2025 from 2010 levels.[29] For the model, it was assumed that an additional 30% reduction in tobacco use prevalence is achieved from 2025 to 2050.	**Burden of Disease (Prevalence)** World Health Organization (2019). *WHO global report on trends in prevalence of tobacco use 2000-2025, third edition*. Geneva: World Health Organization. **Expenditure** Goodchild, M., Nargis, N., & Tursan d'Espaignet, E. (2018). *Global economic cost of smoking-attributable diseases.* Tobacco control, 27(1), 58–64.
Tackling ambient air pollution	2/3rd reduction in health care expenditure on conditions linked to air pollution by 2030, with a further 2/3rd reduction between 2030 and 2050.	The WHO Geneva Action Agenda to Combat Air Pollution has an existing target to reduce the number of deaths associated with air pollution by 2/3rd by 2030.[30] This intervention took this target as a starting point, extending this ambition with a further reduction to 2050.	**Expenditure** OECD. (2016). *The economic consequences of outdoor air pollution.* Paris: OECD Publishing.
Lowering red meat consumption	Expenditure on health care linked to meat consumption scaled in line with a transition to consumption of 43g/day from current levels by 2050.	This intervention was modelled as a transition from current meat consumption levels in each nation to a diet in line with the EAT-Lancet Commission recommendation of 43g/day.[31] This was assumed to correspond to a proportional change in current levels of health expenditure associated with meat consumption.	**Meat consumption** Food and Agriculture Organization of the United Nations. (2017). *Food balance sheets: Meat – food supply quantity (kg / capita / yr)* [Software]. In: Our World in Data. **Expenditure** Springmann, M., Mason-D'Croz, D., Robinson, S., Wiebe, K., Godfray, H., Rayner, M., & Scarborough, P. (2018). *Health-motivated taxes on red and processed meat: A modelling study on optimal tax levels and associated health impacts.* PloS one, 13(11), e0204139.

Reducing obesity	Health care expenditure on obesity-related conditions for each nation reduced to reflect the lower level of health care consumption for overweight citizens compared with obese citizens.	The WHO Global Monitoring Framework for NCDs has set a global target of halting the rise of obesity by 2025 relative to 2010 levels.[32] The assumption used in this model is that obese citizens, with the help of various public health measures, are able to reduce their weight to meet an 'overweight' classification (i.e. people are 'demoted' from obese to overweight)	**Burden of disease (prevalence)** World Health Organization. (n.d.). *Global Health Observatory*. **Expenditure** OECD. (2019). *The heavy burden of obesity: The economics of prevention.* Paris: OECD Health Policy Studies, OECD Publishing.

Table 2. Health interventions, thresholds tested, and data sources used in the global health care emissions model.

Key assumptions and limitations

A summary of the key assumptions and limitations of this study is presented in the following pages.

Structure of footprint

The modelling takes the supply chain structure provided by WIOD for 2014 as its basis, which is the latest year for which data is published for the WIOD model. Forecasts for the future growth in expenditure on health systems, and for the decarbonization trends of key industries, are mapped to this footprint structure to predict future behaviour and emissions characteristics. This does not therefore capture any predicted changes to the structure of the global economy and the health sector supply chain and the resulting impact on emissions. While this limitation is recognized, the overall approach to projecting scenarios from static input-output models has been demonstrated both in the literature by Weibe et al.[33] and in previous analysis by C40 Cities, Arup, and the University of Leeds,[24] and found to present a robust tool for exploring future emissions scenarios.

Consistent growth across sector

When projecting future changes to the scale of the health system in a nation, the IHME health care futures report was used to find the ratio of health system spending relative to 2014 to reflect the changing scale. This growth factor was applied across the entire health system footprint for a nation, without accounting for differing rates of change for different aspects of the health system.

Homogeneous product

The emissions intensities for sectors derived through input-output analysis assume that each economic unit of output of a sector has the same environmental impact across the sector, known as homogeneity. For example, for the “human health and social work activities sector,” it is assumed that for every dollar spent, the environmental impact is uniform, whereas there will be variation within the sector as different activities lead to differing environmental impacts. Therefore, the emissions intensity represents the averaged environmental impact of activities within the sector and cannot easily account for switching from one form of health provision to another.

Pruning and scaling

The SPA analysis was run for the top eight tiers of the supply chain for all nations, and for WIOD, this represents a total 1.4×10^{27} individual paths. Necessarily, not all paths can be quantified, and the majority of these paths will represent near-zero flows of capital and emissions within the model. As presented by Lenzen,[34] this issue can be bypassed through the use of a pruning algorithm to dynamically remove paths during the analysis with contributions below a given threshold.

Throughout the SPA, pruning was undertaken based on both capital flow and emissions value. The algorithm loops through paths in descending order of capital flow, cutting off the analysis for paths below a threshold. This capital pruning threshold was selected based on the magnitude of health expenditure for the nation in question. For the United States, this cut-off was highest, set at $250,000, 0.00001% of the total health expenditure of the United States in 2014. Quantified paths are added to a dictionary (python object for storing variables in key-value pairs) provided their emissions are at least 0.5 tCO_2e.

Through pruning, the computational expense of running a SPA is made manageable, with the models being run on Arup’s high-performance cluster over a period of 24 hours per country. However, through pruning some emissions are missed by the SPA, with a large number of small emission paths being cut from the analysis. Since we have previously analyzed the emissions for all nations through a zero-leakage IO modelling technique for Green Paper 1, we were able to calculate the degree of leakage for all nations. The amount of leakage varied by nation, with Mexico having the lowest leakage with 94% emissions quantification and Switzerland having the highest leakage with 79% emissions quantification. The United States achieved a value of 90%. To ensure all emissions were represented in our published modelling, the leakage is redistributed throughout the supply chain categories (excluding Scope 1 and Scope 2, which are calculated without leakage) according to the ratio of their magnitudes. This scaling allows the structure and breakdown of emissions to be presented for all model nations, while preserving the overall magnitude of their health systems climate footprint.

Categorizations

In reporting the emissions associated with health sector supply chains, this work employs two perspectives. Firstly, a categorization is employed, which seeks to frame emissions against supply chain areas familiar to the health sector policy maker, building upon the reporting practices developed by the NHS SDU. Secondly, emissions are presented in a manner that aligns with the internationally recognized Greenhouse Gas Protocol (GHGP) Corporate Value Chain (Scope 3) Standard,[35] which is used across all sectors of the economy to quantify organizational climate footprints.

When producing the categorizations, WIOD sectors required aggregation and alignment.

The GHGP corporate standard is designed for the reporting of an organizational footprint, whereas our study identified the emissions associated with an economic sector. Framing our results using the categories and language set out in the standard required a number of assumptions to best adjust our whole-sector view to fit this framework. The allocation of WIOD sectors to these categories is shown in Table A.6.

Estimating global emissions from inhalational anaesthetics and MDIs

Available data on emissions from anaesthetic gases and meter-dose inhalers does not provide global coverage. Data from the UNFCCC for NO_2 and MDIs covers UNFCCC Annex 1 nations only. Together, these nations accounted for 15% of the global population, 57% of the global GDP, and 73% of global health expenditure in 2014. The total emissions from these nations have been used in this report, and while these will provide an underestimate on the global total, due to the higher consumption of these goods in wealthy nations it is likely that this value is close to the global total.

For fluorinated anaesthetics, Vollmer et al.[3] used measured atmospheric concentrations of these gases to estimate annual emissions. This study did not differentiate between emissions from human health care and veterinary uses, and it has not been possible gather sufficient evidence to establish the proportions of these emissions associated with each. It has therefore been decided to report the full emissions footprint for these gases.

For future trends in emissions from these gases, it was assumed that the footprint scales directly with health expenditure. Changes in usage between the gases, linked to both fluctuations in price and clinical best practice, may cause the rate of change in emissions to differ due to the differing global warming potentials of the gases involved, an effect that has not been considered here. Global warming potentials range between 130 $kgCO_2e/kg$ (sevoflurane) and 2540 $kgCO_2e/kg$ (desflurane).

Rebound

Where behavioral changes and expenditure reductions are modelled as mitigations, there is the potential for rebound effects – the expenditure is not reduced, rather is redirected to other activities of a higher or lower emissions intensity. Considering rebound effects typically reduce the estimated benefit achieved from an action associated with switching expenditure, rebound effects have not been incorporated into the model. As highlighted under the "structure of footprint" heading, the modelling underpinning this work does will not allow for the impacts of structural changes in health delivery and the wider economy to be investigated.

Budget allocation

The approach to allocating the global health care sector emissions is based on GDP. This assumes that expenditure on a sector is representative of their emissions contribution and ability and responsibility to decarbonize. Other ways to allocate the budget could have been tested and considered, but all rely on underlying assumptions.

Emissions trajectories

The emissions trajectories presented here represent plausible emissions pathways. It should be emphasized that these are not meant to be interpreted as forecasts. They are an illustration of the effort required by countries to reduce emissions and achieve the budget allocated to the global health care sector budget.

Decarbonization trends

The data used to project decarbonization is well cited and respected in the literature. These projections are predictions, and as such, have a degree of uncertainty. However, they represent the best, most comprehensive studies available. Therefore, we believe using them in this methodology is robust.

In the B2DS scenario, technology improvements and deployment are pushed to their maximum practicable limits across the energy system in order to achieve net-zero emissions by 2060, without requiring unforeseen technology breakthroughs or limiting economic growth. This "technology push" approach results in cumulative emissions from the energy sector of around 750 $GtCO_2$ between 2015 and 2100, which is consistent with a 50% chance of limiting average future temperature increases to 1.75°C. Energy sector emissions reach net zero around 2060, supported by negative emissions through deployment of bioenergy with carbon capture and storage. The B2DS falls within the Paris Agreement range of ambition, but does not purport to define a specific temperature target for "well below 2°C."

S-curve intervention adoption

Where an adoption profile for decarbonization was not available in the literature, the rate of adoption has been assumed to follow the S-curve shown in Figure A.21.

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