The *Lancet* Countdown: tracking progress on health and climate change

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The *Lancet* Countdown: *tracking progress on health and climate change* is an international, multidisciplinary research collaboration between academic institutions and practitioners across the world. It follows on from the work of the 2015 *Lancet* Commission, which concluded that the response to climate change could be "the greatest global health opportunity of the 21st century". The *Lancet* Countdown aims to track the health impacts of climate hazards; health resilience and adaptation; health co-benefits of climate change mitigation; economics and finance; and political and broader engagement. These focus areas form the five thematic working groups of the *Lancet* Countdown and represent different aspects of the complex association between health and climate change. These thematic groups will provide indicators for a global overview of health and climate change; national case studies highlighting countries leading the way or going against the trend; and engagement with a range of stakeholders. The *Lancet* Countdown ultimately aims to report annually on a series of indicators across these five working groups. This paper outlines the potential indicators and indicator domains to be tracked by the collaboration, with suggestions on the methodologies and datasets available to achieve this end. The proposed indicator domains require further refinement, and mark the beginning of an ongoing consultation process—from November, 2016 to early 2017—to develop these domains, identify key areas not currently covered, and change indicators where necessary. This collaboration will actively seek to engage with existing monitoring processes, such as the UN Sustainable Development Goals and WHO's climate and health country profiles. The indicators will also evolve over time through ongoing collaboration with experts and a range of stakeholders, and be dependent on the emergence of new evidence and knowledge. During the course of its work, the *Lancet* Countdown will adopt a collaborative and iterative process, which aims to complement existing initiatives, welcome engagement with new partners, and be open to developing new research projects on health and climate change.

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Introduction

WHO estimated that, in 2012, 12·6 million deaths (23% of all deaths worldwide) were attributable to modifiable environmental factors, many of which could be influenced by climate change or are related to the driving forces of climate change.[1] The 2009 UCL–*Lancet* Commission: *managing the health effects of climate change*[2] described the ways in which climate change acts as a force multiplier for threats to global health. This initiative has drawn on long-standing expertise and leadership in the health and climate field, including from institutions such as WHO and the Intergovernmental Panel on Climate Change (IPCC), and a previous call for the systematic monitoring of health outcomes related to climate change.[3,4]

The 2015 *Lancet* Commission on Health and Climate Change: *policy responses to protect public health*[5] built on these foundations and explored the health benefits of climate change mitigation and adaptation policies. As first described in the 2009 *Lancet* series, greenhouse gas mitigation across a range of sectors can result in considerable improvements in public health.[6–10] Taken together, the potential to avoid substantial impacts of climate change and the potential co-benefits of climate change mitigation and adaptation led the 2015 *Lancet* Commission[5] to conclude that "tackling climate change could be the greatest global health opportunity of the 21st century".

The direct impacts of climate change result from rising temperatures, heatwaves, and increases in the frequency of complex extreme weather events such as windstorms, floods, and droughts.[11] The health and social consequences of these events are far-reaching, ranging from reduced labour productivity and heat-related deaths, through to direct injury, the spread of infectious diseases, and mental health effects following widespread flooding. The effects of climate change will also be heterogeneously mediated across different environmental and social systems, resulting in changing patterns of the burden and distribution of infectious diseases, changes in food productivity, and potential effects on food and water shortages, population displacement, and conflict (figure 1).[3] Climate change places undue burden on the countries least responsible and least able to respond, with low-income and middle-income countries experiencing multiple impacts simultaneously.[12]

The Rockefeller Foundation–*Lancet* Commission on planetary health[13] described how sustained human health and development are dependent on flourishing natural systems. This Commission[13] and others[14] have drawn

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attention to the fact that human activities are breaching environmental limits across a range of areas, driving terrestrial and marine biodiversity loss, ocean acidification, depletion of freshwater, soil degradation, and other potentially irreversible processes.

At the international level, the Paris Agreement provides the framework for future international cooperation and national action on climate change. Modelling suggests that the full implementation of all mitigation actions pledged by national governments would limit average global warming to around 2·7°C by 2100—an improvement on the high-end 4·8°C or more scenario, but substantially higher than the agreed UN target of "well below 2·0°C".[15]

Responsibility for implementation of the Paris Agreement now falls on national governments. The next 15 years, from 2016 to 2030, are a crucial window that will determine the trajectory of climate change and human development for the coming century. As part of this transition, countries will have to undergo a shift from understanding climate change solely as a threat, to embracing the response to climate change as an opportunity for human health and wellbeing. Tracking and communicating this transition will be the central focus of the *Lancet* Countdown.

Aims of the *Lancet* Countdown on health and climate change

The *Lancet* Countdown aims to track the impacts of climate change and the speed of the transition to a decarbonised global economy (a transition that is already underway); analyse and show the health benefits available; provide a global picture of successes and obstructions in this shift; draw out exemplary case studies for shared learning; and engage with policy makers and the broader health community to better communicate the opportunities available in responding to climate change both for health and more broadly.

To do this, the *Lancet* Countdown will report annually on key indicators that reflect progress on health and climate change. Published each year, before the international negotiations of the UN Framework Convention on Climate Change (UNFCCC), the annual *Lancet* paper will consider global and selective national, regional, and city-level trends. Five interrelated thematic working groups will cover different aspects of the association between health and climate change, including the health effects of climate change; health resilience and adaptation; the health co-benefits of climate change mitigation; finance and economics; and political and broader engagement.

The *Lancet* Countdown is an international, multi disciplinary research collaboration between academic institutions and experts across the world. Although the 2015 *Lancet* Commission existed as a partnership primarily between European and Chinese academics, the *Lancet* Countdown will build on these foundations to be more global in both expertise and outlook.

Indicators of progress: a call for input and engagement

The work of the *Lancet* Countdown is divided into five working groups, responsible for specific sets of indicators and their integration. Proposed indicator domains for these working groups are outlined in the panel and below. These indicators and indicator domains are presented for consultation with varying degrees of certainty, ranging from the presentation of a specific indicator through to the description of a broad domain within which several indicators might be present.

The ongoing framing and selection of indicators to mark the progress to a low-carbon and climate-resilient society could take various forms, such as focusing on the interactions between society and the environment (as seen in the Driving Force-Pressure-State-Exposure-Effect-Action [DPSEEA] framework, adapted in appendix 1), or the vulnerability, risk, and adaptive capacity to climate change.[16–18] The selected indicators will need to address the challenges of representing and summarising spatial and temporal factors in a concise way. The framing used to select indicators as part of the *Lancet* Countdown is primarily from the health perspective. In turn, the focus is on those indicators that capture the greatest effects that climate change has on health; the anthropogenic drivers that have the greatest contribution to climate change, and the measures and actions that would substantially reduce the effects of climate change or yield health co-benefits of climate change mitigation policies.

The proposed indicators and indicator domains reflect a pragmatic need to capture progress in the key interactions between health and climate change with the best available data that is meaningful to the health community and more widely. These indicators and indicator domains were developed through an iterative process, following an initial, broad consultation process, which involved input from a variety of experts in the field. They were further discussed and refined by the *Lancet* Countdown's academic working groups at a series of multidisciplinary meetings throughout 2016. Each proposed indicator domain was assessed for its ability to address a unique aspect of the association between health and climate change; potential data availability; feasibility given current resource constraints; applicability to countries across a variety of resource settings; and policy relevance.

This collaborative process is intended to complement other monitoring initiatives, such as the information being collected under the WHO climate and health country profiles, the Sustainable Healthy Urban Environments (SHUE) project, the Sendai Framework, and the ClimateWorks Foundation's Carbon Transparency Initiative.[19–22] The work of the *Lancet* Countdown will also draw on the UN Sustainable Development Goals (SDGs) where appropriate. The potential links between these initiatives and the *Lancet* Countdown's indicator domains

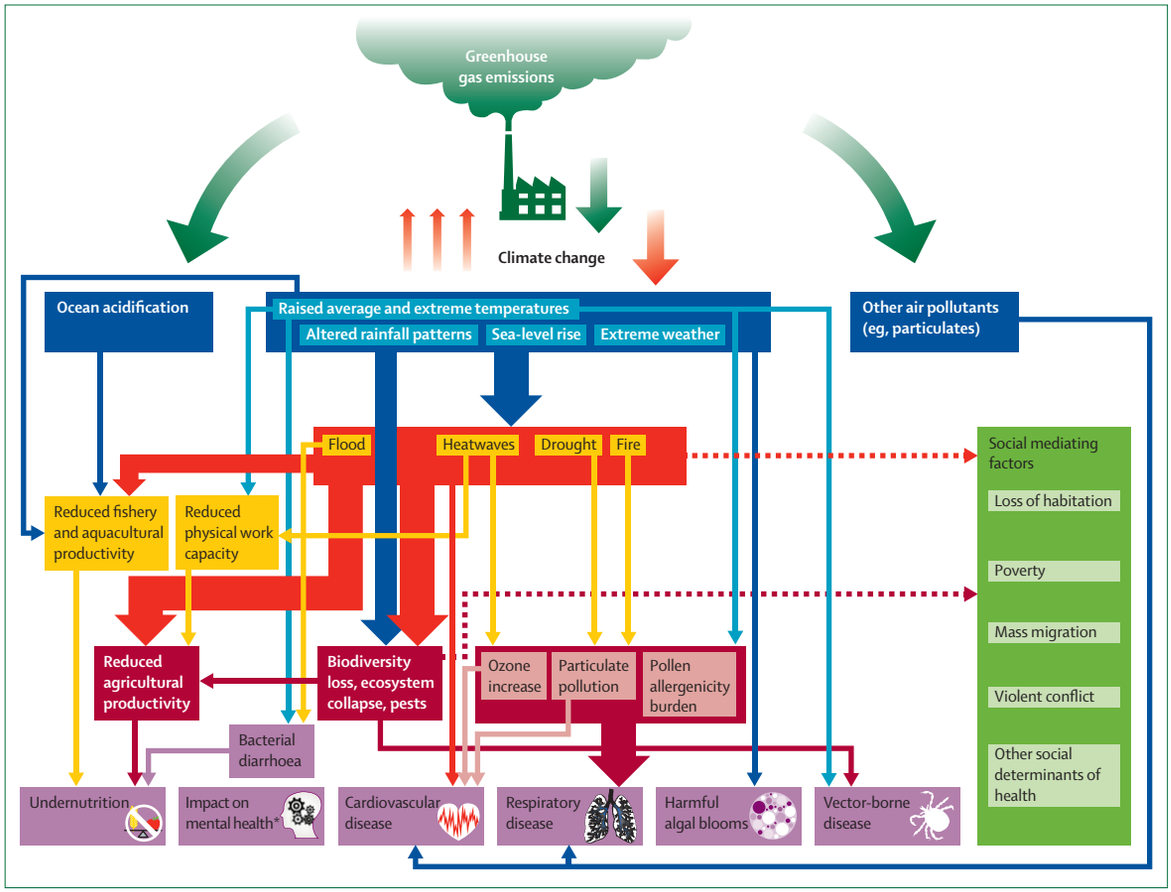

Figure 1: **The health impacts of climate change**
*The mental health effects of climate change are complex and interact with many of the processes shown in the figure. Source: *Lancet* Commission, 2015.[5]

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See Online for appendix

have been summarised in appendix 2. Where relevant crossover exists, the *Lancet* Countdown will build upon and incorporate these data into its work to ensure its overview is more complete and standardised.

This paper marks the beginning of an external consultation process to further refine the suggestions below. Indeed, it is expected that the indicators and metrics used will continuously evolve to make use of emerging evidence and data availability. To this end, the *Lancet* Countdown is committed to maintaining an open approach towards further developing its work programme, inviting external input, and actively consulting over the coming months. This research collaboration welcomes engagement with new academic partners, with the expertise and capacity to make substantial contributions to the final indicator process. The collaboration is also open to developing new research projects on as-yet neglected areas of health and climate change, with the possibility of jointly seeking additional funding and capacity for this work in future. We invite direct input on the content, methods, and data for the proposed indicators and indicator domains, as well as proposals for new partnerships, on the *Lancet* Countdown website.

1: Health impacts of climate hazards

The health effects of climate change are projected to become increasingly severe in the future, and threaten to undermine the gains made in public health and development during the past half-century.[3,5] The effects of climate change are unevenly distributed within and between countries, with all risks having important social, economic, and geographical mediating factors.[19] The first working group of the *Lancet* Countdown proposes seven indicator domains to be considered and then tracked.

1.1–1.5: Human exposure to extreme weather

The first indicators and indicator domains in this working group will use observed meteorological data to track exposure to extremes of weather across five areas: annual mean temperature change, heatwaves, heat index relevant for outdoor labour productivity, flood risk, and drought. These data will be complemented by a review of the detection and attribution studies linking climate change to specific extreme weather events that have affected human health. For consistency and transparency, these indices are deliberately similar to those presented in the

For more on the ***Lancet* Countdown** see http://www.LancetCoundown.org/IndicatorConsultation

Panel: **Proposed indicators and indicator domains for the *Lancet* Countdown on health and climate change**

The proposed indicator domains are heterogeneous: some reflect outcomes (greenhouse gas emissions or health), whereas others reflect process indicators with both direct and indirect links to climate change. Additionally, some can be modelled at a global or national level, whereas others reflect location-specific issues and would depend on data collection at sentinel sites.

1: Health impacts of climate hazards
1.1 Exposure to temperature change
1.2 Exposure to heatwaves
1.3 Changes in labour productivity
1.4 Exposure to flood
1.5 Exposure to drought
1.6 Changes in the incidence and geographical range of climate-sensitive infectious diseases across sentinel sites
1.7 Food security and undernutrition

2: Health resilience and adaptation
2.1 Integration of health into national adaptation plans
2.2 Climate services for health
2.3 Adaptation of finance for health

3: Health co-benefits of climate change mitigation
3.1 Coal phase-out
3.2 Growth in renewable energy
3.3 Access to clean energy
3.4 Energy access for health facilities
3.5 Exposure to ambient air pollution
3.6 Deployment of low-emission vehicles and access to public transport
3.7 Active travel infrastructure and uptake
3.8 Greenhouse gas emissions from the food system and healthy diets
3.9 Greenhouse gas emissions of health-care systems

4: Economics and finance
4.1 Change in annual investment in renewable energy
4.2 Change in annual investment in energy efficiency
4.3 Low-carbon technology patent generation and innovation
4.4 Valuing the health co-benefits of climate change mitigation
4.5 Direct and indirect fossil fuel subsidies
4.6 Coverage and strength of carbon pricing
4.7 Equity of the low-carbon transition

5: Political and broader engagement
5.1 Public engagement with health and climate change
5.2 Academic publications on health and climate change
5.3 Inclusion of health and climate change within medical and public health curricula
5.4 Health and climate change in high-level statements of the UNFCCC and UNGA
5.5 Implementation and estimated health benefits of the nationally determined contributions (NDCs)

2015 *Lancet* Commission[5]. For the *Lancet* Countdown, we will focus on metrics calculated from observational data rather than climate model projections. However, we will aim to maintain comparability between these metrics for monitoring progress and the exposure metrics implied by the future projections presented in the *Lancet* Commission report.[5]

Increases in mean temperature and changes in the severity and frequency of heatwaves bring about substantial and potentially fatal health risks to most populations.[3,23] These include vulnerable individuals with higher outdoor exposure (ie, those engaged in outdoor physical labour), and individuals with reduced capacity to maintain physiological homeostasis, such as infirm individuals, neonates, or older people. The direct association between extremes of heat and heat-related morbidity and mortality is well established; a similar—although comparatively less clear—association exists between indicators of thermal stress, such as wet bulb globe temperature, and reductions in outdoor labour productivity.[24] Examples of direct and indirect health effects were seen in the 2010 heatwave in Russia, which resulted in approximately 11 000 excess deaths arising from heat and poor air quality from subsequent forest fires.[25] The *Lancet* Countdown will utilise the population-related metrics developed from the 2015 *Lancet* Commission[5] to calculate the mean increase in temperature experienced by people. The *Lancet* Countdown will also make use of the index proposed by Jacob and colleagues,[26] defining a heatwave as more than three consecutive days in which the minimum temperature exceeds the 99th percentile relative to summers in the recent past (the 'recent past' is defined as 1986 to 2005, for consistency with the 2015 *Lancet* Commission). In addition, changes in labour productivity will be modelled with the use of wet bulb globe temperature, which has been used to identify thresholds of heat stress.[27]

The fourth indicator domain will follow human exposure to flood, and the fifth indicator domain will look at human exposure to drought. In this context, flood refers to meteorological floods related to rain and storm surges, rather than floods caused by rising sea levels, tsunamis, volcanic eruptions, and melting snow and ice. Drought refers to meteorological drought—a deficit of precipitation—rather than other forms of drought, such as water depletion caused by increasing demand.[28,29] Observational data suggest that many regions with a rising frequency of meteorological drought over the past 60 years overlap with crucial agricultural zones and regions where rapid population growth is expected—in particular, in sub-Saharan Africa and South Asia.[30,31] The analyses in the 2015 *Lancet* Commission[5] projected an additional 1·4 billion person drought exposure events per year by 2100, as a result of population growth and climate change.

The effect that climate change will have on mental health and wellbeing is an issue of particular importance, and is often amplified in low-resource settings with inadequate protective social and public health institutions. The *Lancet* Countdown is currently exploring options to track the mental health effects of climate change.

1.6: Changes in the incidence and geographical range of climate-sensitive infectious diseases across sentinel sites

Infectious diseases contribute substantially to the global burden of disease, and the vectors and reservoirs for

many infectious diseases are directly or indirectly influenced by climate.[32] The distribution and impacts of infectious diseases are already being altered by the various dimensions of climate change observed so far, and are projected to worsen for many infectious diseases in the future.[33–35]

Given the existing information about climate-sensitive infectious diseases, we will first derive a shortlist of relevant diseases or disease groups to road-test the indicator and then expand the list to include other relevant infectious diseases, following wider input from—and consultation with—infectious disease experts. Examples from three key groups will be tracked: food-borne diseases, vector-borne diseases, and parasitic diseases or zoonotic diseases.[36] Each of these groups, and specific diseases within each group, are likely to be affected by climate change in diverse ways. Our aim is to place a finger on the pulse of these impacts at a global scale and facilitate trend tracking through time. The sixth indicator domain will thus leverage surveillance and research networks that monitor and synthesise existing data to model changes in infectious disease impacts, risks, and exposure that are relevant to climate change.[37–39] This process will identify sentinel sites (as comprehensive monitoring is not feasible) across a range of geographical regions.[4] We would welcome suggestions of suitable sites and diseases.

Several sub-indicators will be derived for this purpose, broadly covering the following areas: infectious disease outbreaks; the occurrence and spread of infectious diseases, causative agents, and vector or reservoir species; and the prevalence and incidence of infectious diseases. These sub-indicators will provide a picture of changing trends in exposure to, and impacts from, infectious diseases caused by climate change. Four focal metrics are proposed for each of these indicators: (1) changes in observed and predicted cases in the human population; (2) observed or predicted changes in a geographical or temporal context; (3) observed or predicted changes in environmental suitability for sentinel pathogens, vectors, or reservoirs; and (4) changes in other environmental exposures and confounding factors.

1.7: Food security and undernutrition

Reliable access to sufficient, affordable, and nutritious food can be negatively affected by climate change in many ways. This ranges from the direct impact of drought, flood, and heat on harvest yields, through to the health and social impacts of climate change, resulting in unhealthy populations unable to farm or work enough to earn money to purchase food. Furthermore, food trade could be disrupted as a result of damage to infrastructure caused by climate shocks.[40] Populations in low-income countries reliant on rain-fed agriculture are often particularly vulnerable to climate change and weather shocks. These changes disproportionately affect the availability and cost of staple foods, as access to international markets is unreliable and low food stocks are unable to buffer price spikes.[40]

Although the health implications of food insecurity are local, international and national drivers are also important.[41] Furthermore, measures to ensure climate-resilient food systems improve food security, public health, and community development.[40] Climate-related indicators of food security can address direct availability of food (agricultural production), ability of households to purchase food (household poverty relative to food prices), and resilience to shocks (food stocks and international trade in grains). The seventh proposed indicator domain will therefore focus on food price indices and food stocks as a proxy for food affordability and availability. Other environmental and socioeconomic factors are likely to be key to understanding food security and undernutrition. To this end, the *Lancet* Countdown will seek partnership with external initiatives to fully address this interaction.

2: Health resilience and adaptation

Adaptation interventions designed to minimise the health impacts of climate change are already required. The second working group of the *Lancet* Countdown will therefore focus on the design and deployment of adaptation and resilience interventions. It will particularly draw on data collected for the WHO climate and health country profiles, including responses to surveys from national ministries of health.[19]

2.1: Integration of health into national adaptation plans

Past and ongoing human influence on the atmosphere and ecosystem means we are now committed to climate change for centuries to come. Health and related systems, such as water, sanitation, and nutrition, will need to become more resilient and adaptable to changing climate conditions, to continue to protect and promote health in a changing climate. WHO, UNFCCC and other international agencies are supporting countries to develop the health components of national adaptation plans, and promoting a comprehensive approach to build resilience into the building blocks of health and other relevant systems.[42,43] This proposed indicator will use the monitoring systems established for the SDG indicator 13.2.1, monitoring submissions to the UNFCCC, and survey responses from national ministries of health, to track the number of countries that have developed a health adaptation plan, the range of functions covered, and the extent of implementation.

2.2: Climate services for health

Informed adaptation and sustainable development requires the use of climate information for evidence-based decision making in the health sector. This endeavour depends fundamentally on the availability of relevant, high-quality climate and environmental observations, as well as the institutional and human capacity to transform climate data into reliable and

relevant climate products and services. The availability of, access to, and use of climate services are thus a cornerstone for health adaptation. These services should therefore be monitored as an indicator of the capacity of the health sector to help anticipate and prepare for climate risks, appropriately target long-term and short-term investments, and avoid potentially maladaptive choices.

For the purposes of the *Lancet* Countdown, we plan to collaborate with the World Meteorological Organization to conduct a periodic survey of national hydrological and meteorological services, to monitor the demand, availability, and provision of climate information services provided to the public and national health authorities. Categories of services surveyed could include sharing of historical climate and hydrological observations, tailored forecasts or monitoring exposure to hazardous air quality, pollen, extreme heat, floods, and storms; or provision of tailored climate scenarios and impact projections. This information will also be cross-referenced with WHO surveys of national ministries of health to measure the extent to which countries use this information to inform health surveillance and to develop early warning and response systems. An additional dimension to this indicator domain could involve analyses of national expenditure on climate information services.

2.3: Adaptation of finance for health

Health is widely recognised as a priority for adaptation. For example, over 95% of the least developed countries identified health as a priority in their UNFCCC National Adaptation Programmes for Action.[44] However, this priority is not yet reflected in financial flows, with less than 1·5% of international climate finance for adaptation directed to projects specifically addressing health.[19] This proposed indicator domain will thus use information from monitoring systems of multilateral and bilateral climate finance, including SDG indicator 13.a.1, as well as survey responses from health ministries, to measure the level of investment of international and domestic resources towards health adaptation to climate change.

3: Health co-benefits of climate change mitigation

The existence of ancillary health benefits (co-benefits) of climate change mitigation policies provides a powerful incentive to accelerate policy change, as these benefits are experienced in the near term, whereas the benefits of climate change mitigation are largely observed in the long term. As noted, however, such benefits are not automatic, and care is needed to avoid unintended adverse consequences for health. To assess progress in climate change mitigation and the potential resultant ancillary health effects (mainly co-benefits), the third working group envisions tracking nine indicators across four systems—energy, transport, food, and health care.

Here, relevant categories of data include trends in greenhouse gas emissions and short-lived climate pollutant emissions, indicators relevant to the pathways by which health co-benefits are achieved (exposure to air pollution, transport-related physical activity patterns, and dietary survey data), and regulations (eg, restrictions on polluting vehicles, energy sources, and energy performance) in sectors that are also responsible for emissions. The *Lancet* Countdown will also seek to engage with the Climate and Clean Air Coalition (CCAC) to identify potential opportunities for monitoring the mitigation of short-lived climate pollutants and associated health benefits. Country-specific trends in greenhouse gas emissions can be assessed through the UNFCCC reporting mechanisms, and notification is subject to new reporting requirements.

3.1–3.5: The energy sector

The energy sector (both production and usage) represents the largest single source of anthropogenic greenhouse gas emissions globally, producing an estimated two-thirds of such emissions.[15,45] The energy sector is also the predominant source of air pollution, with almost all globally produced sulphur dioxide and nitrogen oxide emissions, as well as around 85% of particulate matter, resulting from energy production and energy use in buildings, industry, and transport.[46]

3.1: Coal phase-out

Coal use comprises 29% of total global fuel use.[47] Globally, coal is used to generate 40% of electricity and, among all energy sources for electricity production, coal-fired energy generation contributes most (50%) to ambient air pollution (and consequently to adverse impacts on health) and to carbon dioxide emissions.[48] Coal is responsible for approximately 60% of global sulphur dioxide emissions. Coal use grew steadily until 2014, with China being the major user of coal; China has contributed to over 80% of global growth since 2000, and to approximately 50% of total global coal use.[48]

Counts of the number and capacity of coal-fired plants, their use of coal, and their emissions can be monitored, but estimates of the loss of life expectancy attributable to ambient air pollution caused by coal-fired combustion are also needed. Estimation of such burdens is theoretically possible, but requires high-quality emissions inventory data, and modelling on sources of human exposure to air pollution. These estimations are feasible in data-rich settings (primarily developed or high-income countries), but not universally. The International Energy Agency (IEA) produces market reports on coal use and forecasts for both OECD member countries and non-OECD member countries.[48] The data are derived from country-level estimates of installed capacity, fuel consumption, or power generation; the fuel mix of coal and emission standards will be used to derive estimates of coal-related air pollution. Initially, this analysis will be feasible in specific geographical locations, with the ambition to expand the work globally.

3.2: Growth in renewable energy

Globally, renewable energy from wind, solar, thermal, photovoltaic, hydropower, tidal, geothermal, biofuel, and waste sources comprised 14% of the total primary energy supply, 22% of global electricity generation, and accounted for nearly half of the new generation capacity added in 2014.[47,49] Renewable energy offers several important potential mechanisms for addressing climate change and improving health. Most forms of renewable energy produce no direct emissions related to electricity generation (with the exception of biomass) and therefore help alleviate exposure to air pollution. Renewable energy can also be deployed as a decentralised system, providing greater penetration and provision of modern energy to hard-to-reach populations and health facilities.

Growth in the use of renewable energy is primarily measured in terms of capacity and total final energy consumption. The *Lancet* Countdown plans to use this metric and the regularly published estimates of the IEA and International Renewable Energy Agency as an indicator of growth in renewable energy.

3.3: Access to clean energy

Access to adequate and clean energy supplies in households offers numerous benefits to health as well as improved life expectancy.[8,50] In 2013, the IEA estimated that around 1·2 billion people do not have access to electricity and around 2·7 billion people rely on burning unsustainable and inefficient solid fuels for cooking and heating.[47] The household air pollution that results from these fuels and other sources contributes to around 4·3 million deaths annually, which are related to pneumonia, stroke, lung cancer, heart disease, and chronic obstructive pulmonary disease.[51] Although access to electricity is increasing, with the current average national electrification rate being 83%, there is enormous variability, with urban access to electricity as low as 1–4% in South Sudan, Liberia, and the Central African Republic.[52,53]

For the purposes of the *Lancet* Countdown, the IEA and World Bank produce national statistics on metrics of energy use that are based on surveys and data provided by member countries and their own research. These metrics include energy use per capita, the percentage of the population with access to non-solid fuels, and the percentage of the population with access to electricity. The SDG indicators focus on access to non-solid fuels and electricity. The *Lancet* Countdown is also exploring the feasibility of monitoring the expansion of microgrids in low-resource settings as an important component of the expansion of renewable energy and the health effects of changes in household air pollution.

3.4: Energy access for health facilities

Access to energy is crucial for the delivery of health care. A consistent energy supply is essential for provision of adequate lighting, refrigeration and cold chain management of medicines, controlling of indoor thermal exposure, and access to hot water for washing, sterilisation, and clinical procedures. In low-income countries, health-care facilities struggle to ensure access to consistent and affordable energy. A review of health-care facilities in several sub-Saharan countries showed that, on average, 26% of the facilities examined had no access to electricity; 28% had reliable access to electricity, and 7% relied solely on generators.[54] WHO has proposed a multi-tier metric for assessing access to electricity in health-care facilities, and this metric includes peak power capacity, daily energy capacity, duration of supply, evening peak hours supply, affordability, quality, reliability, operational sustainability, environmental sustainability, and environmental health.[55] This metric has yet to be operationalised, but the *Lancet* Countdown will draw on this measure for reporting on energy access in the health-care sector where feasible.

3.5: Exposure to ambient air pollution

An estimated 18 000 people die every day because of exposure to ambient and household air pollution, making it the world's largest single environmental health risk. Potential indicators relevant to exposure to household air pollution are discussed above in indicator domain 3.3. Ambient air pollution is particularly pertinent in urban areas, but it also affects non-urban populations.[56] As figure 2 shows, about 80% of people living in urban areas around the world are exposed to air pollution levels in excess of WHO guidelines. This number rises to 98% for urban populations in low-income and middle-income countries.[46,57] Moreover, current evidence suggests that health effects occur even at concentrations below the WHO guideline levels, so reducing air pollution can be expected to lead to health benefits regardless of initial concentrations.

WHO's Global Urban Ambient Air Pollution Database now includes annual mean outdoor concentrations of the particulates PM10 and PM2·5 for almost 3000 cities. This database will thus serve as an important data source for the *Lancet* Countdown. We propose to track various indicators of urban air pollution, primarily annual mean PM2·5 or PM10, or both, together with other selected pollutants (eg, nitrogen dioxide), using data for individual cities and, where feasible, population-weighted averages for other geographical scales. As it is difficult to measure exposure to household air pollution, it may be best to use the SDG indicators 7.1.1 (Proportion of population with access to electricity) and 7.1.2 (Proportion of population with primary reliance on clean fuels and technology).

3.6 and 3.7: The transport sector

Transportation systems—including road vehicles, rail, shipping, and aviation—are a key source of greenhouse gas emissions, contributing to 14% of global greenhouse gas emissions in 2010.[46,47,58] The transport sector is also a major source of air pollutants, including particulate

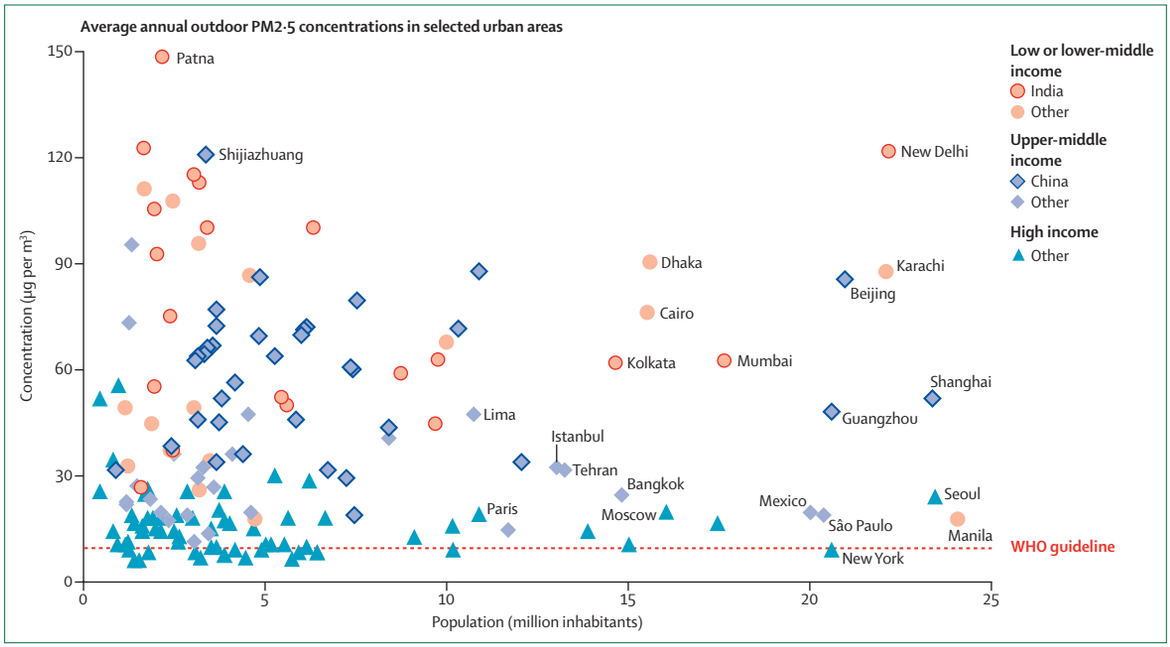

Figure 2: **Average annual outdoor PM2·5 concentrations in selected urban areas**
Reproduced by permission of IEA, 2016.[46]

matter, nitrogen oxides, sulphur dioxide, carbon monoxide, volatile organic compounds, and, indirectly, ozone. The IEA estimates that over half of global nitrogen oxide emissions are produced by the transport sector.[46]

3.6: Deployment of low-emission vehicles and access to public transport

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, in some settings, this approach might counterintuitively lead to greater concentrations of ozone because of the titration effect of nitrogen dioxide.[5] Personal exposure to traffic-related air pollution is a function of both ambient concentrations (a function of vehicle technology and other factors) and time activity patterns.[59–63] The IEA maintains a technical-economic database that includes detailed information on transport activity, vehicle activity, energy demand, and well-to-wheel greenhouse gas and pollutant emissions.[64] The IEA's Global Electric Vehicle Outlook report tracks sales of electric vehicles, and the International Council on Clean Transportation maintains a set of data tables, comparison charts, and a conversion tool for comparing passenger vehicle fuel standards. These types of databases and methods will provide the quantitative backing to this indicator domain for the *Lancet* Countdown, which will track the deployment of clean transport technology (eg, electric vehicles) and sector-specific emission factor trends at a variety of geographical scales. SDG indicator 11.2.1 (Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities) will also be tracked.

3.7: Active travel infrastructure and uptake

Decarbonisation of the vehicle fleet is essential for meeting climate change mitigation targets and improving urban air quality. However, in most settings promoting increased uptake of active travel (walking and cycling) for shorter journeys offers greater opportunity for public health benefits, as active travel can lead to appreciable improvements in levels of physical activity at a population level, with all the attendant benefits in terms of reduced risk of cardiovascular disease, selected cancers, dementia, and diabetes, as well as improvements in mental wellbeing. Although these benefits might be partly offset by increased exposure to road danger and, in some settings, increased exposure to ambient air pollution, the injury risks can be moderated by policies to improve road safety.[7]

Indicators under consideration include (where available) the proportion of journeys taken, and distance covered, on foot and on bicycles in major urban areas. Such data require travel surveys, which are routinely implemented with comparable methods only in selected (mainly high-income) settings. In these cases, data could be collected on the duration of active travel and the number of road crashes that occur. Other population health and activity data could be used to monitor how changes in active travel contribute to population health, but to date they have seldom been assessed outside research studies.

3.8: Greenhouse gas emissions from the food system and healthy diets

There is growing evidence to suggest that more sustainable food systems and dietary changes have a beneficial effect

on health. Sub-indicators under this heading will thus consider how food consumption and production affects and is affected by climate change, and will monitor the additional effects of these processes on health.

Consumption

Although all foods contribute to the emission of climate pollutants to varying extents, meat and dairy products are among those with the greatest greenhouse gas footprints. Meat and dairy products also contribute to water scarcity, land use changes, and erosion, and ultimately increase the risk of cardiovascular disease as well as some cancers (in the case of red and processed meats).[65] Emissions per unit protein produced are especially high for ruminants (cattle, goat, and sheep), compared with pork, poultry, and particularly legume production. Although tracking trends in consumption patterns—especially of meat, dairy, and vegetables—is desirable, calculation of the associated greenhouse gas emissions is particularly complex, as is the computation of any resultant health effects. In certain low-income and middle-income countries, the contribution of livestock to greenhouse gas emissions might be less substantial than in most high-income countries. Additionally, in many low-income and middle-income countries, animal products may provide an invaluable source of nutrients, particularly to children and pregnant women.[66] Measures of consumption of meat, dairy products, fruit, vegetables, nuts, and seeds, derived from standardised population dietary surveys, could be used to track average per capita changes in consumption. However, data from nationally representative surveys are not widely available. Case studies might therefore be a useful tool for highlighting the health and climate benefits of more sustainable diets.

Production

Agricultural production can be a major contributor to greenhouse gas emissions. As such, there is clear room for improvement in management of water, carbon, and nitrogen in over-fertilised regions (eg, China and India) to reduce greenhouse gas emissions and water pollution from agricultural lands and enhance environmental sustainability.[67] For example, it is estimated that in the farmlands of China, an improvement in nitrogen use efficiency from 31% to 50% would cut synthetic nitrogen use by 41%, and greenhouse gas emissions by 39%.[68] The second element of this indicator domain will therefore track changes in food production and food waste over time and the consequent impacts upon greenhouse gas emissions and health. Greenhouse gas emissions associated with agriculture (including livestock systems and biogeochemical processes) will be quantified with the use of existing models (eg, the DAYCENT or DeNitrification-DeComposition [DNDC] models).[69–71]

An understanding is needed of the potential for multiple environmental factors to affect food systems, and the nuances within and between countries and cultures. Further work will be required to refine indicators for this area, and the scientific community is invited to suggest potential metrics and data sources.

3.9: Greenhouse gas emissions of health-care systems

The health sector is a major contributor to greenhouse gas emissions, and has both a special responsibility and an appreciably measurable opportunity to lead by example in reducing its carbon footprint. Pharmaceuticals, for example, are associated with high levels of avoidable greenhouse gas emissions, and there is nearly always scope for savings in transport and procuring of goods needed to support the health-care system.[72] Such actions have already been shown to deliver health, social, environmental, and economic benefits, both immediately and in the long term. Calculation of the carbon intensity and emissions of the health sector has been achieved in England and the USA (serially in England), despite the difficulties in capturing all inputs to provide comparable data over time, place, and sub-sector.[73–75] For the purposes of the *Lancet* Countdown, we will initially collect purposive samples from countries where data are available to raise the profile of the topic within the health community locally, nationally, and globally.

4: Economics and finance

Article 2 of the Paris Agreement establishes the importance of ensuring financial flows consistent with a pathway towards a low-carbon economy. The *Lancet* Countdown's fourth working group will focus on the ways in which flows of finance and economic incentives are developing to accelerate progress on health and climate change. Indicators for this working group will fall into three broad themes: investment in a low-carbon economy; valuing the health co-benefits of climate change mitigation; and pricing the health externalities of fossil fuels.

4.1–4.3: Investing in a low-carbon economy

Having made the case for a comprehensive response to climate change and the resultant health benefits, three of the proposed indicator domains in the fourth working group will track the level of investment in a low-carbon economy—specifically, in renewable energy, energy efficiency, and innovation.

The first two indicator domains in this theme are closely linked: measuring changes in annual investments in renewable energy and in energy efficiency. In order to decarbonise the global energy system and to meet the global climate change commitments outlined in the Paris Agreement, while simultaneously managing a rise in demand for energy over the coming decades, low-carbon technologies and energy efficiency should account for around 90% of the US$2·5 trillion global annual investment required by 2035. In 2014, this value stood at 23%.[76] Data for

annual global investment in renewable energy are compiled and reported by Bloomberg New Energy Finance. Tracking annual global investment in energy efficiency, however, might be more difficult, as there is no standard, agreed definition on what constitutes investment in energy efficiency, which involves a multitude of agents (often without the use of external finance) and is difficult to disaggregate from other activities. One approach is to estimate investment in energy efficiency through modelling techniques. Further work will include discussions with the IEA and other organisations to determine the most appropriate definition and to determine how estimates of investment could be calculated. Estimates of total energy system investment are also published frequently by the IEA, allowing a proportional value for low-carbon technologies and energy efficiency to be calculated.

The third indicator domain in this group would track innovation in the low-carbon sector, by measuring annual changes in the generation of patents for low-carbon and energy-efficient technologies. Data for such calculations could be taken from various databases (eg, the European Patent Office Worldwide Database) and would capture the results of a substantial proportion of research and development efforts, and funding from both the public and private sectors.

4.4: Valuing the health co-benefits of climate change mitigation

Building on work from the third working group, the fourth indicator domain will aim to capture the costs and savings resulting from the health co-benefits of climate change mitigation across several sectors. In particular, this indicator will evaluate the health-related economic benefits (or costs) of changes in coal-based electricity generation and conventional car sales (ie, petrol and diesel), and an increase in active travel. The annual value of the health effects of ambient air pollution, principally caused by coal-based electricity generation and conventional vehicles, is estimated to be as high as \$3·5 trillion (~5% of GDP) in OECD countries, India, and China.[77] Estimates of health-related economic benefits that result from climate change mitigation policies would draw on indicators compiled and reported by the third working group (eg, coal phase-out rates, low-emission vehicle sales, and investment in active travel). Depending on the final form of the indicators presented by the third working group, these indicators could be produced either by relatively simple calculations or through the use of energy system models that compute emissions that result in local air pollution. In both cases, this indicator domain closely relates to the indicator domain corresponding to estimation of the health benefits of nationally determined contributions (NDCs) under the fifth working group; these two indicator domains will thus be jointly refined to ensure they complement each other.

4.5–4.7: Pricing the health externalities of fossil fuels

The final theme within this working group would measure whether we are getting the prices right to encourage the development of a low-carbon economy, and the resultant heath-related benefits this brings, including ensuring that that inequities are addressed. Three areas of work would fall under this theme. The first concerns the presence of subsidies (such as tax breaks) for fossil fuel production and consumption, which incentivise their use and increase relative costs of renewable alternatives. In 2014, direct fossil fuel subsidies stood at around \$490 billion—around four times the level of subsidy afforded to the deployment of renewable energy. Although the reform of such subsidies between 2009 and 2014 means that current subsidy levels are around \$117 billion lower than they would otherwise have been, much more needs to be done.[47] The need for further reform of fossil fuel subsidies is recognised in SDG indicator 12c; this SDG indicator, which assesses these subsidies, could be used by the *Lancet* Countdown's working group once it has been fully developed. However, further work will be needed to determine which definition of fossil fuel subsidies could be suitability used for the purposes of the *Lancet* Countdown.

The second indicator domain in this theme would cover the spread and strength of carbon pricing, which seeks to internalise the market externality of carbon dioxide and other greenhouse gas emissions globally. Carbon pricing instruments currently cover around 12% of global greenhouse gas emissions, although with wide-ranging values (from under \$1 per tonne of carbon dioxide equivalent [tCO_2e] to around \$130/tCO_2e).[78] This indicator might consist of two elements: the change in (and absolute level of) the proportion of global greenhouse gas emissions to which carbon pricing is applied, and the change in (and absolute value of) the weighted-average global carbon price. These data might be drawn directly from, or calculated on the basis of, the World Bank's annual State and Trends of Carbon Pricing report.

The development of such indicators will complement the indicator domains tracking the level of investment in a low-carbon economy. Although the reduction of fossil fuel subsidies and increase in the spread and strength of carbon pricing pushes the flow of finances towards the deployment and development of low-carbon and energy-efficient technologies and measures, other policies such as renewable energy subsidies help to pull the finance flow towards such investments. The indicator domains tracking the level of investment in a low-carbon economy will implicitly measure the impact generated by both influences.

The issues reported thus far do not address potential concerns surrounding the equity of the low-carbon transition, with carbon pricing on fuels having potentially regressive impacts. These impacts might be dampened or avoided with appropriate public policies, such as environmental tax reform. Environmental tax reform

involves shifting the burden of tax from so-called "goods", such as labour, environmentally beneficial products, or actions, to so-called "bads", such as pollution. Such a shift in economic incentives could, when well designed, produce a double dividend of environmental improvement with social and economic benefit.[79] As such, the third indicator domain under this theme concerns the use of revenue generated by carbon pricing instruments, with qualitative consideration for the intended end use of this revenue. Further work is required to determine whether revenue from the reduction of fossil fuel subsidies might also be included in this indicator.

5: Political and broader engagement

The fifth working group will focus on the broader context within which progress on health and climate change is being made. These indicator domains will track the implementation of political commitments within the UNFCCC, alongside analysis of scientific and public engagement with health and climate change, which provide both background and context for policy implementation.

5.1: Public engagement with health and climate change

Globally, public engagement with climate change is mixed. In two surveys of a range of high-income, middle-income, and low-income countries, most people considered that climate change was a "very serious problem" and "a major threat", and would have a direct impact on the conditions for health.[80,81] Asked when they thought climate change would start to substantially harm people in their country (now, in 10 years, in 25 years, in 50 years, in 100 years, or never), the majority of respondents in most countries thought that their citizens were being substantially harmed now. Figure 3 presents the proportions responding "now" and "in 10 years". As insufficient understanding of climate change is one of the largest perceived barriers to individual engagement, it is an important finding that the framing of climate change as a public health issue enhances engagement.[82–84]

The *Lancet* Countdown will bring together evidence on changes in public understanding relating to health and climate change—more specifically, in terms of the perceived threats and opportunities of the responses. One possible long-term but resource-intensive approach would be to use phone-based and online public opinion polling techniques across a range of countries and settings. In the interim, the *Lancet* Countdown proposes to undertake an annual analysis of social media to build a broad understanding of public perceptions and track the evolution of public engagement and knowledge. The *Lancet* Countdown's social media analysis will track levels of public engagement with health and climate change over time and identify (1) key events that cause spikes in engagement; (2) whether such spikes result in longer-term engagement; and (3) countries where engagement is particularly high or low.

5.2 and 5.3: Academic publications on health and climate change, and inclusion of health and climate change within medical and public health curricula

The *Lancet* Countdown will also track scientific engagement with health and climate change. Annual reviews of published scientific articles, with the use of a bibliometric search relating to the terms "climate" and "health", could provide a potentially useful indicator, showing research trends and coverage. Historical trends and research gaps, including disciplinary and geographical focus, could also be explored. This study will provide a more extensive and inclusive overview than previously published reports and reviews, and could also be a useful resource for informing future research funding by identifying gaps and priorities. A study protocol for this scoping review has been written and accepted for publication.[85]

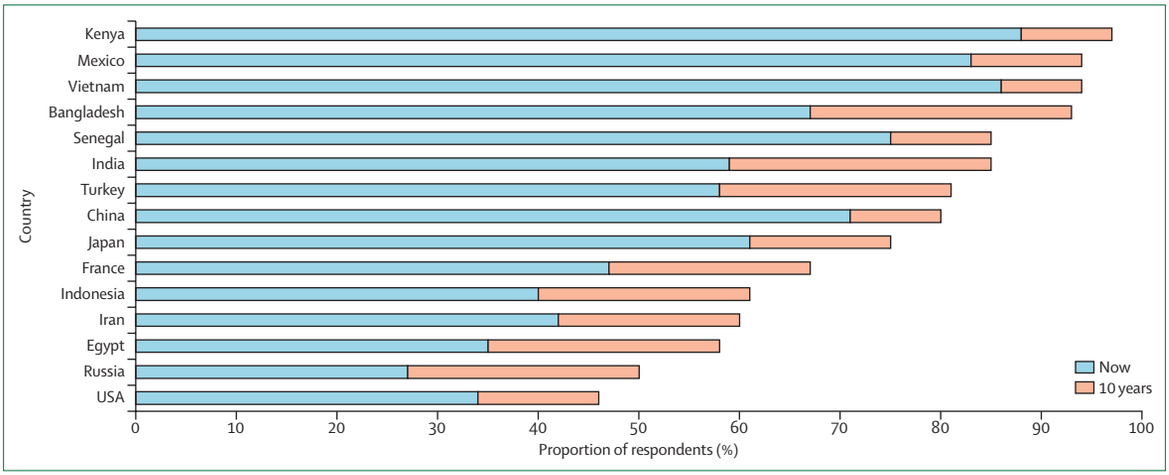

Figure 3: **Proportions of the population who regard climate as substantially harming people in their country now or within 10 years**
Source: World Bank Group, 2009.[81]

To accompany an analysis of the academic literature, the *Lancet* Countdown will also follow the extent to which health and climate change is incorporated into the educational curricula of health professionals (initially focusing on medical professionals) around the world. This analysis would determine not just the inclusion of climate change in these curricula but also the emphasis on these issues (for example, whether this subject matter is mandatory or optional). This could be used to provide background context, rather than as an indicator in its own right.

5.4 and 5.5: Health and climate change in high-level statements of the UNFCCC and UNGA, and implementation and estimated health benefits of the NDCs

At the international level, the UNFCCC negotiations and the Paris Agreement provide an important framework for mitigation and adaptation policies. The final two indicator domains would look to provide an overview of the extent to which human health and wellbeing is considered within these political processes. The penultimate indicator domain would examine the inclusion of health within the transcripts of high-level statements delivered at the UNFCCC's annual Conference of the Parties (COP), and the UN General Assembly. A database of COP transcripts has been compiled on an ad hoc basis and would require additional work, but a database of the UN General Assembly transcripts is readily available. The *Lancet* Countdown would analyse high-level statements to monitor how the inclusion and framing of health and climate change evolves over time. This work could be back-dated to include historical high-level statements, thus providing a longer time series for the analysis.

The final indicator domain for the *Lancet* Countdown will estimate the health benefits or disadvantages of the NDCs. Initially, the NDCs and subsequent reports to the UNFCCC will be explored for substantive references and considerations of the association between public health and climate change. Over time, it is hoped that the potential health co-benefits of mitigation, from a reduction in air pollution, could be modelled. This would be conducted in a similar way to the analysis conducted by Höhne and colleagues[86] in their 2015 assessment. Many of these changes could be captured by the UNFCCC's non-state actor zone for climate action (NAZCA) process—a potential source for future indicators and monitoring.

Conclusion

The *Lancet* Countdown is an international, multidisciplinary research collaboration dedicated to tracking progress on health and climate change from 2016 to 2030. It will be governed by a board comprising the research leads for each working group, and coordinated by a smaller executive team responsible for supporting the working groups to deliver and communicate the academic content. Over the coming months, the Countdown will work to establish an international advisory board, to provide strategic direction to the process and assist with policy and stakeholder engagement. This advisory board will be made up of academics and senior experts on health and climate change from a broad range of geographical regions.

The indicators and indicator domains proposed in this paper are intended to form the foundation of our process, and will be further refined and developed over the coming months and throughout the *Lancet* Countdown's process. We invite ongoing direct input on the content, methods, and data relating to each of these indicators, through the forms available on the *Lancet* Countdown website.

Contributors

The *Lancet* Countdown: *tracking progress on health and climate change* is an international academic collaboration that builds on the work of the 2015 *Lancet* Commission on health and climate change, and is convened by *The Lancet*. The Countdown and the work for this paper was conducted by five working groups, which were responsible for the design, drafting, and review of their individual sections. All authors contributed to the overall paper structure and concepts, and provided input and expertise to the relevant sections. Authors contributing to Working Group 1: W Neil Adger, Peter Cox, Michael Depledge, Anne Johnson, Lu Liang, Mark Maslin, Kris Murray, and Elizabeth Robinson. Authors contributing to Working Group 2: Sonja Ayeb-Karlsson, Peter Byass, Diarmid Campbell-Lendrum, Paula Dominguez-Salas, Delia Grace, Ilan Kelman, Sari Kovats, Georgina Mace, Karyn Morrissey, Tara Neville, Joy Shumake-Guillemot, and Yongyuan Yin. Authors contributing to Working Group 3: Michael Davies, Andy Haines, Ian Hamilton, Melissa Lott, Robert Lowe, Tadj Oreszczyn, Paolo Vineis, Paul Wilkinson, and Jun Yang. Authors contributing to Working Group 4: Paul Drummond and Paul Ekins. Authors Contributing to Working Group 5: Anneliese Depoux, Antoine Flahault, Hilary Graham, Yong Luo, Christine Parthemore, David Pencheon, Maria Nilsson, and Stefanie Schütte. In addition to this, the following authors provided integrating contributions across multiple working groups: Yuqi Bai, Tim Colbourn, Bing Xu, and Chaoqing Yu. The paper was prepared under the general direction of Anthony Costello (Co-Chair), Hugh Montgomery (Co-Chair), Peng Gong (Co-Chair), and Nick Watts (Executive Director), with editorial support from Nicola Wheeler. The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of WHO or the World Meteorological Organization.

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