The *Lancet* Countdown on health and climate change: from 25 years of inaction to a global transformation for public health

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Executive summary

The *Lancet* Countdown tracks progress on health and climate change and provides an independent assessment of the health effects of climate change, the implementation of the Paris Agreement,[1] and the health implications of these actions. It follows on from the work of the 2015 *Lancet* Commission on Health and Climate Change,[2] which concluded that anthropogenic climate change threatens to undermine the past 50 years of gains in public health, and conversely, that a comprehensive response to climate change could be "the greatest global health opportunity of the 21st century".

The *Lancet* Countdown is a collaboration between 24 academic institutions and intergovernmental organisations based in every continent and with representation from a wide range of disciplines. The collaboration includes climate scientists, ecologists, economists, engineers, experts in energy, food, and transport systems, geographers, mathematicians, social and political scientists, public health professionals, and doctors. It reports annual indicators across five sections: climate change impacts, exposures, and vulnerability; adaptation planning and resilience for health; mitigation actions and health co-benefits; economics and finance; and public and political engagement.

The key messages from the 40 indicators in the *Lancet* Countdown's 2017 report are summarised below.

The human symptoms of climate change are unequivocal and potentially irreversible—affecting the health of populations around the world today

The impacts of climate change are disproportionately affecting the health of vulnerable populations and people in low-income and middle-income countries (LMICs). By undermining the social and environmental determinants that underpin good health, climate change exacerbates social, economic, and demographic inequalities, with the impacts eventually felt by all populations.

The evidence is clear that exposure to more frequent and intense heatwaves is increasing, with an estimated 125 million additional vulnerable adults exposed to heatwaves between 2000 and 2016 (Indicator 1.2). During this time, increasing ambient temperatures have resulted in an estimated reduction of 5·3% in outdoor manual labour productivity worldwide (Indicator 1.3). As a whole, the frequency of weather-related disasters has increased by 46% since 2000, with no clear upward or downward trend in the lethality of these extreme events (Indicator 1.4), potentially suggesting the beginning of an adaptive response to climate change. Yet the impacts of climate change are projected to worsen with time, and current levels of adaptation will become insufficient in the future. The total value of economic losses resulting from climate-related events has been increasing since 1990, totalling US$129 billion in 2016. 99% of these economic losses in low-income countries were uninsured (Indicator 4.4). Additionally, in the longer term, altered climatic conditions are contributing to growing vectorial capacity for the transmission of dengue fever by *Aedes aegypti*, reflecting an estimated 9·4% increase since 1950 (Indicator 1.6).

If governments and the global health community do not learn from the past experiences of HIV/AIDS and the recent outbreaks of Ebola and Zika viruses, another slow response will result in an irreversible and unacceptable cost to human health.

The delayed response to climate change over the past 25 years has jeopardised human life and livelihoods

Since the UN Framework Convention on Climate Change (UNFCCC) commenced global efforts to tackle climate change in 1992, most of the indicators tracked by the *Lancet* Countdown have either shown limited progress, particularly with regards to adaptation, or moved in the wrong direction, particularly in relation to mitigation. Most fundamentally, carbon emissions and global temperatures have continued to increase.

An increasing number of countries are assessing their vulnerabilities to climate change, developing adaptation and emergency preparedness plans, and providing climate information to health services (Indicators 2.1, 2.3–2.6). The same is seen at the city level, with more than 449 cities around the world

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reporting having undertaken a climate change risk assessment (Indicator 2.2). However, the coverage and adequacy of such measures in protecting against the growing risks of climate change to health remain uncertain. Indeed, health and health-related adaptation funding accounts for only 4·6% and 13·3% of total global adaptation spending, respectively (Indicator 4.9).

Although there has been some recent progress in strengthening health resilience to climate impacts, it is clear that adaptation to new climatic conditions can only protect up to a point; an analogy to human physiology is useful here. The human body can adapt to insults caused by a self-limiting minor illness with relative ease. However, when disease steadily worsens, positive feedback cycles and limits to adaptation are quickly reached. This is particularly true when many systems are affected and when the failure of one system affects the function of another, as is the case for multiorgan system failure or when the body has already been weakened through repeated diseases or exposures. The same is true for the health consequences of climate change. It acts as a threat multiplier, compounding many of the issues communities already face and strengthening the correlation between multiple health risks, making them more likely to occur simultaneously. Indeed, climate change is not a single-system disease but instead often compounds existing pressures on housing, food and water security, poverty, and many determinants of good health. Adaptation has limits, and prevention is better than cure to avert potentially irreversible effects of climate change.

Progress in mitigating climate change since the signing of the UNFCCC has been limited across all sectors, with only modest improvements in carbon emission reduction from electricity generation. Although sustainable travel has increased in Europe and some evidence suggests a decrease in dependence on private motor vehicles in cities in the USA and Australia, the situation is generally less favourable in cities within emerging economies (Indicator 3.7). In addition to a slow transition away from highly polluting forms of electricity generation, this change has yielded a modest improvement in air pollution in some urban centres. However, global population-weighted fine particular matter ($PM_{2·5}$) exposure has increased by 11·2% since 1990, and about 71% of the 2971 cities in the WHO air pollution database exceed guideline annual $PM_{2·5}$ exposure (Indicator 3.5). The strength and coverage of carbon pricing covers only 13·1% of global anthropogenic carbon dioxide (CO_2) emissions, with the weighted average carbon price of these instruments at $8·81 per tonne of emitted CO_2 in 2017 (Indicator 4.7). Furthermore, responses to climate change have yet to fully take advantage of the health co-benefits of mitigation and adaptation interventions, with action taken to date only yielding modest improvements in human wellbeing. In part, this reflects a need for further evidence and research on these ancillary effects and the available cost savings. However, it also reflects a need for more joined-up policy making by health and non-health ministries of national governments.

This delayed mitigation response puts the world on a high-end emissions trajectory that will result in global warming of 2·6–4·8°C by the end of the century.

The voice of the health profession is essential in driving forward progress on climate change and realising the health benefits of this response

Following in the footsteps of previous *Lancet* Commissions, we argue that the health profession not only has the ability but the responsibility to act as public health advocates by communicating the threats and opportunities to the public and policy makers and ensuring climate change is understood as being central to human wellbeing.

Attention to health and climate change is growing in the media and in academic reports, with global newspaper coverage of the issue increasing 78% and the number of scientific reports more than tripling since 2007 (Indicator 5.1.1 and 5.2). However, despite these positive examples, the 2017 indicators make it clear that further progress is urgently needed.

Although progress has been historically slow, the past 5 years have seen an accelerated response, and in 2017, momentum is building across a number of sectors; the direction of travel is set, with clear and unprecedented opportunities for public health

In 2015, the *Lancet* Commission[2] made ten recommendations to governments to accelerate action in the following 5 years. The *Lancet* Countdown's 2017 indicators track against these 2015 recommendations, with results suggesting that discernible progress has been made in many of these areas (panel 1), breathing life into previously stagnant mitigation and adaptation efforts. Indeed, the transition to low-carbon electricity generation now appears inevitable. Alongside the Paris Agreement, this progress provides reason to believe that a broader transformation is underway.

Following the US Goverment's announced intention to withdraw from the Paris Agreement, the global community has demonstrated overwhelming support for enhanced action on climate change, affirming clear political will and ambition to reach the treaty's targets. The mitigation and adaptation interventions committed to under the Paris Agreement have very positive short-term and long-term health benefits, but greater ambition is now essential. Although progress has been historically slow, there is evidence of a recent turning point, with transitions in sectors that are crucial to public health reorienting towards a low-carbon world. These efforts must be greatly accelerated and sustained in the coming decades to meet the commitments, but recent policy changes and the indicators presented here suggest that the direction of travel is set.

Panel 1: Progress towards the recommendations of the 2015 *Lancet* Commission on Health and Climate Change[2]

In 2015, we made ten policy recommendations. Of these, good progress has been made against the following recommendations.

Recommendation 1: invest in climate change and public health research

Since 2007, the number of scientific papers on health and climate change has more than tripled (Indicator 5.2).

Recommendation 2: scale-up financing for climate-resilient health systems

Spending on health adaptation is 4·63% of global adaptation spend (US$16·46 billion); in 2017, health adaptation from global development and climate financing mechanisms is at an all-time high although absolute spending remains low (Indicators 4.9 and 4.10).

Recommendation 3: phase-out coal-fired power

In 2015, more renewable energy capacity (150 gigawatts) than fossil fuel capacity was added to the global energy mix. Overall, annual installed renewable generation capacity (almost 2000 gigawatt) exceeds that for coal, with about 80% of this recently added renewable capacity located in China (Indicator 3.2). Although investment in coal capacity has increased since 2006, this investment turned and decreased substantially in 2016, and several countries have now committed to phasing out coal (Indicator 4.1).

Recommendation 4: encourage a city-level low-carbon transition to reduce urban pollution

Despite historically modest progress in the past two decades, the transport sector is approaching a new threshold, with electric vehicles expected to reach cost parity with their non-electric counterparts by 2018—a phenomenon that was not expected to occur until 2030 (Indicator 3.6).

Recommendation 6: rapidly expand access to renewable energy, unlocking the substantial economic gains available from this transition

Every year since 2015, more renewable energy has been added to the global energy mix than all other sources, and in 2016, global employment in the renewable energy sector reached 9·8 million people, more than 1 million more people than are employed in fossil fuel extraction sector. The transition has become inevitable. However, in the same year, 1·2 billion people still did not have access to electricity, and 2·7 billion people were relying on the burning of unsafe and unsustainable solid fuels (Indicators 3.3, 4.6, and 3.4).

Recommendation 9: agree and implement an international treaty that facilitates the transition to a low-carbon economy

In December, 2015, 195 countries signed the Paris Agreement, which provides a framework for enhanced mitigation and adaptation and pledges to keep the global mean temperature rise to well below 2°C. Going forward, an enhanced programme of work dedicated to health within the UN Framework Convention on Climate Change would provide a clear and essential entry point for health professionals at the national level, ensuring that the implementation of the Paris Agreement maximises the health opportunities for populations around the world.

Recommendation 10: Develop a new, independent collaboration to provide expertise in implementing policies that mitigate climate change and promote public health, and to monitor progress over the next 15 years

The *Lancet* Countdown is a collaboration between 24 academic institutions and intergovernmental organisations based in every continent and with representation from a wide range of disciplines. It monitors and reports on indicators across five sections and will continue to do so up to 2030.

Between 2017 and 2030, the *Lancet* Countdown will continue to report annually on progress in implementing the commitments of the Paris Agreement, future commitments that build on them, and the health benefits that result.

Introduction

Climate change has serious implications for our health, wellbeing, livelihoods, and the structure of organised society. Its direct effects result from rising temperatures and changes in the frequency and strength of storms, floods, droughts, and heatwaves—with physical and mental health consequences. The impacts of climate change will also be mediated through less direct pathways, including changes in crop yields, the burden and distribution of infectious disease, and in climate-induced population displacement and violent conflict.[3–5] Although many of these effects are already seen, their progression in the absence of climate change mitigation will greatly amplify existing global health challenges and inequalities.[2] The effects also threaten to undermine many of the social, economic, and environmental drivers of health that have contributed greatly to human progress.

Urgent and substantial climate change mitigation will help protect human health from the worst of these effects, and a comprehensive and ambitious response to climate change could transform the health of the world's populations.[2] The potential benefits and opportunities are enormous, including cleaning the air of polluted cities, delivering more nutritious diets, ensuring energy, food,

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Panel 2: **Developing *Lancet* Countdown's indicators: an iterative and open process**

In developing the *Lancet* Countdown's indicators, we took a pragmatic approach, taking into account the considerable limitations in data availability, resources, and time. Consequently, the indicators presented here represent what is feasible for 2017 and will evolve over time in response to feedback and data improvements.

The purpose of this collaboration is to track progress on the links between public health and climate change, and yet much of the data analysed here were originally collected for purposes not directly relevant to health. Initial analysis therefore principally captures changes in exposure, states, or processes as proxies for health outcomes—the ultimate goal. Employing new methodologies to improve attribution to climate change is a particular priority. Subsequent reports will see the *Lancet* Countdown set 2030 targets for its indicators that align more directly with the Paris Agreement, allowing an assessment of its implementation during the next 13 years.

The indicators presented thus far are the beginning of an ongoing, iterative, and open process, which will work to continuously improve as capacity, data quality, and methods evolve. The objectives of the *Lancet* Countdown are both ambitious and essential, relying on support from a broad range of actors. To this end, the collaboration welcomes support from academic institutions and technical experts that are able to provide new analytical methods and novel datasets with appropriate geographical coverage. A short overview of several parallel and complementary processes currently underway is provided in the appendix (pp 1–10).

See Online for appendix

and water security, and alleviating poverty and social and economic inequalities.

Monitoring this transition, from threat to opportunity, is the central role of the *Lancet* Countdown: Tracking Progress on Health and Climate Change.[6] The collaboration is a partnership of 24 academic institutions from every continent and brings together individuals with a broad range of expertise across disciplines (including climate scientists, ecologists, mathematicians, geographers, engineers, energy, food, and transport experts, economists, social and political scientists, public health professionals, and doctors). Until 2030, the *Lancet* Countdown will track a series of indicators of progress and to report annually on the state of the climate, the implementation of the Paris Agreement, and efforts to mitigate and adapt to climate change (panel 2). The initiative was formed after the 2015 *Lancet* Commission on Health and Climate Change,[2] which concluded that "tackling climate change could be the greatest global health opportunity of the 21st century". It builds on and reinforces the work of the expanding group of researchers, health practitioners, national governments, and WHO, who are working to ensure that this opportunity becomes a reality.

For the registry of **nationally determined contributions** see http://unfccc.int/focus/ndc_registry/items/9433.php

Indicators of progress on health and climate change

In 2016, the *Lancet* Countdown proposed a set of potential indicators to be monitored and launched a global consultation to define a conclusive set of indicators for 2017.[6] A number of factors determined the selection of indicators, including: (1) their relevance to public health, both in terms of the impacts of climate change on health and the health effects of the response to climate change; (2) their relevance to the main anthropogenic drivers of climate change; (3) their geographical coverage and relevance to a broad range of countries and income groups; (4) data availability; and (5) resource and timing constraints. These indicators are divided into five broad sections: climate change impacts, exposures, and vulnerabilities; adaptation planning and resilience for health; mitigation actions and health co-benefits; economics and finance; and public and political engagement (panel 3). These sections are aligned with the global action agenda on climate change and health that was agreed to at the Second WHO Global Conference on Health and Climate in July, 2016.

The results and analysis of each indicator are presented alongside a brief description of the data sources and methods. A more complete account of each indicator can be found in the appendix. For a number of areas, such as the impacts of climate change on mental health or hydrological mapping of flood exposure, a robust methodology for an annual indicator has not been reported, reflecting the complexity of the topic and the paucity of data rather than its lack of importance. The thematic groups and indicator titles provide an overview of the domain being tracked, allowing for the growth and development of these metrics (eg, to more directly capture health outcomes) in subsequent years.

Delivering the Paris Agreement for better health

The Paris Agreement[1] has been ratified at the national level by 153 of 197 parties to the UNFCCC, and covers 84·7% of greenhouse gas emissions at present. The agreement set out an ambitious commitment to reduce greenhouse gas emissions and to limit climate change to well below a global average temperature rise of 2°C above pre-industrial levels, with an aim to limit temperature increases to 1·5 °C.

187 countries have committed to near-term (up to 2030) actions to reduce greenhouse gas emission through their nationally determined contributions. Article 4 paragraph 2 of the Paris Agreement[1] states that each signatory "shall prepare, communicate and maintain successive nationally determined contributions that it intends to achieve". However, the nationally determined contributions of the 153 parties that have ratified the agreement now fall short of the necessary reductions by 2030 to meet the 2°C pathway.[11]

The *Lancet* Countdown's indicators place national decisions within a broader context. The indicators highlight that: (1) worldwide, total power capacity of pre-construction coal (commitments for new coal power plants) has halved from 2016 to 2017 alone; (2) every year since 2015, more renewable energy has been added to the global energy mix than all other sources combined; (3) the installed costs of renewable energy continue to decrease (solar photovoltaic electricity generation is now cheaper than conventional fossil fuels in an ever-growing number of countries); (4) electric vehicles are poised to reach cost-parity with their petrol-based counterparts; and (5) in 2016, global employment in renewable energy reached 9·8 million people, over 1 million more than that in fossil fuel extraction.

These positive examples in recent years must not mask the dangerous consequences of failing to meet the Paris Agreement, the past two decades of relative inaction, the economies and sectors lagging behind, and the enormity of the task ahead, which leave achieving the aims of the Paris Agreement in a precarious position. Much of the data presented should serve as a wake-up call to national governments, businesses, civil society, and the health profession.

However, the world has already embarked on a path to a low-carbon and healthier future. Although the pace of action must greatly accelerate, the direction of travel is set.

Section 1: Climate change impacts, exposures, and vulnerability

In this section, we provide a set of indicators that track health impacts related to anthropogenic climate change. Such impacts depend on the nature and scale of the hazard, the extent and nature of human exposure to them, and the underlying vulnerability of the exposed population.[12] The purpose of these indicators is therefore to measure exposure to climatic hazards and vulnerabilities of people exposed to them, and, over time, to quantify the health impacts of climate change. These impacts, in turn, inform protective adaptation and mitigation interventions (Section 2, Section 3), the economic and financial tools available to enable such responses (Section 4), and the public and political engagement that facilitates them (Section 5).

Climate change affects human health primarily through three pathways: direct, ecosystem-mediated, and human institution-mediated pathways.[13] Direct effects are diverse, being mediated, for instance, by increases in the frequency, intensity, and duration of extreme heat and by increases in average annual temperature (leading to, for example, greater heat-related mortality). Rising incidence of other extremes of weather, such as floods and storms, increase the risk of drowning and injury, damage to human settlements, spread of water-borne disease, and mental health sequelae.[13] Ecosystem-mediated impacts include changes in the distribution and burden of vector-borne diseases (such as malaria and dengue) and water-borne infectious disease. Human undernutrition from crop failure,

Panel 3: Sections and indicators for the _Lancet_ Countdown's 2017 report

Section 1: Climate change impacts, exposures, and vulnerability

1.1 Health effects of temperature change
1.2 Health effects of heatwaves
1.3 Change in labour capacity
1.4 Lethality of weather-related disasters
1.5 Global health trends in climate-sensitive diseases
1.6 Climate-sensitive infectious diseases
1.7 Food security and undernutrition
- 1.7.1 Vulnerability to undernutrition
- 1.7.2 Marine primary productivity

1.8 Migration and population displacement

Section 2: Adaptation planning and resilience for health

2.1 National adaptation plans for health
2.2 City-level climate change risk assessments
2.3 Detection and early warning of, preparedness for, and response to health emergencies
2.4 Climate information services for health
2.5 National assessment of vulnerability, impacts, and adaptation for health
2.6 Climate-resilient health infrastructure

Section 3: Mitigation actions and health co-benefits

3.1 Carbon intensity of the energy system
3.2 Coal phase-out
3.3 Zero-carbon emission electricity
3.4 Access to clean energy
3.5 Exposure to ambient air pollution
- 3.5.1 Exposure to air pollution in cities
- 3.5.2 Sectoral contributions to air pollution
- 3.5.3 Premature mortality from ambient air pollution by sector

3.6 Clean fuel use for transport
3.7 Sustainable travel infrastructure and uptake
3.8 Ruminant meat for human consumption
3.9 Health-care sector emissions

Section 4: Economics and finance

4.1 Investments in zero-carbon energy and energy efficiency
4.2 Investment in coal capacity
4.3 Funds divested from fossil fuels
4.4 Economic losses due to climate-related extreme events
4.5 Employment in low-carbon and high-carbon industries
4.6 Fossil fuel subsidies
4.7 Coverage and strength of carbon pricing
4.8 Use of carbon pricing revenues
4.9 Spending on adaptation for health and health-related activities
4.10 Health adaptation funding from global climate financing mechanisms

Section 5: Public and political engagement

5.1 Media coverage of health and climate change
- 5.1.1 Global newspaper reporting on health and climate change
- 5.1.2 In-depth analysis of newspaper coverage on health and climate change

5.2 Health and climate change in scientific journals
5.3 Health and climate change in the United Nations General Assembly

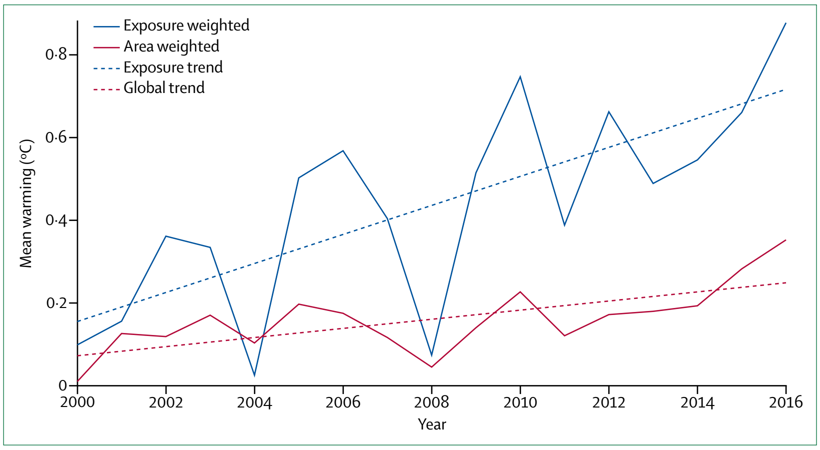

Figure 1: **Mean summer warming relative to the 1986–2008 average**
The time series are global mean temperatures calculated from the gridded data, weighted by area (to avoid bias from measurements near the poles) and by exposure (to show the number of people exposed).

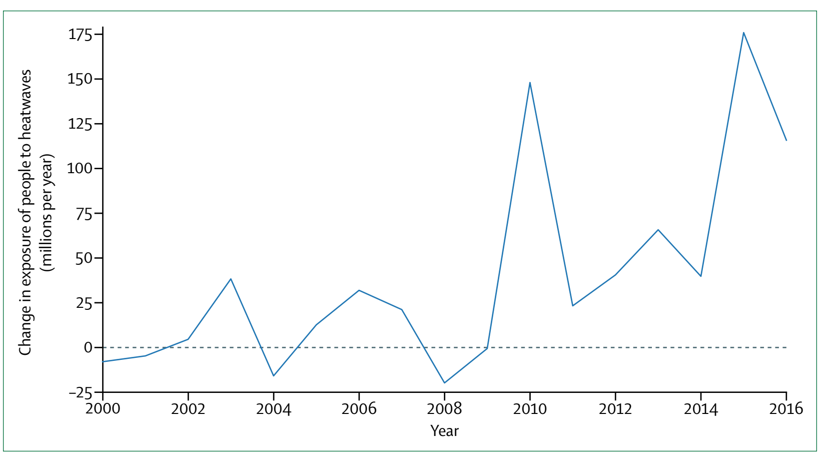

Figure 2: **The change in heatwave exposure (in people older than 65 years), relative to the 1986–2008 average**

For **European Centre for Medium-Range Weather Forecasts** see https://www.ecmwf.int/

For the **European Centre for Medium-Range Weather Forecasts' climate reanalysis** see https://www.ecmwf.int/en/research/climate-reanalysis

For **Socioeconomic Data and Applications Center's Gridded Population of the World v4** see http://sedac.ciesin.columbia.edu/data/collection/gpw-v4

population displacement from sea-level rise, and occupational health risks are examples of human institution-mediated impacts.

Although reported data, and indeed some of the data presented here, have traditionally focused on impacts such as the spread of infectious diseases and mortality from extreme weather, the health effects from non-communicable diseases are just as important. Mediated through a variety of pathways, they take the form of cardiovascular disease, acute and chronic respiratory disease from worsening air pollution and aero-allergens, or the often-unseen mental health effects of extreme weather events or of population displacement.[14,15] Indeed, emerging evidence is suggesting links between a rising incidence of chronic kidney disease, dehydration, and climate change.[16,17]

Eight indicators were selected and developed for this section. Headline findings for all indicators are provided at the beginning of each indicator; additional detailed disussion on the data and methods used (as well as the limitations and challenges encountered in the selection of each indicator) are provided in the appendix (p 16). The indirect indicators (Indicators 1.5–1.8) each provide a proof of concept rather than being fully comprehensive, focusing variably on a specific diseases, populations, or locations. Additionally, in future reports by the *Lancet* Countdown, we will seek to capture indicators of the links between climate change and air pollution, and with mental illness.

Indicator 1.1: Health effects of temperature change

This indicator reports that people experience far more than the global mean temperature rise. This indicator reports that between 2000 and 2016, human exposure to warming was about 0·9°C, more than double the global area average temperature rise during the same period.

Increasing temperatures can exacerbate existing health problems in populations and introduce new health threats (including cardiovascular disease and chronic kidney disease). The extent to which human populations are exposed to this temperature change, and thus the health implications of temperature change, depends on the detailed spatiotemporal trends of population and temperature over time.

Temperature anomalies were calculated relative to 1986–2008 from the European Research Area, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). This dataset uses ECMWF climate reanalysis to give a description of recent climate, produced by combining models with observations.

Changes in each country population were obtained from NASA's Socioeconomic Data and Applications Center and the data were projected onto the gridded population. Exposure-weighted warming from 2000 to 2016 (0·9°C) is much higher than the area-weighted warming (0·4°C) during the same period (figure 1). Hence, mean exposure to warming is more than double the global warming since 2000.

The increase in exposure relative to the global average is driven partly by growing population densities in India, parts of China, and sub-Saharan Africa. Accounting for population when assessing temperature change provides a vital insight into how human wellbeing is likely to be affected by temperature change, with the analysis here showing that temperature change where people are living is much higher than average global warming. Details of the global distribution of this warming can be found in the appendix (p 16).

Indicator 1.2: Health effects of heatwaves

This indicator reports that between 2000 and 2016, the number of vulnerable people exposed to heatwave events increased by about 125 million, with a record 175 million more people exposed to heatwaves in 2015.

The health impacts of extreme heat range from direct heat stress and heat stroke, to exacerbations of pre-existing heart failure, and even an increased incidence of acute kidney injury from dehydration in vulnerable populations. Elderly people, children younger than 12 months, and people with chronic cardiovascular and renal disease are particularly sensitive to these changes.[13]

Our definition of a heatwave is a period of more than 3 days during which the minimum temperature is greater than the 99th percentile of the historical minima (1986–2008 average).[18] This metric therefore focuses on periods of high night-time temperatures, which are crucial in denying vulnerable people vital recuperation between hot days. Heatwave data were calculated against the historical period 1986–2008. The population for the exposure calculations was limited to people older than 65 years (as this age group is most vulnerable to the health impacts of heatwaves), and data were obtained on a per-country basis from the UN World Population Prospects archives for each year considered.

The highest number of exposure events was recorded in 2015, with about 175 million additional people exposed to heatwaves (figure 2). Over time, the mean number of heatwave days experienced by people during any one heatwave (exposure-weighted) increases at a much faster rate than the global mean (area-weighted) number of heatwave days per heatwave (figure 3) because of high population densities in areas where heatwaves have occurred.

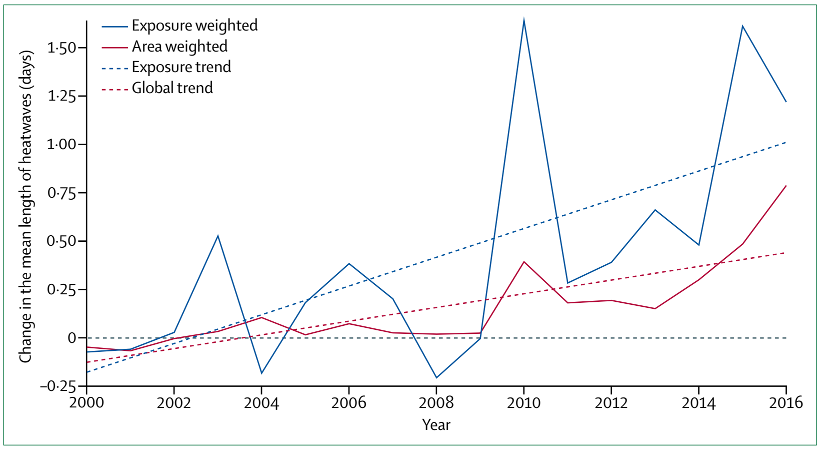

Figure 3: **Change in mean heatwave lengths worldwide, relative to the 1986–2008 average**

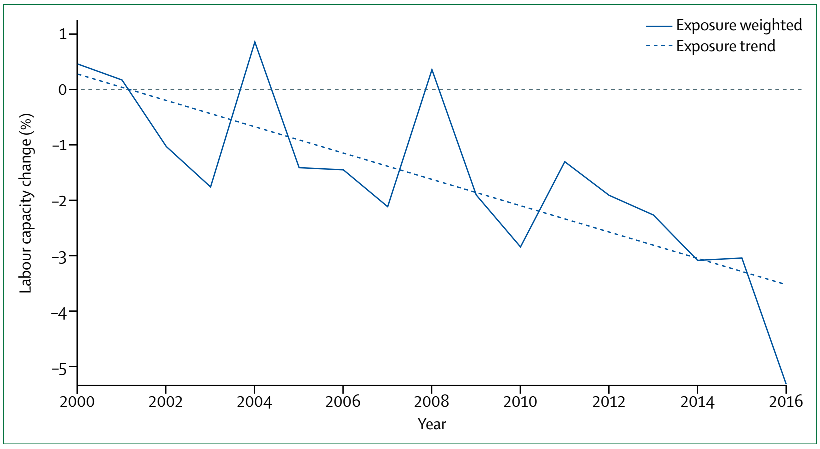

Figure 4: **Labour capacity change worldwide, relative to the 1986–2008 average**

Indicator 1.3: Change in labour capacity

This indicator reports that global labour capacity in rural populations exposed to temperature change is estimated to have decreased by 5·3% from 2000 to 2016.

Higher temperatures pose profound threats to occupational health and labour productivity, particularly for people undertaking manual, outdoor labour in hot areas. This indicator shows the change in labour capacity (and thus productivity) worldwide and for rural regions specifically, weighted by population (appendix p 18). Loss of labour capacity has important implications for the livelihoods of individuals, families, and communities, especially those relying on subsistence farming.

Estimation of labour capacity is based on wet bulb globe temperatures, as described by Watts and colleagues.[2] We estimated change in outdoor labour productivity as a percentage relative to the reference period (1986–2008) (figure 4). Labour capacity is estimated to have decreased by 5·3% between 2000 and 2016, with a dramatic decrease of more than 2% between 2015 and 2016. Although there are some peaks of increased labour capacity (notably in 2000, 2004, and 2008), the overwhelming trend is one of reduced capacity. These effects are most notable in some of the most vulnerable countries in the world (figure 5).

This indicator only captures the effects of heat on rural labour capacity. The *Lancet* Countdown will work to expand this metric to capture impacts on labour capacity in other sectors, including manufacturing, construction, transportation, tourism, and agriculture. Through collaboration with HEAT-SHIELD,[19] the *Lancet* Countdown will work to develop this process, providing more detailed analysis of labour capacity loss and the health implications of heat and heatwaves worldwide.[20]

Indicator 1.4: Lethality of weather-related disasters

This indicator reports that the frequency of weather-related disasters has increased by 46% from 2007 to 2016 (compared with the 1990–99 average), with no clear upward or downward trend in the lethality of these extreme events.

Weather-related events have been associated with more than 90% of all disasters worldwide in the past 20 years. As expected, considering its population and area, Asia is the continent most affected by weather-related disasters. 2843 events were recorded between 1990 and 2016, affecting 4·8 billion people and killing 505 013 people. Deaths from natural hazard-related disasters are largely concentrated in poor countries.[21] Crucially, this must be understood in the context of potentially overwhelming

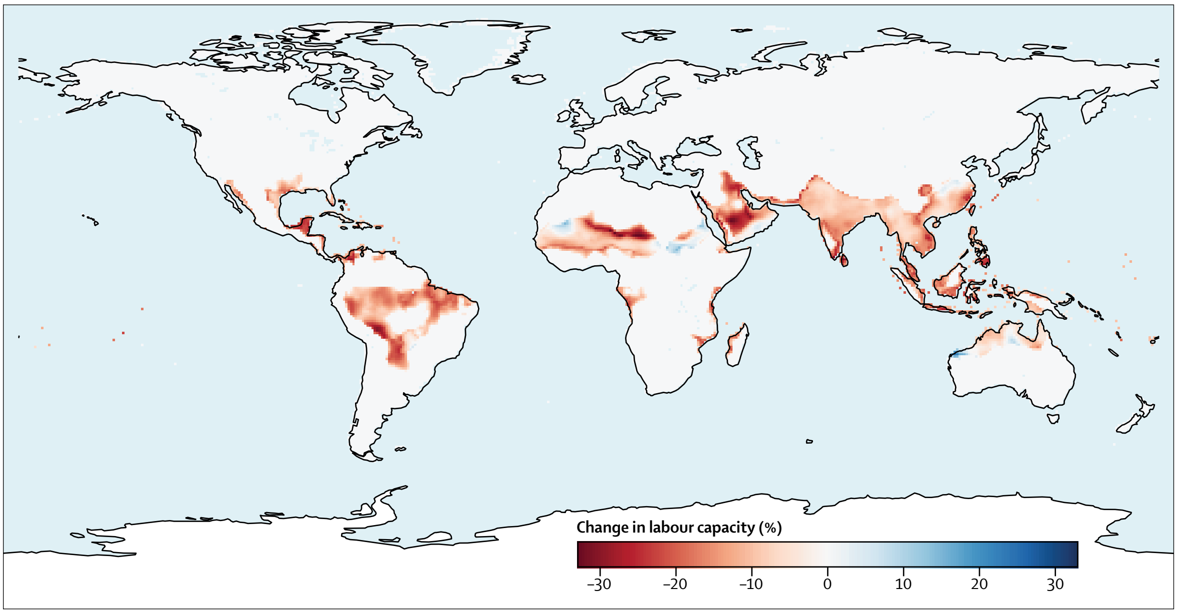

Figure 5: Change in labour capacity loss, relative to the 1986–2008 average

health impacts of future climate change, worsening profoundly in the coming years. Indeed, the 2015 *Lancet* Commission estimated that an additional 1·4 billion drought exposure events and 2·3 billion flood exposure events will occur by the end of the century, showing clear public health limits to adaptation.[2]

Disaster impact is a function of hazard and vulnerability, with vulnerability from a climate change perspective sometimes defined as a function of exposure, sensitivity, and adaptive capacity.[22] This indicator measures the ratio of the number of deaths to the number of people affected by weather-related disasters. Weather-related disasters include droughts, floods, extreme temperature events, storms, and wildfires. The health impacts of weather-related disasters expand beyond mortality alone, including injuries, mental health impacts, spread of disease, and food and water insecurity. Data for the calculations for this indicator come from the Emergency Events Database (EM-DAT). Here, in line with the EM-DAT data used for analysis, a disaster is defined as either: (1) ten or more people killed; (2) 100 or more people affected; (3) a declaration of a state of emergency; or (4) a call for international assistance.

For **EM-DAT** see http://www.emdat.be/

Between 1994 and 2013, the frequency of reported weather-related events (mainly floods and storms) increased substantially. However, this trend might be partially accounted for by information systems having improved in the past 35 years, and statistical data are now more available because of increased sociocultural sensitivity to disaster consequences and occurrence.[23] From 2007 to 2016, EM-DAT recorded an average of 306 weather-related disasters per year, an increase of 46% from the 1990–99 average.[24] However, owing to impressive poverty reduction and health adaptation efforts, this increase in weather-related disasters has not yet been accompanied by any discernible trend in number of deaths or in number of people affected by disasters (or in the ratio of these two; figure 6). Indeed, separating out the disasters by the type of climate and weather hazard associated with the disaster, we found a significant decrease in the number of people affected by floods worldwide, equating to a decrease of 3 million people annually. Importantly, best available estimates and projections expect a sharp reversal in these trends in the coming decades, and it is notable that mortality associated with weather-related disasters has increased in many countries, many of which are high-income countries, illustrating that no country is immune to the impacts of climate change (appendix p 19).

The relative stability of the number of deaths in a disaster as a proportion of those affected, despite an increase in the number of disasters, could be interpreted in a number of ways. One plausible conclusion is that this represents an increase in health service provision and risk reduction. However, although weather-related disasters have become more frequent in the past three to four decades, the data here do not capture the severity of such events—a factor directly relevant to a country's vulnerability and ability to adapt.[22] It is also important to note the difficulties in discerning overall trends, owing to the stochastic nature of the data and the relatively short time series. This poses limitations on the significance of findings that can be drawn from analysis to date. Improving the validity of this indicator will be a focus going forward.

Indicator 1.5: Global health trends in climate-sensitive diseases

This indicator reports that global health initiatives have improved the health profile of populations around the world—a trend that unmitigated climate change is expected to undermine.

Disease occurrence is determined by a complex composite of social and environmental conditions and health service provision, all of which vary geographically. Nonetheless, some diseases are particularly sensitive to variations in climate and weather and might therefore be expected to vary with both longer-term climate change and shorter-term extreme weather events.[13] This indicator draws from Global Burden of Disease (GBD) 2015 mortality estimates to show trends in deaths associated with seven climate-sensitive diseases since 1990 (figure 7).

These disease trends reveal worldwide increases in dengue mortality, particularly in the Asia-Pacific, Latin American, and Caribbean regions, with some peak years (including 1998) known to be associated with El Niño conditions.[25] Beyond climate, likely drivers of dengue mortality include trade, urbanisation, global and local mobility, and climate variability. The association between increased dengue mortality and climate change is therefore complex.[26] It naturally follows that an increased spread of the disease resulting from climate change will be an important contributing factor in the increased likelihood of an associated increase in mortality.

Malignant melanoma is a distinctive example of a non-communicable disease with a clear link to ultraviolet exposure. Mortality has been increasing steadily despite advances in surveillance and treatment, although increased exposures also occur as a result of changing lifestyles (eg, an increase in sun tanning). Heat and cold exposure is a potentially important aspect of climate-influenced mortality, although the underlying attribution of deaths to these causes in the estimates is uncertain.[27–32] Deaths directly related to forces of nature have been adjusted for the effects of the most severe seismic events. Of the ten highest country-year mortality estimates due to forces of nature, seven were directly due to specific seismic activity, and these have been discounted by replacing with the same countries' force of nature mortality for the following year. The remaining major peaks relate to three extreme weather events (Bangladesh cyclone of 1991, Venezuela floods and mudslides of 1999, and Myanmar cyclone of 2008), which accounted for more than 300 000 deaths.

Overall, the findings highlight the effectiveness and success of global health initiatives in largely reducing deaths associated with these diseases since 1990. Furthermore, these trends provide a proxy for the global health profile of climate-sensitive diseases and thus, to some degree, indication of existing vulnerabilities and exposures to them.

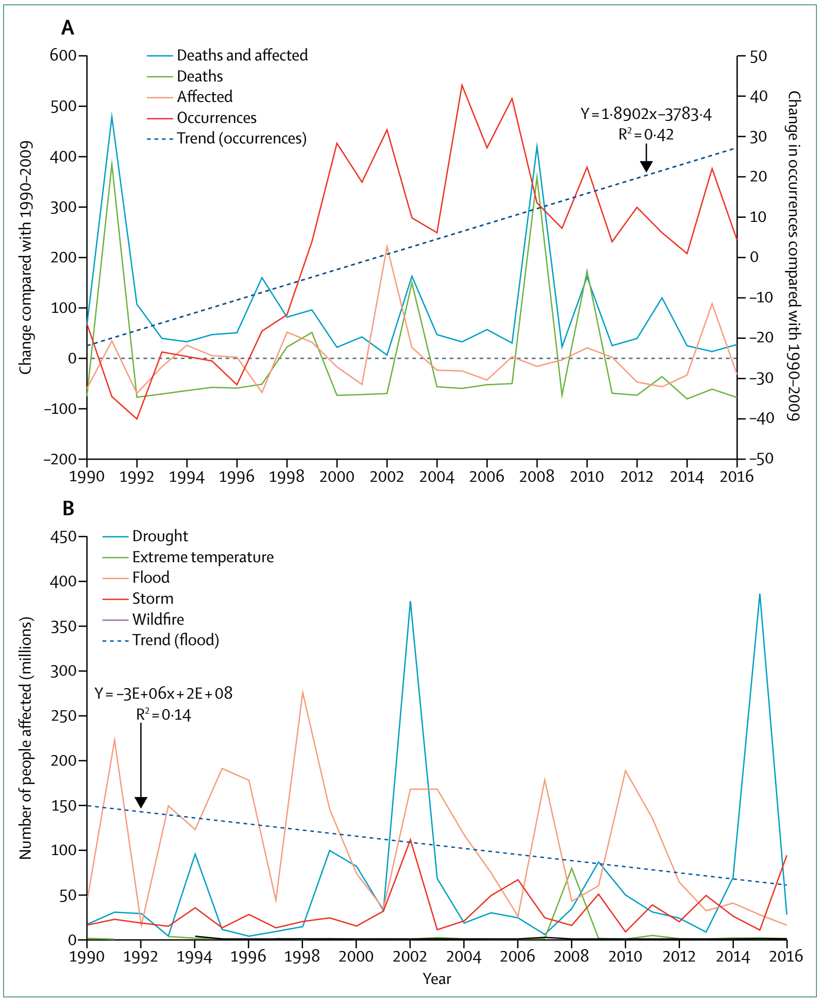

Figure 6: **Number of deaths and people affected by weather-related disasters**
(A) Number of deaths, number of affected people, and the ratio of these (measured against the 1990–2009 average), worldwide. (B) Number of people affected by different weather-related disasters worldwide.

Indicator 1.6: Climate-sensitive infectious diseases

This indicator reports that climate trends have led to a global increase in the vectorial capacity for the transmission of dengue from *A aegypti* and *Aedes albopictus*, of 3·0% and 5·9%, respectively, compared with 1990 levels, and of 9·4% and 11·1%, respectively, compared with 1950 levels.

Despite a decreasing overall trend, infectious diseases still account for about 20% of the global burden of disease and underpin more than 80% of international health hazards, as classified by WHO.[33,34] Climatic factors are routinely implicated in the epidemiology of infectious diseases, and they often interact with other factors, including behavioural, demographic, socioeconomic, topographic, and other environmental factors, to influence infectious disease emergence, distribution, incidence, and burden.[4,35] Understanding the contribution of climate change to infectious disease risk is thus complex but necessary for advancing climate change mitigation and

For **Global Burden of Disease Study 2015 data resources** see http://ghdx.healthdata.org/gbd-2015

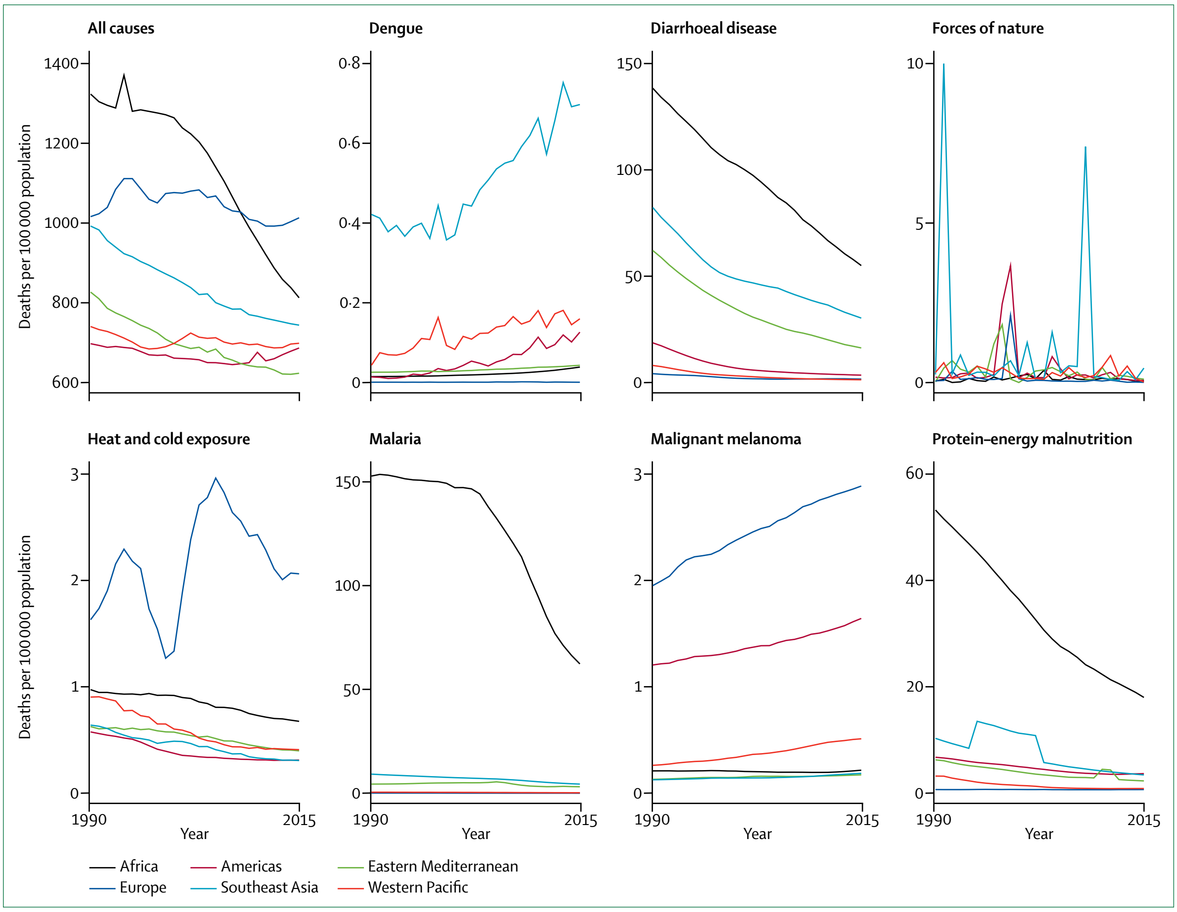

Figure 7: **Trends in mortality from selected causes of death, as estimated by the Global Burden of Disease Study 2015, by WHO region**

adaptation policies.[17] This indicator is divided into two components: (1) a systematic literature review of the links between climate change and infectious diseases; and (2) a vectorial capacity model for the transmission of dengue virus by the climate-sensitive vectors.

For the first component, we systematically reviewed the scientific literature describing effects of climate change and infectious diseases (appendix p 23), in which evolutionary trends in knowledge and direction of the impact of climate change disease risk associations were measured (figure 8). The number of new reports fitting the search criteria in 2016 (n=89) was the highest yet reported, almost double the number of reports in 2015 (n=50) and more than triple the number of reports in 2014 (n=25). During this period, the complexity of interactions between climate change and infectious disease has been increasingly recognised and understood.

Trends in the global potential for dengue virus transmission (as represented by vectorial capacity in the mosquito vectors *A aeqypti* and *A albopictus,* the principal vectors of dengue) are presented in figure 9. WHO defines vectorial capacity as the rate (usually daily) at which a bloodsucking insect population generates new inoculations from a currently infectious case. We conducted a global, mechanistic investigation of changes in annual transmission potential for dengue fever, a model, high-burden, climate-sensitive vector-borne disease. For both vectors, vectorial capacity in locations where these vectors exist reached its highest or equal highest average level in 2015 during the period considered (figure 9). This consolidates a clear and significant increase in vectorial capacity starting in the late 1970s (3·0% and 6·0% increases in vectorial capacity compared with 1990 levels for *A aegypti* and *A albopictus,* respectively). Nearly all *Aedes*-positive countries showed relative increases in vectorial capacity for both vectors during the period considered (figure 9). Annual numbers of cases of dengue fever have doubled every decade since 1990, with 58·4 million apparent cases (95% CI 23·6 million–121·9 million) in 2013, accounting for more than 10 000 deaths and 1·14 million disability-adjusted life-years (95% CI 0·73 million–1·98 million).[36] Climate change has been suggested as one potential contributor to this increase in burden.[37] *A aegypti* and *A albopictus* also carry other important emerging or re-emerging arboviruses, including Yellow Fever, Chikungunya, Mayaro, and Zika viruses, which are probably similarly responsive to climate change.

Indicator 1.7: Food security and undernutrition

Isolating the impact of climate change on health through the indirect impacts on food security is complicated because policies, institutions, and the actions of individuals, organisations, and countries strongly influence the extent to which food systems are resilient to climate hazards and adapt to climate change and whether individual households are able to access and afford sufficient nutritious food. For example, with respect to undernourishment, vulnerability has been shown to be more dependent on adaptive capacity (such as infrastructure and markets) and sensitivity (such as forest cover and rain-fed agriculture) than exposure (such as temperature change, droughts, floods, storms).[38] In view of the role human systems have in mediating the links between climate, food, and health, the chosen indicators focus on abiotic and biotic indicators and population vulnerabilities, considering both terrestrial and marine ecosystems. Undernutrition has been identified as the largest health impact of climate change in the 21st century.[13,39–42]

Indicator 1.7.1: Vulnerability to undernutrition

This indicator reports that the number of undernourished people in the 30 most vulnerable countries (those that are geographically climate-vulnerable, have very high levels of undernutriton, and have high levels of regional dependency for food production) has increased from 398 million people in 1990 to 422 million people in 2016.

The purpose of this indicator is to track the extent to which health will be compromised by climate change in countries where both dependence on domestic production of food and levels of undernourishment (which is strongly related to undernutrition) are already high at present. Climate change could further compromise health through changes in localised temperature and precipitation, manifested in reduced yields.

Food markets are increasingly globalised, and food security is increasingly driven by human systems. In response to decreasing yields caused by temperature increases, governments, communities, and organisations can and will undertake adaptation activities that might variously include breeding programmes, expansion of farmland, increased irrigation, or switching crops. However, the greater the loss of yield potential due to temperature increases, the more difficult adaptation becomes for populations dependent on domestic food supply.

Increasing temperatures have been shown to reduce global wheat production by 6% for each 1°C increase.[43–45] Rice yields are sensitive to increases in night temperatures, with each 1°C increase in growing-season minimum temperature in the dry season resulting in a 10% decrease in rice grain yield.[46] Higher temperatures have been demonstrated rigorously to have a negative impact on crop yields in countries in lower latitudes.[47–49]

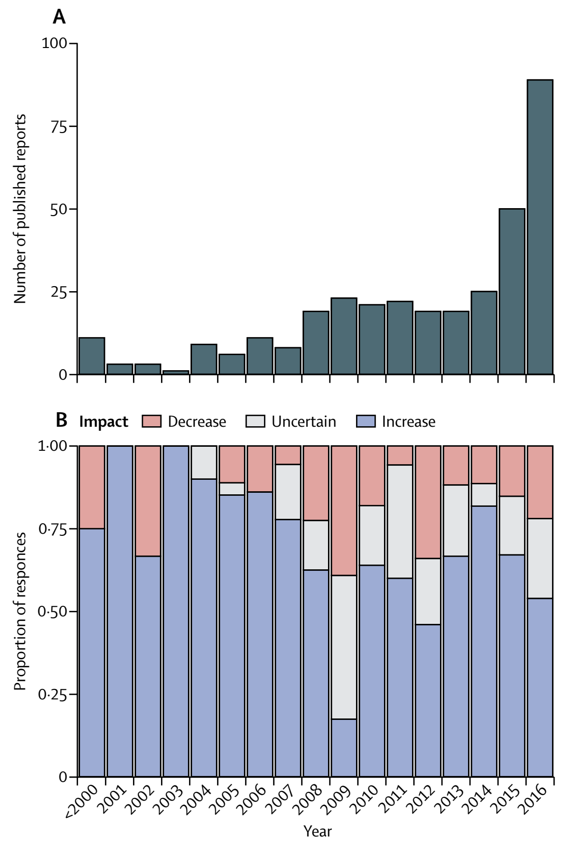

***Figure 8:* Systematic review of scientific literature about climate-sensitive infectious diseases**
(A) Number of academic reports about climate-sensitive infectious diseases, by year. (B) Proportion of responses reported in publications, by year and direction of impact.

Moreover, agriculture in lower latitudes tends to be more marginal, and more people are food insecure.

Using data from the Food and Agriculture Organization of the United Nations (FAO), this indicator focuses on vulnerability to undernutrition. Countries are selected for inclusion on the basis of three criteria: (1) the presence of moderate or high levels of undernourishment, reflecting vulnerability; (2) their physical location, focusing on geographies where a changing climate is predicted with high confidence to have a negative impact on the yields to staples produced; and (3) dependence on regional production for at least half of the population's cereal consumption, reflecting high exposure to localised climate hazards. 30 countries in Africa or southern Asia are included. The aggregated indicators show the total number of undernourished people in these 30 countries, multiplied by total dependence on regional production of grains (figure 10). This gives a measure of how exposed undernourished populations that are already highly dependent on regionally produced grains are to localised climate hazards.

For the **FAO hunger map 2015** see http://www.fao.org/hunger/en

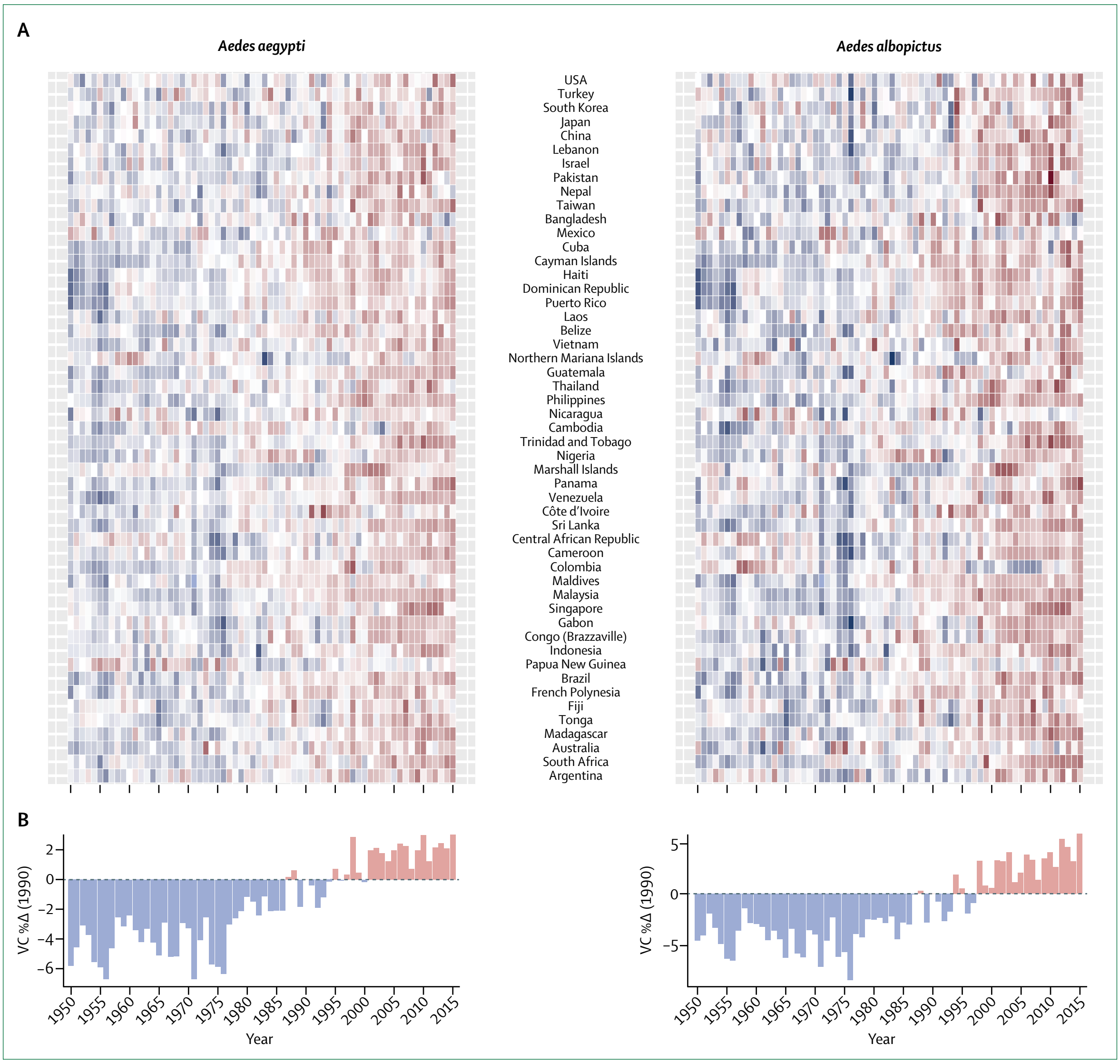

Figure 9: **Average annual vectorial capacity (VC) for dengue in *Aedes aegypti* and *Aedes albopictus* for selected *Aedes*-positive countries**
(A) Matrix coloured relative to country mean in 1950–2015; red indicates relatively higher VC, and blue indicates relatively lower VC. Countries are ordered by centroid latitude (north to south). (B) Average VC for both vectors calculated worldwide (relative to 1990 baseline).

The regions with the highest vulnerability to undernutrition are also areas where yield losses due to climate warming are predicted to be relatively high, thus increasing the vulnerability of these populations to the negative health consequences of undernutrition. High dependence on one crop increases the vulnerability of a country further. For example, Kenya, with a domestic production dependency for cereals of almost 80%, is 69% dependent on maize, is experiencing high levels of undernutrition, and is particularly vulnerable to climate-related yield losses. Going forward, these data will be refined through country-level exploration, incorporation of the predicted impact of warming on yield losses, and incorporation of key temperature indicators such as growing degree days above critical crop-specific thresholds.[50,51]

Indicator 1.7.2: Marine primary productivity

Decreasing fish consumption is an indication of food insecurity, especially in local shoreline communities that depend on marine sources for food. These communities are especially vulnerable to any decreases in marine primary productivity affecting fish stocks.[52] This is particularly concerning for the 1 billion people in the world who rely on fish as their principal source of protein, placing them at increased risk of stunting (prevented from growing or developing properly) and malnutrition from food insecurity.[53] Fish are also important for providing micronutrients such as zinc, iron, vitamin A, vitamin B12,

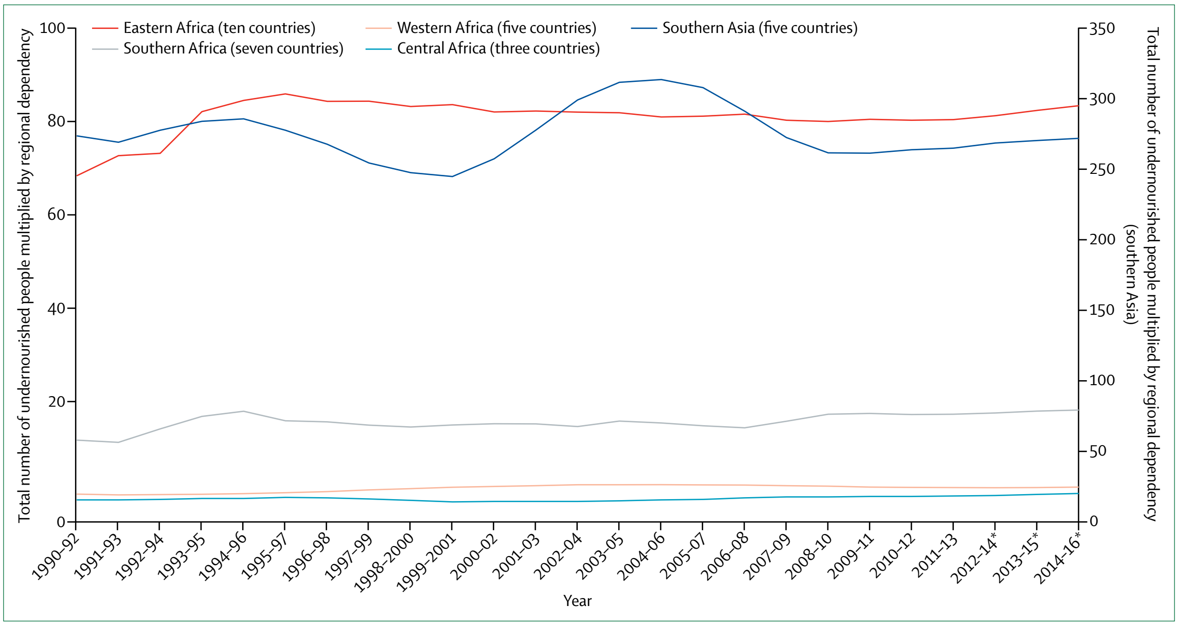

Figure 10: **Total number of undernourished people multiplied by regional dependency on grain production for countries**

and omega-3 fatty acids. If fish stocks continue to decrease, up to 1·4 billion people are estimated to become deficient and at increased risk of certain diseases, particularly those associated with the cardiovascular system.[54,55]

Marine primary productivity is determined by abiotic and biotic factors; measuring these globally and identifying relevant marine basins is complex. Factors such as sea surface temperature, sea surface salinity, coral bleaching, and phytoplankton numbers are key determinants of marine primary productivity. Other local determinants have particularly strong effects on marine primary productivity. For example, harmful algal blooms result from uncontrolled algal growth producing deadly toxins. The consumption of seafood contaminated with these toxins, such as those produced by *Alexandrium tamarense*, is often very dangerous to human health and potentially fatal.[56]

Changes in sea surface temperature and sea surface salinity from 1985 to present are shown for 12 fishery locations essential for aquatic food security. Data were obtained from NASA's Earth Observatory Databank, and mapped across to the important basins outlined in the appendix (p 34). From 1985 to 2016, a 1°C increase in sea surface temperature (from an annual average of 22·74°C to 23·73°C) was recorded in these locations.[57] This indicator requires substantial further work to draw out the attribution to climate change and the health outcomes that might result. A case study on food security and fish stocks in the Persian Gulf is presented in the appendix (p 39).

Indicator 1.8: Migration and population displacement

This indicator reports that climate change is the sole contributing factor for at least 4400 people who are already being forced to migrate, worldwide. The total number of people vulnerable to migration might increase to 1 billion by the end of the century without significant further action on climate change.

Climate change-induced migration can occur through a variety of different social and political pathways, ranging from sea level rise and coastal erosion to changes in extreme and average precipitation and temperature that reduce the arability of land and exacerbating food and water security issues. Estimates of future so-called climate change migrants vary widely, but range from 25 million people to 1 billion people by 2050.[58] Such variation indicates the complexity of the multifactorial nature of human migration, which depends on an interaction of local environmental, social, economic, and political factors. For example, in Syria, many attribute the initial and continued conflict to the rural-to-urban migration that resulted from a climate change-induced drought.[59,60] However, the factors leading to the violence are wide-ranging and complex, with clear quantifiable attribution particularly challenging. Indeed, climate change, as a threat multiplier and an accelerant of instability, is often thought of as important in exacerbating the likelihood of conflict. Nonetheless, migration driven by climate change has potentially severe impacts on mental and physical health, both directly and by disrupting essential health and social services.[61]

Despite the methodological difficulties in proving a direct causal relationship between climate change and population displacement, this is possible in some areas. This indicator focuses on these situations and makes attempts at isolating instances where climate change is

	Population size	Notes on causes of migration
Carteret Islands, Papua New Guinea	1200 people	Migrating due to sea-level rise[7,8]
Alaska*	3512 people	Changing ice conditions leading to coastal erosion and due to permafrost melt, destabilising infrastructure[9,10]
Isle de Jean Charles, LO, USA	25 homes	Coastal erosion, wetland loss, reduced accretion, barrier island erosion, subsidence, and saltwater intrusion were caused by dredging, dikes, levees, controlling the Mississippi River, and agricultural practices; climate change is now bringing sea-level rise

*Communities in Alaska that need to migrate as soon as possible include: Kivalina (398–400 people); Newtok (353 people); Shaktoolik (214 people); and Shismaref (609 people). Communities in Alaska that need to migrate gradually include: Allakeket (95 people); Golovin (167 people); Hughes (76 people); Huslia (255 people); Koyuku (89 people); Nulato (274 people); Teller (256 people); and Unalakleet (724 people). Village names and populations are sourced from the US Government Accountability Office's report.[7–10]

Table 1: **Locations from which populations are migrating now only because of climate change**

***Panel 4:* Mental health and climate change**

Measuring changes in the effects of climate change on mental health and wellbeing is difficult. Although this is partly because of problems of attribution, the main measurement difficulty lies in the inherently complicated nature of mental health, which embraces a diverse array of outcomes (eg, anxiety and mood disorders), many of which co-occur and all of which vary with contexts and during lifetimes. They are products of long and complex causal pathways, many of which can be traced back to distal but potent root causes, such as famine, war, and poverty, of which climate change is an accelerator.[69]

Mental health, with its inherent intricacy, is a field of study where systems thinking is likely to be particularly valuable. A first step, therefore, in tracking progress on mental health and climate change is to build a conceptual framework using systems thinking. Initial work in partnership with the University of Sydney has begun to trace through the many direct and indirect causal pathways to aid the identification of indicators. Many challenges are immediately apparent (eg, how to gather and interpret highly subjective measures across cultures and income settings). Although further work and engagement with other partners will be necessary, potential indicators might focus on a range of issues, including: national and local mental health emergency response capacity to climate-related extreme events; the extent to which climate change is considered within national mental health strategies; or the social and psychological effect of uninsured economic losses that result from extreme weather events.

the sole contributory factor in migration decisions. Sea level rise is the clearest example, although other examples exist (table 1). Estimating the number of people who have involuntarily migrated (both internally and internationally) as a result of climate change alone helps overcome the complexity of accounting for other societal, economic, and environmental factors that also influence migration.

On the basis of data derived from peer-reviewed academic reports (appendix p 40 for full details), the 4400 people who have been forced to migrate solely because of climate change (table 1) is an underestimate because it excludes cases in which more than one factor could be contributing to a migration decision, such as a combination of both climate-related sea level rise and coastal erosion not associated with climate change (possibly such as the village of Vunidogola, relocated by the Fijian Government in 2014 for such reasons, and the planned relocation of the Fijian village of Narikoso by 2018).[62–64]

In the long term, human exposure and vulnerability to ice sheet collapse is increasing as the number of people living close to the coast and at elevations close to sea level increases. In 1990, 450 million people lived within 20 km of the coast and less than 20 m above sea level.[65] In 2000, 634 million people (about 10% of the global population), of whom 360 million live in urban centres, lived below 10 m above sea level (the highest vertical resolution investigated).[66] With 2000 as a baseline, the population living below 10 m above sea level will increase from 634 million people to 1005–1091 million people by 2050 and to 830–1184 million people by 2100.[67] From 2100 and beyond, without mitigation and adaptation interventions, more than 1 billion people might need to migrate because of sea level rise caused by any ice sheet collapse.[67,68]

Although this indicator is not yet able to capture the true number of people forced to migrate because of climate change, that at least 4400 people are already forced to migrate because of climate change only is concerning and demonstrates that there are limits to adaptation. That this is a significant underestimate further highlights the need to mitigate climate change and improve the adaptive capacity of populations to reduce future forced migration. Importantly, only instances of migration where climate change is isolated as the only factor are captured. New approaches will be necessary to more accurately estimate the number of people forced to migrate because of climate change and to capture situations where climate change has an important contributory role alongside other social and economic considerations.

Conclusion

Climate change affects health through diverse direct and indirect mechanisms. The indicators presented here provide an overview of some of these effects and capture exposure, impact, and underlying vulnerabilities. Going forward, indicators will be developed to better measure direct health outcome from climate change in addition to exposure and vulnerabilities.

The indicators will be developed continuously to more directly capture mortality and morbidity outcomes from communicable and non-communicable diseases. Work is already underway to produce new indicators to capture these concepts for future reports. One such ongoing process is focusing on mental health and climate change (panel 4).

Adaptation pathways can help to minimise some of the negative health impacts of global warming, especially for the lower range of projected average temperature rises. However, there are powerful limits to adaptation, and we have drawn attention to the non-linearity and the spatial distribution of the health impacts of climate change. The indicators demonstrate clearly that these impacts are experienced in all parts of the world today and provide a strong imperative for both adaptation and mitigation interventions to protect and promote public health.

Section 2: Adaptation, planning, and resilience for health

Climate change adaptation is defined by the Intergovernmental Panel on Climate Change as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities".[70] With respect to health, adaptation consists of efforts to reduce injury, illness, disability, and suffering from climate-related causes. Resilience has been defined by the Rockefeller Foundation as "the capacity of individuals, communities, and systems to survive, adapt, and grow in the face of stress and shocks, and even transform when conditions require it".[71] In the context of climate change and health, resilience is an attribute of individuals, communities, and health-care systems; resilience at all levels can reduce adverse health outcomes of climate change and should be a goal of adaptation planning.

Identifying indicators of resilience and adaptation is challenging. Resilience is related to, but not synonymous with, preparedness, response, resource management, and coordination capacity. Understanding the resilience of a population's health and health systems at present provides some indication of resilience to climate change, although direct indicators measuring this have not yet been developed by the *Lancet* Countdown. The indicators presented here are predominantly process-based, focusing on health adaptation planning, capacity, and response. Although the underlying resilience of communities is present to some extent in all indicators in this section, it is currently only captured directly for health systems. Most indicators that follow will therefore focus more specifically on health adaptation.

We have identified six indicators. Headline findings for all indicators are provided at the beginning of each indicator; detailed discussion of the data and methods used is available in the appendix (p 49).

Indicator 2.1: National adaptation plans for health

This indicator reports that 30 out of 40 countries responding to the survey have a national health adaptation plan or strategy approved by the relevant national health authority.

Panel 5: WHO—United Nations Framework Convention on Climate Change (UNFCCC) Climate and Health Country Profile project

The WHO–UNFCCC Climate and Health Country Profile Project forms the foundation of WHO's national level provision of information and monitoring of progress in this field. The profiles, developed in collaboration with ministries of health and other health determining sectors, support evidence-based decision making to strengthen the climate resilience of health systems and promote actions that improve health while reducing carbon emissions. In part, the data used in the development of the climate and health country profiles are collected through a biennial WHO Climate and Health Country Survey. Data from this survey are reported on for Indicators 2.1, 2.5, and 2.6.

The 2015 baseline survey findings for 40 responding nations are presented in this report (a complete list of country respondents is provided in the appendix, p 49). The findings include countries from all WHO regions (high-income, middle-income, and low-income groups) and with varying levels of risks and vulnerabilities to the health effects of climate change. The 2015 survey data were validated as part of the national consultation process seeking input on respective WHO–UNFCCC Climate and Health Country Profiles from key in-country stakeholders, including representatives of the ministry of health, ministry of environment, meteorological services, and WHO country and regional technical officers.

The validated data presented in this report tended to include many countries that are actively working on climate and health with WHO; as such, the results here are indicative and are not meant to be inferred as an exact indicator of global status. The number of country respondents is expected to double in subsequent iterations of the survey. As such, the results represent the beginning of the development of a more comprehensive survey and offer insights to findings at the start of this process.

Effective national responses to climate risks require that the health sector identify strategic goals in response to anticipated and unanticipated threats. A crucial step in achieving these strategic goals is developing national health adaptation plans and outlining priority actions, resource requirements, and a specific timeline and process for implementation. This indicator tracks the policy commitments of national governments for health and climate change adaptation, and data are drawn from the recent WHO Climate and Health Country Survey (panel 5).

Of the 40 countries responding to the survey, 30 reported having a national adaptation strategy for health approved by their Ministry of Health or relevant health authority (figure 11). Among these 30 countries are countries with a health component of their National Adaptation Plan, which was established by the UNFCCC to help nations identity medium-term and long-term adaptation needs and develop and implement programmes to address those needs.[72] There is a need for caution in extrapolating the results to global level because many of the respondent countries have received support from WHO in developing and implementing their plans.[73,74] Nonetheless, with 75% of respondents in the survey having an approved national health adaptation plan, there is evidence that the need to adapt to climate change is recognised. Countries with national health adaptation plans are found in all regions and, perhaps most importantly, include some of the most vulnerable countries in Africa, southeast Asia, and South America. In future iterations of the survey, data

For the **UNFCCC's National Adaptation Plans** see http://unfccc.int/adaptation/workstreams/national_adaptation_plans/items/6057.php

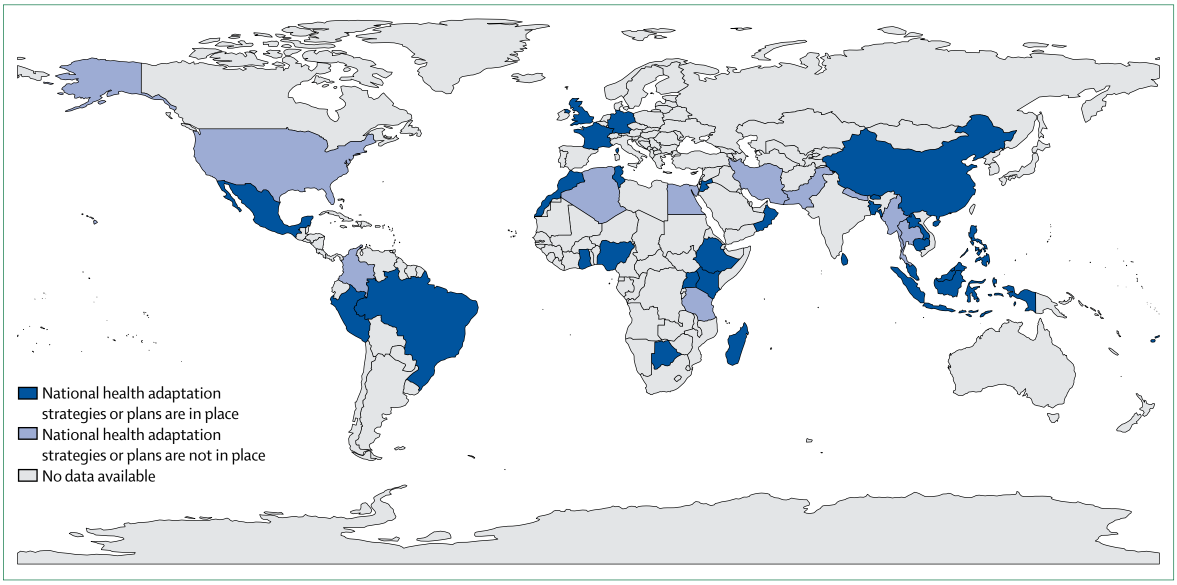

Figure 11: **Countries with national heath climate adaptation strategies or plans**

will be gathered on the content and quality of these adaptation plans, their level of implementation, the main priorities for health adaptation, internal monitoring, and review processes, and the level of funding available to support policy interventions.

Indicator 2.2: City-level climate change risk assessments

This indicator reports that, of the 499 self-reporting cities in the Carbon Disclosure Project 2016 information request, 45% have climate change risk assessments in place.

55% of the world's population lives in cities, where key health infrastructure is often concentrated.[75] These urban centres are increasingly at risk from climate change, with negative impacts predicted for human health and health services. To improve cities' ability to adapt to climate change, National Adaptation Plans must be complemented with city-level responses. Indeed, cities have a unique opportunity to provide adaptation measures that help improve the resilience of urban populations, while also helping to mitigate the impacts of climate change on public health.[76]

For the **Compact of Mayors** see https://www.compactofmayors.org

For the **Carbon Disclosure Project** see https://www.cdp.net/en

Data for this indicator are from the 2016 global survey of the Compact of Mayors and the Carbon Disclosure Project. According to a Carbon Disclosure Project 2016 information request, 45% of the 449 cities with public responses (533 cities responded overall) reported having undertaken a climate change risk or vulnerability assessment for their local government (figure 12).

Most cities with climate change risk assessments are in high-income countries (118 cities), whereas only 42 cities are in low-income countries. This partly reflects the fact that more cities in high-income countries were surveyed and that these cities have a greater capacity to develop such plans. Most respondents were cities in high-income countries (236 cities in high-income countries *vs* 61 cities in low-income countries).

European cities in this survey have the highest number of climate change risk assessments (56 cities, representing 83% of European cities surveyed). Conversely, only 28% of surveyed African cities have climate change risk assessments. This has serious implications for the adaptive capacity of some of the most vulnerable populations to climate change in low-income countries. A concerted effort must be made to increase the number of climate change risk assessments in cities in low-income countries so as to better understand their vulnerability to climate change impacts and implement adaptation actions.

Indicator 2.3: Detection and early warning of, preparedness for, and response to climate-related health emergencies

This indicator reports that, because of focused investment in the implementation of the International Health Regulations (IHR) 2005, national capacities relevant to climate adaptation and resilience, including disease surveillance and early detection, multihazard public health emergency preparedness and response, and the associated human resources to perform these public health functions, have increased markedly from 2010 to 2016 in all world regions.

Many initiatives at community, national, regional, and global levels support strengthening country capacities for health emergency and disaster risk management, and they complement the implementation of the Sendai Framework for Disaster Risk Reduction, Sustainable Development Goal 3D, the Paris Agreement on Climate Change, and the IHR 2005. Under IHR 2005, all States Parties should report annually

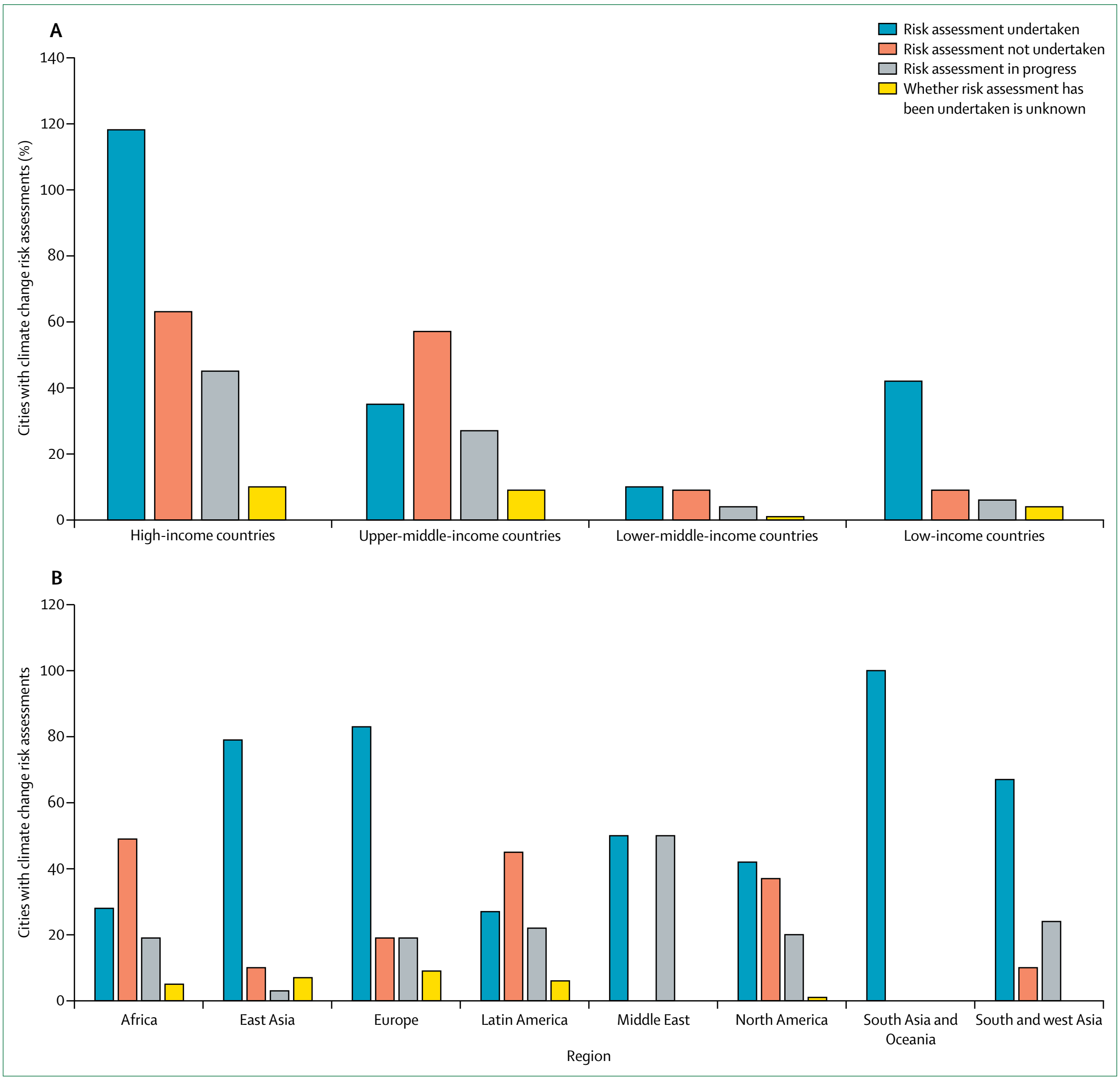

***Figure 12*: Number of global cities undertaking climate change risk assessments, by income grouping and region**

to the World Health Assembly on the implementation of the regulations.[77–79] To facilitate this process, WHO developed an IHR Monitoring questionnaire, interpreting the Core Capacity Requirements in Annex 1 of IHR (2005) into 20 indicators for 13 capacities (panel 6).[80,81] These metrics can serve as important proxies of health-system adaptive capacity and system resilience because they measure the extent to which health systems show a range of attributes necessary to detect, prepare for, and respond to public health emergencies, some of which are climate-sensitive. Four capacities (human resources, surveillance, preparedness, and response) reflecting seven indicators from the IHR Monitoring questionnaire are reported here. Additional details of all four IHR Capacities are available in the appendix (p 51).

The first of these capacities is human resources, which reflects a single indicator: human resources available to implement the IHR Core Capacities. This is a useful proxy in lieu of an indicator that looks at specific capacity for health adaptation to climate change (figure 13A). In 2010, capacity scores ranged from 25% in Africa to 57% in western Pacific. Human resource capacity had improved markedly by 2016, when average capacity was 67% (with the lowest score in the African region reporting 51%, and the highest in the western Pacific region reporting 89%).

Second, surveillance capacity summarises two indicators in the IHR Monitoring questionnaire: (1) indicator-based surveillance includes an early warning function for early detection of a public health event; and (2) event-based surveillance is established and functioning. This capacity score is used as a proxy for a health system's ability to anticipate and identify outbreaks and changing patterns of climate-sensitive infectious diseases, such as zoonosis and food-related outbreaks. Globally, 129 reporting States Parties scored 88% for this capacity in 2016 (figure 13B). This proportion has increased steadily since 2010 (average score of 63%), indicating that health systems have increasing capacity for early detection of public health events.

Third, preparedness capacity reflects that a Multi-hazard National Public Health Emergency Preparedness and Response Plan is developed and implemented. This indicator looks at the presence of a plan, the implementation of the plan, and the ability for this plan to operate under unexpected stress. Of responding countries, progress can be seen in all world regions, from a global average of 49% in 2010 to 76% in 2016 (figure 13C).

Finally, response capacity reflects the availability and functioning of public health emergency response mechanisms and infection prevention and control at national and hospital levels. This capacity is an important proxy for the ability of the health system to mobilise effective responses when shocks or stresses are detected.

Panel 6: The International Health Regulations (IHR, 2005)

The IHR (2005), which entered into force in 2007, is legally binding on 196 States Parties, including all WHO member states. It requires States Parties to detect, assess, notify and report, and respond promptly and effectively to public health risks and public health emergencies of international concern (IHR Article 5, 13) and to develop, strengthen, and maintain the capacity to perform these functions (IHR Article 5). Examples of required core capacities include: national legislation, policy, and financing; public health surveillance; preparedness and response; risk communication; human resources; and laboratory services. Under the IHR (2005), all States Parties should report to the World Health Assembly annually on the implementation of IHR (2005). To facilitate this process, WHO developed an IHR Monitoring questionnaire.[80] The method of estimation calculates the proportion of attributes (a set of specific elements or functions that reflect the performance or development of a specific indicator) reported to be implemented in a country. Since 2010, 195 States Parties have submitted self-reports at least once. Indicator 2.3 is drawn from the results of these questionnaires,[81] to which 129 of 196 States Parties responded in 2016.[81]

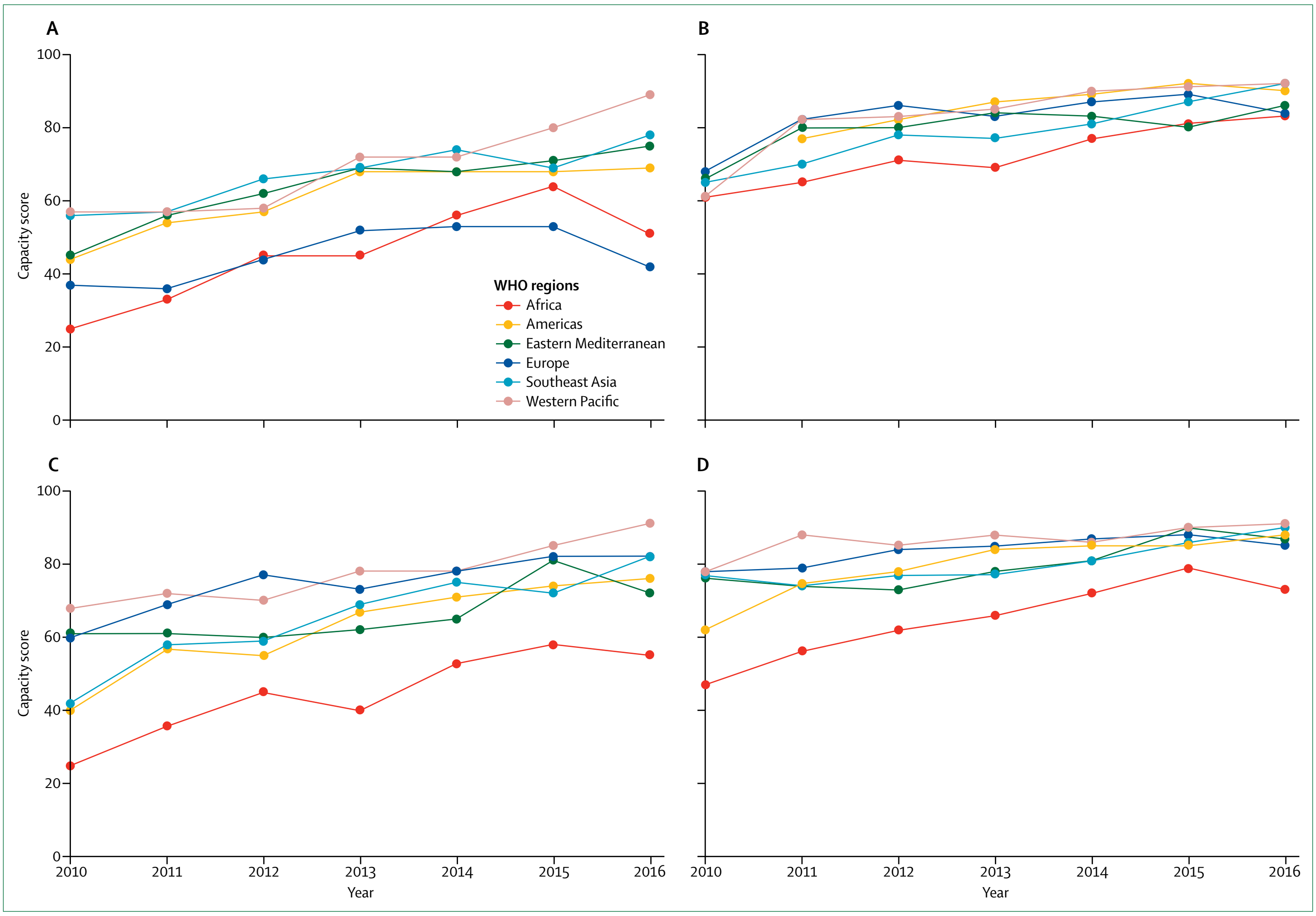

***Figure 13*: International Health Regulations capacity scores by WHO regions**

(A) Human resources capacity score. (B) Surveillance capacity score. (C) Preparedness capacity score. (D) Response capacity score.

All countries had 73–91% response capacity in 2016 (figure 13D), with notable progress in Africa between 2010 (47%) and 2016 (73%).

There are some limitations to considering these capacities. Most importantly, IHR survey responses are self-reported; although national-level external verification has begun, it remains relatively limited. Additionally, these findings capture potential capacity, not action. Finally, the quality of surveillance for early detection and warning, and the impact of that surveillance on public health, are not shown. Response systems have been inadequate in numerous public health emergencies, so the presence of such plans is not a proxy for their effectiveness.

Indicator 2.4: Climate information services for health

This indicator reports that, out of the 100 WHO member states responding to a 2015 survey by the World Meteorological Organization (WMO), 73% report providing climate information to the health sector in their country.

This indicator measures the proportion of countries whose meteorological and hydrological services self-reported to the WMO in 2015 about tailored climate information, products, and services provided to their national public health sector.[82] 73% of the 100 responding WHO member states reported providing climate information to the health sector in their country.

Response rates for the 2015 WMO survey were 71% in the African region, 67% in the eastern Mediterranean region, 79% in the European region, 81% in the Americas, 67% in the southeast Asia region, and 44% in the western Pacific region.

Taking into account the total number of WHO member states (respondent and non-respondent) per WHO region, only 14·8–51·4% are known to provide climate information to the health sector (figure 14), and 18–55% did not provide information.

However, it is important to note that with a 49% non-response rate, this sample is not representative of all countries, and these results were self-reported. Crucially, this indicator does not capture the type of climate products made available, quality of the data provided, the ways in which the health sector makes use of these data (if at all), and whether the data are presented in a format and timely fashion relevant to public health. Future WMO surveys will aim to provide greater insight to the specific applications of climate information. Further information is available in the appendix (p 54).

Indicator 2.5: National assessments of climate change impacts, vulnerability, and adaptation for health

This indicator reports that more than two thirds of countries responding to the survey have conducted a national assessment of climate change impacts, vulnerability, and adaptation for health.

National assessments of climate change impacts, vulnerability, and adaptation for health allow governments to understand more accurately the extent and magnitude of potential threats to health from climate change, the effectiveness of current adaptation and mitigation policies, and future policy and programme requirements. Although national assessments might vary in scope between countries, the number of countries that have done a national assessment of climate change impacts, vulnerability, and adaptation for health is a key indicator to monitor the global availability of information required for adequate management of health services, infrastructure, and capacities to address climate change. This indicator tracks the number of countries that have national assessments and is based on responses to the 2015 WHO Climate and Health Country Survey (panel 5).

More than two thirds of the countries sampled (27 of 40 countries) reported having done a national assessment of impacts, vulnerability, and adaptation for health (figure 15). These countries include all regions, and some countries are particularly vulnerable; for instance, of the nine responding countries in the southeast Asia region, eight countries (Bangladesh, Bhutan, Indonesia, Maldives, Nepal, Sri Lanka, Thailand, and Timor-Leste) reported having national assessments of impacts, vulnerability, and adaptation for health. Increasing global coverage of countries with national vulnerability and adaptation assessments for health is the result of WHO's support to countries through projects and technical guidance.[87]

Indicator 2.6: Climate-resilient health infrastructure

This indicator reports that 16 of 40 responding countries (40%) have implemented activities to increase the climate resilience of their health infrastructure.

Functioning health infrastructure is essential during emergencies. Climate-related events, such as severe storms and flooding, might compromise electricity and water supplies, interrupt supply chains, disable transportation links, and disrupt communications and IT networks, which reduces the capacity to provide medical care. This indicator measures efforts by countries to increase the climate resilience of health infrastructure. The climate resiliency of health infrastructure reflects the extent to which these systems can prepare for and

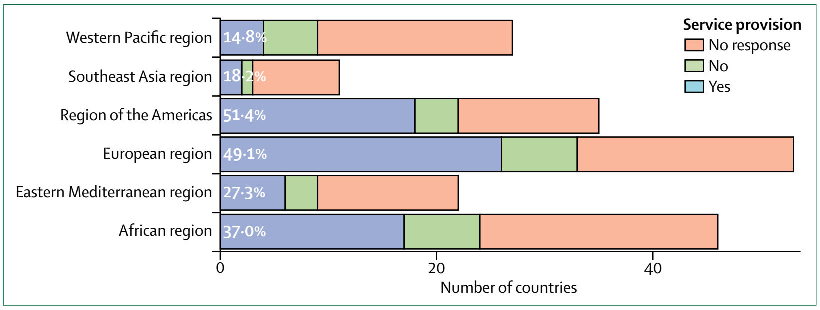

Figure 14: **National Meteorological and Hydrological Services of WHO member states reporting to provide targeted or tailored climate information, products, and services to the health sector**

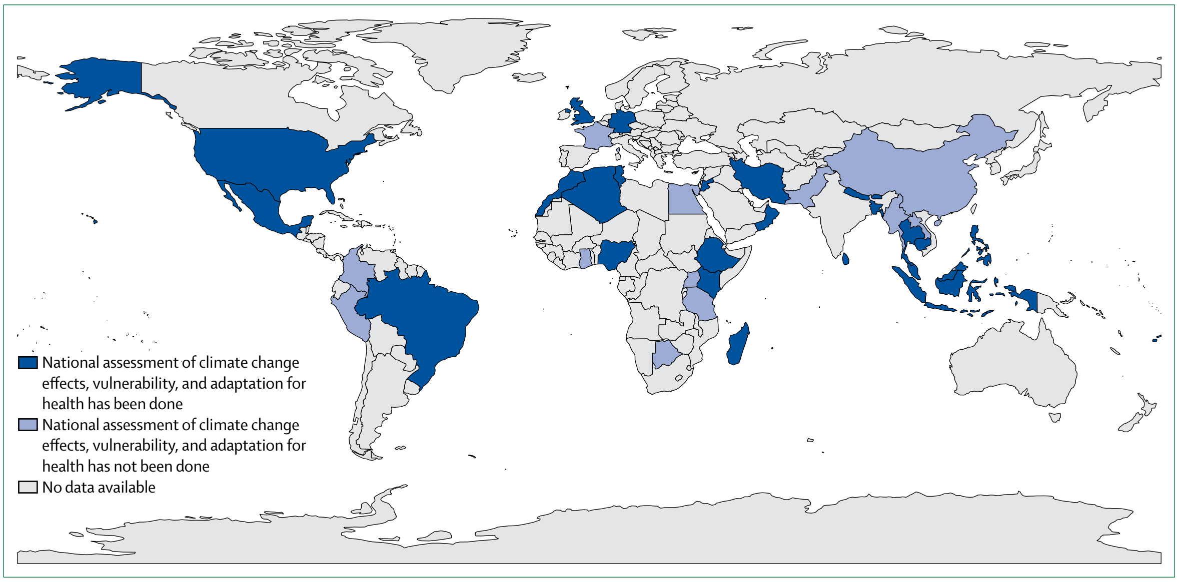

Figure 15: **Countries with national assessment of climate change impact, vulnerability, and adaptation for health**

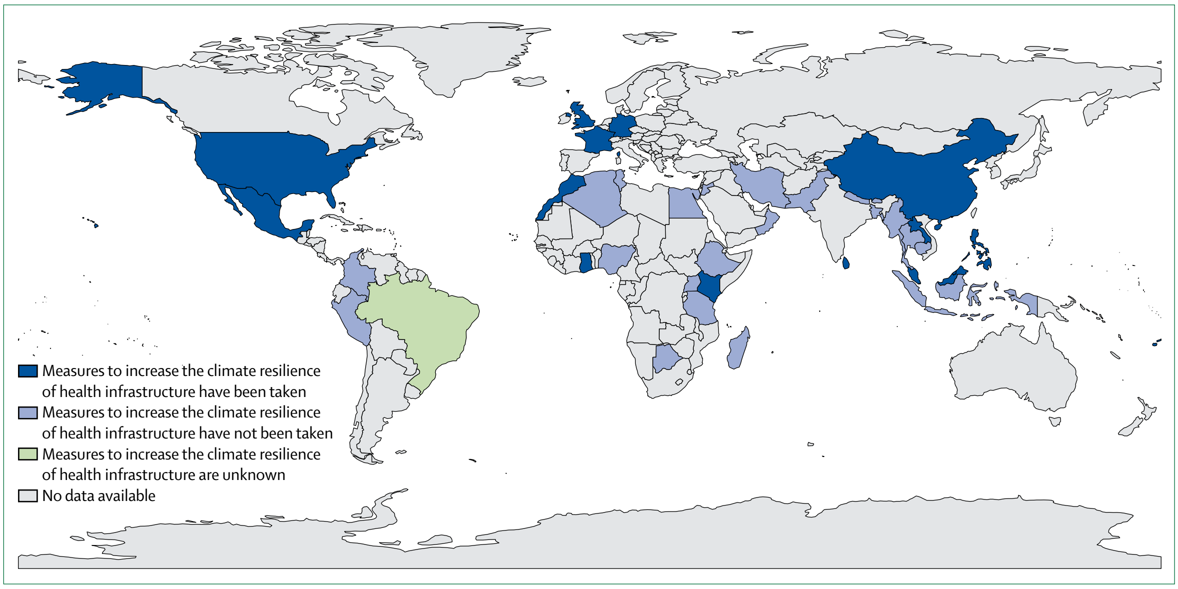

Figure 16: **Countries taking measures to increase the climate resilience of health infrastructure**

adapt to changes in climate affecting the system. Data are drawn from the WHO Climate and Health Country Survey (panel 5). Only 16 of 40 countries (40%) reported having taken measures to increase the climate resilience of their health infrastructure (figure 16). These results suggest widespread vulnerability of health-system infrastructure to climate change. For example, only two of nine responding countries in the African region reported efforts to improve the climate resiliency of health infrastructure. Similar trends were found in other WHO regions.

This indicator does not capture the quality or effectiveness of efforts to build climate-resilient health system infrastructure. Nonetheless, it highlights the importance of ensuring that countries work to implement climate-resilient health infrastructure, as these findings suggest that implementation is generally lacking.

Conclusion

This section has presented indicators across a range of areas relevant to health adaptation and resilience. The public and the health systems they depend on are clearly unprepared to manage the health impacts of climate change.

In many cases, the available data and methods provide only a starting point for an eventual suite of indicators that capture health-specific adaptation, and include both process-based and outcome-based indicators. New indicators will also be necessary to better capture important indicators of resilience.

Section 3: Mitigation, actions, and health co-benefits

In previous sections we have covered the health impacts of climate change, the adaptation available and being implemented at present, and the limits to this adaptation.[13] In this section, we present a series of indicators relevant to the near-term health co-benefits of climate mitigation policies. Accounting for this enables a more complete consideration of the total costs and benefits of such policies and is essential in maximising the cumulative health benefits of climate change mitigation.

The health co-benefits of meeting commitments under the Paris Agreement are potentially immense, reducing the burden of disease for many of the greatest health challenges today and in the future.[88] The indicators presented in this section describe a clear and urgent need to increase the scope of mitigation ambition if the world is to keep global average temperatures well below 2°C.[1]

Countries are accelerating their response to climate change, with Finland, the UK, and China making strong commitments to phase-out or dramatically reduce their dependence on coal.[89–92] By 2017, electric vehicles are poised to be cost-competitive with their petroleum equivalents, a phenomenon that was not expected until 2030. Globally, more renewable energy capacity is being built every year than all other sources combined.[92,93] Consequently, renewable energy is now broadly cost-competitive with fossil fuels, with electricity from low-latitude solar photovoltaic energy being cheaper than natural gas.[92–94]

Tracking the health co-benefits of climate change mitigation

Meeting the Paris Agreement will require global greenhouse gas emissions to peak within the next few years and undergo rapid reduction thereafter, implying near-term actions and medium-term and long-term cuts through country-level activities.[11] Global CO_2 emissions from fossil fuels and industry were 36·3 gigatonnes CO_2 in 2015 (60% higher than in 1990), whereas emission from land use change, which is intrinsically difficult to estimate, was about 4·8 gigatonnes CO_2. In the same year, 41% of the total fossil fuel and industry emissions were estimated to come from coal, 34% from oil, 19% from gas, and 6% from cement.[95] In 2015, the largest emitters of CO_2 were China (29%), the USA (15%), the European Union's 28 member states (EU28; 10%), and India (6·3%). However, per capita emissions of CO_2 belie the disparity driven by consumption, with global mean emissions at 4·8 tonnes CO_2 per person per year compared with 16·8 tonnes CO_2 in the USA, 7·7 tonnes CO_2 in China, 7·0 tonnes CO_2 in EU28, and 1·8 tonnes CO_2 in India.[95]

The actions needed to embark on rapid decarbonisation include avoiding the lock-in of carbon-intensive infrastructure and energy systems, reducing the cost of scaling-up low-carbon systems, minimising reliance on unproven technologies, and realising opportunities of near-term co-benefits for health, security, and the environment.[11] These actions will need to also be cost-effective and supported by non-state actors and industry.

Indicators in this section are broadly considered within the framework of Driving Force-Pressure-State-Exposure-Effect-Action, which is recognised as being suitable for the development of environmental health indicators and for the identification of entry points for policy intervention.[96] An adaptation of the framework to examine the health co-benefits of climate change mitigation is explained in the appendix (p 70).

Health co-benefit indicators are captured for four sectors: energy, transport, food, and health care. Headline findings for all indicators are provided at the beginning of each indicator; more detailed discussion of the data and methods used is available in the appendix (p 57).

Energy supply and demand sectors

Fossil fuel burning is the largest single source of greenhouse gas emissions wordwide, producing an estimated 72% of all greenhouse gas emissions resulting from human activities.[97,98] 66% of these emissions arise in the energy sector from the production of thermal and electric power for consumption in a range of sectors including industry, commercial, residential, and transport sectors.

To meet the climate change mitigation ambitions of the Paris Agreement, it is widely accepted that the energy system will need to largely complete the transition towards near zero-carbon emissions by, or soon after, 2050, and then to negative emissions in the latter part of the century.[99,100] The necessary action has been framed as a halving of CO_2 emissions every decade.[101]

The potential short-term health benefits of such strategies are substantial, with profound improvements from a reduction in indoor and outdoor air pollution; more equitable access to reliable energy for health facilities and communities; and reduced costs of basic energy services for heating, cooking, and lighting to support an improved quality of life.

Indicator 3.1: Carbon intensity of the energy system

This indicator reports that globally, the carbon intensity of total primary energy supply (TPES) of 55–56 tonnes CO_2/TJ has remained stable since 1990, reflecting the huge global challenge of energy-system decarbonisation. This has occurred because the reduction in carbon intensity in the USA, UK, and Germany has been offset by an increased carbon intensity of energy supply in India and China.

To achieve the 2°C target (at a 66% probability), the global energy sector must reduce CO_2 emissions to more

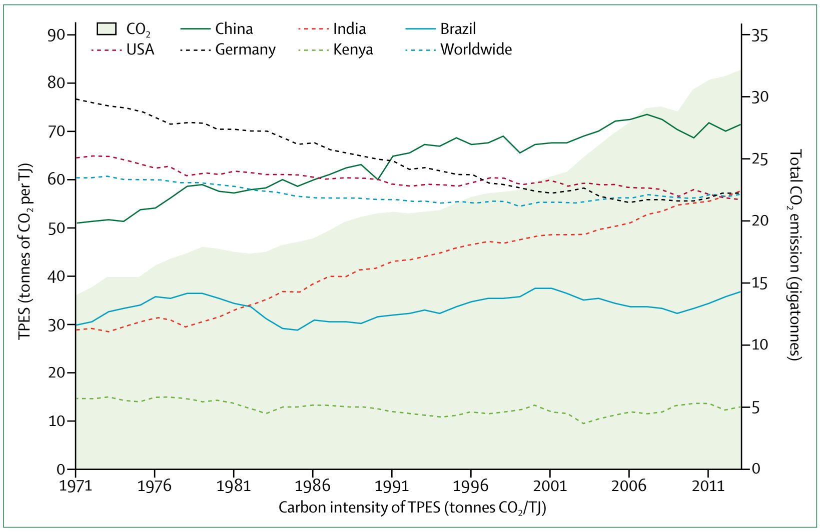

***Figure 17:* Carbon intensity of total primary energy supply (TPES) for selected countries and total carbon dioxide (CO_2) emissions**

Total CO_2 emission is shown as the shaded area against the secondary Y axis.

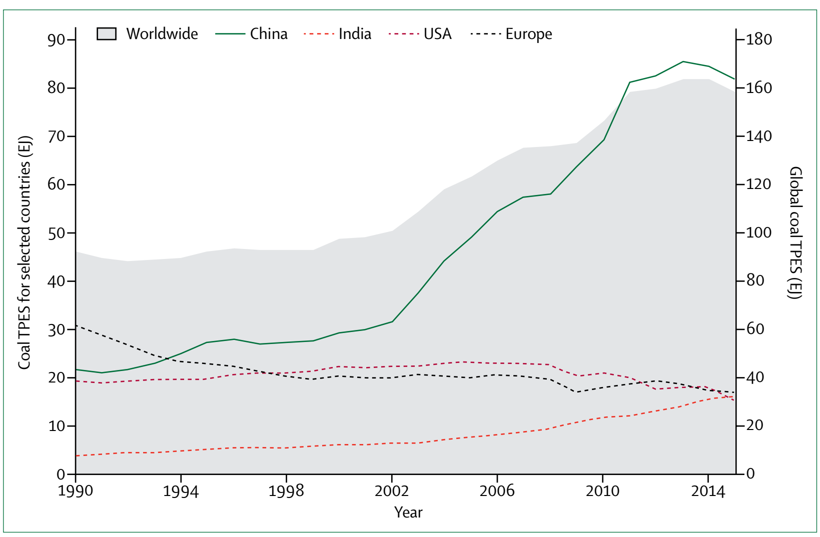

***Figure 18:* Total primary coal supply, by country, region, and globally**

Global primary coal supply is shown as the shaded area against the secondary Y axis. TPES=total primary energy supply.

than 70% below current levels by 2050. This means a large reduction in the carbon intensity of the global energy system, which can be measured as the tonnes of CO_2 for each unit of TPES. TPES reflects the total amount of primary energy used in a specific country, accounting for the flow of energy imports and exports.[102] Commitments under the Paris Agreement should begin to lower the overall carbon intensity of TPES, with the aim of reducing to near zero by 2050.

Drawing on data from the International Energy Agency (IEA), this indicator shows that since the 1990s, the global carbon intensity of TPES has remained 55–56 tonnes CO_2/TJ.[103] However, a 53% increase in energy demand during the period has meant that global CO_2 emissions have increased substantially. Increased coal use in LMICs has driven a rapid increase in carbon intensity since the 1970s (figure 17). For example, India's TPES has almost tripled since 1980, with the share of coal in the energy mix doubling from 22% to 44%. Between 1980 and 2014, a four-fold increase in China's TPES, combined with increasing carbon intensity due to the coal share of TPES increasing from 52% to 66%, has led to strong increase in emissions.

High-income countries such as the USA and Germany have reduced carbon intensity since the 1970s (figure 17) by transitioning away from coal in energy production and use, reducing heavy industrial output, and increasing use of lower carbon fuels, notably moving from coal to natural gas in the power sector and increasing the use of renewable energy.

Indicator 3.2: Coal phase-out

This indicator reports that globally, total primary coal supply has increased from 92 EJ in 1990 to 160 EJ in 2015. However, this peaked in 2013 and is now rapidly declining, with the amount of coal power capacity planned for construction halving from 2016 to 2017.

The primary means of reducing carbon intensity of the energy system within necessary timescales will be the phase-out of coal. Worldwide, coal supplies 30% of energy use and is the source of 44% of CO_2 emissions worldwide. The dirtiest form of coal produces almost twice as much carbon per unit of primary energy than the least carbon-intensive fossil fuel (natural gas).[103] Given that a large share of coal is used for power generation, it is an important sector of focus, both to reduce CO_2 emissions and to mitigate a major source of air pollution.[103]

This indicator of coal phase-out is the total primary coal supply in the energy system (figure 18), which makes use of recent data from the IEA.[103]

Coal use worldwide has increased by just less than 60% since 1990. This is due to strong increases in global energy demand and an increasing share of TPES coming from coal, having increased from 26% in 1990 to 29% in 2014.[103] This worldwide increase in coal use has largely been driven by China's increasing use of coal in industry and electricity production, particularly in the 2000s (figure 18). Crucially, coal use in China has plateaued and reduced since 2013, in large part because the health effects of air pollution have been recognised, slower growth and structural changes in China's economy, and a slowing in energy sector expansion.[104] India has also seen substantial growth in coal use, with the share of coal in TPES increasing from 31% in 1990 to 46% in 2015. The other large coal-consuming regions are the USA and Europe. Consumption has been stable in the USA since the 1990s, but use has recently decreased, particularly in energy production and use, because of the cost-competitiveness of shale gas. Coal use in Europe has been steadily decreasing since the 1990s, again through a move to gas in economies such as the UK, although this

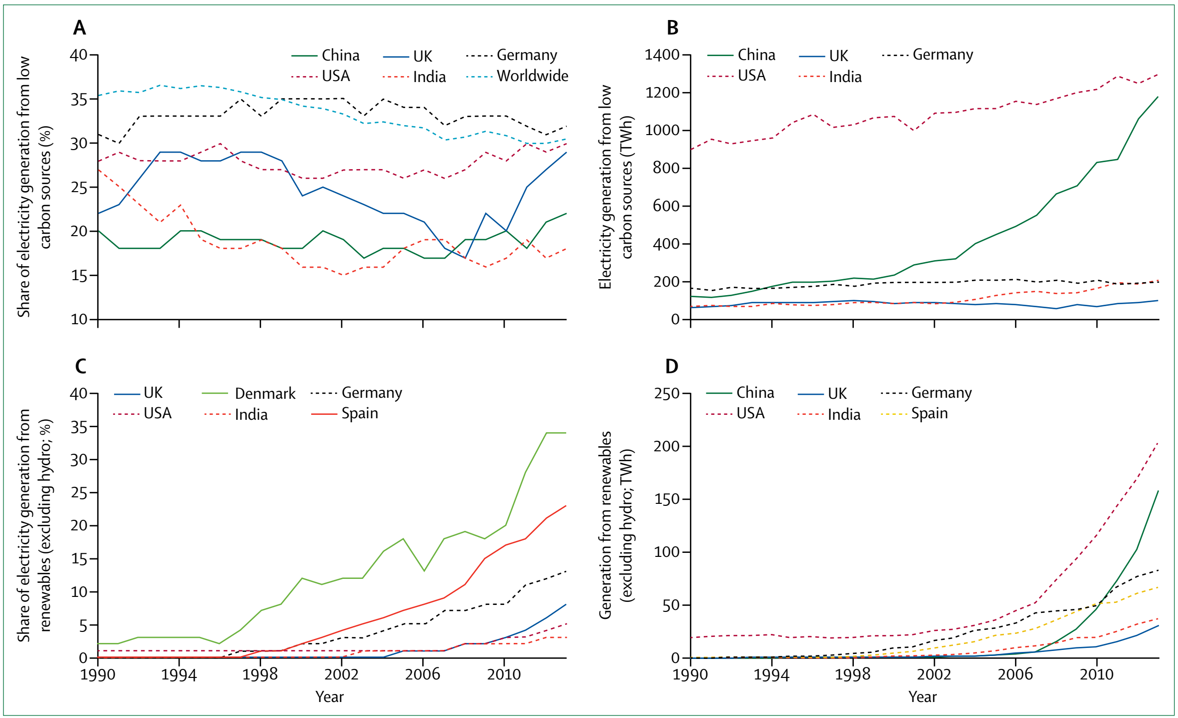

Figure 19: **Renewable and zero-carbon emission electricity generation**
(A) Share of electricity generated from zero-carbon sources. (B) Electricity generated from zero carbon sources. (C) Share of electricity generated from renewable sources (excluding hydro). (D) Electricity generated from renewable sources (excluding hydro).

overall downward trend has transitioned to a plateau in recent years.

China and India have similar shares of electricity generated by coal, at about 75% of total electricity generation. The plateauing coal use in China has not been observed in other parts of Asia, and the rapidly emerging economies of Indonesia, Vietnam, Malaysia, and the Philippines see strong growth from coal.[103]

Meeting the IEA's 2°C pathway and the Paris Agreement requires that no new coal-fired plants be built (beyond those with construction already underway), with a complete phase-out of unabated plants (not fitted with carbon capture and storage) by 2040. Crucially, such a transition might have started, with the amount of coal power capacity in preconstruction planning at 570 gigawatts in January, 2017, compared with 1090 gigawatts in January, 2016.[105] A range of reasons for this large reduction include decreasing planned capacity expansion, a desire to tackle air pollution, and active efforts to expand renewable investment.

Indicator 3.3: Zero-carbon emission electricity

This indicator reports that renewable electricity as a share of total generation has increased worldwide by more than 20% from 1990 to 2013. In 2015, renewable energy capacity added exceeded that of new fossil fuel capacity, with 80% of recently added global renewable energy capacity currently located in China. Where renewables displace fossil fuels (coal in particular), it represents the beginning of reductions in morbidity and mortality from air pollution, and a potentially remarkable success for global health.

As coal is phased out of the energy system, particularly from electricity production, the rapid scale up of zero-carbon energy production and use will be crucial. To remain on a 2°C pathway, renewables-based capacity additions will need to be sustained during the next 35 years, reaching 400 gigawatts per year by 2050, which is 2·5 times the current level. Solar, wind, and hydroelectric renewable technologies will be important for achieving this goal.

Indicator 3.3 draws on IEA data and considers both renewable and zero-carbon electricity.[103] Conversely, renewable energy refers to "all forms of energy produced from renewable sources in a sustainable manner, which include: bioenergy, geothermal, hydropower, ocean energy (tidal, wave, thermal), solar energy and wind energy".[106] By comparison, zero-carbon energy means no greenhouse gas emissions (ie, zero-carbon and carbon equivalent) at the point of energy production and use, which therefore also includes nuclear-powered electricity but excludes biomass.

Both renewable and zero-carbon electricity displace the use of fossil fuels, reducing air pollution and greenhouse gas emissions, and so are important indicators for climate change and for health. One caveat is that combustion of solid biomass fuels such as wood, which is occassionally promoted for climate change mitigation purposes, might increase $PM_{2·5}$ exposure and not be carbon-neutral.[107]

Panel 7: **Energy and household air pollution in Peru**

Universal access to energy is a major challenge in most low-income and middle-income countries, and access to clean energy or energy sources that do not adversely affect health is a considerable problem. In Peru, low-income families spend a higher percentage (5–18%) of average monthly income on energy services than families with higher incomes.[83] Furthermore, more than 80% of Peru's rural population use firewood, dung, or coal for cooking, making indoor air pollution one of the main environmental risk factors.[84]

Since the 1990s, the Peruvian Government and various non-governmental organisations have promoted programmes and policies oriented towards addressing the problem of solid fuels for lighting, cooking, and heating and the inadequate access to energy sources in low-income sectors. In 2009, legislative changes enabled subnational governments to invest up to 2·5% of the national mining revenues in improved cook stove (ICS) deployment, resulting in the installation of more than 280 000 ICSs nationwide (52% public and 43% private) as part of the multisectorial campaign Half Million ICS For A Smokeless Peru. This campaign aims to improve quality of life and health through the instalment of certified ICSs. Studies show that a well kept and certified ICS can reduce personal exposure to fine particulate matter ($PM_{2·5}$).

Peru released its 2010–40 National Energy Policy in 2010. Of the nine goals, two discuss access to energy services to low-income sectors. Special programmes have been developed in rural, high-altitude, and Amazonian regions of Peru to address energy access issues. In 2012, programmes were established to substitute kerosene and other contaminating stoves with liquefied petroleum gas and ICS; and the Social Inclusion Energy Fund was established, promoting access to liquefied petroleum gas for the most vulnerable populations through subsidies. According to the Social Inclusion Energy Fund, more than 1·3 million families had received a liquefied petroleum gas stove by 2015, mitigating 91% of their carbon dioxide (CO_2) emissions and leading to a corresponding reduction of 553 000 tonnes of CO_2 by using cleaner sources of energy.[85,86]

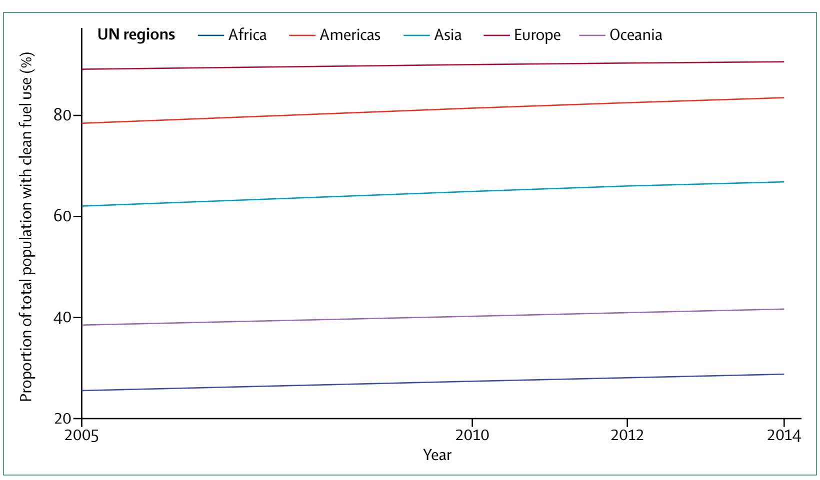

Figure 20: **Proportion of population relying primarily on clean fuels and technology**

For the **World Energy Outlook's 2016 energy access databases** see http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase

As a share of total generation, renewable energy has increased by more than 20% between 1990 and 2013. The renewable energy sector continues to grow rapidly, mainly from increasing wind and solar photovoltaic investment, most notably in the USA, China, and Europe (figure 19). In 2015, more renewable energy capacity (150 gigawatts) was added than fossil fuel capacity globally. Overall, there is now more added renewable generation capacity installed worldwide (almost 2000 gigawatts) than coal. About 80% of this newly installed capacity is in China.[103]

Indicator 3.4: Access to clean energy

This indicator reports that in 2016, 1·2 billion people did not have access to electricity, and 2·7 billion people relied on burning unsafe, unsustainable, and inefficient solid fuels.

Increased access to clean fuels and clean energy technologies will have the dual benefit of reducing indoor air pollution exposure and reducing greenhouse gas emissions by displacing fossil fuels.[108] Use of clean energy for heating, cooling, cooking, and lighting is important for improving health and wellbeing, economic productivity, and reducing the risk of harm from living in energy poverty.[109]

An estimated 1·2 billion people worldwide do not have access to electricity, and 2·7 billion people rely on burning unsustainable and inefficient solid fuels (panel 7). According to the World Energy Outlook Biomass Database and Electricity Access Database, the reduced indoor air quality from burning these fuels is estimated to cause 4·3 million premature deaths related to pneumonia, stroke, lung cancer, heart disease, and chronic obstructive pulmonary disease each year. Access to electricity, an energy source that emits no direct airborne particles (although particles might be emitted indirectly from the fuel used to generate the electrical power), is currently 85·3% worldwide but varies widely between countries and between urban and rural settings.

This indicator draws on and aligns with the proposed Sustainable Development Goal Indicator 7.1.2, which defines clean energy in terms of the emission rate targets and specific fuel recommendations (ie, against unprocessed coal and kerosene) included in the WHO normative guidance.[110] The indicator also estimates the proportion of the population that primarily relies on clean fuels (including liquefied petroleum gas, a fossil fuel that is cleaner than many solid fuels) and technologies for cooking, heating, and lighting relative to all people accessing those services. The estimates of fuel use for this indicator come from WHO household survey data (roughly 800 nationally representative surveys and censuses) that are modelled to estimate the proportion of households' reliance on clean fuels (figure 20).[111]

Indicator 3.5: Exposure to ambient air pollution

This indicator reports that 71% of the 2971 cities in WHO's database do not satisfy WHO annual fine particulate matter exposure recommendations.

Air pollutants directly harmful to health are emitted by combustion processes that also contribute to emissions of greenhouse gas. As such, well designed actions to reduce greenhouse gas emissions will improve ambient

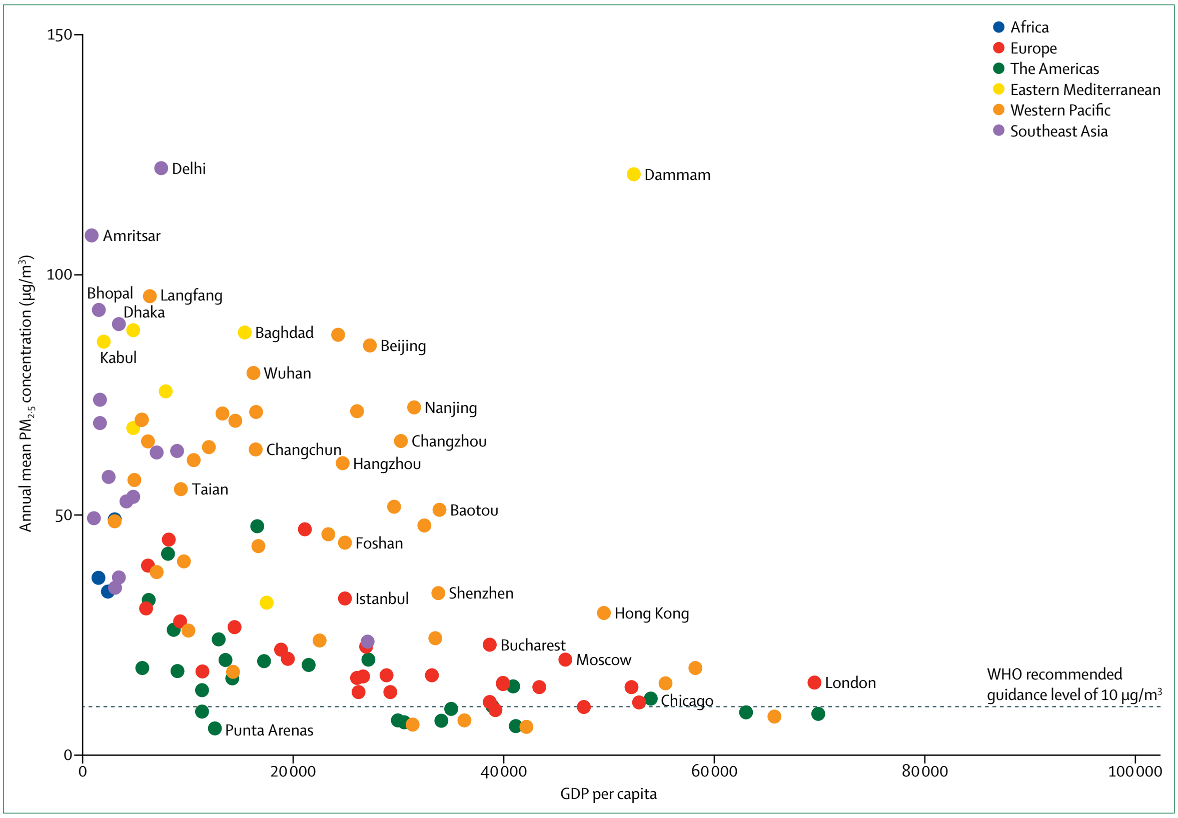

Figure 21: **Annual mean fine particulate matter ($PM_{2·5}$) concentration versus per capita gross domestic product (GDP) for 246 cities in the Sustainable Healthy Urban Environments database**

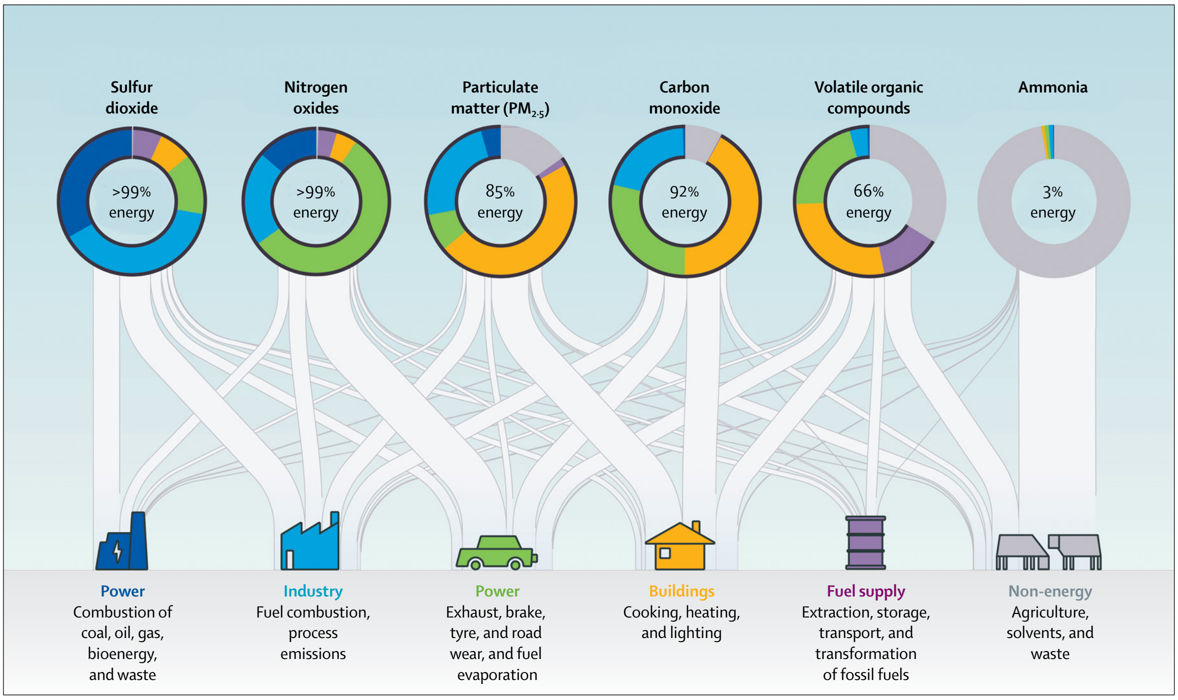

Figure 22: **Selected primary air pollutants and their sources globally in 2015**
Adapted from the World Energy Outlook Special Report: Energy and Air Pollution,[103] by permission of OECD and International Energy Agency Publishing.

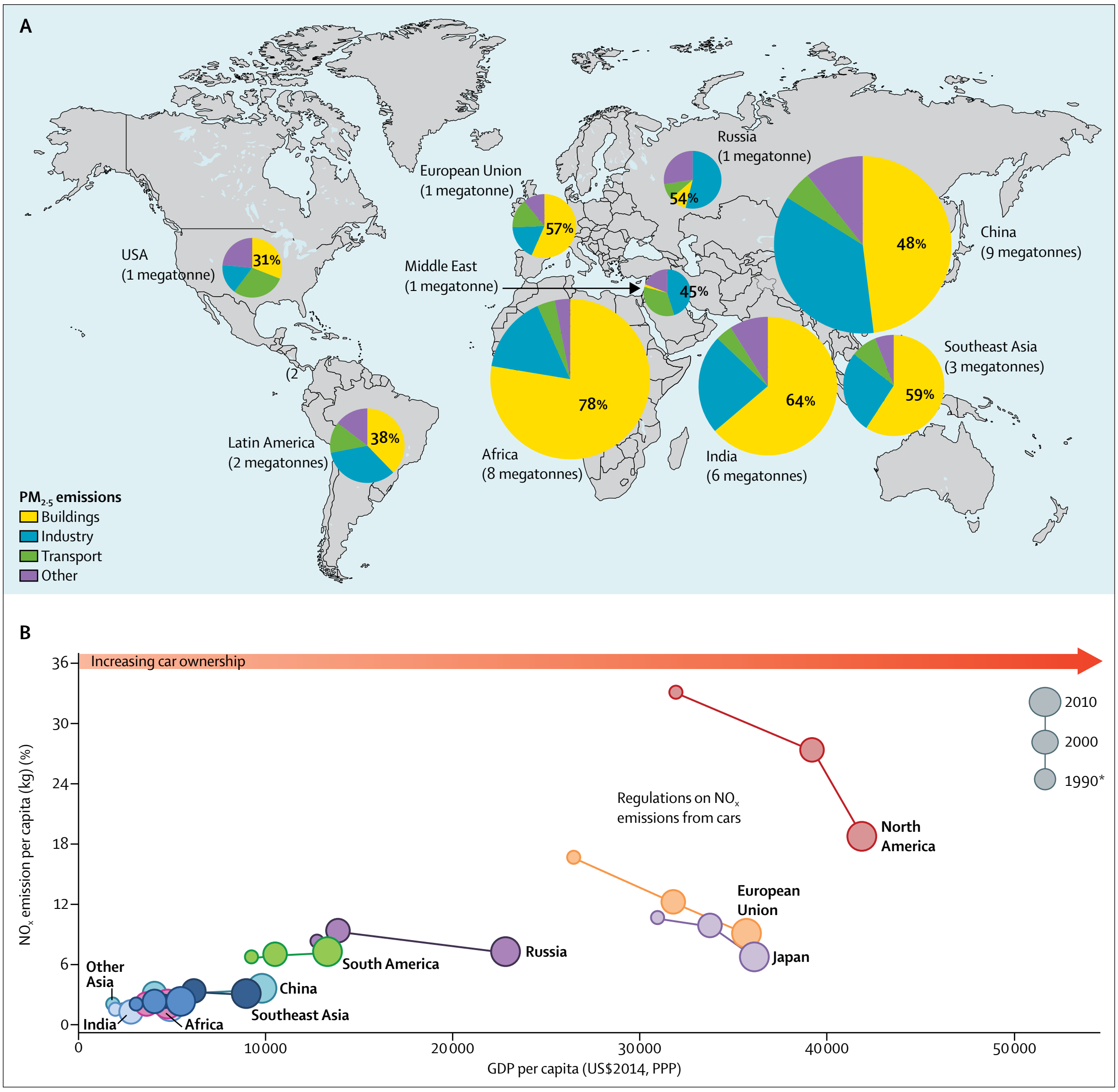

Figure 23: **Sources and trends in particulate pollution**
(A) Energy-related emission of fine particulate matter ($PM_{2\cdot5}$) emissions in 2015. (B) Nitric oxide (NO_x) emissions from transport, 1990–2010, by region. GDP=gross domestic product. PPP=purchasing power parity. *For Russia, 1995 data have been taken into account as first series point. Adapted from the World Energy Outlook Special Report: Energy and Air Pollution,[103] by permission of OECD and International Energy Agency Publishing.

air quality and have associated benefits for human wellbeing.[112] Estimates suggest that global population-weighted $PM_{2\cdot5}$ exposure has increased by 11·2% since 1990.[112,113] To represent levels of exposure to air pollution, this indicator collects information on annual average urban background concentrations of $PM_{2.5}$ in urban settings across the world.

Indicator 3.5.1: Exposure to air pollution in cities

The data for this indicator were extracted from WHO's Urban Ambient Air Pollution Database,[114] which compiles information from a range of public sources, including national and subnational reports and websites, regional networks, intergovernmental agencies, and academic articles. The air pollution measurements are taken from monitoring stations in urban background, residential, commercial, and mixed areas. The annual average density of emission sources in urban areas and the proximity of populations to those sources led us to focus on exposure in cities.

For this indicator, we combined the WHO Urban Ambient Air Pollution Database with the Sustainable Healthy Urban Environments database,[115] presenting data on 246 randomly sampled cities across the world (stratified by national wealth, population size, and Bailey's Ecoregion).

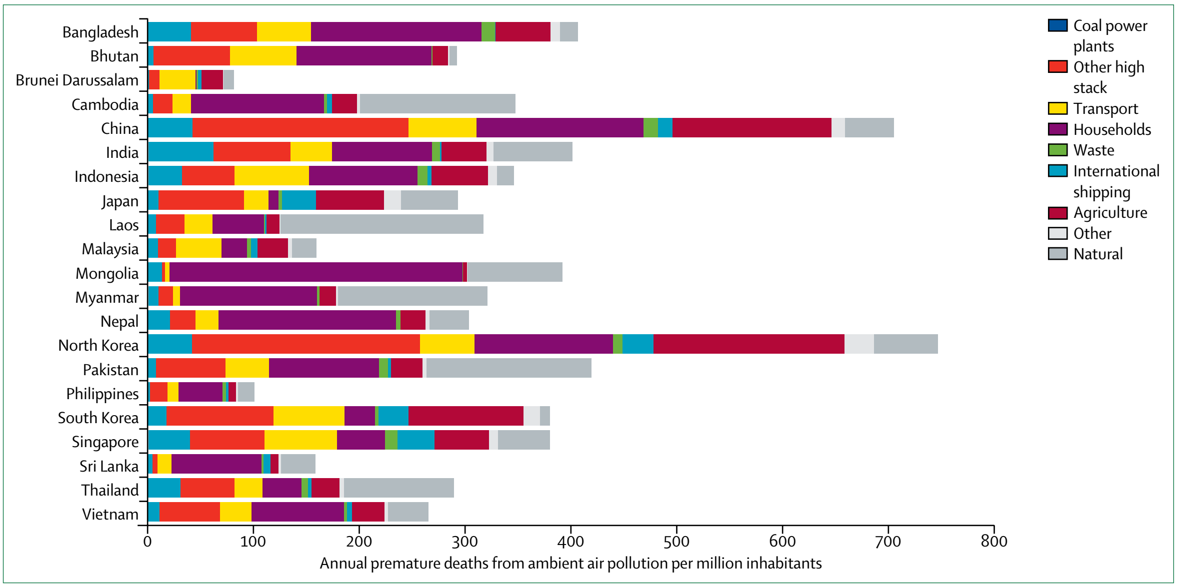

Figure 24: **Health impacts of exposure to ambient fine particulate matter ($PM_{2\cdot5}$) in south and east Asian countries in 2015, by key sources of pollution**
The contributions of individual source sectors to ambient $PM_{2\cdot5}$ concentrations have been calculated using linearised relationships based on full atmospheric chemistry transport model simulations, and premature deaths are calculated following the methodology used by WHO and the Global Burden of Disease 2013 study.

$PM_{2\cdot5}$ concentrations in most cities are well above the WHO's annual guideline of 10 μg/m³, with particularly high concentrations in cities in central, south, and east Asia (figure 21). $PM_{2\cdot5}$ concentrations exceed the guideline concentration in 71·2% of the nearly 3000 cities in the WHO database. However, since monitoring is more common in high-income settings, this is probably an underestimate. 87·3% of randomly selected cities in the Sustainable Healthy Urban Environments database had $PM_{2\cdot5}$ concentrations that exceeded recommended concentrations. The data suggest that air pollution has generally decreased in high-income settings in recent decades but has marginally increased worldwide.[116]

3.5.2: Sectoral contributions to air pollution

The energy sector (both production and use) is the single largest source of man-made air pollution emissions, producing 85% of particulate matter and almost all of the SO_2 and NO_x emitted worldwide (figure 22).[103]

Coal power is responsible for three-quarters of the energy sector's sulpher dioxide (SO_2) emissions, 70% of nitric oxide (NO_x) emissions, and more than 90% of $PM_{2.5}$ emissions.[103] However, in the past decade, these emissions have largely decoupled from increases in coal-fired generation in several geographies because emission standards have been introduced for coal power plants.[117,118]

In 2015, manufacturing and other industries (eg, refining and mining) were responsible for about half of global energy-related SO_2 emissions and 30% of energy-related NO_x emissions (28 megatonnes), whereas the transport sector was responsible for around half of all energy-related NO_x emissions.[103] 30% of $PM_{2\cdot5}$ emissions in 2015 came from the manufacturing industry, and 10% of $PM_{2\cdot5}$ emissions came from the transport sector (figure 23A).[103] Within the transport sector, road vehicles were by far the largest source of NO_x and $PM_{2\cdot5}$ emissions (58% and 73%, respectively), whereas the largest source of SO_2 emissions was shipping.[103] There are marked regional differences in trends of NO_x emissions within the transport sector. As car ownership has increased between 1990 and 2010, the USA, EU, and Japan have decreased NO_x emissions, whereas China and southeast Asia have increased NO_x emissions from transport (figure 23B).

3.5.3: Premature mortality from ambient air pollution by sector

The extent to which emissions of different pollutants from different sectors contribute to ambient $PM_{2\cdot5}$ concentrations depends on atmospheric processes such as the dispersion of primary particles and the formation of secondary aerosols from precursor emissions. Sources with low stack heights that are located close to populations (eg, household combustion for cooking and heating, road vehicles) typically have a disproportionally larger role for total population exposure in relation to their absolute emissions.

Long-term exposure to ambient $PM_{2\cdot5}$ is associated with increased mortality and morbidity from cardiovascular and pulmonary diseases.[119–121] WHO estimated that ambient air pollution causes about 3 million premature deaths worldwide every year.[122] The sources of air pollution and greenhouse gases are overlapping in many cases, so

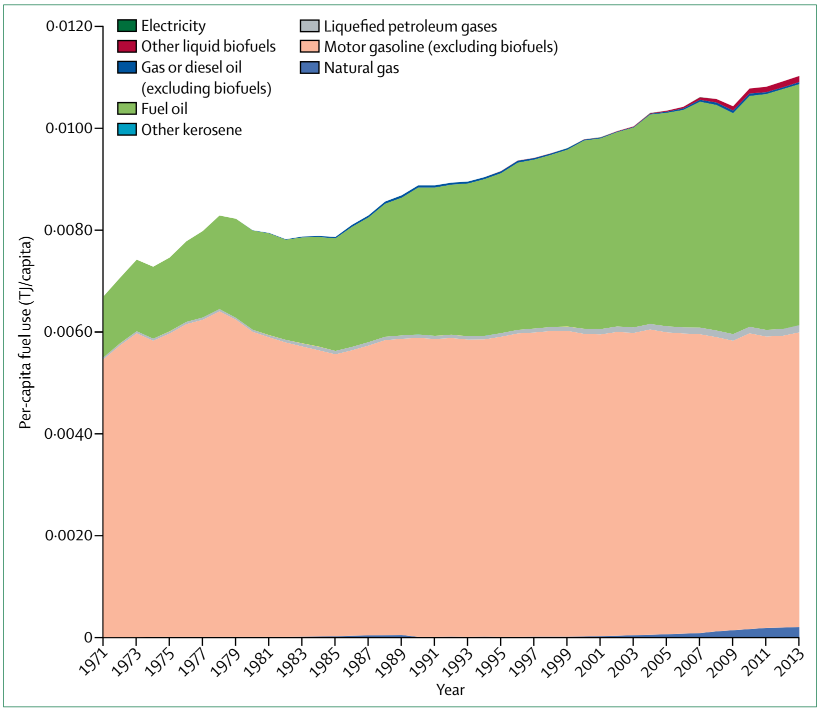

Figure 25: **Per-capita fuel use by type for transport sector with all fuels**

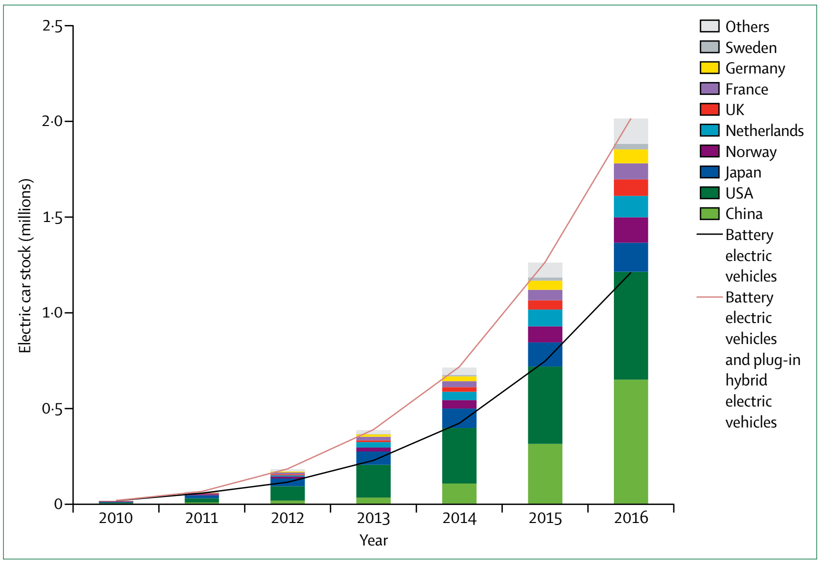

Figure 26: **Cumulative electric vehicle sales worldwide**
Adapted from The Global EV Outloook 2017,[125,126] by permission of OECD and International Energy Agency Publishing.

greenhouse gas mitigation measures can have large co-benefits for human health.

We estimated premature mortality from ambient air pollution, as calculated in the GAINS model and using data from the IEA, for south and east Asian countries in 2015 (figure 24).[123] The contributions of individual source sectors to ambient $PM_{2·5}$ concentrations were calculated using linearised relationships based on full atmospheric chemistry transport model simulations, and premature deaths were calculated following the methodology used by WHO and in the GBD 2013 study.[121,122] In some countries such as China, North Korea, and South Korea, agriculture is a large contributor to premature deaths. Large direct benefits for human health can therefore be expected if these emission sources are addressed by climate policies. For example, additional important benefits could also become available if coal-fired power plants were replaced by wind and solar. Replacement of household combustion of coal in China would result in health benefits not only from ambient (outdoor) but also household (indoor) exposure to air pollution.

Transport sector Transportation systems (including road vehicles, rail, shipping, and aviation) are key sources of greenhouse gas emissions, contributing to 14% of global emissions in 2010.[102,103] To meet the 2°C target, the transport sector must reduce its total greenhouse gas emissions more than 20% below current levels by 2050 and be on a trajectory to zero-carbon emissions in the second half of the century.[124] Compared with other energy-demand sectors, key subsectors of transportation (urban personal and freight transport, long-distance road transport, shipping, short-haul aviation, and long-haul aviation) are difficult to decarbonise because of the high-energy density of fossil fuels, so emission reduction targets are lower for transport than for the energy sector as a whole.

The transport sector is also a major source of air pollutants, including particulate matter, NO_x, SO_2, carbon monoxide, volatile organic compounds, and, indirectly, ozone. Furthermore, exposure to air pollution from road transport is particularly challenging in cities where vehicles emit street-level air pollution. In turn, important opportunities for health exist through the reduction of greenhouse gas emissions from transport systems, both in the near term through cleaner air and increased physical activity, and in the long-term through the mitigation of climate change.

Indicator 3.6: Clean fuel for transport

This indicator reports that transport fuel use on a per-capita basis has increased worldwide by almost 24% since 1990. Although petrol and diesel continue to dominate, use of non-conventional fuels has been rapidly expanding, with more than 2 million electric vehicles sold between 2010 and 2016.

Fuels for transport produce more than half the NO_x and a substantial proportion of particulate matter emitted worldwide.[102,103] Switching to low-emission transport systems is an important component of climate change mitigation and will help reduce concentrations of most ambient air pollutants. However, the transport sector's extremely high reliance on petroleum-based fuels makes this transition particularly challenging.

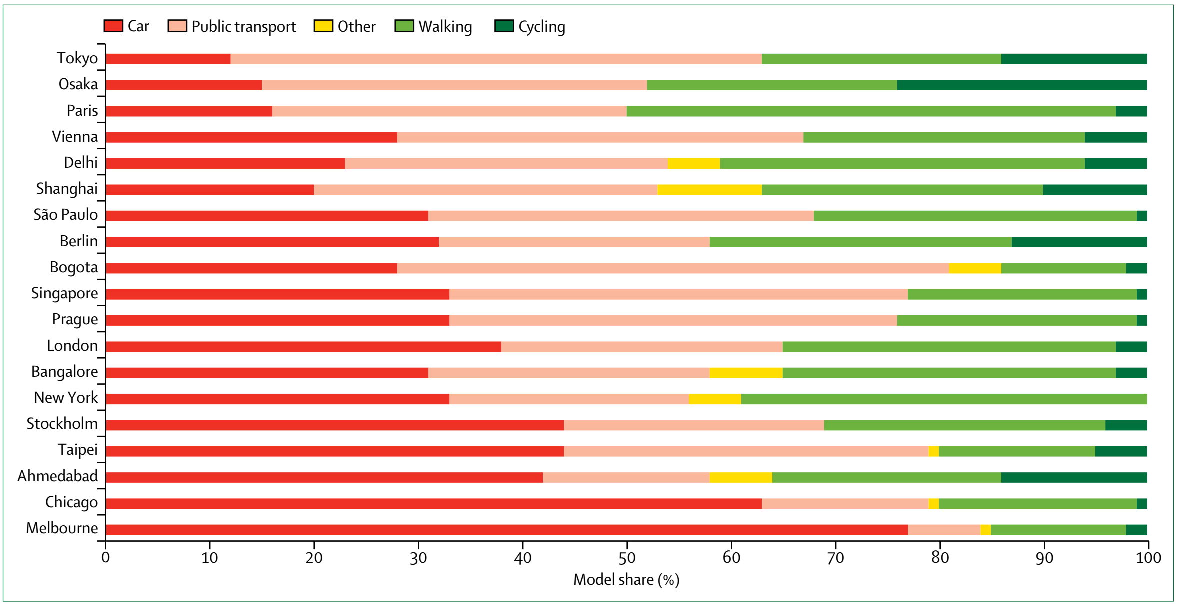

***Figure 27*: Modal shares in world cities**
Other typically includes paratransit (transport for people with disabilities), electric bikes, or both.

This indicator focuses on monitoring global trends in fuel efficiency and on the transition away from the most polluting and carbon-intensive transport fuels. More specifically, this indicator follows the metric of fuel use for transportation on a per-capita basis, by type of fuel. To develop this indicator, we drew on transport fuel data from the IEA and population data from the World Bank.[103]

Although some transport types have transitioned away from carbon-intensive fuel use and fuel efficiency has improved in select countries, transport is still heavily dominated by gasoline and diesel. Transport fuel use on a per-capita basis has increased worldwide by almost 65% since 1970 (figure 25). However, non-conventional fuels (eg, electricity, biofuels, and natural gas) have been rapidly gaining traction since the 2000s, with more than 2 million electric vehicles sold since 2010, mostly in the USA, China, Japan, and some European countries (figure 26).[125] These figures are modest compared with the overall sales of cars per year (77 million in 2017) and the total global fleet of 1·2 billion cars.

Indicator 3.7: Sustainable travel infrastructure and uptake

This indicator reports that levels of sustainable travel appear to be increasing in many European cities, but cities in emerging economies are facing sustainable mobility challenges. Although levels of private transport use remain high in many cities in the USA and Australia, evidence suggests that they are beginning to decrease.

Global trends of population growth and increasing urbanisation suggest that demand for mobility in urban areas will increase. Moving from private motorised transport to more sustainable modes of travel (public transport, walking, and cycling) in urban areas not only helps to reduce emissions from vehicles but also has several health co-benefits. This indicator tracks trends in sustainable travel infrastructure and uptake in urban areas.

Although this indicator would ideally track the proportion and distance of journeys undertaken by different modes of transport over time, data for city-level trends in modal share are particularly scarce. We therefore present data for selected locations, across a limited timescale. Modal shares (ie, estimates of the proportion of trips by different modes of transport in recent years) in world cities are shown in figure 27 (details in appendix, p 64). The data, collated by the Land Transport Authority, come from travel surveys of individual cities and national census data (appendix p 64).[127]

We collated data on trends in modal share in select cities, for which data from at least three timepoints (including one pre-2000 timepoint) are available. Although many cities have begun collecting this information in the past decade, there is a paucity of data on trends from before 2000, with particularly wide gaps in data availability from cities in Asia, Africa, and South America.[138]

In Berlin, London, and Tokyo, the proportion of trips by privatised motor transport has slowly decreased since the late 1990s, whereas levels have remained high in Vancouver and Sydney and appear to be increasing in Santiago (figure 28). Levels of cycling are generally low but appear to be increasing in many cities.

Public transport in emerging cities is often insufficient, inefficient, and in poor condition, potentially leading to further decreases in sustainable travel in

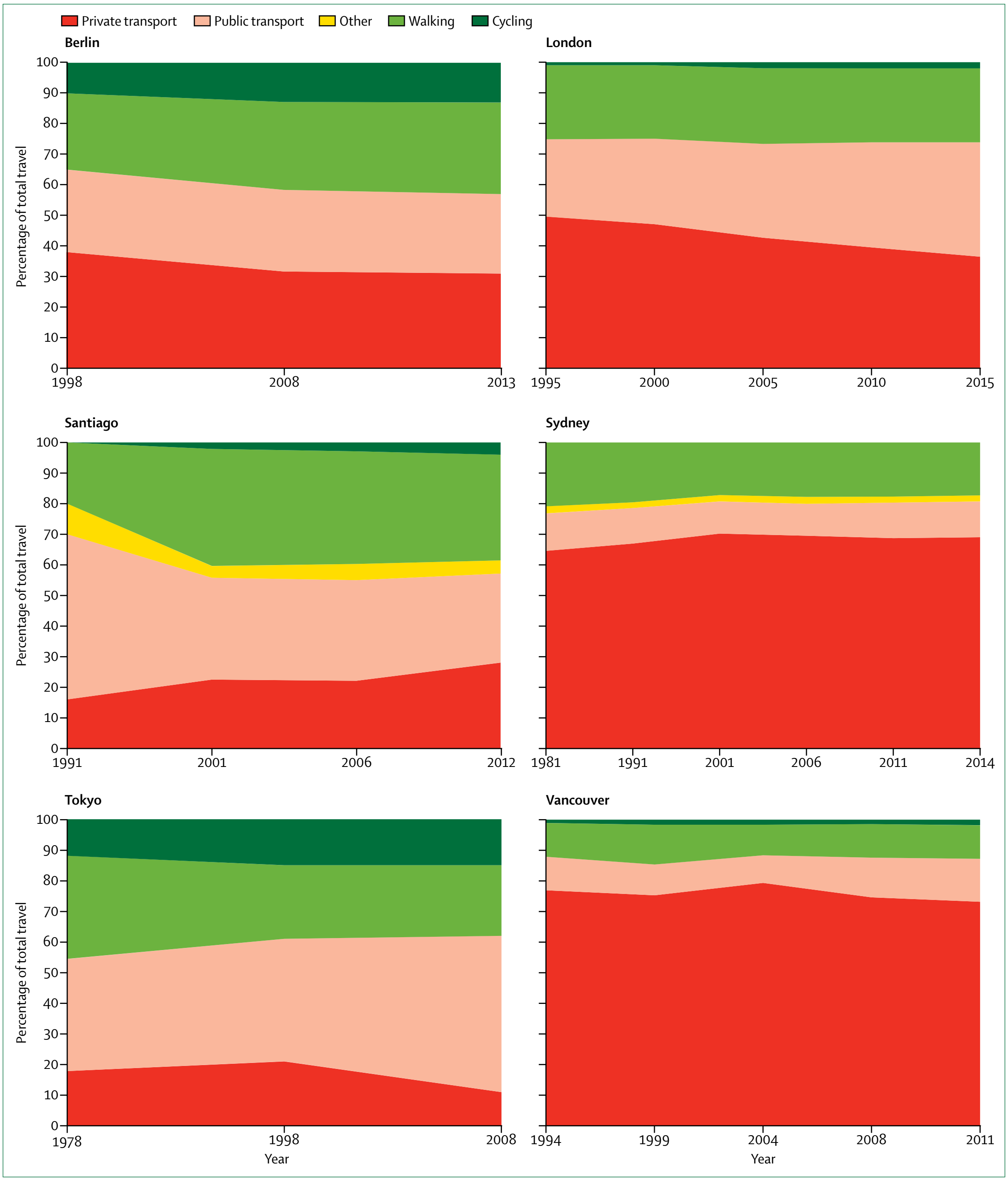

***Figure 28:* Trends in modal share in selected cities**

Data from Santiago in 1991 represents travel on a usual day.[128] Data from Sydney represent weekdays only, and the cycling modal share in Sydney is less than 1%.[129–132] Sources: Institute for Mobility Research (2016),[133] Transport for London (2016),[134] New South Wales Department of Transport (2003, 2009, 2017),[129–132] MetroVancouver Translink (2012),[135] and the SECTRA Road and Transport Program (1992),[128] Rode et al (2015),[136] and City of Berlin.[137]

many rapidly growing cities in the future.[139] As this transition occurs, ensuring the mistakes made in countries within the Organization for Economic Cooperation and Development (OECD) are not repeated will be essential. In particular, it is crucial to improve walking and cycling environments so these become attractive modes of choice and protect road users from injury. The UN recommends devoting 20% of transport budgets to funding non-motorised transport at national and local levels in LMICs.[140]

Food and agriculture

The availability of food is central to human health. Its production, however, is also a major contributor to climate change, with the agricultural sector alone contributing 19–29% of anthropogenic greenhouse gas emissions worldwide.[13,141]

Dietary choices determine food energy and nutrient intake. Inadequate and unhealthy diets are associated with malnutrition and adverse health outcomes including diabetes, cardiovascular diseases, and some cancers. Dietary risk factors were estimated to account for more than 10% of all disability-adjusted life-years lost in 2013.[142] A transition to healthier diets, with reduced consumption of red meat and processed meat and increased consumption of locally and seasonally produced fruits and vegetables, could provide substantial emissions savings.[143]

Tracking progress towards more sustainable diets requires consistent and continuous data on food consumption and related greenhouse gas emissions throughout food product life cycles. This would require annual nationally representative dietary survey data on food consumption. However, due to the complexity and cost of such data collection, dietary surveys are available for a limited number of countries and years only.[144] Efforts to compile data and ensure comparability are underway, but their current format is not suitable for global monitoring of progress towards optimal dietary patterns.[145,146]

Indicator 3.8: Ruminant meat for human consumption

This indicator reports that the amount of ruminant meat available for human consumption worldwide has decreased slightly from 12·09 kg/capita per year in 1990, to 11·23 kg/capita per year in 2013. The proportion of energy (kcal/capita per day) available for human consumption from ruminant meat, as opposed to other sources, has decreased marginally from 1·86% in 1990 to 1·65% in 2013.

This indicator focuses on ruminants because the production of ruminant meat, from cattle in particular, dominates greenhouse gas emissions from the livestock sector (estimated at 5·6–7·5 gigatonnes emitted CO_2 per year). Consumption of red meat also has known associations with adverse health outcomes.[147] This indicator measures the total amount of ruminant meat available for consumption and the ratio of ruminant meat energy supply to total energy supply. Together, these data reflect the relative amount of foods in the system that have high greenhouse gas emissions (figure 29).[148–150] Assuming correlation between ruminant meat supply and consumption, the indicator therefore also provides information about variations in certain diet-related health outcomes (such as colorectal cancer and heart disease).[151,152] This indicator should be viewed in the context of the specific setting where this trend is examined (in some populations, meat consumption is a main source of food energy, provides essential micronutrients, and sustains livelihoods). Data for this indicator were constructed from the FAOSTAT food balance sheets, which comprise national supply and utilisation accounts of primary foods and processed commodities.

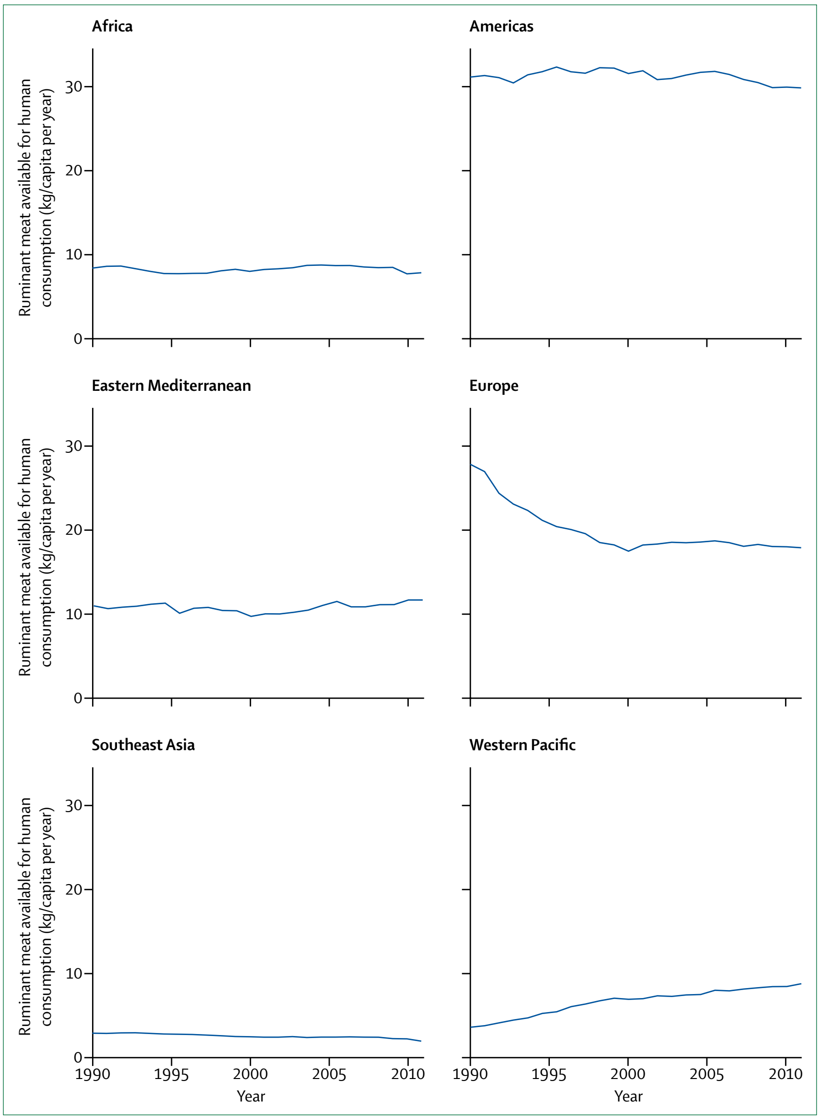

Figure 29: **The total amount of ruminant meat available for human consumption, by WHO-defined regions**

For the **FAOSTAT food balance sheets** see http://www.fao.org/faostat/en/#data/FBS

The amount of ruminant meat available for consumption is high in the Americas and has remained relatively stable between 1990 and 2013. In Europe, the amount of ruminant meat was relatively high in 1990 but decreased rapidly from 1990–2000 and has remained stable from 2000–13. By comparison, amounts of ruminant meat available are moderate in Africa and the eastern Mediterranean and have remained reasonably constant over time. Southeast Asia and the western Pacific have low amounts of

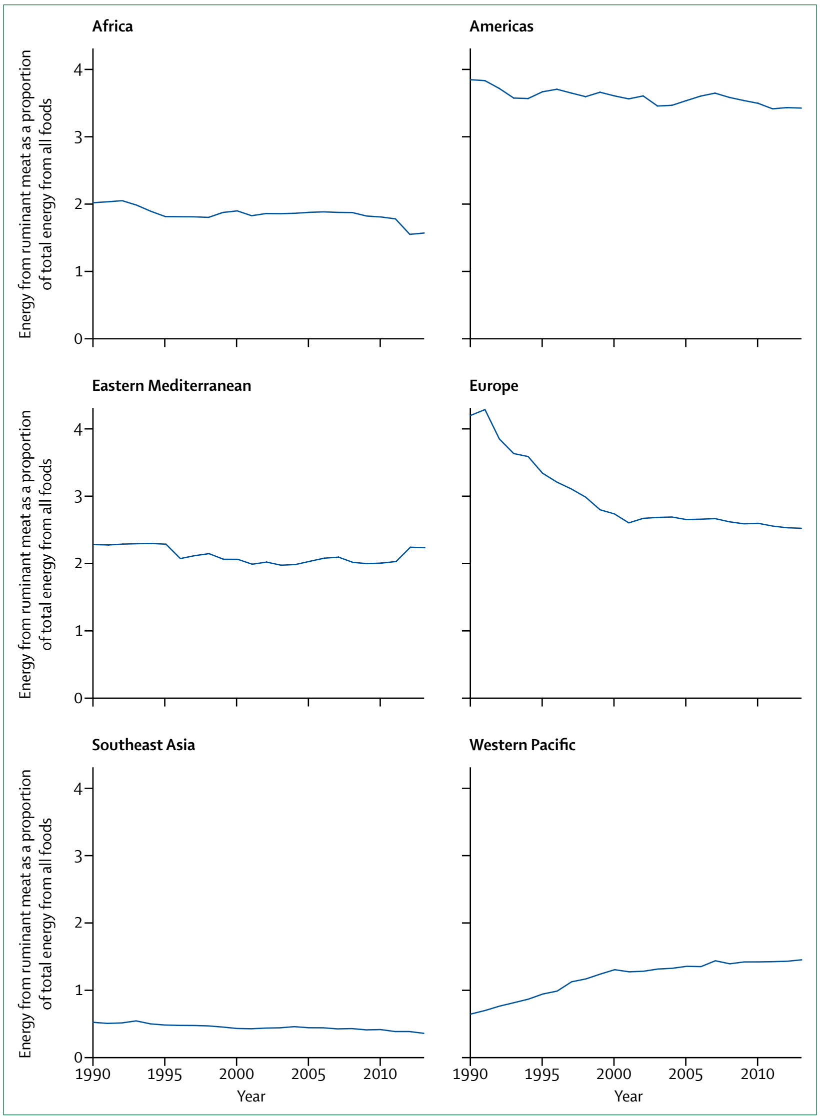

Figure 30: **Energy available from human consumption of ruminant meat as a proportion of total energy from all food sources, by WHO-defined regions**

ruminant meat available, but availability has been slowly increasing in the western Pacific since 1990.

The proportion of energy supply from ruminant meat has been markedly higher in the Americas than in other regions since the 1990s, although the trend has been decreasing over time (figure 30). In Europe, the proportion of energy from ruminant meat rapidly decreased from 1990 to 2000 and has continued to slowly decrease. By contrast, the trend in energy supply from ruminant meat has been increasing in the western Pacific, possibly reflecting the increasing trend in beef consumption in China (16% increase annually).[153]

Health-care sector

The health-care sector is a considerable contributor to greenhouse gas emissions and therefore has both a responsibility and an appreciable opportunity to lead by example in reducing its carbon footprint. In 2013, the estimated US health-care sector emissions were 655 megatonnes CO_2, which exceeded CO_2 emissions in the UK.[154] Greenhouse gas emission in the health-care sector is an obvious externality that contributes to climate change, contradicting the sector's aim of improving population health.

The World Bank estimates that a 25% reduction in CO_2 emissions from health-care sectors in Argentina, Brazil, China, India, Nepal, Philippines, and South Africa would equate to 116–194 million tonne reduction in CO_2 emission (the equivalent of decommissioning 34–56 coal-fired power plants or removing 24–41 million passenger vehicles from the road).[154]

Indicator 3.9: Health-care sector emissions

No systematic global standard for measuring the greenhouse gas emissions of the health-care sector exist, but a number of health-care systems in the UK, the USA, and around the world are working to reduce their contribution to climate change.

Several reduction targets in the health-care sector can be highlighted as positive examples. The UK's National Health Service (NHS) set an ambitious target of a 34% reduction in health-system-wide greenhouse gas emission by 2020. Kaiser Permanente in the USA has set 2025 as a target to become net carbon positive. The Western Cape Government health system in South Africa has committed to a 10% emission reduction by 2020 and a 30% reduction by 2050 in government hospitals. The Albert Einstein Hospital in São Paulo, Brazil, has reduced its annual emissions by 41%.[154]

In the UK, comprehensive reporting of greenhouse gas emissions was facilitated by the centralised structure of the NHS. The Sustainable Development Unit of the NHS has been monitoring greenhouse gas emissions from a 1992 baseline, including major contributions from procurement of pharmaceuticals and other products. NHS greenhouse gas emissions decreased by 11% between 2007 and 2015, despite an 18% increase in activity.[155] Mitigation efforts from the health-care sector provide remarkable examples of hospitals and health-care systems leading by example, yielding impressive financial savings and health benefits for their patients. To this end, the efforts of the hospitals, governments, and civil society organisations driving this work forward must be supported and redoubled to ensure a full transition to a healthier, more sustainable model of climate-smart and increasingly carbon-neutral health care.[154]

Monitoring health-care system emissions is an essential step towards accounting for the externality of these emissions. Comprehensive reporting of national greenhouse gas emissions by the health-care system is only routinely done in the UK. Elsewhere, select health-care organisations, facilities, and companies provide self-reported estimates of emissions, but this reporting is rarely standardised across sites. We will continue our work on developing a standardised indicator on health-care sector emissions for future reports.

Conclusion

The indicators presented in this section have provided an overview of activities in energy, transport, food, and health-care sectors that are relevant to mitigating the effects of climate change on public health. They have been selected for their relevance to both climate change and human health and wellbeing.

A number of areas show remarkable promise, each of which should yield impressive benefits for human health. However, these positive examples must not distract from the enormity of the task at hand. The indicators presented in this section serve as a reminder of the scale and scope of increased ambition required to meet commitments under the Paris Agreement. They demonstrate a world that is only just beginning to respond to climate change and hence only just unlocking the opportunities available for better health.

Section 4: Finance and economics

Interventions to protect human health from climate change have been presented above. In this section, we focus on the economic and financial mechanisms necessary for these interventions to be implemented and their implications. Some of the indicators do not have an explicit link to human health, and yet increasing investment in renewable energy and decreasing investment in coal capacity, for instance, are essential in displacing fossil fuels and reducing their two principal externalities: the social cost of climate change and the health costs from air pollution. Other indicators, such as economic and social losses from extreme weather events, have more explicit links to human wellbeing.

In the 2006 Stern Review on the Economics of Climate Change,[156] the impacts of climate change were estimated to cost the equivalent of reducing annual global gross world product (GWP; the sum of global economic output) by "5–20% now, and forever", compared with a world without climate change. In their Fifth Assessment Report, the Intergovernmental Panel on Climate Change estimates an aggregate loss of up to 2% of GWP even if the rise in global mean temperatures is limited to 2·5°C above pre-industrial levels.[22] However, such estimates depend on numerous assumptions such as the rate at which future costs and benefits are discounted. Furthermore, existing analytical approaches are poorly suited to producing estimates of the economic impact of climate change, and hence their magnitude is probably greatly underestimated.[157,158] In view of such uncertainty, with potentially catastrophic outcomes, risk minimisation through stringent emission reduction seems the sensible course of action.

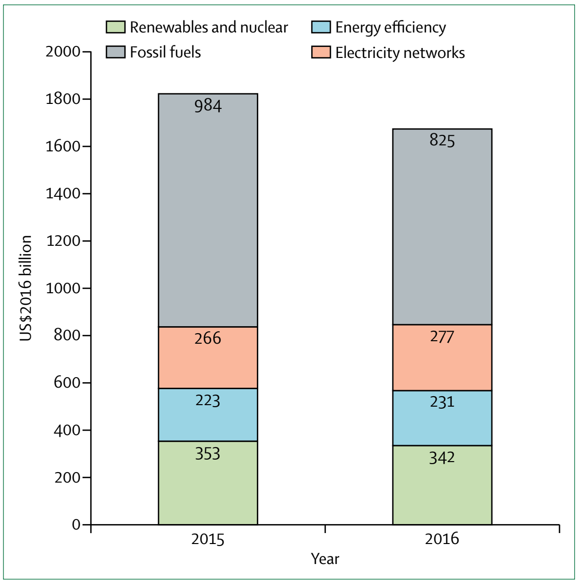

Figure 31: **Annual investment in the global energy system**

The ten indicators in this section seek to track flows of finance and impacts on the economy and social welfare resulting from action (and inaction) on climate change. These indicators fall into four broad themes: investing in a low-carbon economy; the economic benefits of tackling climate change; pricing greenhouse gas emissions from fossil fuels; and adaptation financing. Headline findings for all indicators are provided at the beginning of each indicator; additional detailed disussion of the data and methods used is available in the appendix (p 73).

Indicator 4.1: Investments in zero-carbon energy and energy efficiency

This indicator reports that proportional investment in renewable energy and energy efficiency increased in 2016, whereas absolute and proportional investment in fossil fuels decreased and, crucially, ceased to account for most annual investments in the global energy system.

This indicator tracks the level of global investment in zero-carbon energy and energy efficiency in absolute terms and as a proportion of total energy-system investment. In 2015, total investment in the energy system was around $1·83 trillion (in US$2016), accounting for 2·4% of GWP (figure 31).[159,160] 19% of this investment went to renewables and nuclear energy, and 12% of this investment was for energy efficiency. Most investment (54%) was in fossil fuel infrastructure. Electricity networks accounted for the remaining 15%. In 2016, total investment in the energy system reduced to around $1·68 trillion, accounting for 2·2% of GWP. Although the absolute value of investment in renewables and nuclear energy reduced slightly in absolute (real) terms, its proportional contribution increased to 20% of total investment. Investment in energy efficiency

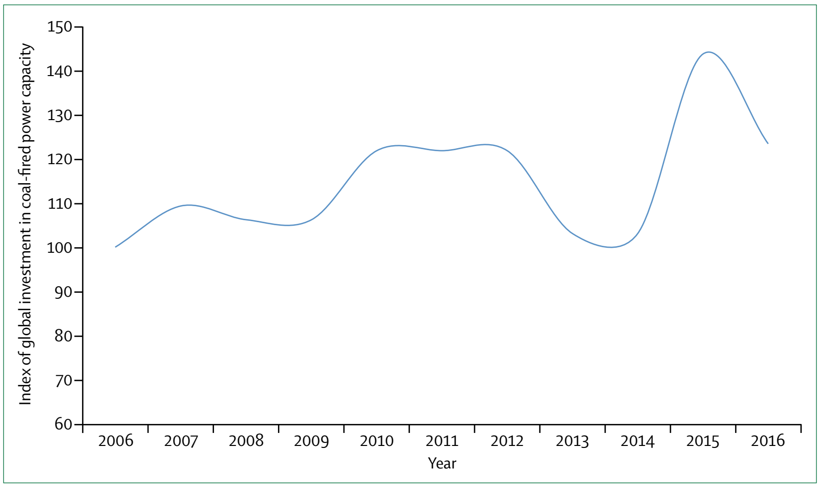

Figure 32: **Annual investment in coal-fired power capacity from 2006 to 2016**
An index score of 100 corresponds to 2006 levels. Source: International Energy Agency.

increased in both absolute and proportional terms to 14% of total investment. Fossil fuel infrastructure suffered a substantial reduction in investment, ceasing to account for the majority of investment (at 49%). Such trends broadly represent a continuation of the trends seen between 2014 and 2015.[161]

Investment in renewables and nuclear energy is driven by renewable electricity capacity (with more than 87% of investment by value in this category in 2016). This, in turn, is largely driven by investments in solar photovoltaic power and onshore wind. Solar photovoltaic capacity additions in 2016 were 50% higher than in 2015 (reaching a record high of 73 gigawatts). This development was driven by new capacity in China, the USA, and India, but it was coupled with just a 20% increase in investment that resulted from a 20% reduction in the cost of solar photovoltaic units. By contrast, investments in onshore wind decreased by around 20% between 2015 and 2016, largely because of changes to incentive schemes and increased wind power curtailment rates in China. The increase in energy efficiency investment was driven by policies that shifted markets towards more energy-efficient goods (eg, appliances and lighting) and buildings (along with the expansion of the construction industry) and an increase in the sales of energy-efficient (and low-carbon) vehicles. Europe accounted for the largest proportion of spending on energy efficiency (30%), followed by China (27%). This change in spending was driven by efficiency investments in the buildings and transport sectors.[160]

The substantially reduced investment in fossil fuel infrastructure, both upstream (eg, mining, drilling, and pipelines, which dominate fossil fuel investment) and downstream (eg, fossil fuel power plants), is driven by a combination of low (and decreasing) fossil fuel prices and cost reductions (particularly upstream, which have on average decreased by 30% since 2014).[160]

To hold a 66% probability of remaining within 2°C of global warming, average annual investments in the energy system must reach \$3·5 trillion between 2016 and 2050, with renewable energy investments increasing by more than 150% and energy efficiency increasing by around a factor of ten.[162]

Indicator 4.2: Investment in coal capacity

This indicator reports that, although investment in coal capacity has increased since 2006, in 2016 this trend turned and investment has decreased substantially.

Coal combustion is the most CO_2-intensive method of generating of electricity.[163] This indicator tracks annual investment in coal-fired power capacity.

Global investment in coal-fired electricity capacity generally increased from 2006 to 2012, before returning to 2006 levels in 2013–14 and rebounding to more than 40% above this level in 2015 (figure 32). This rapid growth was driven principally by China, which increased investment in coal-fired power capacity by 60% from 2014, representing half of all new global coal capacity in 2015 (with investment in India and other Asian non-OECD countries also remaining high).[161] The subsequent reduction in investment in 2016 was similarly driven by reduced investment in China because of overcapacity in generation, concerns about local air pollution, and new government measures to reduce new capacity additions and halt the construction of some plants already in progress.[160]

Indicator 4.3: Funds divested from fossil fuels

This indicator reports that the Global Value of Funds Committing to Divestment in 2016 was \$1·24 trillion, of which Health Institutions was \$2·4 billion; this represents a cumulative sum of \$5·45 trillion (with health accounting for \$30·3 billion).

The fossil fuel divestment movement seeks to encourage institutions and investors to divest themselves of assets involved in the extraction of fossil fuels. Some organisations have made a binding commitment to divest from coal companies, whereas others have fully divested from any investments in fossil fuel companies and have committed to avoiding such investments in the future. Proponents cite divestment as embodying both a moral purpose (eg, reducing the fossil fuel industry's so-called social licence to operate) and an economic risk-reduction strategy (eg, reducing the investor's exposure to the risk of stranded assets). However, others believe active engagement between investors and fossil fuel businesses is a more appropriate course of action (eg, encouraging diversification into less carbon-intensive assets through stakeholder resolutions).[164]

This indicator tracks the global total value of funds committing to divestment in 2016 (\$1·24 trillion) and the value of funds committed to divestment by health institutions in 2016 (\$2·4 billion). The values presented above are calculated from data collected and provided

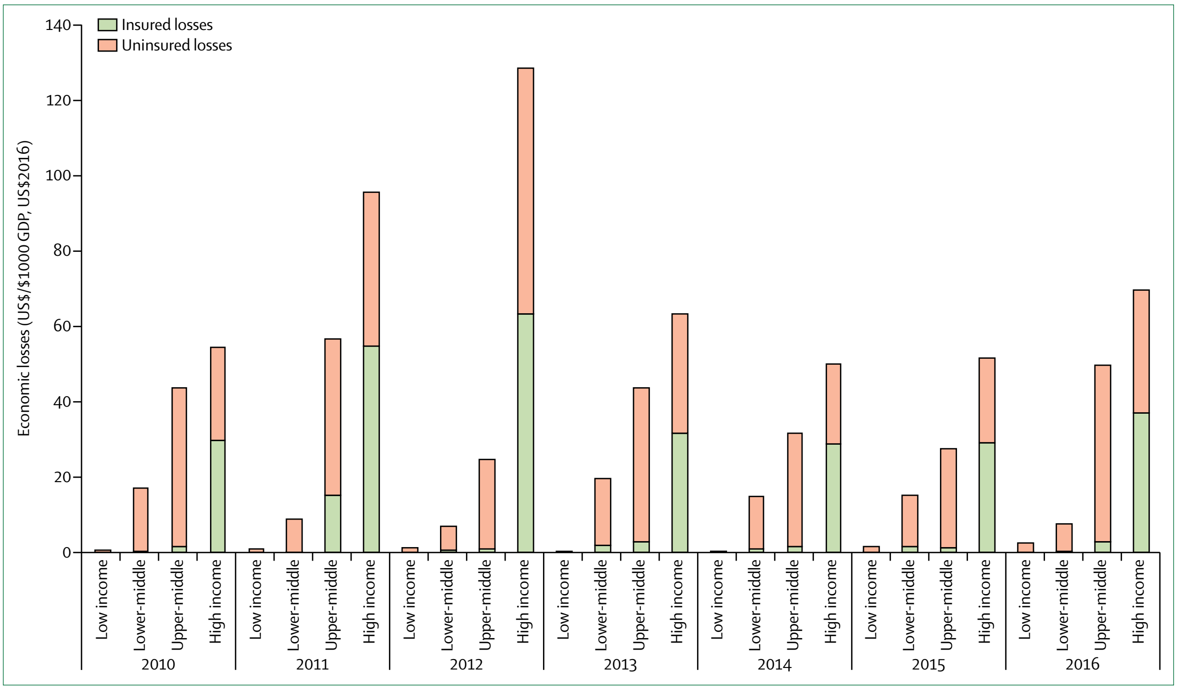

Figure 33: **Economic losses from climate-related events—absolute**
Insured and uninsured economic losses resulting from all large meteorological, climatological, and hydrological events across the world, by country income group. GDP=gross domestic product.

by 350.org. They represent the total assets (or assets under management) for institutions that have committed to divest in 2016 and thus do not directly represent the sums divested from fossil fuel companies. They also only include those institutions for which such information is publicly available (or provided by the institution itself), with non-US$ values converted using the market exchange rate when the commitment was made.

By the end of 2016, 694 organisations with cumulative assets worth at least $5·45 trillion, including 13 health organisations with assets of at least $30·3 billion, had committed to divestment. From the start of January, 2017, to the end of March, 2017, a further 12 organisations with assets worth $46·87 billion joined this total (including Australia's Hospitals Contribution Fund, with assets of $1·45 billion).

Indicator 4.4: Economic losses due to extreme climate-related events

This indicator reportst that in 2016, a total of 797 events resulted in $129 billion in overall economic losses, with 99% of losses in low-income countries uninsured.

Climate change will continue to increase the frequency and severity of meteorological (tropical storms), climatological (droughts), and hydrological (flooding) phenomena across the world. As demonstrated by indicator 1·4, the number of weather-related disasters has increased in recent years. The number of people affected and the economic costs associated with this increase are expected to have risen. This indicator tracks the number of events and the total economic losses (insured and uninsured) resulting from such events. In addition to the health impacts of these events, economic losses (particularly uninsured losses) have potentially devastating impacts on wellbeing and mental health.[165]

For **350.org** see https://350.org/

The data upon which this indicator is based were sourced from Munich Re's NatCatSERVICE. Economic losses (insured and uninsured) refer to the value of physical assets and do not include the economic value of loss of life or ill health, or of health and casualty insurance. Values are first denominated in local currency, converted to US$ using the market exchange rate in the month the event occurred, and inflated to US$2016 using country-specific Consumer Price Indices. This indicator and underlying data do not seek to attribute events and economic losses to climate change per se but might plausibly be interpreted as showing how climate change is changing the frequency and severity of these events.

For the **NatCatSERVICE** see https://www.munichre.com/en/reinsurance/business/non-life/natcatservice/index.html

An annual average of 700 events resulted in an annual average of $127 billion in overall economic losses per year between 2010 and 2016 (figure 33). Around two-thirds of the recorded events and around 90% of economic losses were in upper-middle and high-income countries, with less than 1% attributable to low-income countries. The same ratios for the number of events and economic losses between income groups are present in the data for 1990–2016, despite an increasing trend in the

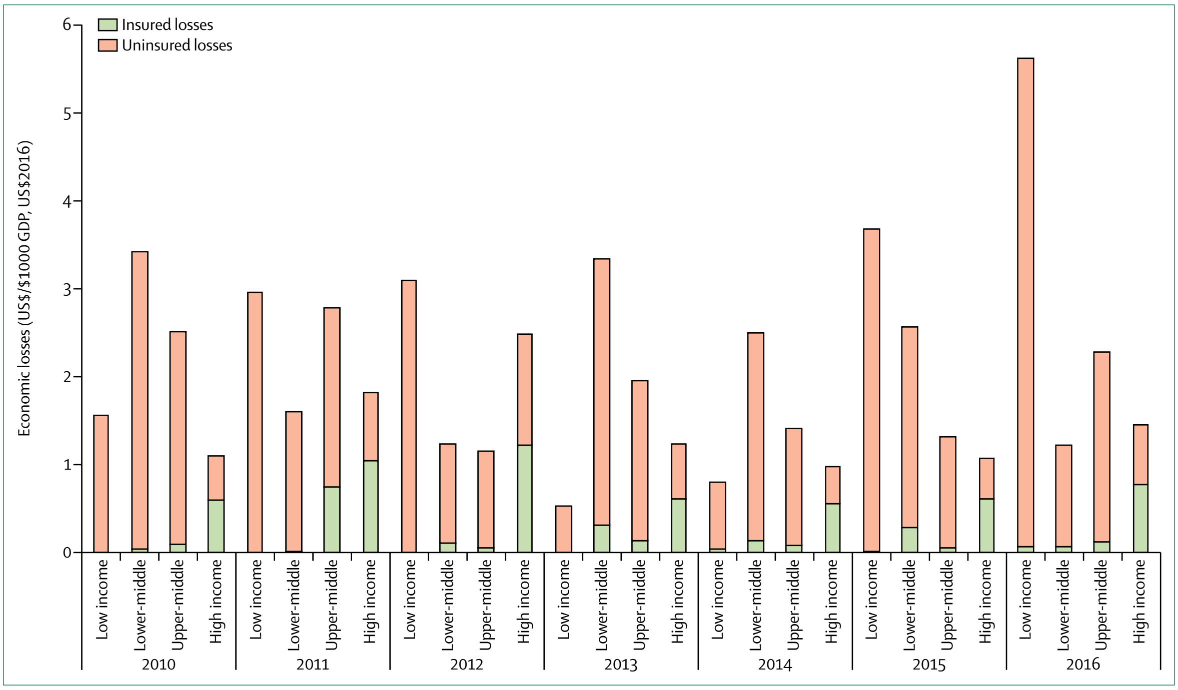

Figure 34: **Economic losses from climate-related events—intensity**
GDP=gross domestic product.

total global number of events and associated total value of economic losses during this period.

However, the data do not indicate the relative scale of impacts across different income groups. For example, although most economic losses have occurred in upper-middle and high-income countries, these countries are among the most populous, with more economically valuable property and infrastructure (in absolute terms). A rather different picture emerges when data are analysed in terms of intensity (insured and uninsured economic losses per $1000 gross domestic product [GDP]; figure 34).

Between 2010 and 2016, high-income and upper-middle-income countries had the lowest average annual economic loss as a proportion of GDP ($1·45/$1000 GDP and $1·95/$1000 GDP, respectively), with low-income and lower-middle-income countries subject to somewhat higher values ($2·65/$1000 GDP and $2·3/$1000 GDP, respectively). Economic losses in low-income countries were more than three times higher in 2016 than in 2010. However, for the period 1990–2016, average annual values vary substantially (full dataset included in the appendix p 77). Although high-income and upper-middle income countries maintain relatively similar values ($1·60/$1000 GDP and $2·9/$1000 GDP, respectively), average annual economic losses in low-income and lower-middle income countries increase substantially (to $10·95/$1000 GDP and $4·22/$1000 GDP, respectively).

On average, economic loss as a proportion of GDP is greater in low-income countries than in high-income countries. However, a more striking result is the difference in the proportion of economic losses that are uninsured. In high-income countries, on average around half of economic losses experienced are insured. This share drops rapidly to less than 10% in upper-middle income countries, and to much less than 1% in low-income countries. From 1990 to 2016, uninsured losses in low-income countries were on average equivalent to more than 1·5% of their GDP. By contrast, according to Global Health Observatory data, expenditure on health care in low-income countries on average for the period 1995–2015 was equivalent to 5·3% of GDP.

Indicator 4.5: Employment in low-carbon and high-carbon industries

This indicator reports that in 2016, global employment in renewable energy reached 9·8 million people, with employment in fossil fuel extraction trending downwards to 8·6 million people.

The generation and presence of employment opportunities in low-carbon and high-carbon industries have important health implications, both in terms of the safety of the work environment itself and financial security for individuals and communities. As the low-carbon transition gathers pace, high-carbon industries and jobs will decline. A clear example is seen in fossil fuel extraction. Some fossil fuel extraction activities, such as coal mining, have substantial impacts on human health. In 2008, coal mining accidents led to more than 1000 deaths in China alone (a rapid decrease from nearly 5000 deaths in 2003), with exposure to particulate matter and harmful pollutants responsible for elevated incidence of cardiovascular, respiratory, and kidney disease in coal mining areas.[166–169] The low-carbon transition is also likely to stimulate the growth of new industries and employment opportunities. With appropriate planning and policy, the transition from employment in high-carbon to low-carbon industries will yield positive consequences for human health.

This indicator tracks global employment levels in fossil fuel extraction industries (coal mining and oil and gas exploration and production) and in renewable energy (figure 35). The data for this indicator are sourced from International Renewable Energy Agency (renewables) and IBIS World (fossil fuel extraction).[170–172]

The number of jobs in the global fossil fuel extraction industry decreased from a peak of 9·1 million jobs in 2014 to 8·6 million in 2016. This change was largely driven by reductions in the coal mining industry, which were the result of a range of factors, including its substitution by cheaper natural gas in the power sector in many countries, reducing the demand for coal and leading to overcapacity, industry consolidation, and the rising automation of extractive activities.[172]

By contrast, employment in the renewable energy industry increased rapidly from more than 7·1 million jobs in 2012 to more than 9·3 million in 2014, reaching 9·8 million in 2016. This growth has largely been driven by the solar photovoltaic industry, which opened more than 1·7 million jobs between 2012 and 2016. Solar photovoltaic energy is now the largest renewable energy employer, overtaking the bioenergy sector, which has seen a reduction of 250 000 jobs since 2012.

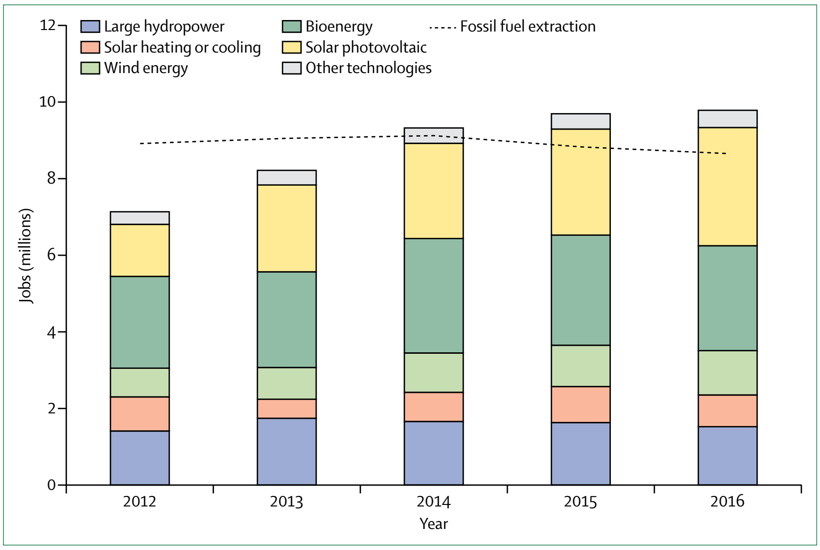

Figure 35: **Employment in renewable energy and fossil fuel extraction sectors**

Indicator 4.6: Fossil fuel subsidies

This indicator reports that in 2015, fossil fuel consumption subsidies followed a trend seen since 2012, decreasing markedly to $327 billion principally as a result of decreasing global oil prices.

The combustion of fossil fuels results in a variety of harmful consequences for human health. Subsidies for fossil fuels, either for its production (such as fossil fuel extraction) or consumption (such as regulated gasoline prices), artificially lowers prices and promotes over-consumption. This indicator tracks the global value of fossil fuel consumption subsidies (figure 36).[161,173]

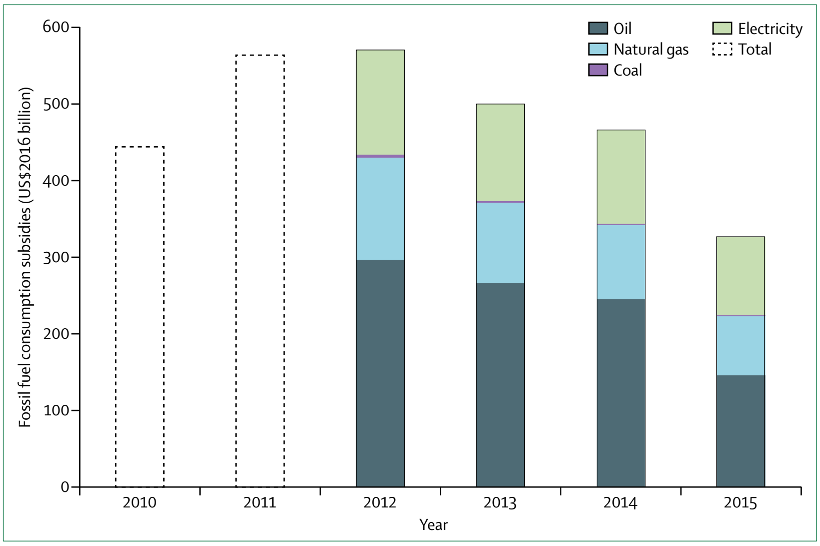

Figure 36: **Global fossil fuel consumption subsidies, 2010–15**

Fossil fuel consumption subsidies, despite increasing from $444 billion in 2010 to a peak of $571 billion in 2012, have decreased markedly to $327 billion in 2015 (in US$2016). The principal driver for this is the doubling in oil price between 2010 and 2012, after which it plateaued, before falling rapidly to below 2010 levels from mid-2014. Fossil fuel consumption subsidies are typically applied to moderate energy costs for low-income consumers (although in practice, 65% of such subsidies in LMICs benefit the wealthiest 40% of the population).[174] As such, increasing oil (and other fossil fuel) prices tend to increase subsidy levels as the differences between market and regulated consumer prices increase, and governments take further action to mitigate the impact on citizens. When fossil fuel prices are reduced, the gap between market and regulated prices decreases, and governments can reform fossil fuel subsidies while keeping overall prices relatively constant.

Between 2014 and 2015, several countries took advantage of this opportunity, particularly regarding oil-based fuels, which accounted for more than 60% of the reduction in total fossil fuel subsidies between 2012 and 2015 (followed by natural gas at around 25%). These countries included India, which in deregulating diesel prices accounted for a $19 billion subsidy reduction between 2014 and 2015 (about 13% of the global total reduction), and the largest oil-producing and natural gas-producing countries (including Angola, Algeria, For the **Carbon Pricing Dashboard** see http://carbonpricingdashboard.worldbank.org

Indonesia, Iran, Qatar, Saudi Arabia, and Venezuela), in which reduced hydrocarbon revenue created pressure for fiscal consolidation and, in turn, consumption subsidy reform.[161] To encourage the low-carbon transition, fossil fuel subsidies should be phased out as soon as possible. The commitment made by the G7 in 2016 to achieve this goal by 2025 should be extended to all OECD counties and to all countries worldwide by 2030.[175]

Indicator 4.7: Coverage and strength of carbon pricing

This indicator reports that so far in 2017, various carbon pricing mechanisms covered 13·1% of global anthropogenic CO_2 emissions, up from 12·1% in 2016. This reflects a doubling in the number of national and subnational jurisdictions with a carbon pricing mechanism over the past decade.

	2016	2017
Global emissions coverage*	12·1%	13·1%
Weighted average carbon price of instruments (current prices, US$)	$7·79	$8·81
Global weighted average prices (current prices, US$)	$0·94	$1·12

Global coverage and weighted average prices per tonne of emitted carbon dioxide. *Global emissions coverage is based on 2012 total anthropogenic greenhouse gas emissions. Source: World Bank Carbon Pricing Dashboard, 2017.

Table 2: **Carbon pricing**

This indicator tracks the extent to which carbon pricing instruments (eg, The World Bank's Carbon Pricing Dashboard) are applied around the world as a proportion of total greenhouse gas emissions, and the weighted average carbon price such instruments provide (table 2).

Between 2016 and 2017, the proportion of global emissions covered by carbon pricing instruments and the weighted average price of these instruments (and thus the global weighted average price for all anthropogenic greenhouse gas emissions) increased. This increase followed the introduction of four new instruments in 2017 (this data runs up to April 1, 2017): the carbon taxes in Alberta, Chile, and Colombia, and an Emissions Trading System (ETS) in Ontario. As such, over 40 national and 25 subnational jurisdictions now put a price on at least some of their greenhouse gas emissions (with substantially varying prices, from less than $1 per tonne emitted CO_2 in Chongqing to more than $126 per tonne emitted CO_2 in Sweden). The past decade has seen a rapid increase in the number of carbon pricing instruments around the world, with a doubling in the number of jurisdictions introducing them.[176] More than 75% of the greenhouse gas emissions covered by carbon pricing instruments are in high-income countries, with most of the remainder covered by the eight pilot pricing instruments in China (figure 37).

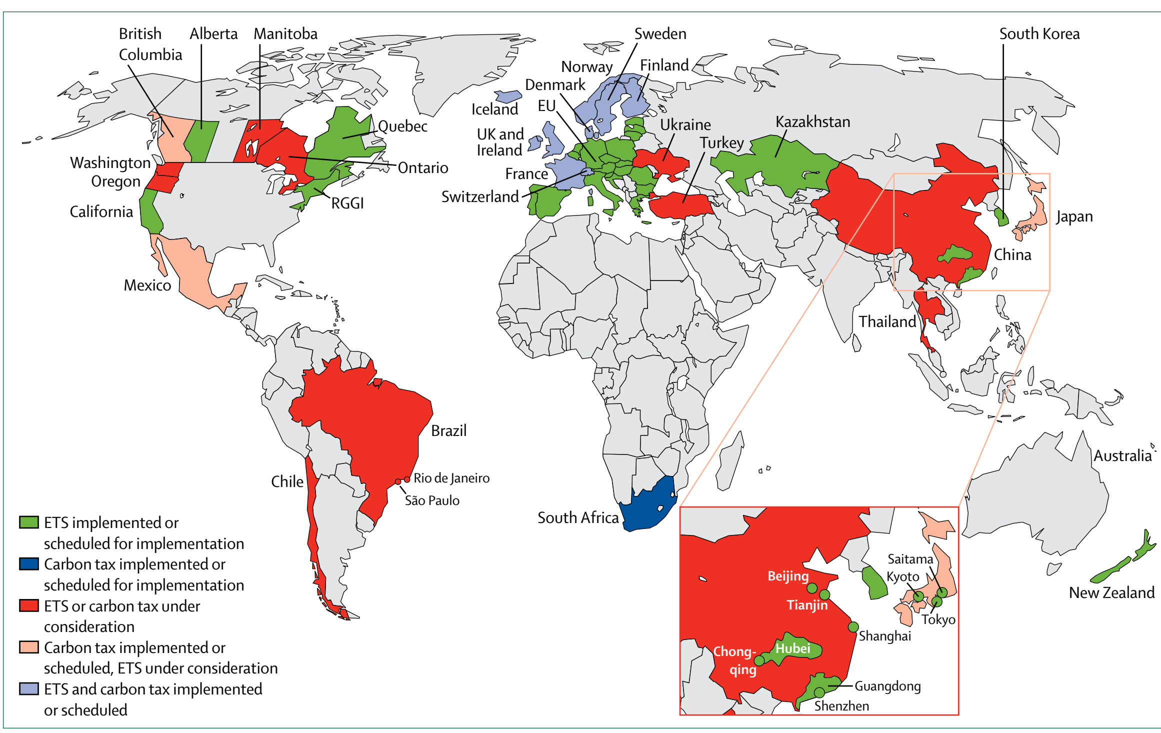

Figure 37: **Carbon pricing instruments implemented, scheduled for implementation, and under consideration**

Prices for 2016 and 2017 are those as of Aug 1, 2016, and April 1, 2017, respectively. For 2017, the indicator includes only instruments that had been introduced by April 1, 2017. Instruments without price data are excluded. ETS=Emissions Trading System. EU=European Union. RGGI=Regional Greenhouse Gas Initiative. Adapted from the Carbon Pricing Watch 2017,[176] by permission of the World Bank.

An additional 21 carbon pricing instruments are either scheduled for implementation or are under consideration. This includes the commencement of a national ETS in China in the second half of 2017. Although a national ETS would replace the eight pilot schemes already in place in China, it could expand their emissions coverage four-fold, surpassing the European ETS to become the largest carbon pricing instrument in the world.[176]

	Mitigation	Adaptation	Environmental tax reform	General funds	Total revenue (US$2016)
Proportion of total funds (%)	40·4%	4%	19·5%	36·1%	··
Value (US$2016)	$9·01 billion	$0·9 billion	$4·34 billion	$8·06 billion	$22·31 billion

Source: World Bank Carbon Pricing Dashboard, 2017.

Table 3: **Carbon pricing revenues and allocation in 2016**

Indicator 4.8: Use of carbon pricing revenues

This indicator reports that 40% of government revenues generated from carbon pricing are spent on climate change mitigation, totalling $9 billion.

Carbon pricing instruments require those responsible for producing the emissions to pay for their emissions. In most cases, this generates revenue for the governments or authorities responsible for introducing the instrument. Such revenue may be put to a range of uses. For example, revenue could be invested in climate change mitigation or adaptation or put towards environmental tax reform (ETR), which involves shifting the burden of tax from negative activities (eg, the generation of pollution) to positive activities (eg, labour or environmentally beneficial products or activities). Such options could produce a double dividend of environmental improvement with social and economic benefits.[177] This indicator tracks the total government revenue from carbon pricing instruments and how such income is allocated.

The total government revenue generated by carbon pricing instruments in 2016, and four categories of expenditure for this revenue are presented in table 3. The largest expenditure category is climate change mitigation, which is in receipt of more than $9 billion in funds annually. Nevertheless, less than half of revenue-generating instruments allocate revenue for mitigation.

ETR policies accounted for around 20% of revenue allocation in 2016. Just two instruments (the Portuguese and British Colombia Carbon Taxes) allocate all their revenue to allowing revenue-neutral reduction in other taxes (eg, income taxes), with another four allocating part of their revenue to this purpose. By contrast, only four instruments do not have any revenue allocated to general government funds (the British Colombian, Swiss, Japanese, and Portuguese carbon taxes), and 11 instruments allocate all revenues to this category (reaching €8 billion, or more than a third of revenues generated in 2016). Data for individual carbon pricing instruments are provided in the appendix (p 88).

Data on revenue generated are provided on the World Bank's Carbon Pricing Dashboard, with revenue allocation information obtained from various sources (appendix p 89). We considered only instruments with revenue estimates and with revenue received by the administering authority before redistribution. Revenue must be explicitly allocated to climate change mitigation or adaptation, or for ETR, to be considered in these categories. If such explicit earmarking is not present, or no data are available, then we assumed revenue to be allocated to general funds.

Indicator 4.9: Spending on adaptation for health and health-related activities

This indicator reports that only 4·63% of the world's total adaptation spending ($16·46 billion) is on health and 13·3% ($47·29 billion) is on health-related adaptation.

This indicator reports estimates of spending on health and health-related climate change adaptation and resilience. Many adaptation activities within and beyond the formal health sector have health co-benefits that are important to understand and capture. Here, estimates of the total health and health-related adaptation spending were derived from the Adaptation & Resilience to Climate Change dataset produced by kMatrix. This global dataset, covering financial transactions relevant to climate change adaptation, was compiled from a relevant subset of more than 27 000 independent databases and sources (such as public disclosures and reports from insurance companies, the financial sector, and governments).[178] In this case, entries were triangulated between at least seven independent sources before being included.

Examples of transactions captured here include the procurement of goods or services (eg, purchasing sandbags for flood levees) and spending on research and development (eg, for vulnerability and adaptation assessments) or staff training.[178] Each of these adaptation activities are grouped into 11 sectors: agriculture and forestry, built environment, disaster-preparedness, energy, health, information and communications technology, natural environment, professional services, transport, waste, and water. Although adaptation spending relevant directly to the formal health sector is clearly important (the health category), interventions outside of the health-care system will also yield important benefits for health and wellbeing. Health-related adaptation spending included additional adaptation spending from the agricultural sector (because food and nutrition are central to health) and the disaster preparedness sector (because these efforts often have direct public health benefits).

Here we report data from the Adaptation & Resilience to Climate Change dataset, showing health and

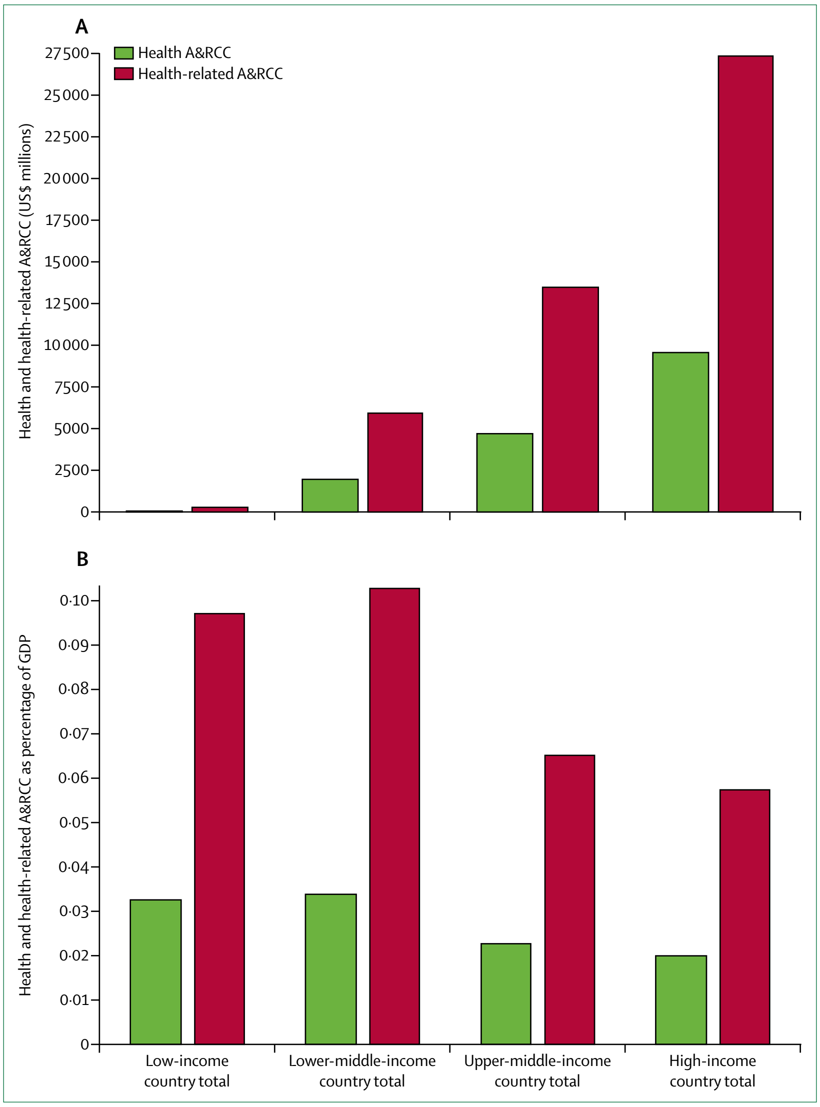

***Figure 38:* Spending on Adaptation & Resilience to Climate Change (A&RCC)**
(A) Health and health-related total spending on A&RCC. (B) Health and health-related spending on A&RCC as a proportion of GDP for the financial year 2015–16. All plots are disaggregated by World Bank Income Grouping. GDP=gross domestic product.

For the **Climate Funds Update** see http://www.climatefundsupdate.org/

health-related adaptation spending for 180 countries for the 2015–16 financial year. Global health adaptation spending for the financial year 2015–16 totalled $16·46 billion, representing 4·63% of the global aggregate adaptation spend. Health-related adaptation spending totalled $47·29 billion, or 13·3% of the global total adaptation spend (figure 38).

Health-related adaptation and resilience spending, both national totals and per capita levels, is extremely low in low-income countries and increases across the continuum towards high-income countries. Health and health-related adaptation spending as a proportion of total adaptation spending is relatively constant across income groups.

Further work is required to more completely determine what should be considered as health-related adaptation spending. First, spending for agriculture and disaster preparedness was included here, but other forms of adaptation spending clearly have important health implications. Second, only economic data relating to the financial year 2015–16 were available, precluding time-trend analysis. Third, since public sector transactions might not leave a sufficient footprint to be picked up by this methodology, adaptation spending data here might exclude some public-sector spending.

Indicator 4.10: Health adaptation funding from global climate financing mechanisms

This indicator reports that between 2003 and 2017, 0·96% of total adaptation funding for development, flowing through global climate change financing mechanisms, was dedicated to health adaptation.

The final indicator in this section was designed in parallel with Indicator 4.9 and aims to capture development funds available for climate change adaptation. It reports global financial flows for health adaptation to climate change, moving through established global climate financing mechanisms. Data were drawn from the Climate Funds Update, an independent source that has been aggregating funding data from multilateral and bilateral development agencies since 2003. Data from the Climate Funds Update is presented in four categories (pledged, deposited, approved, and disbursed); this indicator uses data designated as approved.

Between 2003 and 2017, only 0·96% of approved adaptation funding was allocated to health adaptation, corresponding to a cumulative total of $39·55 million (figure 39). Total global adaptation funding peaked in 2013 at $910·36 million and decreased thereafter. However, health-related adaptation funding peaked in early 2017, resulting in the near doubling in the proportion of adaptation funding allocated to health. A brief overview of growing interest in health and climate change from the international donor community is provided in panel 8.

Conclusion

The indicators presented in this section seek to highlight the status of the economics and finance associated with climate change and health across four themes: investment in a low-carbon economy, economic benefits of tackling climate change, pricing of greenhouse gas emissions from fossil fuels, and adaptation financing.

Many of the trends show positive change with time, most notably in global investment in zero-carbon energy supply, energy efficiency, new coal-fired electricity capacity, employment in the renewable energy sector, and divestment in fossil fuels. However, the change is relatively slow and must accelerate rapidly to meet the objectives of the Paris Agreement.

Section 5: Public and political engagement

Policy change relies on public support and government action. This is particularly true of policies with the reach

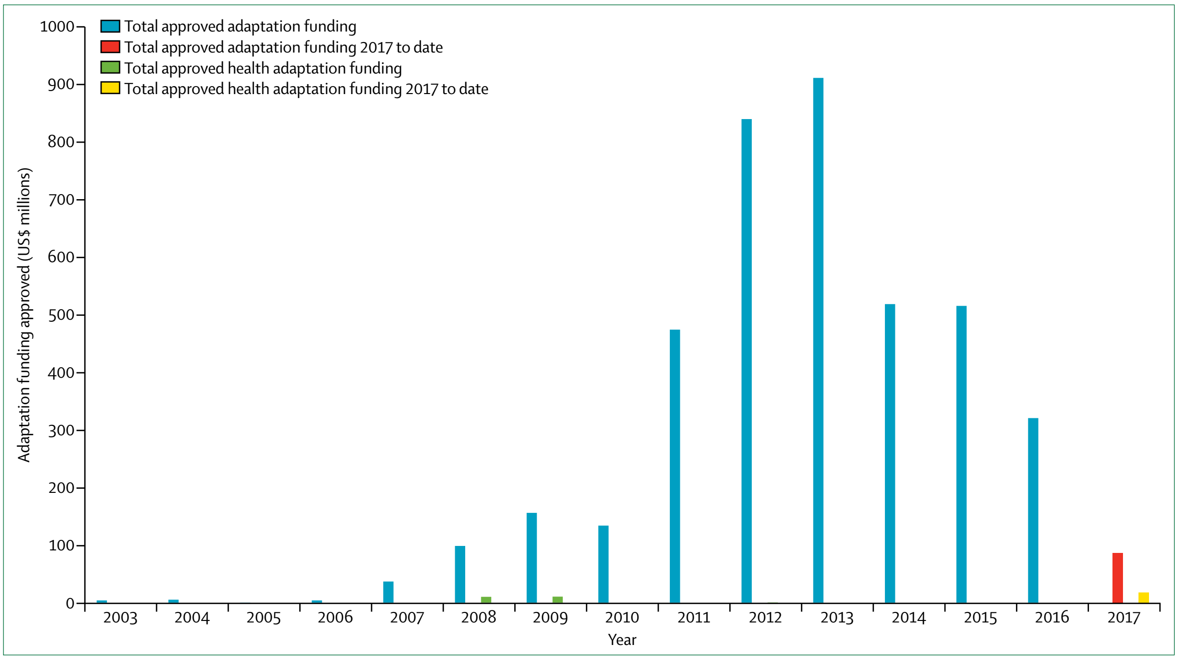

Figure 39: **Year-on-year multilateral and bilateral funding for all adaptation projects and health adaptation projects, from January, 2003, to May, 2017**

and impact to enable societies to transition to a low-carbon future.[179] The overarching theme of this section is therefore the importance of public and political engagement in addressing health and climate change and the consequent need for indicators that track engagement in the public and political domains.

The aim is to track engagement with health and climate change in the public and political domains and to identify trends since 2007. In selecting indicators, priority has been given to high-level indicators, which can be measured globally, tracked over time, and provide a platform for more detailed analysis in future *Lancet* Countdown reports. The indicators relate to coverage of health and climate change in the media, science, and government. Search terms for the indicators are aligned, and a common time-period was selected for all indicators (2007–16). The period runs from before the resolution on health and climate change by the 2008 World Health Assembly, which marked a watershed moment in global engagement in health and climate change; for the first time, member states of the UN made a multilateral commitment to protect human health from climate change.[180]

We present three indicators. Headline findings for each indicator are provided at the beginning of each indicator; additional detailed disussion of the data and methods is provided in the appendix (p 97).

Indicator 5.1: Media coverage of health and climate change

This indicator reports that global newspaper coverage of health and climate change has increased by 78% since 2007, with marked peaks in 2009 and 2015 coinciding with the 15th and 21st Conference of the Parties, respectively.

Media has a crucial role in communicating risks associated with climate change.[181] Knowledge about climate change is related to perceptions of risk and intentions to act.[182,183] Public perceptions of a nation's values and identity are also an important influence on public support for national action.[184] Indicator 5.1 therefore tracks media coverage of health and climate change, with a global indicator on newspaper coverage on health and climate change (Indicator 5.1.1) complemented by an in-depth analysis of newspaper coverage on health

Panel 8: International donor action on climate change and health

In 2017, the World Bank released three independent reports on climate change and health, articulating (1) a new action plan for climate change and health, (2) geographical focus areas, and (3) new strategy for climate-smart health care. In addition to training staff and increasing government capacity, the World Bank outlines an approach to ensuring that at least 20% of new World Bank health investments are climate-smart by 2020, corresponding to as much as US$1 billion in new climate-smart health finance for countries. Other development institutions and foundations are also getting involved. Two separate, large gatherings of public and private funders occurred in Helsinki in May, 2016, and in Chicago, IL, USA, in May, 2017, toward establishing new channels for health and climate finance, and a third is planned for October, 2017 (Washington, DC).

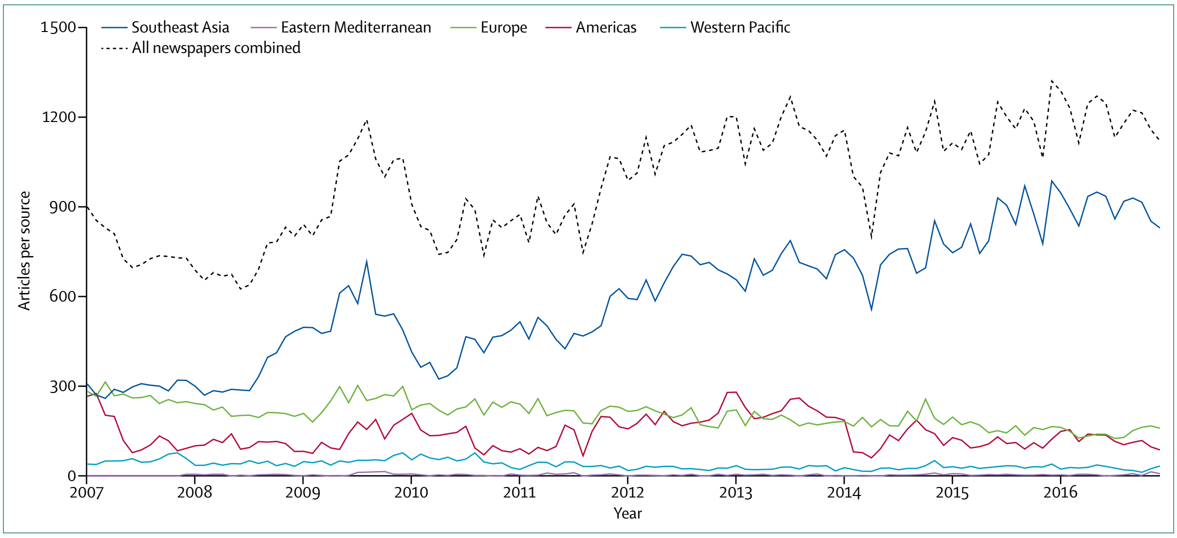

Figure 40: **Newspaper reporting on health and climate change (for 18 newspapers), by WHO region**

and climate change for two national newspapers (Indicator 5.1.2).

Indicator 5.1.1: Global newspaper reporting on health and climate change

Focusing on English-language and Spanish-language newspapers, this indicator tracks global coverage of health and climate change in high-circulation national newspapers from 2007 to 2016. Using 18 high-circulation so-called tracker newspapers, global trends are shown and disaggregated regionally to provide a global indicator of public exposure to news coverage of health and climate change.

Since 2007, newspaper coverage of health and climate change has increased by 78% worldwide (figure 40). However, this trend is largely driven by southeast Asian newspapers. Although mostly due to the higher number of southeast Asian newspapers included in this analysis, their average coverage of health and climate change was higher than in other regions, particularly among Indian sources (appendix p 98). This generally high volume of coverage in the Indian press can be attributed to the centrality of newspapers as communication channels for elite-level discourse in India and to relatively high levels of climate change coverage throughout Asia.[185–187] For the eastern Mediterranean, Americas, and western Pacific, media reporting does not have a strong trend. Apart from some notable peaks in 2009 in Europe, this trend is largely maintained for the rest of the time series. In the Americas, a secondary peak is seen between 2012 and 2014. The first large peak in worldwide coverage was in 2009, coinciding with the Conference of the Parties in Copenhagen, for which expectations were high. Newspaper reporting then dropped around 2010 but has been rising worldwide since 2011.

Data were assembled by accessing archives through the Lexis Nexis, Proquest, and Factiva databases. These sources were selected through the weighting of four main factors: geographical diversity (favouring a greater geographical range), circulation (favouring higher circulating publications), national sources (rather than local or regional sources), and reliable access to archives over time (favouring those accessible consistently for longer periods). Search terms were aligned to those used for the indicators of scientific and political engagement and searches, with Boolean searches in English and Spanish.

Indicator 5.1.2: In-depth analysis of newspaper coverage on health and climate change

The second part of this indicator provides an analysis of two national newspapers: the French *Le Monde* (France) and the German *Frankfurter Allgemeine Zeitung*. Le Monde and FAZ were chosen for this analysis because they are leading newspapers in France and Germany, two countries with political weight in Europe. Both newspapers continue to set the tone of public debates in France and Germany.[188,189]

Only a small proportion of articles about climate change mentioned the links between health and climate change (5% in *Le Monde* and 2% in *Frankfurter Allgemeine Zeitung*). The analysis also pointed to important national differences in reporting on health and climate change. For example, in *Le Monde*, 70% of articles referring to health and climate change represented the health-climate change nexus as an environmental issue, whereas in *Frankfurter Allgemeine Zeitung*, articles had a broader range of references: the economy (23%), local news (20%), and politics (17%). The recommended policy responses also differed; *Le Monde* emphasised mostly adaptation (41% of articles), whereas *Frankfurter Allgemeine Zeitung* emphasised mostly mitigation

(40% of articles). The co-benefits that public health policies can represent for mitigation were mentioned in 17% of *Le Monde* articles and in 9% of *Frankfurter Allgemeine Zeitung* articles. Overall, the analysis points to the marked differences in media reporting of health and climate change and in the information and perspectives to which the public is exposed (appendix p 99).

Indicator 5.2: Health and climate change in scientific literature

This indicator reports that since 2007, the number of scientific papers on health and climate change has more than tripled.

Science is pivotal to increasing public and political understanding of the links between climate change and health, to informing mitigation strategies, and to accelerating the transition to low-carbon societies.[190,191] This indicator, showing scientific engagement with health and climate change, tracks the volume of peer-reviewed reports in English-language scientific journals in PubMed and Web of Science (appendix p 104). The results show a marked increase in published research on health and climate change in the past decade, from 94 reports in 2007, to more than 275 reports in both 2015 and 2016. Within this overall upward trend, the volume of scientific reports increased particularly rapidly in 2007–09 and from 2012, plateauing between these periods (figure 41).

The two periods of growth in scientific outputs coincided with the run-up to the UNFCCC Conference of Parties in Copenhagen in 2009 and in Paris in 2015. This pattern suggests that scientific and political engagement in health and climate change are closely linked, with the scientific community responding quickly to the global climate change agenda and the need for evidence.

Most reports focus on the impacts of climate change and health in Europe and North America. Overall, we identified more than 2000 scientific articles, 30% of which focused on Europe and 29% of which focused on the Americas. Within the Americas, most reports (72%) were about health and climate change in North America (appendix p 106). By contrast, only 10% of articles had a focus on Africa or the eastern Mediterranean region, demonstrating a marked global inequality in the science of health and climate change (appendix p 106).

Among the journals included in the analysis, infectious diseases, particularly dengue fever and other mosquito-transmitted infections, are the most frequently investigated health outcomes; about 30% of selected reports covered these health-related issues. We identified important gaps in the scientific evidence base such as migration and mental health.

For this indicator, we did a scoping review of peer-reviewed reports about health and climate change that were written in English and published between 2007 and 2016, an appropriate approach for broad and inter-disciplinary research fields.[192] We searched PubMed and Web of Science with keywords to identify reports through a bibliometric analysis (appendix p 104).[193] Inclusion and exclusion criteria were applied to capture the most relevant literature about the impacts of climate change on human health within the chosen timeframe, and reports were independently reviewed and screened three times to identify relevant articles.[194]

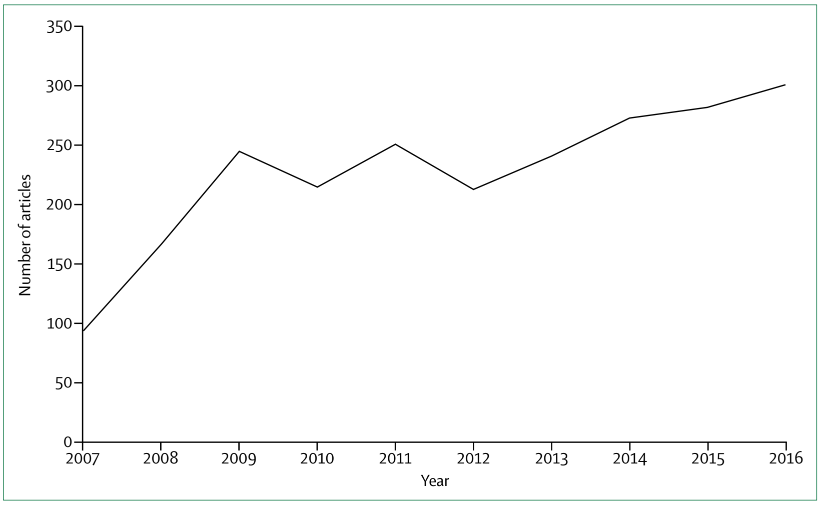

Figure 41: **Number of scientific publications on climate change and health per year (2007–16) from PubMed and Web of Science**

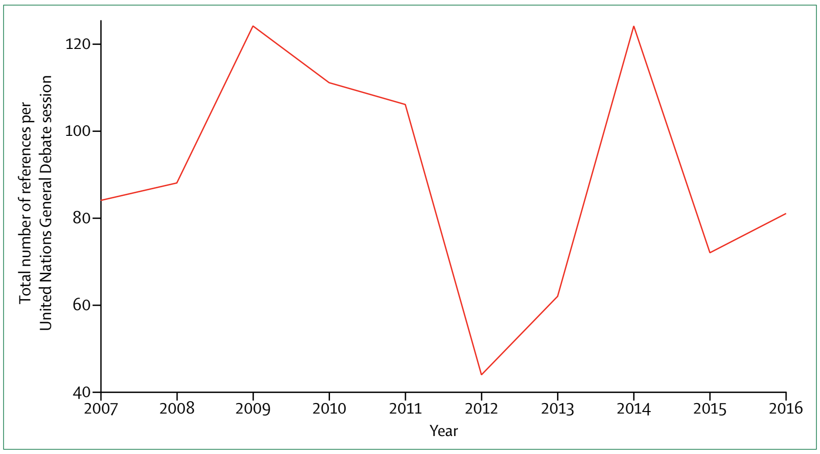

Figure 42: **Political engagement with the intersection of health and climate change, represented by joint references to health and climate change in the United Nations General Debate**

Indicator 5.3: Health and climate change in the United Nations General Assembly

This indicator reports that there is no overall trend in United Nations General Debate (UNGD) references to health and climate change, but the number of references peaked twice, in 2009 and in 2014.

The UNGD takes place every September at the start of each new session of the United Nations General Assembly (UNGA). Governments use their annual statements to present their perspective on events and issues they consider the most important in global politics

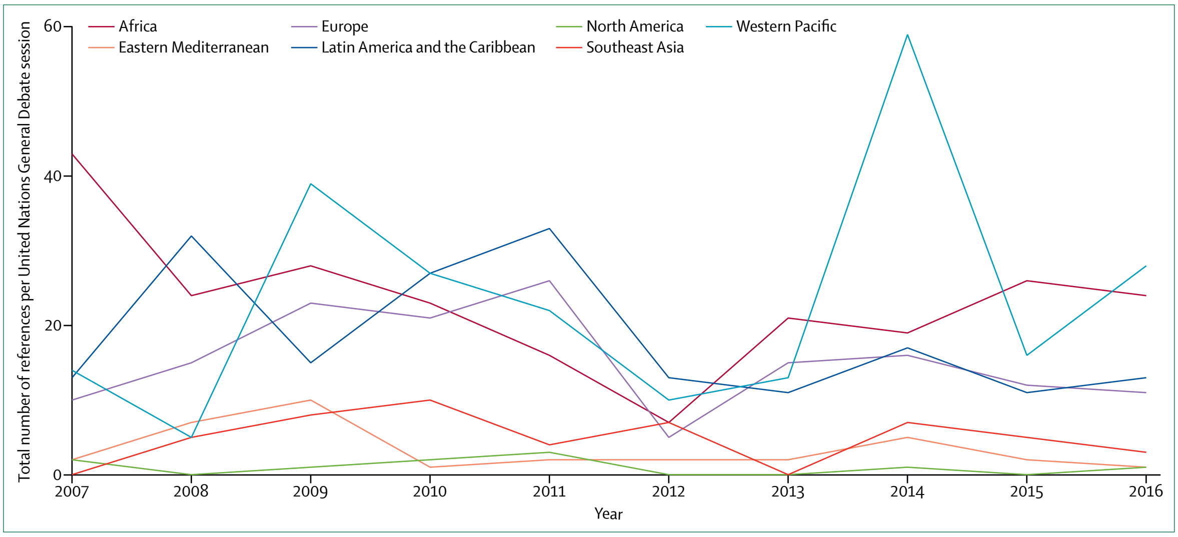

Figure 43: **Regional political engagement with the intersection of health and climate change, represented by joint references to health and climate change in the United Nations General Debate, by WHO region**

and to call for strengthened action from the international community. All UN member states can address the UNGA, free from external constraints. General Debate statements are therefore an ideal data source on political engagement with health and climate change, which is comparable spatially and temporally. This indicator focuses on the extent to which governments refer to linkages between health and climate change issues in their annual statements in the General Debate, with each reference representing one hit.

Health and climate change are often raised in General Debate statements (appendix p 110). However, statements less frequently link health and climate change together. Between 2007 and 2016, between 44 and 124 linked references were made to health and climate change in the annual General Debate (figure 42). By comparison, between 378 and 989 references were made to climate change alone. We found no overall trend in conjoint references to health and climate change across the period.

Although no overall trend is apparent, the number of references that link health and climate change peaked twice, once in 2009–11 and again in 2014. In both 2009 and 2014, 124 references were made to the link between health and climate change in the General Debate statements. The 2009 peak was after the 2008 World Health Day, which focused on health and climate change, and in the build-up to the 2009 Conference of Parties in Copenhagen. The 2014 peak is indicative of the influence of the large UNGA on climate change in 2014 and the lead up to the 2015 Conference of Parties in Paris. The 2015 UNGA, which focused on the Sustainable Development Goals, made relatively limited reference to climate change, and, after the 2014 peak, conjoint references to health and climate change decreased. This irregular pattern points to the importance of key events in the global governance of health and climate change in driving high-level political engagement.

We found many country-level differences in the attention given to health and climate change in General Debate statements (figure 43). Countries in the western Pacific, particularly by the Small Island Developing States in these regions, made most references to the issue. By contrast, governments in the east Mediterranean, the Americas, and southeast Asia made fewest references to health and climate change.

This indicator is based on the application of keyword searches in the text corpus of debates. A new dataset of General Debate statements was used (UNGD corpus), in which the annual statements have been preprocessed and prepared for use in quantitative text analysis (appendix p 108).[195]

Conclusion

The indicators in this section have demonstrated the importance of global governance in mobilising public and political engagement in health and climate change. The UN and the annual Conference of Parties have an important role in clearly influencing media and promoting scientific and political engagement with health and climate change.

To further improve understanding of public and political engagement, indicators relating to national governments' health and climate change legislation, private sector engagement, the inclusion of climate change in professional health education, and the prominence given to health in UNFCCC negotiations are proposed for future analysis. The previous sections in this report have presented findings on the impacts of climate hazards, adaptation and resilience, co-benefits of mitigation, and finance and economics. All of these factors hinge on policy, which in turn depends on public and political engagement.

Conclusion—the *Lancet* Countdown in 2017

In June, 2015, the *Lancet* Commission on Health and Climate Change[2] laid the groundwork for a global monitoring platform designed to systematically track progress on health and climate change and to hold governments to account for their commitments under the then-to-be-finalised Paris Agreement.[1] The *Lancet* Countdown will continue this work, reporting annually on the indicators presented in this Review and on new indicators developed in the future.

The data and analysis presented in this Review cover a wide range of topics and themes from the lethality of weather-related disasters to the phase-out of coal-fired power. The report begins with an indicator set to track the health effects of climate change and climate-related hazards. We found that the symptoms of climate change have been clear for a number of years, with the health impacts far worse than previously understood. These effects have been spread unequally. For example, a 9·4% increase in vectorial capacity of the dengue fever-carrying *A aegypti* has predominantly spread in LMICs since 1950, and India has been disproportionately affected by the additional 125 million exposure events to potentially fatal heatwaves since 2000.

These indicators also suggest that populations are beginning to adapt, with improvements in the world's overall health profile strengthening its resilient capacity and national governments beginning to invest in health-adaptation planning for climate change. About $47·29 billion is spent annually on health-related adaptation (about 13·3% of global total adaptation spend). However, the scientific literature and past experience make it clear that there are very real and immediate technological, financial, and political barriers to adaptation.[13]

The indicators in Section 3 track health-relevant mitigation trends across four sectors, with an ultimate focus of keeping global temperature rise well below 2°C and meeting the Paris Agreement. At an aggregate level, the past two decades have seen limited progress here, with many of the trends and indicators remaining flat or moving strongly in the opposite direction. More recently, trends in the electricity generation (deployment of renewable energy and a dramatic slow-down in coal-fired power) and transport sectors (soon-to-be cost parity of electric vehicles with their petrol-based equivalents) provide cause for optimism because, if sustained, these trends could reflect the beginning of system-wide transformation.

Indicators in Sections 4 and 5 underpin and drive toward this transition. Again, trends in the past two decades reveal concerning levels of inaction. Only in recent years have investment and interventions accelerated. Employment in the renewable energy sector has reached record high levels, overtaking employment in the fossil fuel extraction sector, and fossil fuel consumption subsidies have decreased worldwide. Carbon pricing mechanisms are slowly widening and now cover about 13·1% of worldwide CO_2 emissions. In Section 5 we consider the degree to which the public, political, and academic communities have engaged with the link between climate change and health. Our findings point to uneven patterns of engagement and the pivotal role of global institutions, the UN particularly, in driving forward public, political, and scientific support for enhanced mitigation and adaptation policies.

Overall, the trends elucidated in this Report provide cause for deep concern, highlighting the immediate health threats from climate change and the relative inaction seen in all parts of the world in the past two decades. However, more recent trends in the past 5 years reveal a rapid increase in action, which was solidified in the Paris Agreement. These glimmers of progress are encouraging and reflect a growing political consensus and ambition, which was seen in full force in response to the USA's departure from the 2015 climate change treaty. Although action needs to increase rapidly, taken together, these signs of progress provide the clearest signal to date that the world is transitioning to a low-carbon world, that no single country or head of state can halt this progress, and that until 2030, the direction of travel is set.

Contributors

The *Lancet* Countdown: Tracking Progress on Health and Climate Change is an international academic collaboration that builds off the work of the 2015 *Lancet* Commission on Health and Climate Change, convened by *The Lancet*. The *Lancet* Countdown's work for this report was conducted by its five working groups, each of which were responsible for the design, drafting, and review of their individual indicators and sections. All authors contributed to the overall structure and concepts of the report and provided input and expertise to the relevant sections. Authors contributing to Working Group 1: Jonathan Chambers; Peter M Cox; Mostafa Ghanei; Ilan Kelman; Lu Liang; Ali Mohammad Latifi; Maziar Moradi-Lakeh; Kris Murray; Fereidoon Owfi; Mahnaz Rabbaniha; Elizabeth Robinson; Meisam Tabatabaei. Authors contributing to Working Group 2: Sonja Ayeb-Karlsson; Peter Byass; Diarmid Campbell-Lendrum; Michael Depledge; Paula Dominguez-Salas; Howard Frumkin; Lucien Georgeson; Delia Grace; Anne Johnson; Dominic Kniveton; Georgina Mace; Maquins Odhiambo Sewe; Mark Maslin; Maria Nilsson; Tara Neville; Karyn Morrissey; Joacim Rocklöv; Joy Shumake-Guillemot. Authors contributing to Working Group 3: Markus Amann; Kristine Belesova; Wenjia Cai; Michael Davies; Andy Haines; Ian Hamilton; Stella Hartinger; Gregor Kiesewetter; Melissa Lott, Robert Lowe; James Milner; Tadj Oreszczyn; David Pencheon, Steve Pye; Rebecca Steinbach; Paul Wilkinson. Authors contributing to Working Group 4: Timothy Bouley; Paul Drummond; Paul Ekins. Authors Contributing to Working Group 5: Maxwell Boykoff; Meaghan Daly; Niheer Dasandi; Anneliese Depoux; Antoine Flahault; Hilary Graham; Rébecca Grojsman; Slava Mikhaylov; Stefanie Schütte. The coordination, strategic direction, and editorial support for this paper was provided by Anthony Costello (Co-Chair), Hugh Montgomery (Co-Chair), Peng Gong (Co-Chair), Nick Watts (Executive Director), and Nicola Wheeler (Programme Officer). The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of WHO, the World Bank, or the World Meteorological Organization.

Declaration of interests

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