Court of Appeal File No. C65807

COURT OF APPEAL FOR ONTARIO

IN THE MATTER OF A REFERENCE to the Court of Appeal pursuant to section 8 of the *Courts of Justice Act*, RSO 1990, c. C. 34, by Order-in-Council 1014/2018 respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act*, *No. 1,* SC 2018, c. 12

RECORD OF THE INTERVENOR, INTERGENERATIONAL CLIMATE COALITION (GENERATION SQUEEZE ET AL)

(Reference returnable April 15-18, 2019)

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AFFIDAVIT OF PAUL KERSHAW
AFFIRMED ON DECEMBER 18, 2018
FILED ON BEHALF OF THE INTERVENOR,
INTERGENERATIONAL CLIMATE CO

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AFFIDAVIT OF PAUL KERSHAW

I, PAUL KERSHAW, of 440 – 2206 East Mall, Vancouver, British Columbia, V6T 1Z3,

AFFIRM THAT:

1. I have personal knowledge of the facts and matters deposed to in this affidavit except where the same are stated to be on information and belief, in which case I believe those facts to be true.

2. I am an Associate Professor at the University of British Columbia ("UBC")'s School of Population and Public Health and the founder of Generation Squeeze, a national non-profit organization that seeks to raise awareness of, and address, generational inequities to effect federal and provincial public policy.

3. I make this Affidavit in support of the Intergenerational Climate Coalition's application for leave to intervene in this matter, to assist the court in this matter, and for no improper purpose.

Generation Squeeze – A Voice for Young Canadians

4. Generation Squeeze is a voice for young Canadians, the children they raise and future generations. Our mission is to understand the challenges facing young people in Canada and to identify and advocate for policy solutions to address these inequalities.

5. We have over 30,000 supporters across Canada – almost half in central Canada – and use cutting-edge research to identify and address the disproportionate burdens facing Canadian youth. An important area of our research is the impact of resource use and waste on future generations, including the impacts of climate change.

Research from the Generation Squeeze Lab at UBC

6. The research I coordinate at the Generation Squeeze Lab out of UBC's School of Population and Public Health assesses the intergenerational fairness of public finance decisions.

7. Our research has revealed how, contrary to common understanding, Canadian youth are not favoured by public policy. Canadian governments have not prioritised intergenerational justice, instead Canadian governments have:

   (a) Increased annual per capita spending and social investments for Canadians over 65 years of age 4.2 times faster than for Canadians under 45 years of age;

   (b) Responded to demographic changes for older Canadians more generously than for younger Canadians, increasing annual spending on medical care and retirement security for those over 65 by $92 billion, while only increasing postsecondary and childcare spending by $2.7 and $3.6 billion. This relative lack of investment in childcare is why Canada ranks among the bottom of OECD countries for investment in early childhood education;

(c) Failed to ensure that social spending on younger Canadians keeps pace with economic growth. Spending per person over 65 has grown 6% faster than economic growth while spending per person under 45 has grown 29% slower than economic growth; and

(d) Allowed health care spending to exceed other social spending, despite evidence that the conditions in which Canadians are born, grow, live, work and age drive health, not the provision of medical care.

Meanwhile, baby boomers enjoy on average a higher standard of living than previous generations because of their accumulation of housing wealth, while the earnings of young Canadians have lost ground relative to home prices. Attached hereto, and marked as **Exhibit "A"** is a copy of my Written Submission for the Pre-Budget Consultations in Advance of the 2019 Federal Budget, submitted to the House of Commons, informed by my paper, "International Justice in Public Finance: A Canadian Case Study", which was published in the journal *Intergenerational Justice Review* this year.

8. I have received national and provincial awards in recognition of my research into intergenerational equities, particularly for my recent work on housing affordability in BC and Ontario. Attached hereto and marked as **Exhibit "B"** is a copy of my curriculum vitae.

Disproportionate Impacts of Greenhouse Gas Emissions on Canadian Youth

9. Urged by our members, who identified climate change as one of their top concerns, Generation Squeeze has become increasingly engaged in the issue of how the challenges already facing young Canadians will be exacerbated by the impacts of climate change as they are being left with larger environmental debts and a lower quality of life than previous generations.

10. Generation Squeeze's concerns about the disproportionate impacts of climate change on Canadian youth are also supported by my research that has revealed the unfair burden placed on Canadian children and youth to reduce their ecological footprint – a measurement of the impact of human consumption on the biosphere. Canadian children and youth must decrease their ecological footprint (and associated consumption) at three times the pace of older Canadians if we are to live within the means of our planet's resources. This reality is exacerbated by unequal public finance decisions which privilege older Canadians over young Canadians. Attached hereto and marked as **Exhibit "C"** is a copy of my paper "Intergenerational Justice in Public Finance: A Canadian Case Study", published in the journal *Intergenerational Justice Review* this year.

11. These disproportionate impacts also include greater health risks. *The Lancet*, one of the most prestigious health journals on the planet, has identified climate change as the most serious challenge to human health, and recognized that addressing climate change is the greatest opportunity to protect public health. Climate change will cause a variety of physical changes, including the inexorable rise of sea levels, caused by the annual loss of 159 billion tons of ice from the Antarctic ice sheet, extreme temperatures and extreme

weather that pose a range of threats to human health and survival. Young children are a specific subpopulation that will bear the greatest burden of these risks in all regions. *The Lancet* also identifies the significant investments and costs of adaptation – up to $1 trillion per year – required to have an 80% chance of achieving climate stabilisation. Attached hereto and marked as **Exhibit "D"** is a copy of *The Lancet* article from 2015 entitled "Health and climate change: policy responses to protect public health."

12. It is well established that climate change is a cumulative problem. As more greenhouse gas ("GHG") emissions are released, the economic, environmental and public health effects will get worse. An October 2018 report by the Intergovernmental Panel on Climate Change (the "IPCC") indicates that:

   (a) If warming beyond 1.5°C is not avoided the environmental and other impacts will be much more severe; and

   (b) A failure to limit total cumulative global emissions today means extreme reductions are required in the future to limit warming to 1.5°C or even 2°C.

In other words, failures to reduce GHG emissions today will cause more severe impacts and will require more extreme reductions by young Canadians in the future. Attached hereto and marked as **Exhibit "E"** is an excerpt from the IPCC report entitled "Global Warming of 1.5 °C – Summary for Policy Makers". The entire report can be accessed at https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_High_Res.pdf.

13. If left unabated, GHG emissions pose an existential threat to humanity, a burden that future generations will be forced to bear. A paper published in the *Proceedings of the*

National Academy of Sciences of the United States of America, a prestigious and peer-reviewed scientific journal, in July 2018 analyzes a planetary threshold that, if crossed, could prevent stabilization of the climate and allow warming to continue even as GHGs are reduced. Based on this framework, the authors argue that:

> social and technological trends and decisions occurring over the next decade or two could significantly influence the trajectory of the Earth System for tens to hundreds of thousands of years and potentially lead to conditions that resemble planetary states that were last seen several millions of years ago, conditions that would be inhospitable to current human societies and to many other contemporary species.

Attached hereto, and marked as **Exhibit "F"** is a copy of that paper by Steffen et. al, titled "Trajectories of the Earth System in the Anthropocene".

14. Based on this, and other research, I believe climate change is a critical threat to the health and well-being of Canadians, now and into the future, and that the economic, health and environmental costs of climate change will fall most heavily on young people, the children they raise, and future generations. Generation Squeeze is critically concerned about these impacts on young Canadians, particularly given the generational inequities our research shows they already face. Generation Squeeze believes this constitutes unacceptable discrimination against young Canadians and future generations.

The Need for a National Backstop Price on Greenhouse Gas Emissions

15. Pricing carbon is widely recognized as a critical policy tool in reducing GHGs and reducing the threats climate change poses to Canadian youth, children and future generations.

16. *The Lancet* 2015 article, attached at Exhibit D to this affidavit, explains that pricing GHG emissions is required to challenge and change the deeply entrenched use of fossil fuels causing climate change, and that a GHG price is the measure economists prefer to address GHG emissions.

17. In 2015, more than 60 Canadian scholars from every province, with particular expertise in climate change and academic specialties ranging from engineering to sociology, unanimously recommended putting a price on carbon, in addition to a number of other viable solutions for GHG reductions in Canada. Attached hereto and marked as **Exhibit "G"** is an excerpt from the paper "Acting on Climate Change: Solutions from Canadian Scholars." The entire paper can be accessed at https://www.crcresearch.org/sites/default/files/u443/en_15mars_17h_lowres.pdf

18. In March 2015, Generation Squeeze officially endorsed this paper, and its recommendations including pricing carbon, with the objective of reducing the environmental burdens on young Canadians that will be caused by climate change. Our endorsement identified how citizens over the age of 45 are much more likely to vote than younger Canadians and how:

> [t]his age pattern in voting and political organization poses a major barrier to the translation of research about climate change into budgets and policy adaptations, because the risks of inaction to reduce GHGs are born primarily by younger stakeholders, and the families they will be raising in the middle of this century.

A copy of Generation Squeeze's formal endorsement of the paper, "Acting on Climate Change: Extending the Dialogue Among Canadians", is attached hereto as **Exhibit "H".**

19. The Nobel-prize winning economist William Nordhaus highlights the difficulty of ensuring collective action needed to reduce GHG emissions. Nordhaus identifies the concepts of:

(a) Free-riding, which occurs when parties rely on the emission reductions of others without contributing to the costs of reductions themselves; and

(b) Temporal free-riding occurs when present generations benefit from consumption with high carbon emissions, while future generations pay for those emissions in lower consumption or a degraded environment.

Attached hereto and marked as **Exhibit "I"** is an excerpt from the paper by William Nordhaus, titled "Climate Clubs: Overcoming Free-riding in International Climate Policy." The entire paper can be accessed at https://pubs.aeaweb.org/doi/pdf/10.1257/aer.15000001.

20. The United Nations Environment Programme ("UNEP") regularly assesses the "emissions gap" between where GHG emissions are likely to be and where we need them to be. In its Emissions Gap Report 2018, released in November 2018, the UNEP found that Canada is not on track to meet its commitments under the Paris Agreement. Attached hereto and marked as **Exhibit "J"** is an excerpt from the UNEP Emissions Gap Report 2018. The entire report can be accessed at http://wedocs.unep.org/bitstream/handle/20.500.11822/26895/EGR2018_FullReport_EN.pdf?isAllowed=y&sequence=1.

21. Generation Squeeze is concerned about both temporal free-riding and free-riding by jurisdictions, including certain provinces. Collective action is urgently needed for a price on GHG emissions to successfully reduce the unequal burden that has been placed on young Canadians and future generations. A federal backstop is essential to intergenerational solidarity that ensures Canadian youth and future generations are not left cleaning up, and living with, the mess caused by those who came before them.

The Intergenerational Climate Coalition

22. On the basis of the above, and additional research by both myself and other academics and organizations, I believe that climate change is the greatest threat to the quality of life of young Canadians and future generations. Putting a federal price on GHG emissions is a critical component of addressing these threats and reducing the intergenerational inequities climate change will exacerbate.

23. We seek leave to intervene in a manner that is consistent with our commitment to intergenerational justice on climate policy. For this reason, we have formed the Intergenerational Climate Coalition consisting of the:

(a) Saskatchewan Public Health Association;

(b) Public Health Association of British Columbia;

(c) Youth Climate Lab;

(d) Canadian Coalition for the Rights of Children ("CCRC"); and

(e) Canadian Association of Physicians for the Environment ("CAPE");

(collectively, the "Coalition").

24. On December 10, 2018, the Coalition was granted leave to intervene in the reference case regarding the constitutionality of the *Greenhouse Gas Pollution Pricing Act* in the Saskatchewan Court of Appeal.

25. The Saskatchewan Public Health Association is a non-profit organization that, for over 60 years, has promoted the health of people of Saskatchewan. Attached hereto and marked as **Exhibit "K"** is a copy of the December 17, 2018 letter of support I received from the Saskatchewan Public Health Association.

26. The Public Health Association of British Columbia is a non-profit organization whose mission is to promote health, well-being and equity for all British Columbians, including future generations, through leadership in public health. Attached hereto and marked as **Exhibit "L"** is a copy of the December 14, 2018 letter of support I received from the Public Health Association of British Columbia.

27. The Youth Climate Lab is an Ottawa based organization dedicated to supporting and creating youth-driven, innovative projects for climate action. Recognizing that today's youth will inherit the consequences of climate policy decisions being made now, Youth Climate Lab joined the Intergenerational Climate Coalition. Attached hereto and marked as **Exhibit "M"** is a copy of the December 16, 2018 letter of support I received from the Youth Climate Lab.

28. The CCRC is a network of organizations and individuals who promote respect for the rights of children, with an emphasis on the United Nations' Convention on the Rights of the Child. Attached hereto and marked as **Exhibit "N"** is a copy of the December 17, 2018 letter of support I received from the CCRC.

29. That letter from the CCRC referred to "General comment No. 15 (2013) on the right of the child to the enjoyment of the highest attainable standard of health (art. 24)" by the UN Committee on the Rights of the Child, which elaborates the right to the enjoyment of the highest attainable standard of health under the Convention on the Rights of the Child and provides guidance to states on how to implement that right. General Comment No. 15 recommends, among other things, that states should "put children's health concerns at the centre of their climate change adaptation and mitigation strategies"." Attached hereto and marked as **Exhibit "O"** is an excerpt from General Comment No. 15. The entire General Comment No. 15 can be accessed at https://www2.ohchr.org/english/bodies/crc/docs/GC/CRC-C-GC-15_en.doc.

30. That letter from the CCRC also referred to the May 2017 "Analytical study on the relationship between climate change and the full and effective enjoyment of the rights of the child" from the Office of the United Nations High Commissioner for Human Rights, which found, among other things that all children are exceptionally vulnerable to the negative impacts of climate change, including the increasing frequency and intensity of natural disasters, changing precipitation patterns, food and water shortages, and the increased transmission of communicable diseases. Attached hereto and marked as **Exhibit "P"** is an excerpt from that May 2017 analytical study. The entire study can be accessed at https://undocs.org/en/a/hrc/35/13.

31. That letter from the CCRC also referred to the January 2018 "Report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment" from the Special Rapporteur on human

rights and the environment to the United Nations General Assembly Human Rights Council. That report found that, among other things:

(a) no group is more vulnerable to environmental harm than children, and environmental harm has especially severe effects on children under the age of five;

(b) a healthy environment is necessary for children's enjoyment of the rights to life, development and health; and

(c) the cumulative effects of long-term environmental harm, such as climate change and the loss of biodiversity, increase over time, so that decisions taken today will affect children much more than adults.

Attached hereto and marked as **Exhibit "Q"** is an excerpt from the Special Rapporteur report referred to in that letter. The full Special Rapporteur report can be accessed at http://undocs.org/A/HRC/37/58.

32. CAPE is a national organization of health professionals that seeks to protect human health by protecting the environment. Attached hereto and marked as **Exhibit "R"** is a copy of the December 14, 2018 letter of support I received from CAPE.

33. That letter from CAPE referred to the 2017 *Lancet* Countdown: Tracking Progress on Health and Climate Change report, which found, among other things, that the delayed response to climate change over the past 25 years has jeopardised human life and livelihoods. Attached hereto and marked as **Exhibit "S"** is an excerpt from the 2017

Lancet Countdown Report. The full 2017 Lancet Countdown Report can be accessed at https://www.thelancet.com/action/showPdf?pii=S0140-6736%2817%2932464-9.

34. That letter from CAPE also referred to the *Lancet Countdown Policy Brief: Canada in 2018*, on which the President of CAPE was the lead author. That 2018 Lancet Canada Policy Brief noted that, among other things:

(a) trends in climate change impacts, exposures, and vulnerabilities demonstrate an unacceptably high level of risk for the current and future health of populations across the world;

(b) children and pregnant women are among populations that are especially vulnerable to the effects of climate change; and

(c) Canada's GHG emissions increased more than 100 megatonnes between 1990 and 2016.

Attached hereto and marked as **Exhibit "T"** is an excerpt from that 2018 Lancet Canada Policy Brief. The full 2018 Lancet Canada Policy Brief can be accessed at https://cape.ca/wp-content/uploads/2018/11/2018-Lancet-Countdown-Policy-Brief-Canada.pdf.

AFFIRMED BEFORE ME at the City of North Vancouver, in the Province of British Columbia, on the 18th day of December, 2018.	))))
A Commissioner for taking Affidavits for British Columbia	) PAUL KERSHAW)))

Nathan Hume

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GENERATION **squeeze**

Written Submission for the Pre-Budget Consultations in Advance of the 2019 Federal Budget.

By: Dr. Paul Kershaw of the University of B.C. on behalf of Generation Squeeze.

Generation Squeeze is a voice for younger Canadians in politics and the market, supported by cutting-edge research
www.gensqueeze.ca

August 1, 2018

This is Exhibit "A" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

....
A Commissioner for taking Affidavits within British Columbia

Recommendations for Economic Growth: Ensuring Canada's Competitiveness

Since the growing ratio of elderly citizens relative to those in the paid workforce dampens economic growth, and enhancing productivity from younger Canadians is necessary to maintain national competitiveness as the population ages, Generation Squeeze recommends:

1. That the government ***report age patterns in its spending and revenue collection since 1976***, when today's aging population started out as young adults.
2. That the government ***report changes in the ability to pay of younger and older Canadians today by comparison with the same age groups four decades earlier*** to support MPs to evaluate the age trends in government spending and revenue collection.
3. That the government devote ***time of one staff person in the Ministry of Finance*** to perform this reporting using existing budget information, and historical data from Statistics Canada. A peer-reviewed, academic methodology to perform this reporting is included as a link to support Finance staff to conduct this work.
4. That the government ***grow annual combined spending on child care and parental leave as of 2022 by at least one-third of the amount it grows annual spending on Old Age Security over the same period.***
5. That the government use the Department of Finance's review of federal tax expenditures as an opportunity to ***review the Age and Pension Income credits*** to confirm they remain the most target-efficient uses of public spending as the budget for old age security grows, as well as ***the tax treatment of housing wealth***. The latter is a growing source of inequality between younger and older Canadians. Revisions to the tax treatment of housing wealth could pay for cuts to income taxes to improve Canadian competitiveness, while narrowing the gap between earnings and housing costs.

Background

Canada is adapting to an aging population. Whereas there were nearly seven workers for every senior in 1976 when today's aging population started as young adults, there are now four workers and soon there will be fewer than three (Statistics Canada 2014). Population aging slows economic growth, and recent research finds that a 10% increase in the population over age 60 decreases GDP growth per person by 5.5% (Maestas, Mullen & Powell 2016). Such evidence underscores the need for public policy makers to anticipate the health and financial needs of a growing group of retirees while also adapting to new challenges facing younger generations and investing in their productivity to maintain national competitiveness.

Canadians are hindered in planning optimally for these demographic and economic changes because government budget documents do not report spending and revenue trends by age. Whereas the European Union now provides member countries with analyses of intergenerational trends in public finance every three years, currently no senior level of government in Canada provides public finance data broken down by age. **Generation Squeeze recommends that the Canadian government begin reporting age trends in public finance starting in 2019.** Reporting should compare today to 1976 (when today's aging population started out as young adults), and account for inflation and economic growth in line with the four themes identified below. By doing so, age analyses would be integrated as part of the "+" in the government's recent commitment to GBA+ (Gender-Based Analyses+) to inform budget decisions. (For more information on why Generation Squeeze recommends age comparisons in public finance, see: https://www.gensqueeze.ca/why_we_make_generational_comparisons)

A Peer-Reviewed Methodology to Follow

The Generation Squeeze Lab, led by Dr. Paul Kershaw at the University of BC, has prepared a peer-reviewed methodology for the Government of Canada to adapt (see "Intergenerational Justice in Public Finance: A Canadian Case Study" at https://www.gensqueeze.ca/intergenerational_injustice_in_canadian_public_finance). The study examines public finance data in 2016 compared to 1976 in light of four themes:

a) Change in the ratio of social spending for those age 65+ relative to those under age 45
b) Change in taxes paid for OAS and Medical Care for those age 65+
c) Ability to pay of different age groups, now and in the past
d) Sustainability measured as government debt per person under age 45 and the ecological footprint measured per capita

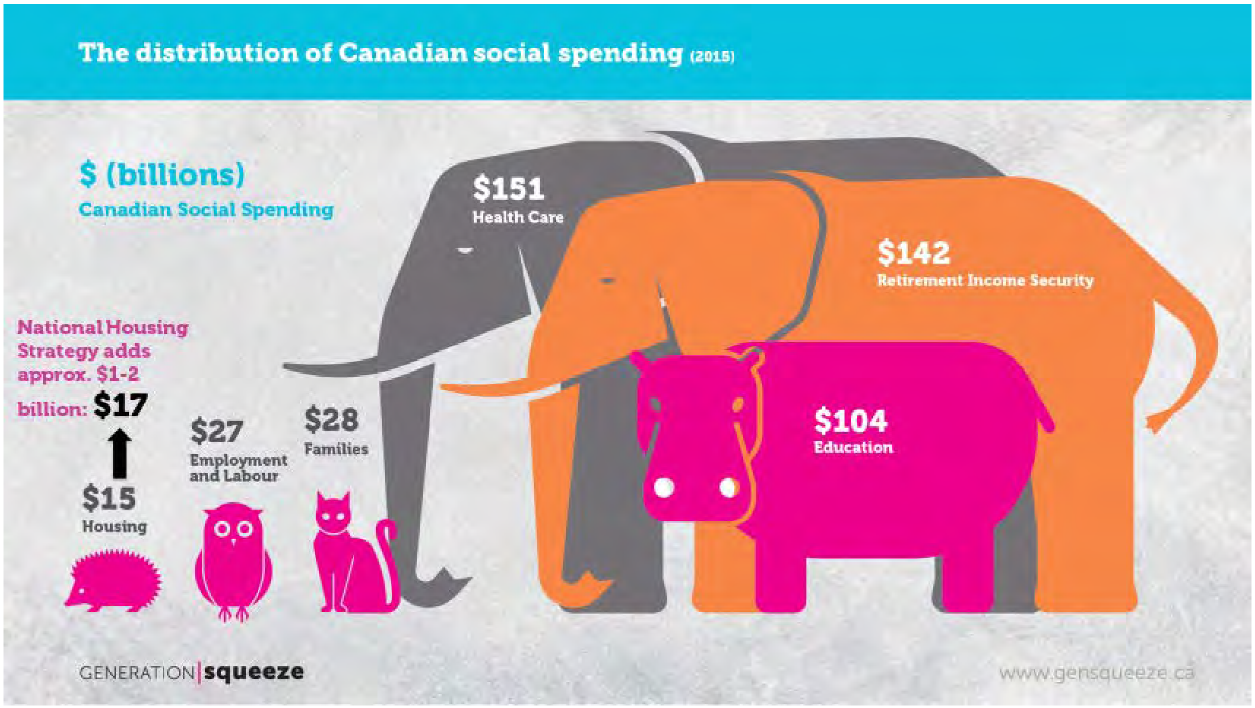
It is possible to update these analyses for the 2019 budget with time from one Finance staff person. The most recent data show:

Spending: 1976-2016

- *Spending has grown faster for those age 65+.* Governments increased annual per capita spending for seniors 4.2 times faster since 1976 than for those under the age of 45.
- *Governments responded to demographic changes for older Canadians more generously than for younger Canadians.* The 4 million increase in seniors today compared to 1976 coincided with a $92 billion increase in annual spending on medical care and retirement security for those over 65. By contrast, the 4.6 million increase in Canadians under age 45 who have postsecondary credentials coincided with little change to postsecondary spending – up $2.7 billion. Similarly, there are 2.3 million more women age 25-44 in the

labour force. Despite the resulting increase in demand for child care, annual spending on this budget line grew approximately $3.6 billion.

- *Social spending on younger Canadians hasn't kept pace with economic growth.* Since 1976, spending per person age 65+ grew 6% faster than economic growth. By contrast, spending per person under age 45 grew 29% slower than economic growth, or $1,052 less per person under age 45. This equals $21.3 billion less in annual spending when multiplied by all the people under age 45 – a sum that represents enough to fund, for example, a high-quality, universal childcare programme twice over, or nearly a 50% increase to the post-secondary budget.
- *Governments allowed health care spending to leave other social spending behind.* Governments have disproportionately used economic growth over the past four decades to invest in medical care. However, new research affirms that health does not start with health care. Health starts with the conditions into which Canadians are born, grow, live, work and age – conditions that are shaped by social spending on income security or major costs like child care, housing, time at home with newborns, education, etc. New research affirms that Canadian governments are more likely to improve life expectancy, and reduce preventable mortality, by ensuring that social spending keeps pace with medical spending (Dutton et al. 2018).



Revenue: 1976-2016

- *Canadian governments have prioritized cuts to income tax rates.* In addition to prioritizing investments in medical care and retirement income, Canadian governments used economic growth since 1976 to reduce income tax rates, particularly for middle and higher earners.
- *Younger Canadians today pay more in income taxes toward the elderly.* Despite the shift to lower income tax rates, the dramatic growth in spending on medical care and old age security means that public finance requires younger Canadians to contribute 22%-62% more in income taxes for the elderly now by comparison with 1976. Not only do these revenue trends leave less fiscal room to adapt to new challenges facing younger residents (like the much larger gap between home prices and median earnings, or climate change),

they require younger citizens to pay thousands of dollars more over their working lives toward benefits for the aging population than the latter paid on behalf of their elders.

Ability to Pay: 1976-2016

Prioritizing larger spending increases for retirees and asking more in taxes for such programs from today's younger Canadians may be appropriate if the latter have a greater ability to pay compared to when today's aging population started out as young adults. However, data reveal that the contemporary aging population has a greater ability to pay than cohorts immediately before and after them.

- *Seniors today have more prosperity on average than did elderly Canadians four decades ago.* They have lower levels of poverty, higher median earnings, and more wealth in their homes.
- *Older Canadians today also generally encountered more favourable socioeconomic circumstances as younger adults in 1976 than do younger Canadians now*. Older Canadians started with higher median earnings, which could stretch further when paying for rent, saving for a down payment, and paying a mortgage.

Sustainability: 1976-2016

- *Young people inherit larger debts today than four decades earlier.* Government debt has grown from $15,000 per person under 45 in 1976 to over $44,000 today.
- Today's seniors reduced their ecological footprint at one-third of the rate that young adults must now do given the risks of climate change.

Age Trends in the 2018 Federal Budget

The 2018 federal budget projects a $16.1 billion annual increase in spending on old age security (OAS) as of 2022 (Government of Canada 2018a, p. 324). By contrast, annual spending on child care is projected to increase $540 million, while spending on parental leave will increase by $330 million (Government of Canada 2018a, pp. 332-335 and 351). Since supporting parental attachment to the labour market and work-life balance are important for enhancing the productivity of today's younger Canadians, ***Generation Squeeze recommends that the federal government grow annual combined spending on child care and parental leave as of 2022 by at least one-third of the amount it grows annual spending on Old Age Security over the same period.***

As the Finance department continues to review federal tax expenditures, attention should be given to the Age credit, Pension Income credit, and Pension Income Splitting credit. These expenditures are projected to cost the federal government, respectively, $3.83 billion, $1.31 billion and $1.415 billion in 2019 (Government of Canada 2018b). Generation Squeeze recommends that the government ***review these expenditures to confirm they remain the most target-efficient uses of public spending as the budget for OAS grows faster than any line item in the federal budget***.

When evidence emerges of intergenerational imbalance in public finance, the search for policy responses should target cleavages between age groups. A current cleavage is the gap between home prices and earnings, which reduces the ability to pay among young adults, while driving wealth accumulation for many seniors. An extensive international literature observes that residential property often enjoys favourable tax treatment, including in Canada. For example, capital gains from the sale of principal residences are not counted as income for tax purposes, representing a federal tax expenditure of $6 billion in 2019 (Government of Canada 2018b), and corresponding reductions for provincial coffers. Simultaneously, annual revenue from municipal property taxation is down $4.4 billion as a share of GDP compared to 1976 (Kershaw 2018). ***Generation Squeeze encourages the federal government to review the tax treatment of high value homes*** as an opportunity to pay for cuts to income taxes, narrow the gap between earnings and housing costs, grow revenue for old age security, and pay for policy investments in younger generations as part of a national growth and competitiveness strategy.

References

Dutton, Daniel J, Pierre-Gerlier Forest, Ronald D Kneebone, and Jennifer D Zwicker. 2018. "Effect of provincial spending on social services and health care on health outcomes in Canada: an observational longitudinal study." *Canadian Medical Association Journal* 190 (3):E66-71.

Government of Canada. 2018a. “Budget 2018: Equality & Growth.” Department of Finance, https://www.budget.gc.ca/2018/home-accueil-en.html

Government of Canada. 2018b. "Report on Federal Tax Expenditures: Concepts, Estimates and Evaluations." Department of Finance, https://www.fin.gc.ca/taxexp-depfisc/2018/taxexp-depfisc18-eng.pdf.

Kershaw, Paul. 2018. “Intergenerational Justice in Public Finance: A Canadian case study.” *Intergenerational Justice Review* 12(1):32-46.

Maestas, Nicole, Kathleen J. Mullen, and David Powell. 2016. "The effect of population aging on economic growth, the labor force and productivity." *NBER Working Paper Series* (Working Paper 22452), http://www.nber.org/papers/w22452

Statistics Canada. 2014. "Population projections: Canada, the provinces and territories, 2013 to 2063." Industry Canada, http://www.statcan.gc.ca/daily-quotidien/140917/dq140917a-eng.htm.

Dr. Paul Kershaw, Curriculum Vitae

This is Exhibit "B" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

A Commissioner for taking Affidavits within British Columbia

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Founder, Generation Squeeze – a voice for younger Canadians in politics and the market, backed by cutting edge research. www.gensqueeze.ca

Education

Ph.D. 2002. University of British Columbia. Interdisciplinary Studies (Political Science, Law, Economics).

B.A. 1997. McGill University. Philosophy.

Awards & Distinctions

2018 inaugural recipient of the Canada Mortgage and Housing Corporation "Knowledge to Action" Award instituted as part of Canada's National Housing Strategy

2017 Affordable Housing Champion. Awarded by the BC Non-Profit Housing Association.

2016 Ehor Boyanowsky Academic of the Year Award. Awarded by the Confederation of University Faculty Associations of BC.

2007 Jill Vickers Prize. Awarded by the Canadian Political Science Association for Outstanding Gender & Politics Scholarship.

2005 Jill Vickers Prize. Awarded by the Canadian Political Science Association for Outstanding Gender and Politics Scholarship. **Note: I was the first multiple winner of the Jill Vickers Prize.*

Publications

As part of my award-winning Scholarship, I have published multiple books, and dozens of articles for the academy and the community. (Since there are too many for 5 pages, please see the sample below).

Sample Publications for the Academy

Kershaw, Paul. Forthcoming. "A Tax Shift: The case for rebalancing the tax treatment of earnings and housing wealth." *Canadian Tax Journal* 66 (3).
This article documents the growing gap between home prices and young people's earnings, along with age trends in housing wealth. In response, it recommends reducing taxes on income & increasing taxes on high value homes.

Kershaw, Paul. 2018. "Intergenerational Justice in Public Finance: A Canadian Case Study." *Intergenerational Justice Review* 12 (1):32-46.
This article measures the socioeconomic conditions of different age cohorts in Canada, along with the implications for public finance. It finds that Baby Boomers enjoy on average a higher standard of living than did the previous generation of seniors because of their accumulation of housing wealth, and that Baby Boomers had a greater ability to pay as young adults than do you adults today because the earnings of the latter have lost ground relative to home

<u>prices</u>. Against this socioeconomic backdrop, the article finds that Canadian governments have increased social investment for Canadians age 65+ faster than for Canadians under age 45, and provides a framework for assessing the intergenerational fairness of public finance decisions.

Kershaw, Paul. 2018. "The need for health in all policies in Canada." *Canadian Medical Association Journal* 190 (64):E64-65.
Health doesn't start with health care. It starts with the conditions into which people are born, grow, live, work and age. Since the growing gap between earnings and home prices is eroding these conditions for younger Canadians, the article <u>recommends linking the intergovernmental Health Accord to the new National Housing Strategy</u>.

Kershaw, Paul, Eric Swanson and Andrea Stucchi. 2017. "A surgical intervention for the body politic: Generation Squeeze applies the Advocacy Coalition Framework to social determinants of health knowledge translation." *Canadian Journal of Public Health.* 108(2): e199-e204.
This article describes <u>the "knowledge to action" strategy that Dr. Kershaw designed</u> when founding Generation Squeeze.

Kershaw, Paul, and Lynell Anderson. 2016. Measuring the Age Distribution in Canadian Social Spending. *Canadian Public Administration, 59*(4), 556-579.
This article provides a comprehensive analysis of Canadian government social spending, <u>including on housing</u>, and examines the distribution of that spending by age.

Sample Publications for the Community

Kershaw, Paul. 2017. "Code Red: B.C. is the worst performing economy in Canada for younger generations." Report published by Generation Squeeze: Vancouver, BC. 45 pages. Available at: http://bit.ly/GS_BCworsteconomy Downloaded 971 times.
While BC has reported some of strongest economic growth in recent years, this article observes that this GDP growth reflects faster expansion of the real estate, rental and leasing sector. These now represent 18% of provincial GDP, but less than 3% of provincial employment. This paper documents the growing gap between young people's earnings and home prices according to <u>3 Housing Squeeze indicators: years to save for a down payment; months to pay for annual mortgage; months to pay for annual rent</u>. These indicators are <u>calculated for every province</u>, revealing that BC is now the province where hard work pays off the least in Canada when it comes to young people paying for their major cost of living – housing. The Housing Squeeze indicators are also calculated for Metro Vancouver, Victoria, Kelowna, Kamploops and Prince George.

Kershaw, Paul. 2017. "Code Red: Ontario is the second worst economy in Canada for younger generations." Report published by Generation Squeeze: Vancouver, BC. 45 pages. Available at: http://bit.ly/GS_ON2ndworstecon Downloaded 324 times.
While Ontario has reported some of the fastest rates of economic growth in recent years, this article observes that this GDP growth reflects faster expansion of the real estate, rental and leasing sector. These now represent 14% of provincial GDP, but less than 3% of provincial employment. This paper documents the growing gap between young people's earnings and home prices according to <u>3 Housing Squeeze indicators: years to save for a down payment; months to pay for annual mortgage; months to pay for annual rent</u>. These indicators are <u>calculated for every province</u>, revealing that Ontario is the second worst performing economy in Canada when measured in terms of young people paying for their major cost of living. The Housing Squeeze indicators are also calculated for the Greater Toronto Area, Ottawa, Hamilton, Kitchener, London and Windsor.

Kershaw, Paul. 2017. "Swamplight: Making sense of the BC 2017 election platforms for voters under age 45." Report published by Generation Squeeze: Vancouver, BC. 14 pages. Available at: http://bit.ly/GS_SwamplightBC2017 Downloaded 424 times.
This study provided an evidence-based, non-partisan analysis of the housing promises included in the BC political party platforms in the 2017 provincial election.

Kershaw, Paul and Eric Swanson. 2016. "Building Housing Common Ground." Report published by Generation Squeeze: Vancouver, BC. 15 pages. https://www.gensqueeze.ca/building_housing_common_ground_report Downloaded 791 times.
This study is the proceedings from a day-long event that gathered a diverse group of housing leaders from Vancouver and Toronto to search for common ground to the challenges posed by home prices leaving behind local earnings. Participants included developers, home builders, realtors, financial institutions, non-profit housing providers, landlords & property managers, renters groups, people living the squeeze, academics, think tank researchers, mayors, councilors and senior municipal planners. Together, we identified 10 common ground principles to guide policy adaptations. These principles subsequently guided Generation Squeeze policy advocacy.

Kershaw, Paul and Anita Minh. 2016. "Code Red: Rethinking Canadian Housing Policy." Report published by Generation Squeeze: Vancouver BC. 28 pages. Available at: http://bit.ly.GSCodeRed Downloaded 2,041 times.
This study examined BC Assessment data to find that just 15% of Metro Vancouver's housing supply in 2013 cost less than half a million dollars while providing access to more than two bedrooms. By contrast, half a million dollars bought two entire average priced homes in 1976 (after adjusting for inflation). In response, the authors propose 10 principles for housing policy reform, including a surge in supply, a reduction in harmful demand, and rebalancing the tax treatment of earnings and housing wealth. Note: when the data were updated for 2017, we found that just 2% of homes in Metro Vancouver cost less than half a million dollars and provided access to more than two bedrooms. The same is now true in Victoria, and only 14% of homes in Kelowna meet these criteria.

Knowledge to Action Experience

See Kershaw et al. (2017) for the Knowledge to Action framework that guides my activities, including:

Make meaning of socioeconomic changes and shape public opinion:

- *Publish studies:* see examples above
- *Media:* I have written or been cited in over 1,200+ print articles between 2015 and 2017, as tracked by Troy Media Monitoring, and delivered an additional 300+ TV and Radio interviews.
- *Invited presentations to community stakeholders:* 112 presentations between 2015 and 2017.
- *Briefings to Decision makers:* 97 briefings in 2016 & 2017.

Frame policy beliefs, set an agenda, build a coalition, and mobilize person power:

Generation Squeeze: I founded Generation Squeeze to become a voice for Canadians in their 20s, 30s and 40s in the world of politics and the market so that younger voices could be a conduit for academic research to shape decision making. The organization has attracted 32,666 supporters (over 24,000 are part of our email list serve). Many participate by lending their voice in support of housing issues, including:

- Homes First Petition: https://www.gensqueeze.ca/code_red Currently, there are 4,251 signatures.
- Toronto Vacant Homes Tax Petition: https://www.gensqueeze.ca/vht_gta 3,247 signatures submitted to Toronto in 2017 by City Councilor Ana Bailao.
- Toronto Close the Rental Loophole Petition: https://www.gensqueeze.ca/1991_rent_loophole_success 3,233 signatures submitted to Government of Ontario in 2017 by the Minister of Housing.
- YIMBY Voices. Volunteers resists NIMBY'ism by speaking in favour of projects that add supply suitable for younger generations in cities throughout Metro Vancouver. Over 20 projects supported in the last 18 months. See https://www.gensqueeze.ca/housing_supply_summary
- Support a BC #TaxShift: https://www.gensqueeze.ca/support_the_taxshift 501 letters sent in June 2018 to BC Premier, Finance Minister and local MLAs in support of lower taxes on local earnings, higher taxes on unhealthy home values, and better investment in young and old alike.

*Knowledge to Action Housing Policy Victory Featured for CMHC Gold Roof Award

Adding Young Adults to the "Most In Need" Group in the National Housing Strategy (NHS). Promoted via:

- March 11 & March 23, 2016: Brief Hilary Leftick, policy staff re Youth Portfolio in Prime Minister's Office
- June 17, 2016: Invited to advise at Prime Minister's Vancouver Expert Roundtable on the Housing Crisis
- June 27, 2016: Invited to advise Minister Duclos and CMHC President Evan Siddall re National Housing Strategy.
- September 6, 2016: Brief MP Murray Rankin about Gen Squeeze housing recommendations
- September 14, 2016: Brief Colleen Lamothe, policy staff for Minister Duclos
- September 20, 2016: Brief Mathieu Laberge, policy staff for Minister Duclos
- September 30, 2016: Brief MP Dan Ruimy re Gen Squeeze re housing policy recommendations
- October 4, 2016: Brief Federal Standing Committee on Finance re Generation Squeeze recommendations
- October 6, 2016: Briefing Note submitted to CHMC Let's Talk Housing Consultation for NHS
- November 2, 2016: Brief Tim Krupa, policy staff in Prime Minister's Office re Gen Squeeze recommendations
- November 27, 2016: Op Ed for Post Media chain following the release of the CMHC "What We Heard Report." Article suggests that the National Housing Strategy risks being outdated before it is even launched if it does not identify "young adults" among the "most in need" group. https://theprovince.com/opinion/paul-kershaw-is-the-national-housing-strategy-outdated-before-it-begins
- December 22, 2016: Brief Colleen Lamothe, policy staff for Minister Duclos, re Gen Squeeze's concern that young adults are omitted from "most in need" group in CMHC "What We Heard" Report
- March 22, 2017: Federal budget continues to omit "young adults" from NHS' "most in need" group
- March 23, 2017: Brief Tim Krupa, policy staff in Prime Minister's Office, re Gen Squeeze concern that young adults are omitted from "most in need" group in the 2017 federal budget discussion of the NHS
- March 23, 2017: Analysis of 2017 federal budget shared with Gen Squeeze list serve of over 24,000. It highlights that young adults are omitted from "most in need" group in the budget's discussion of funds for the National Housing Strategy.
- March 27, 2017: Briefing with Dylan Marando, policy staff to Minister Duclos, re Gen Squeeze's concern that young adults are omitted from "most in need" group
- April 3, 2017: Briefing with Elliot Hughes, Department of Finance, re the age implications of the current tax treatment of housing wealth.
- April 18, 2017: Briefing with Debbie Stewart, Director of Housing Needs, Policy and Research, and Michel Tremblay, Senior VP at CMHC re Gen Squeeze housing policy recommendations
- May 26, 2017: Briefing with MP Erskine-Smith re Gen Squeeze housing recommendations and concern that young adults are omitted from "most in need" group
- October 25, 2017: Briefing with MP Wilkonson re Gen Squeeze housing recommendations and concern that young adults are omitted from "most in need" group
- October 25, 2017: Briefing with MP Erskine-Smith re Gen Squeeze recommendations and concern that young adults are omitted from "most in need" group
- October 25, 2017: Briefing with Peter Schiefke re Gen Squeeze recommendations and concern that young adults are omitted from "most in need" group
- October 26, 2017: Briefing with MP Lametti re Gen Squeeze recommendations and concern that young adults are omitted from "most in need" group
- October 26, 2017: Briefing with Joyce Murray re Gen Squeeze recommendations and concern that young adults are omitted from "most in need" group
- November 1, 2017: Briefing with Bob Dugan, Chief Economist, and Vinay Bhardwaj, Director Market Analysis, CMHC re Gen Squeeze housing research, recommendations and concern that young adults are omitted from "most in need" group
- November 2, 2017: Briefing with Dylan Marando and Colleen Lamothe, policy staff to Minister Duclos, re Gen Squeeze housing recommendations and concern that young adults are omitted from "most in need" group

➢ November 22, 2017: National Housing Strategy included "young adults" among the "most in need" group.

Vancouver Quadra MP Joyce Murray, Parliamentary Secretary to Treasury, writes: *"Dr. Kershaw has contributed to the direction of the National Housing Strategy, engaged young people in the national discussion on housing, and provided invaluable research on the evolution of the housing market in Canada. My staff and I have attended a number of his presentations in Ottawa where Dr. Kershaw shared his research with policy makers. He also enthusiastically participated in a discussion I hosted on the current financial situation faced by millennials, for which housing affordability is a key factor."*

<u>Other Knowledge to Action Housing Victories include:</u>

1. City of Vancouver Empty Homes Tax, the first of its kind in North America
2. Housing Vancouver Strategy, including revisions to zoning that previously privileged single-detached homes

I was invited by the City of Vancouver to brief decision makers 17 times in 2016 and 2017, deliver three presentations at its international conference that invited experts to advise on its plans, review a draft of the city's new Housing Strategy, and participate in media activities with the Mayor to support new policy trajectories, including at the media scrum for the announcement of the Empty Homes Tax, and in the media release for the Housing Vancouver Strategy. The latter strategy specifically cites Generation Squeeze research.

<u>Vancouver Mayor, Gregor Robertson, writes:</u> "The spike in Vancouver's housing prices and low rental vacancy rates are hitting our younger residents particularly hard, and Generation Squeeze has played an important role in advocating for them in the housing conversation. Generation Squeeze brings a fresh and collaborative approach to the policy process, and as a result the organization has been an integral part of Vancouver's work to develop responsive housing policy that meets the needs of our city's residents."

3. Elimination of Ontario policy that allowed limitless rent increases for units built after 1991

I was invited by the Government of Ontario to provide 9 briefings in 2017 about housing policy, and was the only member of its Fair Housing Plan Advisory that was appointed from outside of the province. The government arranged for Generation Squeeze to participate in media events with the Ministers of Finance and Housing to explain the changes to rent control on the day following the Fair Housing Plan announcement. The Housing Minister invited me specifically to the legislature on April 27, 2017 to thank Generation Squeeze for our work, refer to the over 3,000 signatures we collected in support of policy change, and identify our activities as a key motivation for policy reform.

<u>James Janeiro, Senior Policy Advisor in the Office of the Ontario Premier, writes:</u> "I have been consistently impressed with the quality of research Generation Squeeze produces and the accessible, people-friendly way in which they present their findings. Their work on housing issues in particular was of great use to the government. I look forward to working with them in future."

4. Development Approvals for Housing Projects facing NIMBY resistance

See summary of 20+ projects supported at https://www.gensqueeze.ca/housing_supply_summary

<u>Virginia Bird, of Pottinger Bird Community Relations, writes:</u> "We recently engaged the team at Gen Squeeze on a rental housing proposal in the City of North Vancouver. We were impressed by their ability to mobilize a group of diverse, passionate volunteers in support of rental housing. We look forward to continuing our relationship with Gen Squeeze and supporting their mission to ease the squeeze for all Canadians."

<u>North Vancouver Mayor, Darrel Mussatto, writes:</u> "Gen Squeeze is an essential voice for housing affordability in Vancouver and across Canada. I have had several opportunities to speak with Dr. Kershaw about Gen Squeeze and its successes and goals in rethinking housing policy in Canada, and am both impressed and appreciative of his leadership in this regard. His recent presentation to North Shore elected officials stimulated important discussions about what each level of government can do to support housing affordability for younger Canadians, and gave us the building blocks to move forward in collaborating for greater affordability on the North Shore."

<u>Mayor of Victoria, Lisa Helps, writes:</u> "Generation Squeeze is emerging as a clear thought leader on affordability and liveability, critical issues facing their generation, and affecting us all. And they are turning their thinking into action, most importantly by informing decision makers and shaping public policy. They work across sectors and draw people together into meaningful and collaborative dialogue. Their inclusive and diverse approach means that the solutions they propose get support and buy in from a wide cross section of the community. Generation Squeeze is already having a positive and lasting impact on our community."

Intergenerational Justice in Public Finance: A Canadian case study

by Paul Kershaw

Abstract: This study examines whether Canadian governments have adapted budgets for the ageing population in accordance with norms of intergenerational justice. Public finance data in 2016 are analysed compared to 1976 in light of three constructs: the elderly/non-elderly ratio of social spending change, intergenerational reciprocity, and ability to pay. Findings include that (i) governments increased per capita spending for seniors 4.2 times faster than for those under the age of 45; (ii) public finance requires younger Canadians to contribute 22%-62% more in income taxes for the elderly now by comparison with 1976; and (iii) the contemporary ageing population has a greater ability to pay than cohorts immediately before and after them.

***Keywords:** Taxes, Government Expenditures, Generational Equity, Housing Wealth, Public Reporting*

Canada, like many countries, is ageing. Seniors represent 16.5% of the population, up from 8.7% in 1976.[1] In countries experiencing such trends, there are worries about "bankruptcy for publicly funded health care and pension systems [...], unfair treatment of children vis-à-vis the elderly [...] and the burdening of future generations" (Lee/Mason 2011: 3). Canada is no exception. The federal government has made, and repealed, changes to the age of eligibility for Old Age Security. Provincial premiers launched a Task Force on Aging, and the national social science agency prioritised the research question "What are the future implications of state regulation from cradle to grave?" that arise from "Life cycle issues... challenging society."[2] This study helps to answer the question by reviewing the evolution of key age-related policies in Canadian public finance over the last four decades in light of norms of intergenerational justice.

Several recent comparative public finance studies about generational equity include Canada (Tepe/Vanhuysse 2010; Bradshaw/Holmes 2013). The most sophisticated is by Vanhuysse (2013), who finds that Canada is among the worst 9 of 29 nations for intergenerational justice. Generally, even the strongest comparative studies omit spending on medical care, tax expenditures, and sometimes even education, which undermine their utility.[3] In response, more scholars are producing country-specific analyses.[4] For example, the anthology by Lee and Mason features over 20 single country studies in recognition that "designing effective policy [...] is a complex, detailed, and inherently country-level task that is best carried out one country at a time" (Lee/Mason 2011: 30). I design this study accordingly.

Generational equity in public finance received substantial attention in the 1990s when funding for the Canada and Quebec Public Pensions (C/QPP) factored prominently in public debate. Much of this work responded to Oreopoulos and Kotlikoff (1996), who estimated that total government spending in 1995 required taxes of future generations that were twice what current generations were paying. Following government adaptations to the C/QPP, Statistics Canada published an anthology edited by Corak (1998). This included an updated study by Oreopoulos and Vaillaincourt (1998), who concluded that spending cuts, tax increases and revisions to C/QPP between 1995 and 1998 restored balance to tax collection between contemporary and future generations. By 1999, total government revenue collection was 43.6% of GDP, while total expenditure was 41.9%.[5] There has been little analysis of generational fairness in Canadian public finance since then, and no government routinely reports on this theme. Given that government revenue fell 4.7% of GDP in the subsequent years, while expenditure dropped only 1.7%,[6] it is timely to revisit questions about intergenerational justice.

Canada, like many countries, is ageing. Seniors represent 16.5% of the population, up from 8.7% in 1976.

This article has five sections. I begin by summarising the theoretical framework and methods, focusing on three constructs that are common in the literature: the elderly/non-elderly spending ratio; intergenerational reciprocity; and the ability to pay of different age cohorts. Sections 2 to 4 apply the constructs to analysis of Canadian data. These data provide evidence that Canadian governments did not prioritise intergenerational justice over the last four decades and, as discussed in the final section, illuminate opportunities to rebalance public finance between the young and aged.

Theoretical framework and methods

Guided by the United Nations' vision of a society for all ages,[7] I focus on whether governments *budget for all ages*, drawing on population health scholarship. A robust scientific literature reveals that health does not start with health care. It starts with the social determinants of health where we are born, grow, live, work and age.[8] These include the distribution of wealth, income, education, employment, housing, human impact on the climate, and the government policies that shape these other determinants. Biological sensitivity to the social determinants is particularly strong during our earliest years (Commission on the Social Determinants of Health 2008: chapter 5; Keating/Hertzman 1999). As a result, budgeting for all ages requires legislators to promote "health in all policies" in recognition that health promotion is the domain of social, economic and environmental ministries, whereas medical ministries treat illness more than they prevent it (Commission on the Social Determinants of Health 2008: chapter 10; Kershaw 2018).

I operationalise the concept of budgeting for all ages in three stages. First, following the path-breaking scholarship of Lynch (2006: 20) and Vanhuysse (2013), I calculate the *elderly/non-elderly ratio of spending changes* over the last four decades. For the elderly, I examine spending on retirement income and medical care. For non-elderly, I prioritise programmes that invest in generations raising young children, because epigenetics literature reveals opportunities to advance life-long health by investing in this demographic (Keating/Hertzman 1999; Boyce 2007). In accordance with Kershaw and Anderson (2016), I conceive of this age group as those under the age of 45,[9] and focus on childcare services, parental leave, cash supports for families with children, education and medical care. These represent major policies by which governments can adapt costs for younger generations, although it is not an exhaustive list.

Canadian governments did not prioritise intergenerational justice over the last four decades.

I calculate changes in spending on programmes for 2016 compared to 1976, and interpret these in the light of revenue changes over the same period. Aggregate and per capita figures are assessed. All expenditures are adjusted for inflation and economic growth using consumer price index[10] and gross domestic product (GDP) data available at Statistics Canada. 1976 is selected for comparison, because it marks the beginning of the five-year period in which the largest part of the Baby Boom generation (born 1946-64) came of age as young adults. I thus examine government spending at two pivotal stages for Boomers: when raising children 40 years ago, to which I compare public finance now for Canadians under 45, a cohort that includes many of their children; and now at retirement, to which I compare spending 40 years ago for the cohort of seniors that included many of their parents.

The second stage of analysis digs further into revenue collection to explore the *intergenerational golden rule* recommended by Wolfson et al. (1998: 108). With roots in reciprocity theories of intergenerational justice (Gosseries 2009), this norm implies that "one generation, when it becomes old and frail, should not expect to be treated any better by its children than it treated its parents' generation in their old age" (Wolfson et al. 1998: 108). I examine this theme by calculating income taxes owed by representative 35 year-olds, measuring the amount of taxes paid to medical care and Old Age Security for contemporary seniors. I then repeat the tax calculations for inflation-adjusted incomes in 1976 to assess whether young taxpayers today pay more, or less, for programmes targeting the elderly by comparison with when today's elderly were young. I use Statistics Canada's Social Policy Simulation Database and Model (SPSD/M) to calculate taxes. It is widely used to analyse the financial interactions of governments and individuals in Canada.[11]

[I]t may be appropriate for a generation to pay more in taxes or transfers than its predecessors, if that generation inherits more affluence than did its parents.

The third stage of analysis examines whether generations come of age in more, or less, advantageous circumstances, with unearned implications for their relative need or ability to pay. I refer to this theme as the *lottery of timing*, which is important to scholars of intergenerational justice who build on the tradition of Rawls (Rawls 1971: section 44). Behind a veil of ignorance where parties do not know if they will inherit poor or affluent circumstances or to what generation they may belong, Rawls judges that the obligations of one generation to save on behalf of successors or invest in elders will vary in proportion to the epochal conditions in which they live. This insight anticipates that it may be appropriate for a generation to pay more in taxes or transfers than its predecessors, if that generation inherits more affluence than did its parents. I analyse this theme by reporting on indicators selected by Vanhuysse (2013) for his Intergenerational Justice Index. I pay additional attention to earnings relative to housing costs, and explore implications for wealth accumulation. Ultimately, the third stage invites evaluation of whether intergenerational adaptations in public finance are made in proportion to the social determinants of health faced contemporarily by different age cohorts, as well as relative to the advantages and disadvantages inherited by those cohorts.[12]

Spending on the elderly and on those under the age of 45: 1976 and 2016

This section describes changes in public spending by all levels of Canadian government for citizens aged 65+ and under the age of 45 in 2016 by comparison with 1976 (see Table 1). Almost all spending comes from general revenue, which grew by $11.3 billion in 2016.[13] The Canada and Quebec Public Pensions (C/QPP) are the exception, with separate revenue streams to which citizens prepay for later benefits. C/QPP revenue had increased $36.5 billion by 2016.

As general revenue hovered around 35% of GDP in both years, governments increased spending for seniors on medical care by $36.1 billion in 2016,[14] and Old Age Security (OAS) by $4.9 billion.[15] OAS spending grew little, because retirement income spending grew primarily in the C/QPP, which surged by $48.5 billion.[16] The $91.6 billion increase in spending (half from general revenue) partly reflects there are 4 million more seniors today than in 1976, as the population aged 65+ increased from 8.7% to 16.5%.

As general revenue hovered around 35% of GDP in both years, governments increased spending for seniors on medical care by $36.1 billion in 2016, and Old Age Security (OAS) by $4.9 billion.

Substantial demographic changes among younger Canadians, however, did not drive comparably large aggregate expenditure increases. For example, 4.6 million more Canadians under 45 now have post-secondary credentials than in 1976, as graduation from university, college or trades increased from 28% to 70% for people aged 25-44.[17] But post-secondary spending remained relatively flat over the two years, up $2.7 billion.[18] Similarly, 2.3 million more women aged 25-44 are in the labour force, as their participation increased from 54% in 1976 to 83% in 2016.[19] Despite the resulting increase in demand for child care, annual spending on this budget line grew just $3.6 billion.[20] Such comparisons reveal that substantial new spending on the ageing population reflects factors beyond demography,[21] since other comparable demographic changes did not motivate similarly-sized spending increases.[22]

As spending on seniors from general revenue increased four times more than revenue, governments dealt with resulting budget shortfalls in two ways. They increased the debt/GDP ratio by half a trillion dollars,[23] and reduced spending elsewhere. Reductions

	Aggregate spending					Major demographic changes				Spending per capita 2016$						
	1976	2016	2016 minus 1976			Population		Female LFP	Postsec Enrol	Aggregate 1976 spending before adjusting for Growth			* Growth		2016 minus 1976	
			%GDP	$ millions		1976	2016	2016/1976 ratio		/pop	*LFP	*Postsec	*1.54	2016	w/o Growth	* Growth
GDP ($ millions, per capita)	205,123	2,027,544								36,196				55,876		
Revenue																
Total Gov't General Revenue	34.99%	35.55%	0.56%	**11,349**	*Population grows from*	23,397,056	36,286,425			**12,666**			*19,553*	**19,866**	**7,200**	*313*
CPP/QPP Revenue	1.60%	3.39%	1.80%	**36,483**	*23.4 million to 36.3 million.*	23,397,056	36,286,425			**577**			*891*	**1,897**	**1,319**	*1,005*
Total	36.59%	38.95%	2.36%	**47,832**	*GDP/person grows 54%*	23,397,056	36,286,425			**13,243**			*20,444*	**21,762**	**8,519**	*1,318*
Spending 65+																
From general revenue																
Medical care to 65+	1.94%	3.82%	1.88%	**38,108**	*4.0 million more seniors, up*	1,969,837	5,990,511			**8,322**			*12,847*	**12,913**	**4,591**	*66*
sensitivity analysis	1.79%		2.03%	41,089	*from from 8.7% to 16.5% of population.*					7,690			*11,871*		5,223	*1,042*
OAS	2.10%	2.34%	0.24%	**4,947**	*Consistent enrolment rate in*	1,969,837	5,990,511			**9,023**			*13,929*	**7,929**	**-1,094**	*-6,000*
General revenue Subtotal	*4.03%*	*6.16%*	*2.12%*	**43,056**	*programmes. Per capita use of*					*17,345*			*26,776*	*20,842*	*3,497*	*-5,933*
From C/QPP Revenue	0.54%	2.93%	2.39%	**48,501**	*medical spending up 55%*	1,969,837	5,990,511			**2,303**			*3,556*	**9,910**	**7,606**	*6,354*
Total	4.57%	9.09%	4.52%	**91,556**		1,969,837	5,990,511			**19,648**			*30,331*	**30,752**	**11,104**	*420*
Spending <45																
Child care services	0.05%	0.23%	0.18%	**3,559**		16,987,225	20,216,021	1.54		25	**38**		*59*	**226**	**188**	*167*
sensitivity analysis					*2.3 million more women <45 in*	4,585,620	4,700,034			92	141		*218*	972	831	*754*
Parental leave	0.07%	0.19%	0.12%	**2,418**	*LF, up from 54% to 83%*	16,987,225	20,216,021	1.54		35	**53**		*83*	**190**	**136**	*107*
sensitivity analysis						705,802	784,192			837	1,287		*1,986*	4,887	3,601	*2,901*
					<age 45 from 72% to 56%											
Family income support	0.95%	1.04%	0.09%	**1,790**	*Consistent enrolment rate*	16,987,225	20,216,021			**472**			*729*	**1,038**	**566**	*309*
Elementary & Secondary	4.72%	3.30%	-1.41%	**-28,643**	*0.5 million fewer students*	16,987,225	20,216,021			**2,352**			*3,630*	**3,314**	**962**	*-316*
sensitivity analysis					*Consistent enrolment rate*	5,634,883	5,110,835			7,089			*10,944*	13,109	6,020	*2,165*
Post-secondary	2.20%	2.33%	0.13%	**2,721**	*4.6 million more grads, from 28%*	16,987,225	20,216,021		2.49	1,095		**2,725**	*4,207*	**2,338**	**-387**	*-1,869*
sensitivity analysis					*to 70% of 25-44 yrs*	9,593,025	13,144,475			1,940		4,826	*7,450*	3,596	-1,230	*-3,854*
					<age 45 from 72% to 56%											
Medical care <45	2.29%	2.31%	0.01%	**297**	*Consistent enrolment rate. Per*	16,987,225	20,216,021			**1,143**			*1,764*	**2,314**	**1,171**	*550*
sensitivity analysis	2.40%		-0.09%	-1,799	*capita use up 102%*					1,194			*1,844*		1,120	*470*
Total	10.27%	9.39%	-0.88%	**-17,857**		16,987,225	20,216,021			5,122		**6,784**	*10,472*	**9,420**	**2,637**	*-1,052*
Debt	19.20%	43.88%	24.68%	**500, 405**		23,397,056	36,286,425			**6,951**			*10,730*	**24,521**	**17,570**	*13,790*

Sources: Population data from Statistics Canada (2017a): CANSIM Table 051-0001; Revenue, OAS, C/QPP, Family income from Statistics Canada (2018a): CANSIM Table 380-0080; GDP data from Statistics Canada (2018b): CANSIM Table 380-0063; Medical care data from CIHI 2017: Tables A.3.3.1, E.1.18.2 and E.1.1.2; Childcare from Government of BC 1977: D.41; and Friendly et al. 2015: 136; Parental leave from Canadian Tax Foundation (1979): Table 7-9; and Government of Canada (n.d.): Chart 2; Elementary & Secondary data from Statistics Canada (2017d): CANSIM Table 478-0014; Post-secondary spending data from Statistics Canada (2018d): CANSIM Table 380-0081; 2016 post-secondary utilisation data from Statistics Canada (2017b); 1976 data from Statistics Canada 1978a, 1978b; Female labour force data from Statistics Canada (2017c): CANSIM Table 282-0002; Debt data from Statistics Canada (n.d. a): CANSIM Table 378-0073 and (2018e): CANSIM Table 378-0121; Inflation adjustment data from Statistics Canada (2018c): CANSIM Table 326-0021.

Table 1: Change in the government spending on the elderly and on those under the age of 45: 1976 to 2016

		1976								2016							2016 minus 1976		
		Total Taxes		Taxes to medical for age 65+		Taxes to OAS for age 65+		*Total $ to medical & OAS*	Total taxes		Taxes to medical for age 65+		Taxes to OAS for age 65+		*Total $ to medical & OAS*	**Total taxes**	***Total $ to medical & OAS for age 65+***	
Age 35 income percentile	2016 income	Average rate	$ amount	% of total taxes	$ amount	% of total taxes	$ amount		Average rate	$ amount	% of Total Taxes	$ amount	% of total taxes	$ amount			**$ change**	**% change**
25th	24,797	9.2%	2,283	5.0%	114	5.4%	123	*237*	10.3%	2,554	9.2%	236	5.8%	149	*385*	**271**	**147**	**62%**
50th	45,570	17.6%	8,022	5.0%	400	5.4%	434	*834*	14.9%	6,778	9.2%	626	5.8%	395	*1,021*	**-1,244**	**187**	**22%**
75th	71,274	23.1%	16,436	5.0%	820	5.4%	889	*1,709*	20.3%	14,437	9.2%	1,333	5.8%	840	*2,174*	**-1,999**	**465**	**27%**
99th	203,506	38.1%	77,449	5.0%	3,863	5.4%	4,189	*8,052*	35.8%	72,930	9.2%	6,736	5.8%	4,246	*10,982*	**-4,519**	**2,929**	**36%**

Sources: Income percentile data from Statistics Canada (n.d. b): Data Table, Total Income percentiles. Taxes are author calculations using Statistics Canada Social Policy Simulation Database and Model (SPSD/M) versions 8.1 and 26.1. All assumptions and interpretations are the responsibility of the author.

Table 2: Income taxes paid, 1976 vs 2016, by 2016 income percentiles (2016$)

include a $28 billion decline in spending on grade (elementary and secondary) school as the number of school-age children fell by half a million.[24] While some of this reduction may be interpreted to pay for the small spending increases for post-secondary and child care discussed above, as well as cash transfers to families (up $1.8 billion) (Statistics Canada 2018), parental leave (up $2.4 billion),[25] and medical care for those under 45 (up $297 million), most of the grade school reduction was reallocated elsewhere. In total, the suite of programmes on which younger Canadians rely fell by $17.9 billion.

> [S]ubstantial new spending on the ageing population reflects factors beyond demography, since other comparable demographic changes did not motivate similarly-sized spending increases.

Aggregate public finance trends need interpretation in light of per capita figures. Alas, Canadian governments do not publish age analyses of per capita spending. Kershaw and Anderson fill this gap, finding all levels of government combine to allocate over $33,000 per person aged 65+ by comparison with less than $12,000 per person for those under the age of 45 (Kershaw/Anderson 2016). Unfortunately, data are not available to replicate their comprehensive analysis for 1976. To examine change over time, I instead analyse per capita budgeting for the policies featured above, adjusting first for inflation, and then economic growth. It is necessary to separate these factors to reveal how governments invested the proceeds from growth, with options including further investment in well-established programmes, like medical care or post-secondary; growing a nascent programme, like child care; or reducing tax rates.

The Canadian population increased from 23.4 million to 36.3 million since 1976.[26] Per capita general revenue increased $7,200 by 2016, while funds for C/QPP increased by $1,319.[27] Over the same period, GDP per person rose 54%, or nearly $20,000.[28] This means total general revenue per person increased by $313 beyond the rate of growth, as did C/QPP revenue by $1,005.

Per capita spending on medical care and retirement income for Canadians aged 65+ increased by $11,104 since 1976,[29] whereas per capita spending on programmes for Canadians under the age of 45 grew by $2,637. As a result, the elderly/non-elderly (under-age-45) ratio in change of spending is 4.2 to 1.[30] This ratio signals that Canadian governments prioritized per capita spending increases for the ageing population at a rate that is over four times faster than for citizens under 45.

The per capita increase for Canada's 6.0 million seniors is 57% higher than the $19,468 per capita spending in 1976, which represents an increase that is slightly faster than economic growth ($420/senior). The increase for each of the 20.2 million Canadians under the age of 45 is 39% higher than the $6,784 per capita spending in 1976, approximately 71% of economic growth. The slower rate of increase by comparison with economic growth represents $1,052 less per person for the under-45s as of 2016 – or $21.3 billion less when multiplied by all the people in the age group. This sum represents enough to fund, for example, a high-quality, universal childcare programme twice over (Kershaw/Anderson 2009), or a 46% increase to the post-secondary budget.[31]

Of the new spending on seniors, the $4,591 increase in medical care spending per person aged 65+ is notable for two reasons. First, it is 74% larger than the entire increase per person under the age of 45 for child care, parental leave, family income support, education and medical spending. Second, additional medical spending comes from general revenue, whereas increases to retirement income come from C/QPP. Canadians prepay the latter, meaning that the larger benefits now enjoyed by seniors partly reflect their larger contributions than past generations. This is not the case for larger medical expenditures, which taxpayers fund in response to annual demand. Since Canadian data show demand rises as individuals age,[32] I explore the implication for taxes paid by younger Canadians now versus the past when examining the intergenerational golden rule.

Post-secondary expenditures represent the largest per capita decline for younger Canadians: down $387 from 1976 after inflation, and down $1,869 compared to economic growth projections.[33] Per capita medical care spending is also noteworthy, because it is the largest increase (up $1,171) for young people, rising $550 faster than economic growth would predict. Since social spending in Canada correlates with improvements in life expectancy and preventable mortality more so than medical spending (Dutton et al. 2018), this allocation likely compromises young people's wellbeing. Budgeting for all ages requires concern for the ratio between social and medical spending given the extensive scientific literature that finds health begins where we are born, grow, live, work and age – not with medical spending (Kershaw 2018).[34]

> As spending on seniors from general revenue increased four times more than revenue, governments dealt with resulting budget shortfalls in two ways. They increased the debt/GDP ratio by half a trillion dollars, and reduced spending elsewhere. Reductions include a $28 billion decline in spending on grade school as the number of school-age children fell by half a million.

Some may worry the population under the age of 45 is too large a denominator to provide adequate comparisons between spending on seniors and younger people. I therefore perform sensitivity analyses reported in Table 1, beginning by apportioning childcare spending entirely to those under the age of 12 to find a per capita increase of $831. When post-secondary spending is allocated only to those age 18-45, there is a per capita reduction of $1,230. If parental leave spending is assigned just to children under the age of 1 and a primary caregiver, the per capita increase is $3,601. If grade school spending is assumed to benefit only children aged 5-17, not parental labour force attachment, the per capita increase is $6,020.[35] This latter change is of the same magnitude as the $4,591 increase in medical care per senior, or $6,513 combined increased to C/QPP and OAS. As such, the $29 billion reduction to aggregate grade school funding (measured as %GDP) is smaller than would have been expected from the drop in school-age population.

	All earners				Full-time earners only			
Age	1976-80	2012-2016	2012-2016 minus 1976-1980	% change	1976-80	2012-2016	2012-2016 minus 1976-1980	% change
25-34	41,720	36,640	-5,080	-12%	53,040	49,200	**-3,840**	**-7%**
35-44	46,980	46,340	-640	-1%	60,140	59,740	**-400**	**-1%**
45-54	44,800	45,880	1,080	2%	57,740	59,880	**2,140**	**4%**
55-64	34,200	39,180	4,980	15%	53,400	56,920	**3,520**	**7%**
65-plus	14,420	26,900	12,480	87%	43,160	57,540	**14,380**	**33%**

Sources: All earners: Statistics Canada (2018g): CANSIM Table 206-0052; Full-time earners: Statistics Canada (n.d. d): Custom Table C856285.

Table 3: Median total income 2016$, by age, 1976 and 2016

Intergenerational golden rule: evolution in taxes paid by younger citizens

The previous section reveals that governments increased per capita spending for seniors 4.2 times faster than for Canadians under the age of 45, as spending increased beyond the rate of economic growth for seniors, but slower for young people. In this section, I examine implications for individual taxes owed by young people, guided by the intergenerational golden rule introduced in the methods section. All else being equal, it implies elderly Canadians today should expect transfers from their offspring that are on a par with transfers they made as young adults to their parents' generation when elderly (Wolfson et al. 1998: 108).

To explore this concept, I examine total income taxes paid by a young person in 2016 compared to 1976, along with the sub-total paid to medical care for seniors and OAS.[36] I refer to simulated 35-year-olds with incomes from employment that represent the 25th, 50th, 75th and 99th percentiles in 2016,[37] and adjust these for inflation to calculate federal and provincial taxes owed in 1976 and today.[38] From the diversity of provincial tax codes, I select Ontario because it is the largest province.

[T]he elderly/non-elderly (under-age-45) ratio in change of spending is 4.2 to 1. This ratio signals that Canadian governments prioritised per capita spending increases for the ageing population at a rate that is over four times faster than for citizens under 45.

There are two broad findings, summarised in Table 2. First, income taxes owed in 2016 are generally lower than in 1976, with average tax rates down 2-3 percentage points. Low-income earners are the exception for whom the average tax rate is now one percentage point higher. Whereas an earner at the 25th percentile pays $271 more in income taxes today, the median earner pays $1,244 less, the 75th percentile pays $1,999 less, and the top one per cent pays $4,519 less. This finding signals there is less progressivity in Canada's income tax code now than four decades ago. Tax rates are lower for middle and higher earners today while still generating more revenue as a share of the economy, because GDP per capita increased 54% over the period.

Second, as taxes generally fell, the amount of taxes paid on behalf of seniors increased. 5% of total government revenue went to medical care for seniors in 1976; now 9.2% does. The revenue share for OAS rose more modestly from 5.4% to 5.8%.[39] Given these changes, a 35 year-old at the 25th percentile now pays $147 more a year to medical care for seniors and OAS than in 1976, equal to a 62% increase. A median earner adds $187 (up 22%); an earner at the 75th percentile contributes an extra $465 (up 27%); and a young person in the top one per cent pays an extra $2,929 (up 36%).[40]

These findings reveal that the cohort retiring today expects more in taxation from its children than it paid for its parents' generation when elderly. In addition, lower average tax rates permit some citizens aged 65+ to pay less in tax toward their offspring than their elderly parents contributed toward them in 1976. The two trends erode government fiscal capacity to invest in – or mitigate the risks facing – contemporary younger cohorts.

The lottery of timing: variations in ability to pay among age cohorts

The first two stages of analysis reveal that governments used the proceeds from economic growth to (i) raise per capita spending on Canadians aged 65+ over four times faster than for citizens under 45; and (ii) reduce tax rates, while requiring younger Canadians to contribute more in income taxes for elderly citizens now by comparison with 1976. The final stage of analysis invites questions about the fairness of these public finance patterns. Since some are born into favourable eras, and others are not, scholars of justice like Rawls (1971: section 44) signal it is important to examine intergenerational public finances by reference to the standard of living inherited by different age groups, and the socioeconomic circumstances they currently face. In response, I now consider how the standard of living for contemporary seniors compares with that of elderly Canadians four decades earlier; and how the standard of living four decades earlier when contemporary seniors were young adults compares with that of young people today.

I follow Vanhuysse's Intergenerational Justice Index to examine this theme, starting with his focus on child and elderly poverty rates (Vanhuysse 2013).

This shift in economic insecurity aligns with other income and wealth changes that signal prosperity more generally shifted from younger to older Canadians.

Canada has two low-income measures that date back to 1976. The first is the low-income cut-off (LICO), which measures the share of residents who spend 20% more on food, shelter and clothing than the average size-adjusted family. The second is a low-income measure (LIM), which measures the proportion of residents who fall below 50% of median adjusted income.[41] The after-tax LICO shows reductions in low-income for both children (under 18) and the elderly (65+) since 1976: dropping from 13.4% to 7.3% for children in 2016, and from 29% to 4.7% for seniors. By contrast, the LIM shows little change in low-income for children: 14.3% in 1976 and 14.0% in 2016. For seniors, the LIM dropped from 30.6% to 14.2%. Both metrics convey a substantial shift in the ratio of child/elderly low-income. Whereas children had less than half the rate of low-income of elderly Canadians in 1976 on both

Housholds, by age of primary earner	1977 ($ adjusted to 2016) Home ownership rate	Total market value minus total mortgage debt (millions $)	Share of total net value in principal residences	2016 Home ownership rate	Total market value minus total mortgage debt (millions $)	Share of total net value in principal residences	2016 minus 1977 % change in rate of home owners	Change in total market value minus total mortgage debt (millions $)	% change in share of total net value in principal residences
under 35	41%	92,604	15%	35%	223,080	7%	-14%	130,476	-55%
35-44	73%	130,182	22%	64%	439,867	14%	-12%	309,685	-37%
45-54	74%	146,923	24%	70%	757,038	24%	-6%	610,115	-3%
55-64	70%	119,951	20%	77%	832,780	26%	10%	712,829	30%
65+	63%	114,459	19%	67%	965,077	30%	7%	850,618	58%
Total		604,119			3,217,842			2,613,722	

Sources: 1977 data: Statistics Canada (1977): Survey of Consumer Finance Micro Data File; 2016 data: Statistics Canada (2017g): CANSIM Table 205-0002.

Table 4: Total net value in Canadian principal residences, by age: 1977 vs 2016

measures, now they have the same rate when measured by the LIM, and 155% of the rate when measured by the LICO.[42]

This shift in economic insecurity aligns with other income and wealth changes that signal prosperity more generally shifted from younger to older Canadians. Table 3 shows that median income fell $5,080 (-12%) for Canadians age 25-34 since 1976-80, and down $640 (-1%) for those age 35-44.[43] The decline persists after controlling for the evolution in part-time work and post-secondary enrolment by measuring only full-time, full-year earners, for whom median income is down $3,840 and $400 respectively.[44] Over the same period, median income rose over $12,000 for Canadians aged 65+ (up 87% for all earners, and 33% for full-time earners).[45]

As earnings fell for young Canadians, their primary cost of living surged. Whereas an average home cost $210,089 in 1976, the price had reached $490,495 by 2016.[46] The ratio of median full-time income for a 25-34 year-old relative to average home cost therefore increased from 4:1 to 10:1.[47] This young person must now work 13.4 years to save a 20% down payment on an average home, up from five years in 1976-80.[48] Even with historically low interest rates, the typical 25-34 year-old must make mortgage payments that are 15% higher now than in 1976-1980.[49] Average rents have also increased in large urban centres.[50]

While escalating home prices require more work of young people (and all renters), they shift housing wealth from younger to older Canadians. Price escalation increased net wealth in owner-occupied principal residences by $2.6 trillion since 1976.[51] Table 4 shows that 5% of the additional wealth is owned by households under the age of 35, which represent 29% of the adult population. One-third of the additional wealth is owned by Canadians aged 65+, who make up 21% of the adult population. Given lower ownership rates for younger Canadians,[52] the typical household headed by an adult under 35 faces higher rents without reaping wealth gains from rising prices. By contrast, Table 5 shows that the typical senior household reports an increase of $277,903 in net housing wealth by comparison with the same age group in 1977.[53]

As earnings fell for young Canadians, their primary cost of living surged. Whereas an average home cost $210,089 in 1976, the price reached $490,495 by 2016. The ratio of median full-time income for a 25-34 year-old relative to average home cost therefore increased from 4:1 to 10:1.

Vanhuysse (2013) supplements metrics about private income trends for different age cohorts with two metrics for public space. The first is debt per younger person,[54] which increased from $14,779 per person under the age of 45 in 1976 to $44,013.[55] The second is the ecological footprint per capita, which measures how much demand human consumption places on the biosphere. At present, a footprint of 1.7 global hectares per person is necessary if each global citizen is to live within the means of our planet's resources (Global Footprint Network 2018). In 1976, the Canadian ecological footprint per person was 10.3 global hectares. As of 2014, it was 8.0 global hectares, the seventh largest on the planet (Global Footprint Network 2018). This change signals that Canadians reduced our footprint on average by 0.06 hectares per year since 1976. To achieve 1.7 global hectares by mid-century, a key time commitment in the Paris Agreement (United Nations 2015), Canadians must now accelerate threefold the pace at which we reduce our footprint to 0.18 hectares per year.[56]

In sum, findings from this third analysis suggest today's ageing population has "lucked out" in the lottery of timing by comparison with those who preceded and follow them, and thus enjoy a greater ability to pay, or lesser need. Seniors today have more prosperity on average than did elderly Canadians four decades ago. They have lower levels of poverty, higher median earnings, and more wealth in their homes.

Older Canadians today also generally faced more favourable socioeconomic circumstances as younger adults in 1976 than do

Housholds, by age of primary earner	1977 (all $ adjusted to 2016) % home owners	Market value minus mortgage ($)	Mortgage debt ($)	2016 % home owners	Market value minus mortgage ($)	Mortgage debt ($)	**2016 minus 1977** **Change in % home owners**	**Change in market value minus mortgage**	**Change in mortgage debt ($)**	**Change in debt for extra $1 of net value ($)**
under 35	41%	81,219	76,468	35%	185,552	214,248	**-14%**	**104,333**	**137,780**	**1.32**
35-44	73%	130,164	51,131	64%	255,975	204,025	**-12%**	**125,811**	**152,895**	**1.22**
45-54	74%	156,785	29,471	70%	377,000	143,900	**-6%**	**220,215**	**114,429**	**0.52**
55-64	70%	151,297	12,579	77%	381,852	76,348	**10%**	**230,555**	**63,769**	**0.28**
65+	63%	131,568	3,194	67%	409,471	22,529	**7%**	**277,903**	**19,335**	**0.07**

Sources: 1977 data: Statistics Canada (1977): Survey of Consumer Finance Micro Data File; 2016 data: Statistics Canada (2017g): CANSIM Table 205-0002.

Table 5: Mean change in individual household net housing value and mortgage debt, by age: 1977 vs 2016

younger Canadians now. Older Canadians started with higher median earnings, which could stretch further when paying for rent, saving for a down payment, and paying a mortgage. Today's seniors also inherited smaller government debts as young people, and reduced their ecological footprint at just one-third of the rate that young adults must now do. As a counterpoint to this general trend, 1976 witnessed higher rates of low-income among children when measured by the LICO, but not the LIM.

It is relative to this lottery of timing that the justness of public finance trends can begin to be assessed. Three findings give reason to worry that Canadian governments strayed from norms of intergenerational justice since 1976. First, governments invested in later life course stages at a rate that is 4.2 times faster than for earlier life course stages, and did so on behalf of a cohort that enjoyed more affluence by comparison with cohorts that preceded and followed them. Second, governments violated the intergenerational golden rule. Younger Canadians now transfer 22%-62% more in income taxes to elderly citizens than today's seniors contributed to their forebears, even though contemporary young people have a lesser ability to pay. Third, the interaction of the first two trends crowd out resources to support younger people to adapt to new risks, including lower earnings, higher costs, less time at home when children are young, and climate change.

Older Canadians today [...] generally faced more favourable socioeconomic circumstances as younger adults in 1976 than do younger Canadians now. Older Canadians started with higher median earnings, which could stretch further when paying for rent, saving for a down payment, and paying a mortgage. Today's seniors also inherited smaller government debts as young people, and reduced their ecological footprint at just one-third of the rate that young adults must now do.

Since life expectancy at birth for Canadians aged 25 in 1976 is 7 to 10 years higher than for Canadians aged 65 in 1976,[57] time comparisons of spending on seniors are difficult to interpret. Some may judge that contemporary older Canadians must financially manage more birthdays than did seniors in the past, and thus have greater need. Some may judge that additional birthdays ahead of contemporary seniors mean they are "younger," less frail, and thus have a greater ability to pay (Sanderson/Scherbov 2008). However one aligns with these perspectives, the data from this study invite public dialogue about whether Canadian public finance has found the right balance in adapting for older Canadians in proportion to the initial circumstances they inherited, and to new realities now facing them and younger citizens. This dialogue will be shaped by values as much as by empirical data.

Policy recommendations

Generational inequities in public finance are more likely to be ignored if not monitored. It is time for Canadian governments to publish routine reports that feature data about the elderly/non-elderly ratio of spending changes; trends in tax rates, and taxes paid in allegiance to the golden rule; along with metrics that assess the relative ability to pay of various age cohorts. Because of concerns about government deficit and debt as metrics of fiscal sustainability, offices of Parliament should also perform fiscal gap and generational accounting every three years as the European Union now does for member countries (Kotlikoff 2017:59).

When evidence emerges of intergenerational imbalance, the search for public finance responses should target cleavages between age groups. A current cleavage is the gap between home prices and earnings, which reduces the ability to pay among young adults, while driving wealth accumulation for many seniors. An extensive international literature observes that residential property often enjoys favourable tax treatment (Freebairn 2016; O'Sullivan/Gibb 2012; Cho/Francis 2011), including in Canada (Boadway 2015: 261). For example, capital gains from the sale of principal residences are not counted as income for tax purposes, representing a federal tax expenditure of $7 billion annually (Government of Canada 2017:39), and corresponding reductions for provincial coffers. Simultaneously, annual revenue from municipal property taxation is down $4.4 billion as a share of GDP compared to 1976.[58]

It is time for Canadian governments to publish routine reports that feature data about the elderly/non-elderly ratio of spending changes; trends in tax rates, and taxes paid in allegiance to the golden rule; along with metrics that assess the relative ability to pay of various age cohorts.

Since all provinces have infrastructure to assess annually the market value of homes, shifting the balance of revenue generation toward housing wealth is an optimal starting point for renewing commitment to intergenerational justice in Canadian public finance.[59] This tax shift would target the primary trend creating a socio-economic fissure between older and younger citizens. It also taps older Canadians with financial means for additional taxation in recognition that they disproportionately accumulated housing wealth over the last four decades; and their generation passes down larger public medical care bills to their children than their parents passed down to them. Tax deferment could accommodate "home-rich but income-poor" citizens by postponing collection of new annual taxes on high-value homes until the sale of the property. On top of funding medical care for the ageing population, additional taxation of housing wealth would preserve fiscal capacity for governments to address new social risks for younger Canadians, and reduce incentives for speculative demand on real estate to cool down housing prices. That could be a win-win-win for all generations.

Notes

1 Statistics Canada (2017a): CANSIM Table 051-0001.

2 Social Sciences and Humanities Research Council (n.d.).

3 Such omissions undermine the utility of comparative projects, because medical care spending is consumed disproportionately in later life, while education is consumed earlier. Likewise, the omission of tax expenditures means one country's baby bonus will be counted as a traditional budget expense when another country's child tax credit will not, although the two are functionally equivalent.

4 For example, Bradshaw/Holmes 2013.

5 Revenue data from Statistics Canada (2018a): CANSIM Table 380-0080. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

6 Revenue data from Statistics Canada (2018a): CANSIM Table 380-0080. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

7 United Nations (2002) assemblies on ageing emphasise the rights of older persons to independence, participation, care,

self-fulfilment and dignity, while the United Nations (1989) convention on the rights of the child invokes special protections for children, and implies investment in their guardians.

8 For a summary of this literature, see the Commission on the Social Determinants of Health 2008.

9 By examining spending on Canadians under the age of 45, I largely avoid the problem of apportioning benefits between parents and children. Tenuous assumptions would otherwise be required when calculating the portion of cash transfers to families from which parents benefit apart from their children, or what quantity of childcare and school expenditures provide early development opportunities for children by comparison with the portion that supports parents to connect to the labour market, etc. As Lynch (2006:20) observes, there is "considerable overlap between the wellbeing of children and non-elderly adults, and the scant similarity between the wellbeing of seniors and of their children's and grandchildren's age groups."

10 The CPI figure for 1976 is 31.1 The CPI figure for 2016 is 128.4. See Statistics Canada (2018c): CANSIM Table 326-0021.

11 2016 tax calculations rely on SPSD/M version 26.1 and 1976 calculations rely on version 8.1. Since the released version of the latter only included years 1984 to 2005, Statistics Canada staff updated the parameters for this study to reflect the 1976 tax structure for federal and provincial taxes. The updates were provided by Laurie Plager (laurie.plager@canada.ca) on 19 January 2018. The assumptions and calculations underlying the simulations were prepared by the author, and the responsibility for the use and interpretation of these data is entirely that of the author.

12 Some may lament that this study does not perform generational accounting (GA). Developed by Auerbach, Gokhale, Kotlikoff (1991) and colleagues, it is a methodology widely used among economists to study whether a government's current fiscal policy is balanced in terms of taxes owed and benefits received between contemporary and future generations, assuming current policy persists indefinitely. If there is imbalance, GA permits estimation of the scale of revenue and/or expenditure adaptations needed to restore balance. The method is motivated by critique that conventional concepts of deficit and debt "do not constitute meaningful measurements of the fiscal burden being foisted on young and future generations" because of arbitrary accounting practices that keep some liabilities off government books (Kotlikoff 2017: 60).

In their recent GA study of pension reform in Norway, Germany and Poland, Laub and Hagist (2017: 72) observe that the success of policy adaptations to promote intergenerational justice "is highly dependent on whether people accept them, and adapt to them or not. Thus a transparent reform process and a broad approval of reform steps taken" are necessary for the revisions to be politically viable. While GA can contribute to this process by providing a measure of the fiscal gap between contemporary and future generations, they conclude "it has to be complemented by other assessments" that help to bring along the public and decision-makers. This study falls in the "other" category, by focusing on a retrospective, descriptive analysis of changes to public finance so that Canadians can better understand trends that produced the current suite of intergenerational policies. As Kotlikoff (2017: 57) acknowledges in his review of GA scholarship over recent decades, "how well current generations fared in the past may matter for assessing the justice of current generation policy."

13 Revenue data from Statistics Canada (2018a): CANSIM Table 380-0080. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

14 2016 age estimates for medical spending are calculated in three steps. The Canadian Institute for Health Information (CIHI) provides per capita data about provincial medical spending reported for five-year age ranges (2017: Table E.1.18.2). The most recent are for 2015. I first apply 2015 per capita data to the Canadian population in 2016 to estimate total projected spending. Second, I calculate the percentage of this projected spending for Canadians under the age of 45 (29.2%) and aged 65+ (46.7%). Third, I attribute these percentages to the $163.3 billion actually forecasted as total public spending on medical care for Canada in 2016 (CIHI 2017: Table A.3.3.1). These calculations reflect average per capita figures of $2,314 per person under 45 and $12,913 per person aged 65+ (See Table 1). GDP data are from Statistics Canada (2018b): CANSIM Table 380-0063.

I calculate the age distribution of medical spending in 1976 in the same way, with one exception. CIHI data about per capita use of medical care date back to 1998 (2017: Table E.1.1.2). To estimate per capita spending in 1976, I calculate the average annual change between 1998 and 2014 for each five-year age group, and attribute that average change to each year between 1976 and 1997. These figures are applied as step 1 to the population in 1976 to estimate total projected spending. I calculate in step 2 the percentage of projected spending on Canadians under the age of 45 (43.5%) and 65+ (36.7%). I then apply these percentages to the total spending of $10.8 billion in 1976 reported by CIHI (2017: Table A.3.3.1). These calculations reflect average per capita assumptions of $1,143 per person under 45 and $8,322 per person aged 65+ after adjusting for inflation into 2016 dollars (See Table 1).

As a sensitivity analysis for the 1976 calculation, I change step 1 by attributing the per capita spending values in 1998 to the population distribution in 1976. This sensitivity analysis predicts 45.4% of spending in 1976 went to those under the age of 45, and 33.9% went to those aged 65+. These predictions reflect assumptions of $1,194 per person under 45 and $7,690 per person aged 65+. (See Table 1).

The sensitivity analysis suggests that primary figures underestimate the annual increase in medical care spending for Canadian seniors by $3 billion in aggregate, and over $600 per capita. Similarly, the sensitivity analysis suggests that primary figures underestimate a decline in spending for the under-45 population by approximately $2 billion in aggregate, and overestimate the resulting per capita increase by around $50.

15 Old Age Security data from Statistics Canada (2018a): CANSIM Table 380-0080. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

16 Canada and Quebec public pension data from Statistics Canada (2018a): CANSIM Table 380-0080. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063. Legislation requires that C/QPP revenues remain separate from other taxation so that arms-length boards invest prepayments to fill the gap between contributions and projected expenditures.

17 2016 data about post-secondary credentials are from Statistics Canada (2017b). 1976 data are from two sources. Statistics Canada (1978a): "Table 30. Population 15 years and older not attending school full time by age groups and sex, showing level of schooling, for Canada and provinces 1976." Statistics Canada

(1978b): "Table 14. Population 15 Years and Over by Age Groups and School Attendance, Showing Labour Force Activity and Sex, for Canada and Provinces, 1976." Due to data limitations, note that the 1976 calculations assume (i) all people in post-secondary in that year have a certificate/degree, and (ii) all people over the age of 35 in post-secondary fall in the under-age-45 cohort. These assumptions overestimate the percentage of people under the age of 45 who had post-secondary credentials in 1976, and thus underestimate the increase in the proportion of people under 45 with post-secondary credentials as of 2016. The latter underestimation means the per capita decrease in spending on post-secondary as of 2016 is likely larger than reported in Table 1.

18 Post-secondary spending data from Statistics Canada (2018d): CANSIM Table 380-0081. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

19 Labour force data from Statistics Canada (2017c): CANSIM Table 282-0002.

20 Childcare expenditure data are from Friendly/Grady/Macdonald/et al. (2015: 136). GDP data are from Statistics Canada (2018b): CANSIM Table 380-0063. Since comprehensive data on childcare spending do not exist for 1976, I estimate spending based on the province of British Columbia, and then adjust for the portion of the national population represented by BC in 1976 to generate a national estimate. BC data are from Government of British Columbia 1977: D.41. The $3.6 billion increase is approximately $10 billion less than Kershaw and Anderson (2009) estimate is required to build a high-quality system, and why Canada ranks among the bottom of OECD countries for investment in early childhood education (Petersson/Mariscal/Ishi 2017: 19).

21 The data reviewed in this study are in keeping with Barer, Evans and Hertzman (1995: 194), who find that population ageing alone accounts for little of the increased utilisation of health care by seniors in Canada. Utilisation is driven more by the fact that the health system is doing more to and for seniors than in the past, "suggesting that the appropriate care of elderly people should be a central issue for health care policy and management."

22 These findings are consistent with Tepe and Vanhuysse (2010), who report that dramatic demand-side demographic trends influence public finance relatively little in advanced democracies, although the historical timing of when governments begin addressing social risks shapes spending patterns.

23 Debt data from Statistics Canada (n.d. a): CANSIM Table 378-0073 and Statistics Canada (2018e): CANSIM Table 378-0121. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

24 Elementary and secondary school spending data from Statistics Canada (2017d): CANSIM Table 478-0014. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

25 Parental leave spending data in 2016 from Government of Canada (n.d.): Chart 2. Parental leave data in 1976 from Canadian Tax Foundation 1979: Table 7-9. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

26 Statistics Canada (2017a): CANSIM Table 051-0001. There are 3.2 million more people under the age of 45, 5.6 million more people age 45-64, and 4 million more seniors.

27 Revenue data from Statistics Canada (2018a): CANSIM Table 380-0080. Population data from Statistics Canada (2017a): CANSIM Table 051-0001.

28 GDP data from Statistics Canada (2018b): CANSIM Table 380-0063. Population data from Statistics Canada (2017a): CANSIM Table 051-0001.

29 Medical care calculations are based on Canadian Institute of Health Information (2017) data about total health spending by governments, and analysis of per capita health spending by age group. See note 32 for further detail. The per capita figures account for an estimated 55% increase in use of publicly-paid medical care services per person aged 65+ between 1976 and 2016 (from $8,322 to $12,913); and an estimated increase of 102% per person under the age of 45 (from $1,143 to $2,314).

30 Per capita figures for childcare and parental leave in Table 1 account for the increased demographic demand for these programmes as a result of the 54% increase in labour force participation among women age 25-44 between 1976 and 2016. Similarly, the figure for post-secondary accounts for the 149% increase in the share of Canadians age 25-44 who earned post-secondary credentials by comparison with 1976. Even if these adjustments to per capita spending on younger Canadians are not made, the elderly/non-elderly (under the age of 45) ratio of change in social spending is 2.6 to 1; and the $4,591 rise in medical care spending per senior is on its own larger than the $4,299 increase in spending on the entire suite of programmes for younger generations ($4,299 = $9,420 - $5,122). See Table 1 for further detail.

31 Post-secondary spending data from Statistics Canada (2018d): CANSIM Table 380-0081. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

32 The Canadian Institute for Health Information has reported the age pattern in health care consumption from 1998 onward (with a 2-3 year data lag). These data consistently reveal escalation in medical spending over the life course. For example, the 2015 figures reveal less than $2,000 in spending per person age 1-24, and $2,000 to $3,000 per person age 25-49. By aged 65-69, the figure is around $6,600, and rises to over $29,000 for Canadians 90+. The one exception to this trend is spending on infants, approximately $11,000, reflecting the costs associated with birthing. For further discussion of the age pattern in Canada, see also Forget et al. (2008).

33 In keeping with per capita reductions in government spending on university, college and the trades, annual undergraduate tuition rose from $2,332 in 1976 to $6,373 in 2016 (Statistics Canada (2017e): CANSIM Table 477-0077; and Statistics Canada (n.d. g): Tuition Living Accommodation Costs (TLAC) Standard Table 8E.1a) Weighted average tuition fees for full-time Canadian Undergraduate students by province and Canada total, in current dollars, 1972-2006). This finding is consistent with Cheung et al. (2012) who report that tuition fees in Canada increased 40% between 1997 and 2011, and that Canadian public investment in tertiary education provides a low level of grant funding, and a high level of loan funding, by comparison with the OECD average.

34 This observation is especially important in Canada, where public funding for medical care is relatively high by international standards, but purchases below-average access to doctors and diagnostics, along with well-remunerated physicians (OECD 2017: 156, 168, 170).

35 All population estimates are from Statistics Canada (2017a): CANSIM Table 051-0001.

36 An optimal analysis would examine age patterns in revenue from taxation of individual income and goods/services. Canadian

data do not permit age analyses of the latter. However, it is likely that goods/services taxation is down for most or all age groups, because the tax mix has shifted away from taxes on goods/services in favour of additional income taxation. Income taxes represented 28.5% of total government revenue in 1976 and 30.3% of total revenue in 2016. By contrast, taxes on goods/services represented 33.8% of total revenue in 1976 and 30.9% in 2016. This shift represents a $27.4 billion increase in taxation of individual income (measured as a share of GDP), compared to a $7.2 billion reduction in taxation of goods/services. (Revenue data from Statistics Canada (2018a): CANSIM Table 380-0080. Population data from Statistics Canada (2017a): CANSIM Table 051-0001). GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.

37 Statistics Canada (n.d. b): Data Table, Total Income percentiles.

38 Taxes owed are calculated using versions 8.1 and 26.1 of Statistics Canada's Social Policy Simulation Database and Model (SPS-D/M). See note 27 for further information.

39 These findings are consistent with Evans, Hertzman and Morgan (2007: 302-303), who report that "several provincial governments have in the last decade made significant cuts to their income tax rates, and then cut expenditures to restore budget balance. Since cutting health spending is so politically charged, they have chosen to cut other programs more."

40 Larger income tax transfers from young people to seniors reflect in part that there were nearly seven workers for every Canadian aged 65+ in 1976, while there are now fewer than four, and projections anticipate fewer than three in the decades ahead (Statistics Canada 2014).

41 Statistics Canada (n.d. c).

42 Low income data from Statistics Canada (2018f): CANSIM Table 206-0041.

43 Median income data from Statistics Canada (2018g): CANSIM Table 206-0052. I examine five-year time periods from 1976-1981 and the first half of the current decade to dampen the influence of the business cycle on time comparisons.

44 Full-time, full-year median income data from Statistics Canada (n.d. d): Custom Table C856285. Younger Canadians who work full-time, full-year earn less today despite the trend toward more education discussed earlier. 70% of 25-44 year-olds now have post-secondary credentials compared to 28% four decades ago. While people with post-secondary still earn more on average than those without, more recent labour market entrants do not enjoy as large a return for their post-secondary investments as did graduates in the past (see Beaudry/Green 2000. Moos 2014).

45 Lower median income for Canadians under the age of 45 coupled with higher median income for those over 45 are consistent with the stagnation in Canadian earnings reported by Rouillard and Rouillard (2015) since 1980. These age patterns are also in line with evidence from Chen, Ostrovsky and Piraino (2017) who find that research from the late 1990s overestimated intergenerational income mobility in Canada.

46 Canadian Real Estate Association (n.d.): Custom Table. Average home prices today reflect the fact that many more young people now purchase homes in condominiums or apartments without yards, or in suburbs that require longer commutes than the past (Kershaw/Minh 2016).

47 The ratio increases from 4:1 to 9:1 when mean full-time, full-year earnings are swapped for the median figures reported in this section.

48 Guided by Rea et al. (2008) and Statistics Canada, I assume that the typical Canadian trying to buy into the housing market can save 15% of their income for a down payment on top of rent or other shelter payment. This rate of saving is more aggressive than the 10% rate assumed by CityLab (2012) when making similar calculations for US cities. My findings are consistent with Moos (2014: 2096), who reports for younger Canadians that "Housing costs are higher and more income is required to attain a similar kind of housing status to those of previous cohorts." See also Cheung (2014), who reports that housing prices have increased significantly over the past decade, requiring first-time home-buyers to spend more of their income to purchase homes, and coinciding with a shortage in rental housing in several cities.

49 Building on the analysis of work required to save a 20% down payment, I calculate mortgage payments for a loan that equals 80% of the value of an average-priced home. Average home price data from Canadian Real Estate Association (n.d.): Custom Table. Interest rate data from Statistics Canada (n.d. e): CANSIM Table 176-0043. Interest payments calculated using the Vancity Credit Union (n.d.) Mortgage Calculator.

50 Rental data from Statistics Canada (2017f): CANSIM Table 027-0040.

51 Housing wealth data for 1977 from Statistics Canada 1977. Data for 2016 from Statistics Canada (2017g): CANSIM Table 205-0002.

52 Home ownership is down 12%-14% for people under 45 today by comparison with 1977, while ownership is up 7%-10% for Canadians aged 55 and older. Home ownership data for 1977 from Statistics Canada 1977. Data for 2016 from Statistics Canada (2017g): CANSIM Table 205-0002.

53 These findings about wealth accumulation via increased housing capital are in line with Lemieux and Riddell (2016), who report that the share of national income in Canada received by workers has dropped when compared to income received by owners of capital.

54 Vanhuysse (2013) calculates the debt per child. Consistent with my focus on the generations raising children, I calculate the debt per person under the age of 45. As Kotlikoff (2017) rightly critiques, public debt suffers from arbitrary accounting decisions that limit its accuracy as a metric of fiscal sustainability. Still, as the dominant fiscal debt measure of which the public is aware, an increasing level of debt per capita signals lesser prioritization of fiscal sustainability among decision-makers accountable to the public. It is therefore meaningful to examine if lesser priority is given to sustainability, even if the metric may not be an accurate measure of the actual level of (un)sustainability.

55 Debt data from Statistics Canada (n.d. a): CANSIM Table 378-0073 and Statistics Canada (2018e): CANSIM Table 378-0121. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063. Population data from Statistics Canada (2017a): CANSIM Table 051-0001.

56 Similarly, the Intergovernmental Panel on Climate Change Working Group III (2001: 89) reports that greenhouse gas emissions must fall below two tonnes per person to avoid severe damage to the climate. In order to achieve this reduction by 2050, decarbonisation plans could have been phased in more gradually in 1976 than today. At that time, the International Energy Association (2017: CO2/population) estimated Canada emitted 16.59 tonnes per person, which required annual reductions of 0.2 tonnes per

year. By this logic, per capita emissions should now be under nine tonnes – not the 15.32 tonnes recorded by the IEA in 2015. Given the slow pace of adaptation in previous decades, carbon-reduction must now occur at twice the pace, dropping 0.4 tonnes per year.
57 Statistics Canada (n.d. f): CANSIM Table 102-0512.
58 Property tax data from Statistics Canada (2018a): CANSIM Table 380-0080. GDP data from Statistics Canada (2018b): CANSIM Table 380-0063.
59 Support for including home wealth more in calculations of taxes owed or fees required to pay for the costs of population ageing is also growing in Australia (Ong 2016) and the UK (Searle/McCollum 2014, O'Sullivan/Gibb 2012), given the substantial escalation in home prices experienced in those countries in recent decades. In addition, several commentators speak of the value of recurrent taxation of property wealth for efficiency reasons (Wood/Ong/Cigdem 2016, Eerola/Maattanen 2013, Evans 2012), observing that sheltering of housing wealth accelerates investment in real estate at the expense of capital investment in more productive sectors.

References

Auerbach, Alan J. / Gokhale, Jagadeesh / Kotlikoff, Laurence J. (1991): Generational Accounts: A Meaningful Alternative to Deficit Accounting. In: Tax Policy and the Economy, NBER, 5.

Barer, Moris L. / Evans, Robert G. / Hertzman, Clyde (1995): Avalanche or Glacier? Health Care and the Demographic Rhetoric. In: Canadian Journal on Aging, 14 (2), 193-224.

Beaudry, Paul / Green, David (2000): Cohort Patterns in Canadian Earnings: Assessing the Role of Skill Premia in Inequality Trends. In: Canadian Journal of Economics, 33 (4), 907-936.

Boadway, Robin (2015): Tax Policy for a Rent-Rich Economy. In: Canadian Public Policy, 41 (4), 253-264.

Boyce, W. Thomas (2007): A biology of misfortune: Stress reactivity, social context, and the ontogeny of psychopathology in early life. In: Masten, Ann S. (ed.). Multilevel Dynamics in Developmental Psychopathology: Pathways to the Future. Minneapolis: University of Minnesota, 45-82.

Bradshaw, Jonathan / Holmes, John (2013): An Analysis of Equity in Redistribution to the Retired and Children over Recent Decades in the OECD and UK. In: Journal of Social Policy, 42 (1), 39-56.

Canadian Real Estate Association (n.d.): Custom Table. Average home prices by province and selected cities, 1976 onward. Table provided by jlemoine@crea.ca on 15 January 2018 and 16/17 January 2017.

Canadian Institute for Health Information (2017): National Health Expenditure Trends, 1975-2017: Data tables on health spending. https://www.cihi.ca/sites/default/files/document/nhex2017-full-datatables-en.zip. Viewed on on 18 April 2018.

Canadian Tax Foundation (1979): The National Finances 1977/78. Toronto: Canadian Tax Foundation.

Chen, Wen-Hao / Ostrovsky, Yuri / Piraino, Patrizio (2017): Lifecycle variation, errors-in-variables bias and nonlinearities in intergenerational income transmission: new evidence from Canada. In: Labour Economics, 44, 1-12.

Cheung, C. (2014): Deconstructing Canada's Housing Markets: Finance, Affordability and Urban Sprawl. In: OECD Economics Department Working Papers, No. 1145. Paris: OECD Publishing.

Cheung, C. / Guillemette, Y. / Mobasher-Fard, S. (2012): Tertiary Education: Developing Skills for Innovation and Long-Term Growth in Canada. OECD Economics Department Working Papers, No. 991. Paris: OECD Publishing.

Cho, Sang-Wook (Stanley) / Francis, Johanna L. (2011): Tax treatment of owner occupied housing and wealth inequality. In: Journal of Macroeconomics, 33, 42-60.

CityLab (2012): "How Long Will You Need to Save to Buy a Home In Your City?" In: The Atlantic. http://www.citylab.com/housing/2012/08/how-long-will-you-need-save-buy-home-your-city/3085/. Viewed on 21 November 2014.

Commission on the Social Determinants of Health (2008): Closing the gap in a generation: health equity through action on the social determinants of health. Final Report of the Commission on Social Determinants of Health. World Health Organization. http://www.who.int/social_determinants/thecommission/finalreport/en/index.html. Viewed on 15 January 2010.

Corak, Miles (ed.) (1998): Government Finances and Generational Equity. Ottawa: Ministry of Industry, Government of Canada.

Dutton, Daniel J. / Forest, Pierre-Gerlier / Kneebone, Ronald D. et al. (2018): Effect of provincial spending on social services and health care on health outcomes in Canada: an observational longitudinal study. In: Canadian Medical Association Journal, 190 (3), E66-71.

Eerola, Essi / Maattanen, Niku (2013): The Optimal Tax Treatment of Housing Capital in the Neoclassical Growth Model. In: Journal of Public Economic Theory, 15 (6), 912-938.

Evans, Alan W. (2012): Optimal tax theory and the taxation of housing in the US and the UK. In: Journal of Property Research, 29 (4), 368-378.

Evans, Robert / Hertzman, Clyde / Morgan, Steve (2007): Improving Health Outcomes in Canada. In: Leonard, Jeremy / Ragan, Christopher / St-Hilaire, France (eds): A Canadian Priorities Agenda: Policy Choices to Improve Economic and Social Well-Being. Montreal: Institute for Research on Public Policy, 291-327.

Forget, Evelyn L et al. (2008): Variations in Lifetime Healthcare Costs across a Population. In: Healthcare Policy, 4 (1), e149-e167.

Freebairn, John (2016): Taxation of Housing. In: The Australian Economic Review, 49 (3), 307-316.

Friendly, Martha / Grady, Bethany / Macdonald, Lyndsay et al.

(2015): Early Childhood Education in Canada 2014. Toronto, ON: Childcare Resource and Research Unit. http://childcare-canada.org/sites/default/files/ECEC-2014-full-document-revised-10-03-16.pdf. Viewed on 24 January 2018.

Global Footprint Network (2018): Ecological Footprint per Person. http://data.footprintnetwork.org/#/. Viewed on 2 May 2018.

Global Footprint Network (2018): Open Data Platform: NFA 2018 Edition. https://api.footprintnetwork.org/v1/data/33/all/earth. Viewed on 16 April 2018.

Gosseries, Axel (2009): Three Models of Intergenerational Reciprocity. In: Meyer, Lukas / Gosseries, Axel (eds): Intergenerational Justice. Oxford: Oxford University Press, 119-146.

Government of British Columbia (1977): Public Accounts. Victoria, BC: Ministry of Finance.

Government of Canada (2017): Report on Federal Tax Expenditures. Ottawa: Department of Finance Canada.

Government of Canada (n.d.): Employment Insurance Monitoring and Assessment Report for the fiscal year beginning April 1, 2015 and ending March 31, 2016. Chapter II - 1. Employment Insurance benefits overview. Ottawa: Employment and Social Development Canada. https://www.canada.ca/en/employment-social-development/programs/ei/ei-list/reports/monitoring2016/chapter2/ei-overview.html#section1.1. Viewed on 23 January 2018.

Intergovernmental Panel on Climate Change Working Group III (2001): Climate Change 2001: Mitigation. Intergovernmental Panel on Climate Change. http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=0. Viewed on 24 January 2018.

International Energy Association (2017): CO2 emissions from fuel combustion 2017 database. www.iea.org/publications/freepublications/publication/CO2-emissions-from-fuel-combustion-highlights-2017.html. Viewed on 24 January 2018.

Keating, Daniel P. / Hertzman, Clyde (eds) (1999): Developmental Health and the Wealth of Nations: Social, Biological, and Educational Dynamics. New York: The Guilford Press.

Kershaw, Paul (2018): The need for health in all policies in Canada. In: Canadian Medical Association Journal, 190 (64), E64-65.

Kershaw, Paul / Anderson, Lynell (2016): Measuring the Age Distribution in Canadian Social Spending. In: Canadian Public Administration, 59 (4), 556-579.

Kershaw, Paul / Anderson, Lynell (2009): Is a pan-Canadian system of early child development possible? Yes, when we redress what ails Canadian culture. In: Paediatrics and Child Health, 14 (10), 685-688.

Kershaw, Paul / Minh, Anita (2016): Code Red: Rethinking Canadian Housing Policy. Vancouver: Generation Squeeze. http://bit.ly/GSCodeRed. Viewed on 24 June 2016.

Kotlikoff, Laurence (2017): Measuring Intergenerational Justice. In: Intergenerational Justice Review, 11 (2), 56-63.

Laub, Natalie / Hagist, Christian (2017): Pension and Intergenerational Balance: A case study of Norway, Poland and Germany using Generational Accounting. In: Intergenerational Justice Review, 11 (2), 64-76.

Lee, Ronald / Mason, Andrew (eds) (2011): Population Aging and the Generational Economy: A Global Perspective. Cheltenham, UK: Edward Elgar Publishing.

Lemieux, Thomas / Riddell, Craig (2016): Who Are Canada's Top 1 Percent? In: Green, David / Riddell, Craig / St-Hilaire, France (eds): Income Inequality: The Canadian Story. Montreal: Institute for Research on Public Policy, 103-155.

Lynch, Julia (2006): Age in the Welfare State: The Origins of Social Spending on Pensioners, Workers and Children. Cambridge: Cambridge University Press.

Moos, Markus (2014): Generational Dimensions of Neoliberal and Post-Fordist Restructuring: The Changing Characteristics of Young Adults and Growing Income Inequality in Montreal and Vancouver. In: International Journal of Urban and Regional Research, 38 (6), 2078-2102.

OECD (2017): Health at a Glance 2017. Paris: OECD publishing. http://dx.doi.org/10.1787/health_glance-2017-en. Viewed on 23 January 2018.

Ong, Rachel (2016): Financing aged care: The role of housing wealth and intergenerational relationships. In: Kendal, Hal / McDonald, Peter/ Piggott, John (eds): Population Ageing and Australia's Future. Acton: Australian National University Press, 261-280.

Oreopoulos, Philip / Kotlikoff, Laurence J. (1996): Restoring Generational Balance in Canada. In: Choices, 2 (1), 2-52.

Oreopoulos, Philip / Vaillancourt, Francois (1998): Applying Generational Accounting to Canada: Findings and Fallacies. In: Corak, Miles (ed.): Government Finances and Generational Equity. Ottawa: Statistics Canada, Ministry of Industry, 7-20.

O'Sullivan, Anthony / Gibb, Kenneth (2012): Housing Taxation and the Economic Benefits of Homeownership. In: Housing Studies, 27 (2), 267-279.

Petersson, Bengt / Mariscal, Rodrigo / Ishi, Kotaro (2017): Women are Key for Future Economic Growth: Evidence from Canada. International Monetary Fund. https://www.imf.org/en/Publications/WP/Issues/2017/07/19/Women-Are-Key-for-Future-Growth-Evidence-from-Canada-45047. Viewed on 24 January 2018.

Rawls, John (1971): A Theory of Justice. Cambridge, MA: Harvard University Press.

Rea, Willa / Yuen, Jennifer / Engeland, John et al. (2008): The dynamics of housing affordability. In: Perspectives, 20, 15-26.

Rouillard, Jacques / Rouillard, Jean-François (2015): Salaires et productivité du travail au Canada depuis le début du 20e siècle: les travailleurs bénéficient-ils de la croissance économique? In: Relations Industrielles / Industrial Relations, 70 (2), 353-377.

Sanderson, Warren / Scherbov, Sergei (2008): Rethinking Age and Aging. In: Population Bulletin, 63 (4), 3-16.

Searle, Beverley A / McCollum, David (2014): Property-based welfare and the search for generational equality. In: International Journal of Housing Policy, 14 (4), 325-343.

Social Sciences and Humanities Research Council (n.d.): Future Challenge Areas and Subquestions. Ottawa: Government of Canada. http://www.sshrc-crsh.gc.ca/society-societe/community-communite/Future_Challenge_Areas-domaines_des_defis_de_demain-eng.aspx#4. Viewed on 23 January 2018.

Statistics Canada (2018a): CANSIM Table 380-0080: Revenue, expenditure and budgetary balance - General governments, quarterly (dollars). Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=3800080. Viewed on 15 May 2018.

Statistics Canada (2018b): CANSIM Table 380-0063: Gross domestic product, income based, quarterly (dollars). Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=3800063. Viewed on 15 May 2018.

Statistics Canada (2018c): CANSIM Table 326-0021: Consumer Price Index. Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a05?lang=eng&id=3260021. Viewed on 15 May 2018.

Statistics Canada (2018d): CANSIM Table 380-0081: Revenue, expenditure and budgtary balance - Provincial administration, education and health, quarterly (dollars). Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=3800081&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (2018e): CANSIM Table 378-0121: National Balance Sheet Accounts, quarterly (dollars). Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=3780121&&pattern=&stByVal=1&p1=1&p2=31&tabMode=dataTable&csid=. Viewed on May 15 2018.

Statistics Canada (2018f): CANSIM Table 206-0041: Low income statistics by age, sex and economic family type, Canada, provinces and selected census metropolitan areas (CMAs), annual. Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=2060041&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (2018g): CANSIM Table 206-0052. Income of individuals by age group, sex and income source, Canada, provinces and selected census metropolitan areas, annually (Number unless specified). Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=2060052&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (2017a): CANSIM Table 051-0001. Estimates of population, by age group and sex for July 1, Canada, provinces and territories. Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=510001. Viewed on 15 May 2018.

Statistics Canada (2017b): 2016 Census, Catalogue Number 98-400-X2016241. Highest Certificate, Diploma or Degree (15), Major Field of Study - Classification of Instructional Programs (CIP) 2016 (82), Age (9) and Sex (3) for the Population Aged 15 Years and Over in Private Households of Canada, Provinces and Territories, Census Metropolitan Areas and Census Agglomerations, 2016 Census - 25% Sample Data. Ottawa: Industry Canada. http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/dt-td/Ap-eng.cfm?LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GID=0&GK=0&GRP=0&PID=110633&PRID=10&PTYPE=109445&S=0&SHOWALL=0&SUB=0&Temporal=2017&THEME=123&VID=0&VNAMEE=&VNAMEF=. Viewed on 15 May 2018.

Statistics Canada (2017c): CANSIM Table 282-0002: Labour force survey estimates (LFS), by sex and detailed age group, annually (Persons). Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/pick-choisir?lang=eng&searchTypeByValue=1&id=2820002. Viewed on 15 May 2018.

Statistics Canada (2017d): CANSIM Table 478-0014: Public and private elementary and secondary education expenditures, annual (dollars). Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=4780014&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (2017e): CANSIM Table 477-0077: Canadian and International Tuition Fees by Level of Study. Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=4770077&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (2017f): CANSIM Table 027-0040. Canada Mortgage and Housing Corporation, average rents for areas with a population of 10,000 and over. Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0270040&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (2017g): CANSIM Table 205-0002. Survey of Financial Security (SFS), assets and debts held by economic family type, by age group, Canada, provinces and selected census metropolitan areas (CMAs), occasional (2016 constant dollars unless otherwise noted).

Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=2050002&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (2014): Population projections: Canada, the provinces and territories, 2013 to 2063. In: The Daily, http://www.statcan.gc.ca/daily-quotidien/140917/dq140917a-eng.htm. Viewed on 26 January 2018.

Statistics Canada (1978a): 1976 Census of Canada. Population: Demographic Characteristics. Level of Schooling by Age Groups. Ottawa: Ministry of Supply and Services, Canada.

Statistics Canada (1978b): 1976 Census of Canada: Labour Force Activity. Labour Force Activity by Age, Sex and Educational Characteristics. Ottawa: Ministry of Supply and Services, Canada.

Statistics Canada (1977): Survey of Consumer Finances 1977. Micro Data File: Income (1976), Assets and Debts (1977) of Economic Families and Unattached Individuals. Ottawa: Consumer Income and Expenditure Division, Statistics Canada, Industry, Canada.

Statistics Canada (n.d. a): CANSIM Table 378-0073: National balance sheet, government, annually (dollars). Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=3780073&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (n.d. b): Data Table: Total income percentiles (single years of age), Census of population, 1986, 1996, 2006, 2016. Ottawa: Industry Canada.

Statistics Canada (n.d. c): Low Income Definitions. Ottawa: Industry Canada, https://www.statcan.gc.ca/pub/75f0011x/2012001/notes/low-faible-eng.htm. Viewed on 2 May 2018.

Statistics Canada (n.d. d): Custom Table C856285. Ottawa: Income Statistics Division, Survey of Labour and Income Dynamics & Canadian Income Survey, Industry Canada.

Statistics Canada (n.d. e): CANSIM Table 176-0043. Financial market statistics, last Wednesday unless otherwise stated, Bank of Canada. Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=2050002&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (n.d. f): CANSIM Table 102-0512: Life expectancy at birth, by sex, by province. Ottawa: Industry Canada. http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=1020512&&pattern=&stByVal=1&p1=1&p2=49&tabMode=dataTable&csid=. Viewed on 15 May 2018.

Statistics Canada (n.d. g): Tuition Living Accommodation Costs (TLAC) Standard Table 8E.1a) Weighted average tuition fees for full-time Canadian Undergraduate students by province and Canada total, in current dollars, 1972-2006. Ottawa: Industry Canada.

Tepe, Markus / Vanhuysse, Pieter (2010): Elderly bias, new social risks and social spending: change and timing in eight programmes across four worlds of welfare, 1980-2003. In: Journal of European Social Policy, 20 (3), 217-234.

United Nations (2015): Paris Agreement, http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf. Viewed on 24 January 2018.

United Nations (2002): Report of the Second World Assembly on Ageing. Madrid, 8-12 April 2002: United Nations publication. A/CONF.197/9. Sales No. E.02.IV.4. http://daccess-ods.un.org/access.nsf/Get?Open&DS=A/CONF.197/9&Lang=E. Viewed on 26 January 2018.

United Nations (1989): Convention on the Rights of the Child, http://www.unhcr.org/uk/4aa76b319.pdf. Viewed on 9 October 2017.

Vancity Credit Union (n.d.): Mortgage Calculator, https://www.vancity.com/Mortgages/MortgageCalculators/. Viewed on 16 April 2018.

Vanhuysse, Pieter (2013): Intergenerational Justice in Aging Societies: A Cross-national Comparison of 29 OECD Countries. Gütersloh: Bertelsmann Stiftung. https://www.bertelsmann-stiftung.de/en/publications/publication/did/intergenerational-justice-in-aging-societies/. Viewed on 16 September 2016.

Wolfson, Michael et al. (1998): Historical Generational Accounting with Heterogeneous Populations. In: Corak, Miles (ed.): Government Finances and Generational Equity. Ottawa: Industry Canada, 107-125.

Wood, Gavin / Ong, Rachel / Cigdem, Melek (2016): Housing Tax Reform: Is There a Way Forward? In: Economic Papers, 35 (4), 332-346.

Dr Paul Kershaw received the award for Academic of the Year in 2016 from the Confederation of University Faculty Associations of British Columbia for his work on generational equity. The Canadian Political Science Association has twice honoured Kershaw with national prizes for his research.

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This is Exhibit "D" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018

A Commissioner for taking Affidavits within British Columbia

Health and climate change: policy responses to protect public health

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Executive summary

The 2015 *Lancet* Commission on Health and Climate Change has been formed to map out the impacts of climate change, and the necessary policy responses, in order to ensure the highest attainable standards of health for populations worldwide. This Commission is multi-disciplinary and international in nature, with strong collaboration between academic centres in Europe and China.

The central finding from the Commission's work is that tackling climate change could be the greatest global health opportunity of the 21st century. The key messages from the Commission are summarised below, accompanied by ten underlying recommendations to accelerate action in the next 5 years.

The effects of climate change are being felt today, and future projections represent an unacceptably high and potentially catastrophic risk to human health

The implications of climate change for a global population of 9 billion people threatens to undermine the last half century of gains in development and global health. The direct effects of climate change include increased heat stress, floods, drought, and increased frequency of intense storms, with the indirect threatening population health through adverse changes in air pollution, the spread of disease vectors, food insecurity and under-nutrition, displacement, and mental ill health.

Keeping the global average temperature rise to less than 2°C to avoid the risk of potentially catastrophic climate change impacts requires total anthropogenic carbon dioxide (CO_2) emissions to be kept below 2900 billion tonnes ($GtCO_2$) by the end of the century. As of 2011, total emissions since 1870 were a little over half of this, with current trends expected to exceed 2900 $GtCO_2$ in the next 15–30 years. High-end emissions projection scenarios show global average warming of 2·6–4·8°C by the end of the century, with all their regional amplification and attendant impacts.

Tackling climate change could be the greatest global health opportunity of the 21st century

Given the potential of climate change to reverse the health gains from economic development, and the health co-benefits that accrue from actions for a sustainable economy, tackling climate change could be the greatest global health opportunity of this century. Many mitigation and adaptation responses to climate change are "no-regret" options, which lead to direct reductions in the burden of ill-health, enhance community resilience, alleviate poverty, and address global inequity. Benefits are realised by ensuring that countries are unconstrained by climate change, enabling them to achieve better health and wellbeing for their populations. These strategies will also reduce pressures on national health budgets, delivering potentially large cost savings, and enable investments in stronger, more resilient health systems.

The Commission recommends that over the next 5 years, governments:

1 Invest in climate change and public health research, monitoring, and surveillance to ensure a better understanding of the adaptation needs and the potential health co-benefits of climate mitigation at the local and national level.

2 Scale-up financing for climate resilient health systems world-wide. Donor countries have a responsibility to support measures which reduce the impacts of climate change on human wellbeing and support adaptation. This must enable the strengthening of health systems in low-income and middle-income countries, and reduce the environmental impact of health care.

3 Protect cardiovascular and respiratory health by ensuring a rapid phase out of coal from the global energy mix. Many of the 2200 coal-fired plants currently proposed for construction globally will damage health unless replaced with cleaner energy alternatives. As part of the transition to renewable energy, there will be a cautious transitional role for natural gas. The phase out of coal is proposed as part of an early and decisive policy package which targets air pollution from the transport, agriculture, and energy sectors, and aims to reduce the health burden of particulate matter (especially $PM_{2.5}$) and short-lived climate pollutants, thus yielding immediate gains for society.

4 Encourage a transition to cities that support and promote lifestyles that are healthy for the individual and for the planet. Steps to achieve this include development of a highly energy efficient building stock; ease of low-cost active transportation; and

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increased access to green spaces. Such measures improve adaptive capacity, whilst also reducing urban pollution, greenhouse gas emissions, and rates of cardiovascular disease, cancer, obesity, diabetes, mental illness, and respiratory disease.

Achieving a decarbonised global economy and securing the public health benefits it offers is no longer primarily a technical or economic question—it is now a political one

Major technical advances have made buildings and vehicles more efficient and renewable energy sources far more cost effective. Globally, there is plentiful financial resource available, however much of it is still being directed towards the fossil-fuel industry. Bold political commitment can ensure that the technical expertise, technology, and finance to prevent further significant climate change is readily available, and is not a barrier to action.

The Commission recommends that over the next 5 years, governments:

5 Establish the framework for a strong, predictable, and international carbon pricing mechanism.

6 Rapidly expand access to renewable energy in low-income and middle-income countries, thus providing reliable electricity for communities and health facilities; unlocking substantial economic gains; and promoting health equity. Indeed, a global development pathway that fails to achieve this expansion will come at a detriment to public health, and will not achieve long-term economic growth.

7 Support accurate quantification of the avoided burden of disease, reduced health-care costs, and enhanced economic productivity associated with climate change mitigation. These will be most effective when combined with adequate local capacity and political support to develop low-carbon healthy energy choices.

The health community has a vital part to play in accelerating progress to tackle climate change

Health professionals have worked to protect against health threats, such as tobacco, HIV/AIDS, and polio, and have often confronted powerful entrenched interests in doing so. Likewise, they must be leaders in responding to the health threat of climate change. A public health perspective has the potential to unite all actors behind a common cause—the health and wellbeing of our families, communities, and countries. These concepts are far more tangible and visceral than tonnes of atmospheric CO_2, and are understood and prioritised across all populations irrespective of culture or development status.

Reducing inequities within and between countries is crucial to promoting climate change resilience and improving global health. Neither can be delivered without accompanying sustainable development that addresses key health determinants: access to safe water and clean air, food security, strong and accessible health systems, and reductions in social and economic inequity. Any prioritisation in global health must therefore place sustainable development and climate change front and centre.

The Commission recommends that over the next 5 years, governments:

8 Adopt mechanisms to facilitate collaboration between Ministries of Health and other government departments, empowering health professionals and ensuring that health and climate considerations are thoroughly integrated in government-wide strategies. A siloed approach to protecting human health from climate change will not work. This must acknowledge and seek to address the extent to which additional global environmental changes, such as deforestation, biodiversity loss, and ocean acidification, will impact on human health and decrease resilience to climate change.

9 Agree and implement an international agreement that supports countries in transitioning to a low-carbon economy. Whilst the negotiations are very complex, their goals are very simple: agree on ambitious and enforceable global mitigation targets, on adaptation of finance to protect countries' rights to sustainable development, and on the policies and mechanisms that enable these measures. To this end, international responsibility for reducing greenhouse gas emissions is shared: interventions that reduce emissions and promote global public health must be prioritised irrespective of national boundaries.

Responding to climate change could be the greatest global health opportunity of the 21st century.

To help drive this transition, the 2015 *Lancet* Commission on Health and Climate Change will:

10 Develop a new, independent Countdown to 2030: Global Health and Climate Action, to provide expertise in implementing policies that mitigate climate change and promote public health, and to monitor progress over the next 15 years. The Collaboration will be led by this Commission, reporting in *The Lancet* every 2 years, tracking, supporting, and communicating progress and success along a range of indicators in global health and climate change

Introduction

In 2009, the UCL–*Lancet* Commission on Managing the Health Effects of Climate Change called climate change "the biggest global health threat of the 21st century".[1] 6 years on, a new multidisciplinary, international Commission reaches the same conclusion, whilst adding that tackling climate change could be the greatest global opportunity of the 21st century.

The Commission represents a collaboration between European and Chinese climate scientists and geographers, social and environmental scientists, biodiversity experts, engineers and energy policy experts, economists, political scientists and public policy experts, and health professionals—all seeking a response to climate change that is designed to protect and promote human health.

The physical basis

The Intergovernmental Panel on Climate Change (IPCC) has described the physical basis for, the impacts of, and the response options to climate change.[2] In brief, short-wave solar radiation passes through the Earth's atmosphere to warm its surface, which emits longer wavelength (infrared) radiation. Greenhouse gases (GHGs) in the atmosphere absorb this radiation and re-emit it, sharing it with other atmospheric elements, and with the Earth below. Without this effect, surface temperatures would be more than 30°C lower than they are today.[3] One such GHG is carbon dioxide (CO_2), primarily released when fossil fuels (ie, oil, coal, and natural gas) are burned. Others, such as methane (CH_4) and nitrous oxide (N_2O), are generated through fossil-fuel use and human agricultural practice. GHG emissions have steadily climbed since the industrial revolution.[4] CO_2 remains in the atmosphere for a long time, with a part remaining for thousands of years or longer.[5] As a result, atmospheric GHG concentrations have risen steeply in the industrial age, those of CO_2 reaching more than 400 parts per million (ppm) in 2014, for the first time since humans walked the planet. Every additional ppm is equivalent to about 7·5 billion tonnes of atmospheric CO_2.[6,7]

In view of their proven physical properties, such rising concentrations must drive a net positive energy balance, the additional heat distributing between gaseous atmosphere, land surface, and ocean. The IPCC's 2014 report confirms that such global warming, and the role of human activity in driving it, are unequivocal. The oceans have absorbed the bulk (90% or more) of this energy in recent years and ocean surface temperatures have risen.[8] However, temperatures at the Earth's surface have also risen, with each of the last three decades being successively warmer than any preceding decade since 1850. Indeed, 2014 was the hottest year on record. Overall, the Earth (global average land and ocean temperature) has warmed

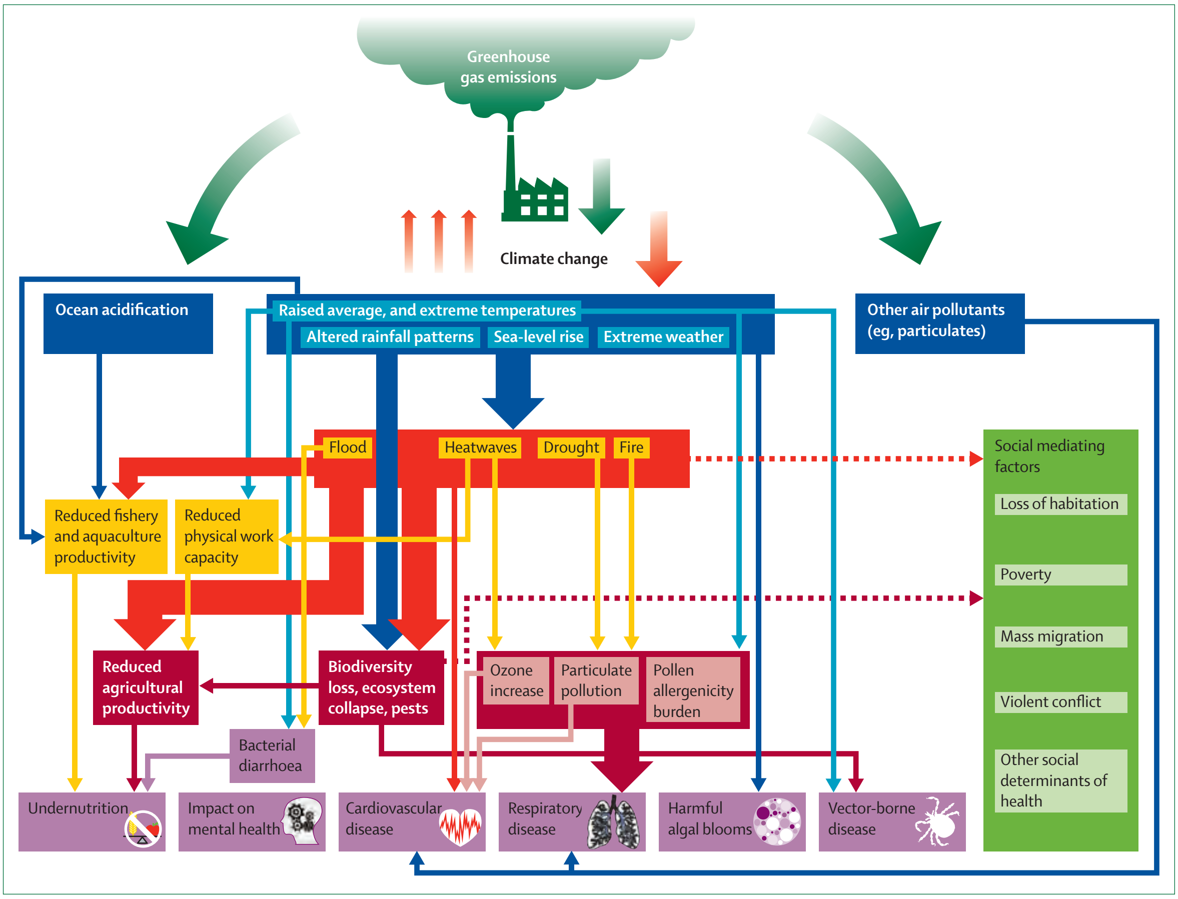

Figure 1: **An overview of the links between greenhouse gas emissions, climate change, and health**
The causal links are explained in greater detail in the section about climate change and exposure to health risks.

by some 0·85°C between 1880 and 2012.[8] Arctic sea ice is disappearing at a rate of up to 50 000 km² per year, the Antarctic ice sheet is now losing 159 billion tonnes of ice each year, and sea levels are rising inexorably.[9]

Much of past emissions remain in the atmosphere and will drive continued warming in the future. GHG concentrations in the atmosphere are continuing to rise at a rate that is incompatible with limiting warming to 2°C in the coming 35 years (by 2050), and which exceeds the IPCC's "worst case scenario".[10] We are on track for a global average temperature rise of more than 4°C above pre-industrial temperatures in the next 85 years, at which point global temperature will still be increasing by roughly 0·7°C per decade (due to the lag in reaching equilibrium). This distribution will not be even: the so-called polar amplification phenomena might cause temperatures in parts of the Arctic to increase by 11°C in this timeframe.[8]

The health impacts of climate change

The resultant climate change poses a range of threats to human health and survival in multiple, interacting ways (figure 1). Impacts can be direct (eg, heatwaves and extreme weather events such as a storm, forest fire, flood, or drought) or indirectly mediated through the effects of climate change on ecosystems (eg, agricultural losses and changing patterns of disease), economies, and social structure (eg, migration and conflict). After only 0·85°C warming, many anticipated threats have already become real-world impacts. Table 1 summarises the evidence attributing climate change to specific extreme weather events, outlining the role that climate change is playing in the present day (2013). It demonstrates increasing certainty that climate change significantly alters the probability of extreme weather, most often in directions that have dangerous health consequences.

	Summary statement	Anthropogenic influence increased event likelihood or strength	Anthropogenic influence decreased event likelihood or strength	Anthropogenic influence not found or uncertain	Number of papers
Heat	Long-duration heatwaves during the summer and prevailing warmth for annual conditions are becoming increasingly likely because of a warming planet	Europe heat, 2003 (Stott et al, 2004[11]); Russia heat, 2010 (Rahmstorf and Couman, 2011;[12] Otto et al, 2012[13]); USA heat, 2012 (Diffenbaugh and Scherer, 2013;[14] Knutson et al, 2013);[14] Australia heat, 2013 (Arblaster et al, 2014; King et al, 2014; Knutson et al, 2014; Lewis et al, 2014; Perkins et al, 2014);[15] Europe heat, 2013 (Dong et al, 2014);[15] China heat, 2013 (Zhou et al, 2014);[15] Japan heat, 2013 (Imada et al, 2014);[15] Korea heat, 2013 (Min et al, 2014)[15]	..	..	14
Cold	Prolonged cold waves have become much less likely than they were previously, such that the probability of reoccurrence of the 2013 severely cold winter in the UK might have fallen by 30 times because of global warming	..	UK cold spring, 2013 (Christidis et al, 2014)[15]	UK extreme cold, 2010–11 (Christidis and Stott, 2012)[16]	2
Heavy precipitation and flood	Extreme precipitation events were found to have been much less influenced by human-induced climate change than extreme temperature events	UK floods, 2011 (Pall et al, 2011);[17] USA seasonal precipitation, 2013 (Knutson et al, 2014);[15] India precipitation, 2013 (Singh et al, 2014)[15]	USA Great Plains drought, 2013 (Hoerling et al, 2014)[15]	Thailand floods, 2011 (Van Oldenborgh et al, 2012);[16] UK summer floods, 2012 (Sparrow et al, 2013);[14] north China floods, 2012 (Tett et al, 2013);[14] southwest Japan floods, 2012 (Imada et al, 2013);[14] southeast Australia floods (2012); (King et al, 2013,[14] Christidis et al, 2013);[14] southern Europe Precipitation, 2013 (Yiou and Cattiaux, 2014);[15] central Europe precipitation, 2013 (Schaller et al, 2014)[15]	14
Drought	Droughts are highly complex meteorological events and research groups have analysed different factors that affect droughts, such as sea surface temperature, heat, or precipitation	East African drought, 2011 (Funk et al, 2012);[16] Texas drought, 2011 (Rupp et al, 2012);[16] Iberian Peninsula drought, 2011 (Trigo et al, 2012);[16] east African drought 2012, (Funk et al, 2012);[16] New Zealand drought, 2013 (Harrington et al, 2014);[15] USA California drought, 2013 (Swain et al, 2014)[15]	..	Central USA drought, 2012 (Rupp et al, 2013);[14] USA California drought, 2013 (Funk et al, 2014);[16] (Wang and Schubert, 2014)[15]	9
Storms	No clear evidence of human influence was shown for any of the four very intense storms examined	..	..	USA hurricane Sandy, 2012 (Sweet et al, 2013);[14] cyclone Christian, 2013 (von Storch et al, 2014);[15] Pyrenees snow, 2013 (Anel et al, 2014);[15] USA south Dakota blizzard, 2013 (Edwards et al, 2014)[15]	4
Number of papers	..	23	2	18	43

References are in Peterson et al, 2012;[16] Peterson et al, 2013;[14] Herring et al, 2014;[15] or listed separately. Adapted from the Bulletin of the American Meteorological Society.

***Table 1*: Detection and attribution studies linking recent extreme weather events to climate change**

Some population groups are particularly vulnerable to the health effects of climate change, whether because of existing socioeconomic inequalities, cultural norms, or intrinsic physiological factors. These groups include women, young children and older people, people with existing health problems or disabilities, and poor and marginalised communities. Such inequalities are often also present in relation to the causes of climate change: women and children both suffer the majority of the health impacts of indoor air pollution from inefficient cookstoves and kerosene lighting, and so mitigation measures can help to reduce existing health inequities such as these.

Non-linearities, interactions, and unknown unknowns

The magnitude and nature of health impacts are hard to predict with precision; however, it is clear that they are pervasive and reflect effects on key determinants of health, including food availability. There are real risks that the effects will become non-linear as emissions and global temperatures increase. First, large-scale disruptions to the climate system are not included in climate modelling and impact assessments.[18] As we proceed rapidly towards 4°C warming by the end of the century, the likelihood of crossing thresholds and tipping points rises, threatening further warming and accelerated sea-level rise. Second, small risks can interact to produce larger-than-expected chances of catastrophic outcomes, especially if they are correlated (panel 1).[22,23]

Such impacts (and their interactions) are unlikely to be trivial and could be sufficient to trigger a discontinuity in the long-term progression of humanity.[24] Whilst the poorest and most vulnerable communities might suffer first, the interconnected nature of climate systems, ecosystems, and global society means that none will be immune. Indeed, on the basis of current emission trajectories, temperature rises in the next 85 years may be incompatible with an organised global community.[25]

Panel 1: Teeth in the tails

Tail risks are those whose probability of occurring is low (ie, >2 or 3 SDs from the mean). The size of the tail and the combination of tails will decide the chance of extreme or catastrophic outcomes. Interactions between tail risks greatly affect the risk of several happening at once—eg, interactions between crop decline and population migration, or between heatwaves, water insecurity and crop yields. The 2008 global financial crisis is an example. Here, rating agencies catastrophically mispriced the risks of pooled mortgage-related securities. For example, Nate Silver showed that if five mortgages, each with a 5% risk of defaulting, are pooled, the risks of a default of all five is 0·00003% as long as the default is perfectly uncorrelated.[19] If they are perfectly correlated (as almost happened with the housing crash) the risk is 5%. In other words, if rating agencies assumed no interaction, their risk would be miscalculated by a factor of 160 000.[19]

We must not assume that individual climate tail risks will be uncorrelated. In complex systems, individual events might become more highly correlated when events place the whole system under stress. For example, in the UK in 2007, flooding threatened electricity substations in Gloucestershire. The authorities requested the delivery of pumps and other equipment to keep one of these substations, Walham, from flooding. Loss of the substation would have left the whole county, and part of Wales and Herefordshire without power, and many people without drinking water. Equipment had to be delivered by road. Parts of the road system in the region of the substation flooded, which almost prevented the delivery of equipment. Under normal conditions, disturbances to the three subsystems—roads, electricity, and the public water supply—are uncorrelated and simultaneous failure of all three very unlikely. With extreme flooding they became correlated under the influence of a fourth variable, resulting in a higher than expected probability of all three failing together.[20,21] Indeed, these extremes of weather, which will occur more frequently with unmitigated climate change, are the ones that are often most important for human health.

The health co-benefits of emissions reduction

Acting to reduce GHG emissions evidently protects human health from the direct and indirect impacts of climate change. However, it also benefits human health through mechanisms quite independent of those relating to modifying climate risk: so-called health co-benefits of mitigation.[26]

Reductions in emissions (eg, from burning fossil fuels) reduce air pollution and respiratory disease, whilst safer active transport cuts road traffic accidents and reduces rates of obesity, diabetes, coronary heart disease, and stroke. These are just some of the many health co-benefits of mitigation, which often work through several causal pathways via the social and environmental determinants of health. Protecting our ecosystems will create the wellbeing we gain from nature and its diversity.[27]

Affordable renewable energy will also have huge benefits for the poorest. WHO found that in 11 sub-Saharan African countries, 26% of health facilities had no energy at all and only 33% of hospitals had what could be called "reliable electricity provision", defined as no outages of more than 2 h in the past week.[28] Solar power is proposed as an ideal alternative energy solution, providing reliable energy that does not harm cardiovascular or respiratory health in the same way that diesel generators do. Clean cookstoves and fuels will not only protect the climate from black carbon (a very short-lived climate pollutant), but also cut deaths from household air pollution—a major killer in low-income countries. Buildings and houses designed to provide better insulation, heating efficiency, and protection from extreme weather events will reduce heat and cold exposure, disease risks from mould and allergy, and from infectious and vector-borne diseases.[29]

Many other co-benefits exist across different sectors, from agriculture to the formal health system. The cost savings of the health co-benefits achieved by policies to cut GHG emissions are potentially large. This is particularly important in a context where health-care expenditure is growing relative to total government expenditure globally. The health dividend on savings must be factored into any economic assessment of the costs of mitigation and adaptation. The poorest people are also most vulnerable to climate change, meaning that the costs of global development will rise if we do nothing, and poverty alleviation and sustainable development goals will not be achieved.

This Commission

6 years ago, the first *Lancet* Commission called climate change "the biggest global health threat of the 21st century".[1] Since then, climate threats continue to become a reality, GHG emissions have risen beyond worst-case projections, and no international agreement on effective action has been reached. The uncertainty around thresholds, interactions and tipping points in climate change and its health impacts are serious enough to mandate an immediate, sustained, and globally meaningful response.

This report further examines the evidence of threat, before tabling a prescription for both prevention and symptom management. We begin in section 1 by re-examining the causal pathways between climate change and human health, before offering new estimates of exposure to climate health risks in the coming decades. The changes in the spatial distribution of populations, and their demographic structure over the coming century, will put more people in harm's way.

Given that the world is already locked in to a significant rise in global temperatures (even with meaningful action to reduce GHG emissions), section 2 considers measures that must be put in place to help lessen their unavoidable health impacts. Adaptation strategies are those that reduce vulnerability and enhance resilience—ie, the capacity of a system to absorb disturbance and re-organise—so as to retain function, structure, identity, and feedbacks.[30] We identify institutional and decision-making challenges related to uncertainty, multicausal pathways, and complex interactions between social, ecological, and economic factors. We also show tangible ways ahead with adaptations that provide clear no-regret options and co-benefits for food security, human migration and displacement, and dynamic infectious disease risks.

Symptomatic intervention and palliation must, however, be accompanied by immediate action to address the cause of those symptoms: the epidemiology and options for scaling up low-carbon technologies and technical responses are discussed in section 3, in addition to the necessary measures required to facilitate their deployment. This section also explores the health implications of various mitigation options, with particular attention to those which both promote public health and mitigate climate change.

Transformation to a global low-carbon economy requires political will, a feasible plan, and the requisite finance. Section 4 examines the financial, economic, and policy options for decarbonisation. The goal of mitigation policy should be to reduce cumulative and annual GHG emissions. Early emissions reduction will delay climate disruption and reduce the overall cost of abatement by avoiding drastic and expensive last-minute action. Immediate action offers a wider range of technological options, allows economies of scale and prospects for learning, and will reduce costs over time. The window of opportunity for evolutionary and revolutionary new technologies to develop, commercialise, and deploy is also held open for longer.

In section 5, we examine the political processes and mechanisms that might play a part in delivering a low-carbon economy. Multiple levels are considered, including the global response (the UN Framework Convention on Climate Change), national and subnational (cities, states, and provinces) policy, and the role of individuals. The interaction between these different levels, and the lessons learnt from public health are given particular attention.

Finally, in section 6 we propose the formation of an international Countdown to 2030: Global Health and Climate Action. We outline how an international, multidisciplinary coalition of experts should monitor and report on: the health impacts of climate change; progress in policy to reduce GHG emissions, and synergies used to promote and protect health; and progress in health adaptation action to reduce population vulnerability to build climate resilience and to implement climate-ready low-carbon health systems. A Countdown process would complement rather than replace existing IPCC reports, and would bring the full weight and voice of the health and scientific communities to this critical population health challenge.

Section 1: climate change and exposure to health risks

No region is immune from the negative impacts of climate change, which will affect the natural world, economic activities, and human health and wellbeing in every part of the world.[31] There are already observed impacts of climate change on health, directly through extreme weather and hazards and indirectly through changes in land use and nutrition. Lags in the response of the climate system to historical emissions means the world is committed to significant warming over coming decades.

All plausible futures resulting from realistic anticipated emissions trajectories expose the global population to worsening health consequences. In 2014, WHO estimated an additional 250 000 potential deaths annually between 2030 and 2050 for well understood impacts of climate change. WHO suggest their estimates represent lower bound figures because they omit important causal pathways. The effects of economic damage, major heatwave events, river flooding, water scarcity, or the impacts of climate change on human security and conflict, for example, are not accounted for in their global burden estimates.[32] Without action to address continued and rising emissions, the risks, and the number of people exposed to those risks, will likely increase significantly. WHO emphasises that the importance of the interactions between climate change and many other trends affecting public health, stressing the need for interventions designed to address climate change and poverty—two key drivers of ill health.[32] Similarly, the authors of the IPCC assessment of climate change on health emphasise that the health impacts become amplified over time.[21]

This report provides new insights into the potential exposure of populations, showing that when demographic trends are accounted for, such as ageing, migration, and aggregate population growth, the populations exposed to climate change that negatively affect health risk are more seriously affected than suggested in many global assessments. It involves new analysis on specific and direct climate risks of heat, drought and heavy precipitation that directly link climate change and wellbeing. The number of people exposed to such risk is amplified by social factors: the distribution of population density resulting from urbanisation, and changes in population demographics relating to ageing.

Thus, human populations are likely to be growing, ageing, and migrating towards greater vulnerability to climate risks. Such data emphasise the need for action to avoid scenarios where thresholds in climate greatly increase exposure, as well as adaptation to protect populations from consequent impacts.

How climate affects human health

Mechanisms linking climate and health

The principal pathways linking climate change with health outcomes are shown in figure 2, categorised as direct and indirect mechanisms that interact with social dynamics to produce health outcomes. All these risks have social and geographical dimensions, are unevenly distributed across the world, and are influenced by social and economic development, technology, and health service provision. The IPCC report documents in expansive detail the scientific knowledge on many individual risks.[31] Here, we discuss how these risks could change globally as a result of a changing climate and of evolving societal and demographic factors.

Changes in extreme weather and resultant storm, flood, drought, or heatwave are direct risks. Indirect risks are mediated through changes in the biosphere (eg, in the burden of disease and distribution of disease vectors, or food availability), and others through social processes (leading, for instance, to migration and conflict). These three pillars, shown in figure 2, interact with one another, and with changes in land use, crop yield, and ecosystems that are being driven by global development and demographic processes. Climate change will limit development aspirations, including the provision of health and other services through impacts on national economies and infrastructure. It will affect wellbeing in material and other ways. Climate change will, for example, exacerbate perceptions of insecurity and influence aspects of cultural identity in places directly affected.[33]

Thus, in figure 2, climate risks might be both amplified and modified by social factors. The links between food

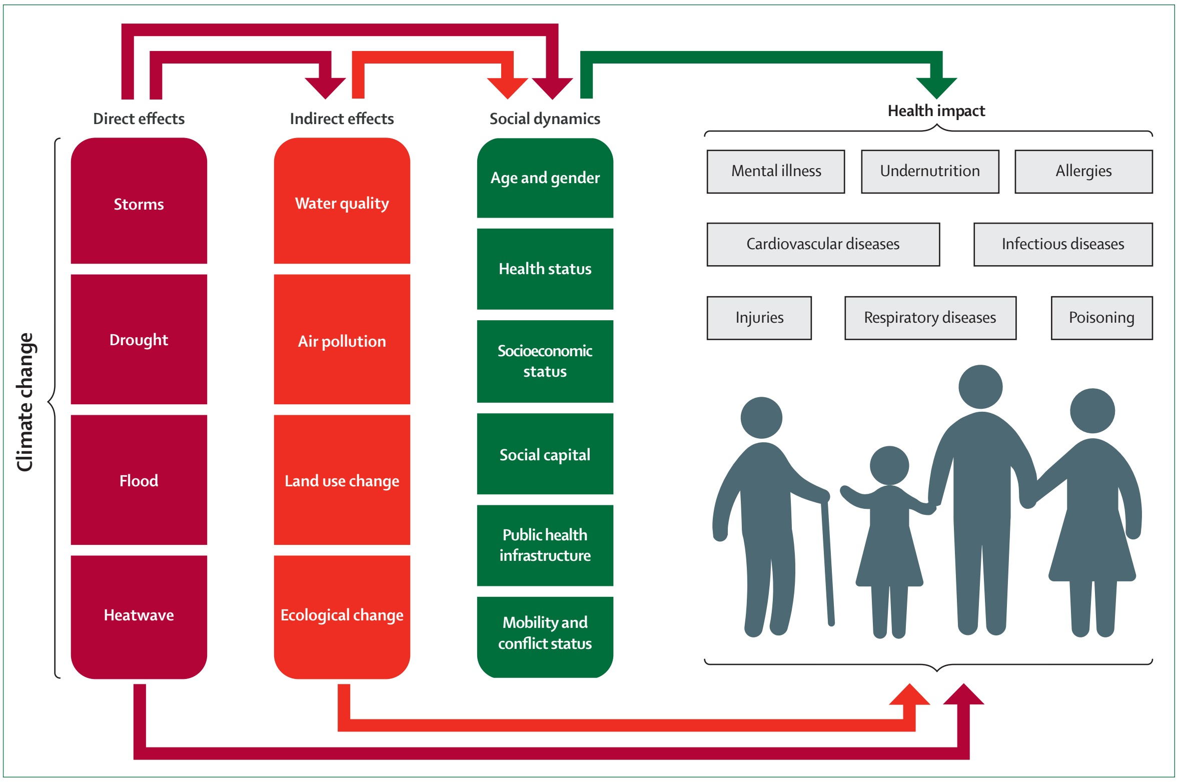

Figure 2: **The direct and indirect effects of climate change on health and wellbeing**
There are complex interactions between both causes and effects. Ecological processes, such as impacts on biodiversity and changes in disease vectors, and social dynamics, can amplify these risks. Social responses also ameliorate some risks through adaptive actions.

production and food security in any country, for instance, are strongly determined by policies, regulations and subsidies to ensure adequate food availability and affordable prices.[34] Vulnerabilities thus arise from the interaction of climatic and social processes. The underpinning science shows that impacts are unevenly distributed, with greater risks in less developed countries, and with specific subpopulations such as poor and marginalised groups, people with disabilities, the elderly, women, and young children bearing the greatest burden of risk in all regions.[31]

In many regions, the consequences of lower socio-economic status and cultural gender roles combine to increase the health risks that women and girls face as a result of climate change relative to men and boys in the same places, although the converse might apply in some instances. Whilst in developed countries, males comprise approximately 70% of flood disaster fatalities (across studies in which sex was reported), the converse is generally true for disaster-related health risks in developing country settings, in which the overall impacts are much greater.[35,36] For example, in some cultures women may be forbidden from leaving home unaccompanied, are less likely to have learnt how to swim, and may have less political representation and access to public services. Additionally, women's and girls' nutrition tends to suffer more during periods of climate-related food scarcity than that of their male counterparts, as well as starting from a lower baseline, because they are often last in household food hierarchies.[37]

Direct mechanisms and risks: exposure to warming and heatwaves

While societies are adapted to local climates across the world, heatwaves represent a real risk to vulnerable populations and significant increases in the risks of extreme heat are projected under all scenarios of climate change.[38] On an individual basis, tolerance to any change is diminished in those whose capacity for temperature homoeostasis is limited by, for example, extremes of age or dehydration. There is a well-established relationship between extreme high temperatures and human morbidity and mortality.[39] There is also now strong evidence that such heat-related mortality is rising as a result of climate change impacts across a range of localities.[31]

Evidence from previous heatwave events suggests that the key parameters of mortality risk include the magnitude and duration of the temperature anomaly and the speed of temperature rise. The risks are culturally defined, even temperate cities experience such mortality as it is deviation from expectations that drives weather-related risks. This is especially true when hot periods occur at the beginning of summer, before people have acclimatised to hotter weather.[38] The incidence of heatwaves has increased in the past few decades, as has the area affected by them.[40,41]

The most severe heatwave, measured with the Heat Wave Magnitude Index, was the summer 2010 heatwave in Russia.[40] More than 25 000 fires over an area of 1·1 million hectares[42] raised concentrations of carbon monoxide, nitrogen oxides, aerosols, and particulates (PM_{10}) in European Russia. The concentration of particulate matter doubled from its normal level in the Moscow region in August, 2010, when a large smoke plume covered the entire capital.[43] In combination with the heat wave, the air pollution increased mortality between July and August, 2010, in Moscow, resulting in more than 11 000 additional deaths compared with July to August, 2009.[44] Projections under climate scenarios show that events with the magnitude of the Russian heatwave of 2010 could have become much more common and

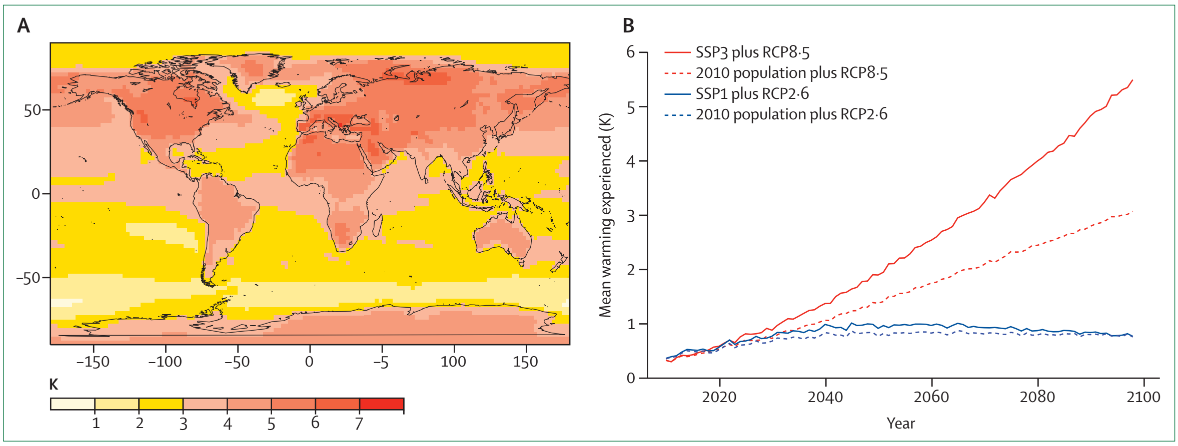

Figure 3: Exposure to warming resulting from projections of 21st century climate and population change
Changes in summertime temperatures (June–July–August for the northern hemisphere, and December–January–February for the southern hemisphere) between 1995 and 2090, for the RCP8.5 scenario, using the mean of the projections produced by the CMIP5 climate models (A). Change in the mean warming experienced by a person under RCP8.5 (red lines) and RCP2.6 (blue lines), calculated using the 2010 population (dashed lines), and time-varying future population scenarios (continuous lines; B). To encompass the range of possible exposures, we have paired the high-growth SSP3 population scenario with RCP8.5 and the low-growth SSP1 population scenario with RCP2.6. RCP=Representative Concentration Pathway.

with high-end climate scenarios could become almost the summer norm for many regions.[40,45]

Rising mean temperatures mean that the incidence of cold events is likely to diminish. The analysis here focuses on the heat-related element because the health benefits of reductions in cold are not established. Whilst there is an increase in deaths during winter periods in many climates, the mechanisms responsible for this increase are not easily delineated. Most winter-related deaths are cardiovascular, yet the link between temperature and cardiovascular mortality rates is weak. There is a stronger link between respiratory deaths and colder temperatures but these account for a smaller percentage of winter deaths.[46]

The impact of cold temperatures can be measured considering seasonal means, extreme cold spells, and relative temperature changes. Seasonal means and extreme cold spells (or absolute temperature) have relatively small or ambiguous relationships with numbers of winter deaths, however temperature cooling relative to an area's average temperature does more clearly correlate with mortality rates.[46,47] There may be modest reductions in cold-related deaths; however, these reductions will be largely outweighed at the global scale by heat-related mortality.[46] Whilst climate change will have an impact on cold-related deaths, particularly in some countries with milder climates, the overall impact is uncertain.[48,49]

Population growth, urbanisation trends, and migration patterns mean that the numbers exposed to hot temperature extremes, in particular, will increase, with major implications for public health planning. Urban areas will expand: urban land cover is projected to triple by 2030 from year 2000 levels.[50] Many assessments of climate risks, including those for heat, do not consider the detail of demographic shifts, in effect, overlooking the location of vulnerable populations as a part of the calculus. We have produced models that consider both climate and population projections. We use Shared Socioeconomic Pathway (SSP) population projections to

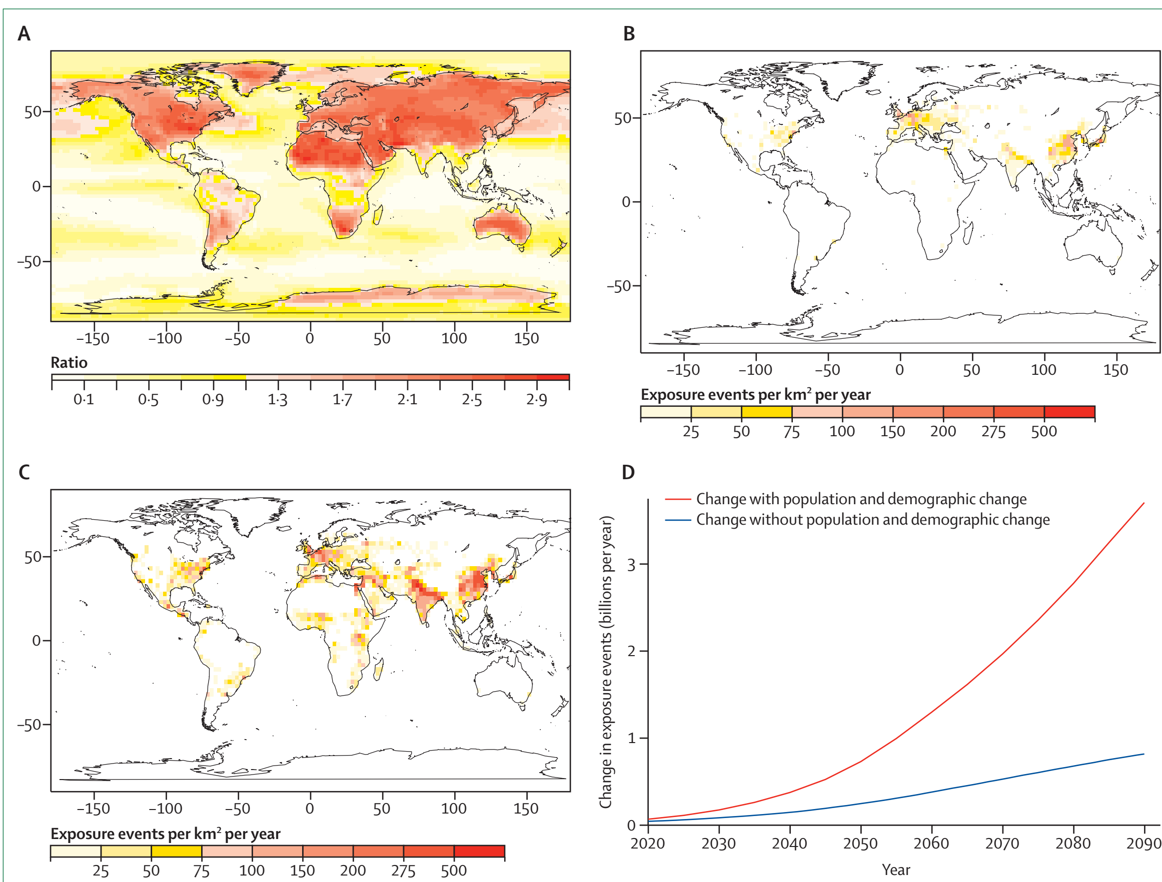

Figure 4: **Changing exposure to heatwave resulting from projections of 21st century climate and population and demographic change**
Change in heatwave frequency between 1995 and 2090 for the RCP8.5 scenario, in which a heatwave is defined as more than 5 consecutive days for which the daily minimum temperature exceeds the summer mean daily minimum temperature in the historical period (1986–2005) by more than 5°C (A). Change in the mean number of heatwave exposure events annually per km² for people older than 65 years as a result of the climate change in panel A and assuming the 2010 population and demography (B). The same scenario as for panel B, but for the 2090 population and demography under the SSP2 population scenario (C). Time series of the change in the number of annual heatwave exposure events for people older than 65 years with (red line) and without (blue line) population and demographic change (D).

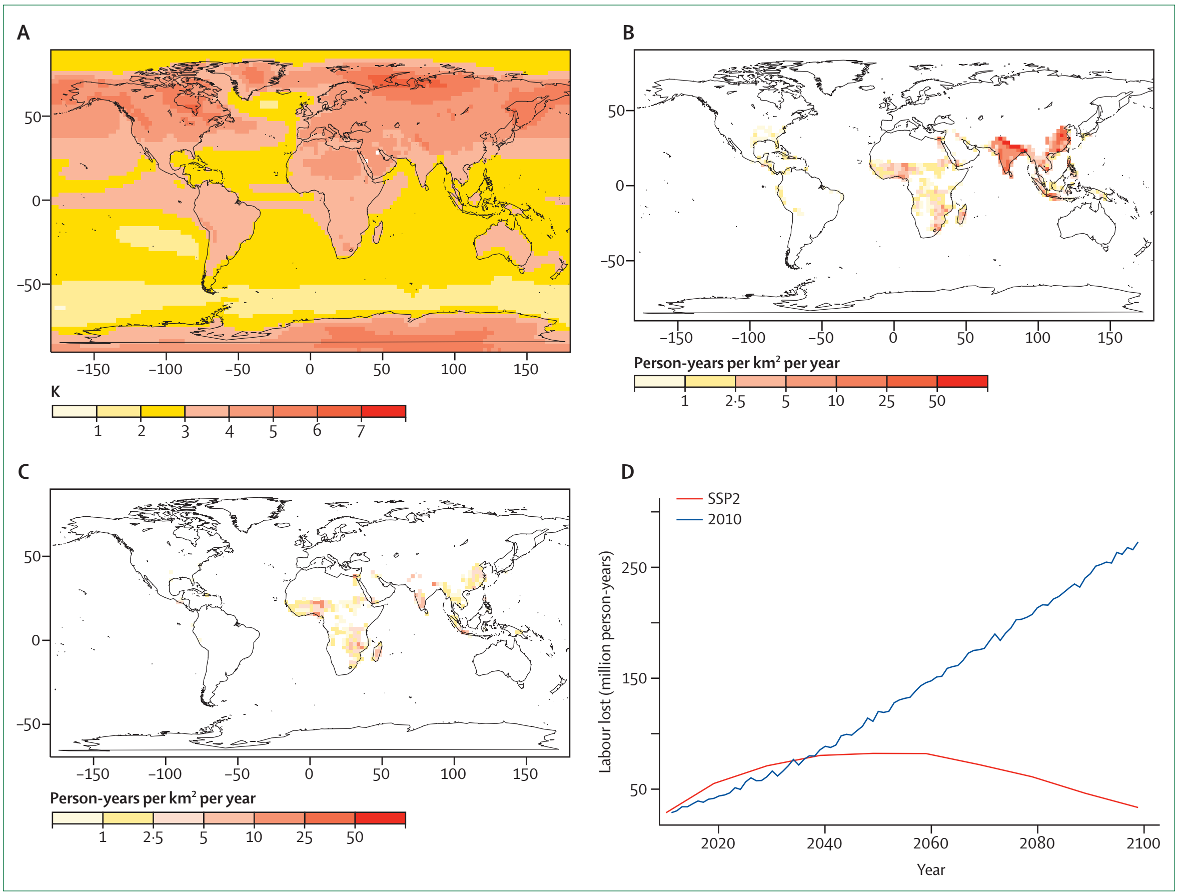

***Figure 5:* Change in outdoor labour productivity resulting from projections of 21st century climate and rural population change**
Change in summer mean (June–July–August for the northern hemisphere, and December–January–February for the southern hemisphere) wet-bulb globe temperature[65] for the RCP8.5 scenario (A). Annual loss of outdoor labour productivity due to the climate change in panel A and assuming the 2010 rural population (B). The same scenario as for panel B, but for the 2090 rural population under the SSP2 population scenario (C). Time series of the annual loss of outdoor labour with (red line) and without (blue line) rural population change (D).

See Online for appendix 1

calculate future demographic trends alongside Coupled Model Intercomparison Project Phase 5 (CMIP5) climate models (as used in the IPCC 5th Assessment report) and projected emission pathways (so-called Representative Concentration Pathways [RCPs]).[51–54] Appendix 1 outlines assumptions, together with the data and the climate and population scenarios used to estimate the scale of various health risks for the 21st century, shown in figures 3–7.

The projected global distribution of changes in heat in the coming decades is shown in figure 3A using the high-emission projections of RCP8.5, as explained in appendix 1. This focuses on summer temperatures, hence the graph represents the summer months for both the northern (June to August) and southern (December to February) hemispheres. Climatic impact will not be experienced uniformly across the globe. At such levels of warming, the return period of extreme heat events, such as those experienced in 2003 in western Europe, is significantly shortened. Figure 3B makes clear that future health risks arising from exposure to warming (measured as the mean temperature increase experienced by a person) might also be extensively driven by demographics, shown as the divergence between red and blue lines driven by different warming and population scenarios across the incoming decades. In other words, population change in areas of the world where population growth is significant, fundamentally affects the increase in numbers of people exposed to the impacts of climate change.

Whilst hotter summers increase vulnerability to heat-related morbidity, heatwaves in particular have a negative impact on health. Figure 4 re-analyses projections from the latest climate models (the CMIP5 models as used in the IPCC 5th Assessment report) in terms of the number of exposure events per year for heatwaves. Heatwaves here are defined as 5 consecutive days of daily minimum night-time temperatures more than 5°C greater than the presently observed patterns of daily minimums. Although heatwaves have different characteristics, this definition focuses on health impacts based on deviation from normal temperature, duration, and extent.

Elderly populations are especially vulnerable to heatwaves, and demographic and climatic changes will

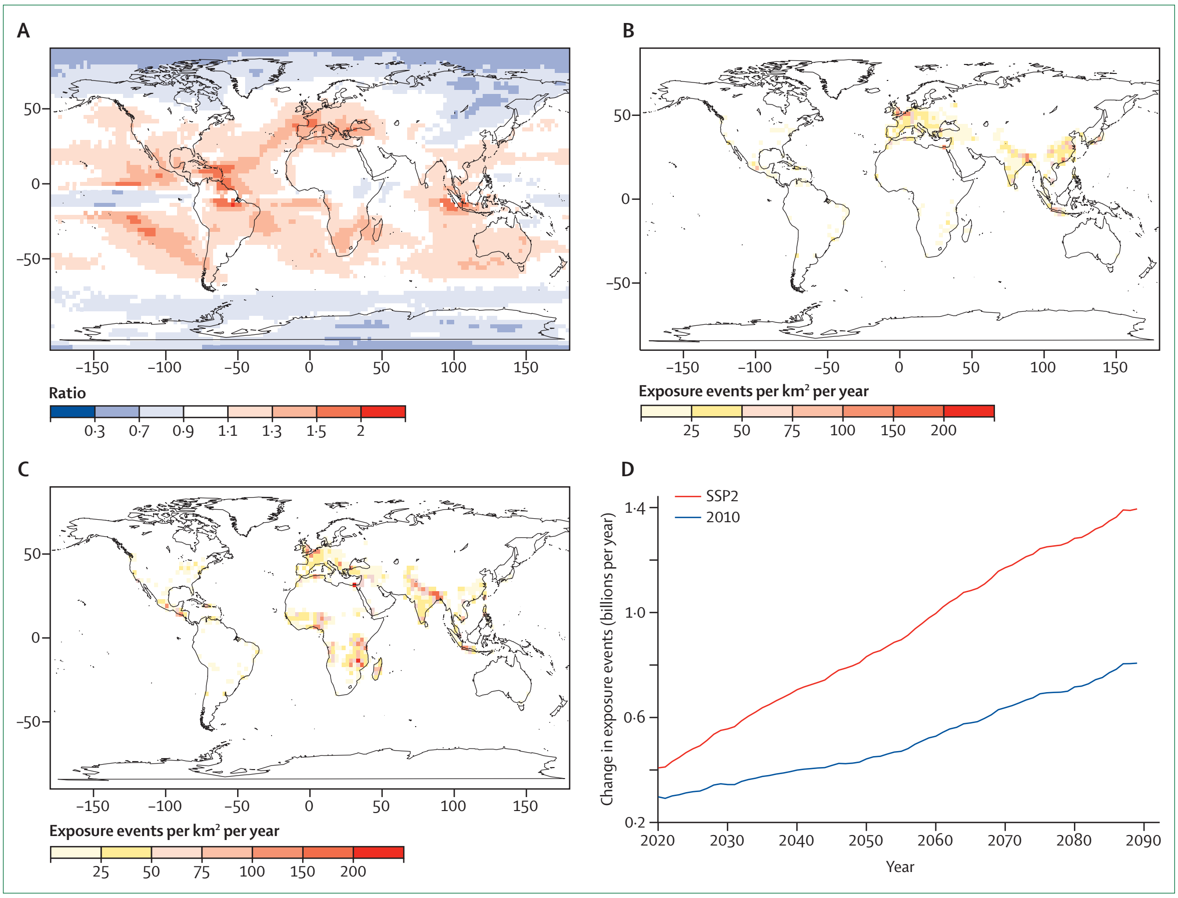

Figure 6: **Changing exposure to drought resulting from projections of 21st century climate and population change**
Change in drought intensity between 1995 and 2090 for the RCP8.5 scenario, defined as the ratio of the mean annual maximum number of consecutive dry days (2080–99, 1986–2005), in which a dry day is any day with less than 1 cm of precipitation (A). Change in the mean number of drought exposure events annually per km² as a result of the climate change in panel A and assuming the 2010 population (B). The same scenario as for panel B, but for the 2090 population under the SSP2 population scenario (C). Time series of the change in the number of annual drought exposure events with (red line) and without (blue line) population change (D).

combine to shape population heatwave vulnerability in coming decades (figure 4).[55] We use populations projected over 65 years of age rather than a frailty index, recognising the underlying health of elderly populations and the cultural context of ageing are both likely to change over time.[56] Educational levels and other demographic factors are also important in the ability of societies to cope with extreme events.[57] Allowing for these caveats, figure 4D shows growing exposure in global projections of the number of people older than 65 years exposed to heatwave risks. The numbers of events of elderly people experiencing high temperatures reaches more than 3 billion towards the end of the century. A key message is that demographic change added to climate changes will expose increasing numbers of elderly people to increasing numbers of heat waves, especially in the developed and transition economies.

Heat also poses significant risks to occupational health and labour productivity in areas where people work outdoors for long hours in hot regions.[58] Heavy labour in hot humid environments is a particular health and economic risk to millions of working people and their families in hot tropical and sub-tropical parts of the world.[59] These have been documented in young and middle-aged men in France 2003,[60] agricultural workers in the USA,[61] and sugar-cane harvesters in Central America.[62] The Climate Vulnerability Monitor 2012 estimated the annual costs in China and India at US$450 billion in 2030.[63] The percentage of GDP losses due to increasing workplace heat is greater than the current spending on health systems in many low-income and middle-income countries.[64]

Impacts of heat on labour productivity will be compounded in cities by increased urbanisation and the corresponding heat island effect, but will also be offset by reductions in populations working outdoors in sectors (eg, construction and agriculture).[38] Tolerance to any given temperature will be influenced by humidity, which alters the capacity for thermoregulation through the evaporation of sweat. These measures are combined in an index known as wet-bulb globe temperature (WBGT), used to determine how long an individual can work before a break, with work capacity falling substantially after WBGT 26–30°C.[58]

Using projections from RCP8.5 and SSP2, figure 5 estimates the extent of lost labour productivity (on the basis of the response function between temperature and productivity used by Dunne et al, 2012[65]) across the coming decades, focusing on proportion of the labour force in rural and urban areas. Again the impact of climate change is greater in regions such as sub-Saharan Africa and India. But some trends offset the potential impact, including the trend towards employment in service and other sectors where exposure is reduced (assumed in the SSP2 used here; figure 5C, D). As demographic trends towards urban settlement and secondary and tertiary sector employment progress, increasing urbanisation may reduce the negative impacts of warming on total outdoor labour productivity, depending on the population scenario (SSP2 in figure 5D).

Loss of agricultural productivity through impaired labour will be amplified by direct climate change impacts on crop and livestock production.[66] The impact of increasing temperatures on labour productivity can be mitigated—eg, by use of air conditioning or by altering working hours. However, these actions are predicated on affordability, infrastructure, the suitability of a job to night labour, and energy availability.[67]

Indirect and complex mechanisms linking climate change and health

Most climate-related health impacts are mediated through complex ecological and social processes. For risks associated with transmission vectors and water, for example, rising temperatures and changes in precipitation pattern alter the viable distribution of disease vectors such as mosquitoes carrying dengue or malaria. Climate conditions affect the range and reproductive rates of malarial mosquitoes and also affect the lifecycle of the parasitic protozoa responsible for malaria. The links between climate change, vector populations and hence malarial range and incidence may become significant in areas where the temperature is currently the limiting factor, possibly increasing the incidence of a disease that causes 660 000 deaths per year.[68] In some highland regions, malaria incidence has already been linked to warmer air temperatures although successful control measures in Africa have cut the incidence of malaria in recent decades, and there are long established successes of managing malaria risk in temperate countries including in southern USA and in Europe.[69,70] There are equally complex relationships and important climate-related risks associated with dengue fever, cholera and food safety.[54,71,72] Dengue fever for example has 390 million recorded infections each year, and the number is rising.[54,73]

Changing weather patterns are also likely to affect the incidence of diseases transmitted through infected water sources, either through contamination of drinking water or by providing the conditions needed for bacterial growth.[74] Cholera is transmitted through infected water sources and often occurs in association with seasonal algal blooms with outbreaks sometimes experienced following extreme weather events such as hurricanes that result in the mixing of wastewater and drinking water, and in association with El Niño events.[72] Such extreme weather events are likely to increase in frequency in the coming decades and waterborne epidemics need to be planned for and monitored carefully.

In effect, all health outcomes linked to climate variables are shaped by economic, technological, demographic, and governance structures. Institutions and social norms of behaviour and expectation will play a significant part in how new weather patterns impact health.[38,71] Changes in temperature, precipitation frequency, and air stagnation also affect air pollution levels with significant risks to health. Climate affects pollution levels through pollutant formation, transport, dispersion, and deposition. In total, fine particulate air pollution is estimated to be responsible for 7 million additional deaths globally in 2012, mainly due to respiratory and cardiovascular disease.[75] Its effect is amplified by changes in ambient temperature, precipitation frequency, and air stagnation—all crucial for air pollutant formation, transport, dispersion and deposition.

Ground-level ozone (GLO) and particulate air pollutants are elements that will be most affected by climate change. Whilst the net global effect is unclear, regional variation will see significant differences in local exposure.[31,76] GLO is more readily created and sustained in an environment with reduced cloudiness and decreased precipitation frequency, but especially by rising temperatures.[77] Thus, ozone levels were substantially elevated during the European heatwave of summer 2003.[76,78] Climate change is predicted to elevate GLO levels over large areas in the USA and Europe, especially in the summer, although the background of GLO in the remote areas shows a decreased trend.[77,79–82] In the USA, the main impact of future climate change on GLO is centred over the northeast and mid-west where the future GLO are expected to increase by 2–5 ppbv (about 3–7%) in the next 50–90 years under the IPCC A1 scenario.[79,81] Knowlton and colleagues estimated that ozone-related acute mortality in the USA would rise by 4·5% from 1990 to 2050, through climate change alone.[83] Likewise, climate change is predicted to increase concentrations of fine particulate matter (2·5 micron particles [$PM_{2.5}$]) in some areas.[80,84]

The interactions between air pollution and climate are highly differentiated by region. In China, for example, the interactions between climate and a range of pollutants is especially acute. While action on carbon emissions dominate energy policy in China, climatic changes will have a significant impact on air pollutants in all regions of the country.[84,85] Chinese ozone concentrations in 2050 have been projected to likely increase beyond present levels under many climate scenarios through the combined effects of emissions and climate change. The greatest rises will be in eastern and northern China.[85]

Compared with ozone, $PM_{2.5}$ levels rely more on changes in emissions than temperature. The concentrations of SO_4^{2-}, black carbon and organic carbon are projected to fall, but those of NO_3^- to rise, across China under many possible climate futures.[84] Levels of aerosols (especially NO_3^-) in the eastern Chinese spring will be especially affected by 2030. Falling emissions would reduce overall $PM_{2.5}$ concentrations by 1–8 μg/m³ in 2050 compared with those in 2000 despite a small increase (10–20%) driven by climate change alone.[84] Although emission changes play a key part in projections, climate-driven change should not be ignored if warming exceeds 2°C. $PM_{2.5}$ is sensitive to precipitation and monsoon changes and global warming will alter Chinese precipitation seasonally and regionally, thereby changing the regional concentration of $PM_{2.5}$.[76,86] Independent of climate change, China's air pollution has already come at great cost, with an annual pollution-related mortality of 1·21 million in 2010.[87]

Climate change has important implications for livelihoods, food security, and poverty levels, and on the capacity of governments and health systems to manage emerging health risks. Crops and livestock have physiological limits to their health, productivity, and survival, which include those related to temperature. For every degree greater than 30°C, the productivity of maize production in Africa might be reduced by 1% in optimum conditions and 1·7% in drought, with a 95% chance of climate change-related harm to the production of South African maize and wheat in the absence of adaptation.[88,89]

Sensitivity of crops and livestock to weather variation has a substantial impact on food security in regions that are already food insecure, pushing up food prices and ultimately affecting food availability and affordability to poor populations and contributing to malnutrition.[90] This effect is amplified by polices on food stocks, reactions to food prices by producer countries, and by the global demand for land to hedge against climate shifts. The increased volatility of the global food system under climate change has impacts on labour, on farmer livelihoods and on consumers of food, with attendant health outcomes for all these groups.[66]

Within this complex relationship between climate and food security, the availability of water for agricultural production is a key parameter. Figure 6 shows very significant changes in exposure to drought-like meteorological conditions over the coming decades. The analysis shows that the population changes (from SSP2) alongside climate change could lead to 1·4 billion additional person drought exposure events per year by the end of the century. Importantly, the geographical distribution of this exposure is highly localised and variable (eg, across Asia and Europe), acutely degrading water supply and potentially quality. But all such estimates focus on availability of surface water, whereby both long-term water availability and supply for specific regions are also affected by groundwater resources, which have been shown to be in a critical state in many regions.[91,92]

Increased frequency of floods, storm surges, and hurricanes will have a substantial effect on health. Extreme events have immediate risks, exemplified by more than 6000 fatalities as a result of typhoon Haiyan in the Philippines in late 2013. Floods also have long-term and short-term effects on wellbeing through disease outbreaks, mental health burdens, and dislocation.[93]

Risks related to water shortages, flood, and other mechanisms involve large populations. Projections suggest, for example, that an additional 50 million people and 30 000 km² of land could be affected by coastal storm surges in 2100, with attendant risks of direct deaths and of infectious diseases.[94,95] Involuntary displacement of populations as a result of extreme events has major public health and policy consequences. In the longer term, flooding affects perceptions of security and safety, and can cause depression, anxiety, and post-traumatic stress disorder.[93,96]

Figure 7 shows estimates of extreme precipitation events (events exceeding 10 year return period) under the RCP8.5 (high-emission) scenario. We estimate that there would be around 2 billion additional extreme rainfall exposure events annually (individuals exposed once or multiple times during any year), partly due to population growth in exposed areas and partly due to the changing incidence of extreme events associated with climate change. Whilst not all extreme rainfall events translate into floods, such extreme precipitation will inevitably increase flood risk. Regions of large population growth dominate changes in the number exposed to flood risk (especially in sub-Saharan Africa and South Asia).[97]

All these climate-related impacts are detrimental to the security and wellbeing of populations around the world. Whilst there is, as yet, no definitive evidence that climate change has increased the risk of violent civil conflict or war between states, there are reasons for concern. The IPCC concludes that climate change will directly affect poverty, resource uncertainty and volatility, and the ability of governments to fulfil their obligations to protect settlements and people from weather extremes.[33,98] These factors are important correlates of violent conflict within states, suggesting that climate change is detrimental to peaceful and secure development, even if they do not directly enhance conflict risks.[99] Similarly, migration has significant complex consequences for human security. The continued movement of migrant populations into cities, the potential for climate hazards in high-density coastal mega-cities, and impaired air quality create significant public health challenges, not least for migrants themselves.[100,101]

The direct and indirect effects of climate change outlined here represent significant risks for human health. The precautionary case for action is amplified with three additional dimensions: (1) interventions to adapt to evolving climate risks as discussed in section 2 might not be as effective as required; (2) unforeseen

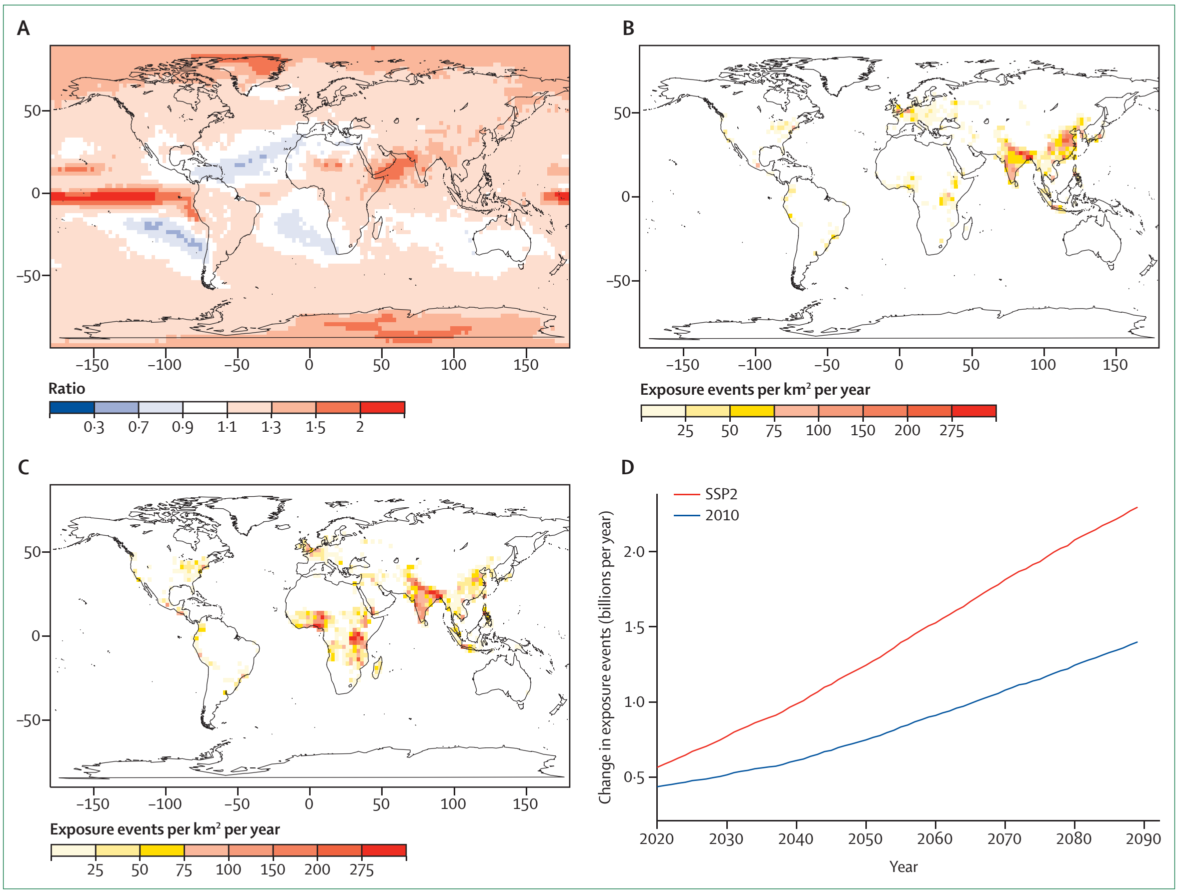

***Figure 7*: Changing exposure to flood resulting from projections of 21st century climate and population change**

Change in flood frequency between 1995 and 2090 for the Representative Concentration Pathway (RCP) 8.5 scenario, in which a flood event is defined as a 5 day precipitation total exceeding the 10 year return level in the historical period (1986–2005; A). Change in the mean number of flood exposure events annually per km² due to the climate change in panel A and assuming the 2010 population (B). The same scenario as for panel B, but for the 2090 population under the SSP2 population scenario (C). Time series of the change in the number of flood exposure events with (red line) and without (blue line) population change (D).

interactions and amplifications of climate risks are possible (eg, emerging zoonotic and other diseases being affected through complex ecological changes, covered in more detail in the *Lancet* Commission on Planetary Health); (3) the risk that tipping elements in the climate system could rapidly accelerate climate change at regional or global scale. Lags in warming and climate impacts mean that irrespective of the mitigation pathway taken, many impacts and risks will increase in the coming decades.

Section 2: action for resilience and adaptation

Adaptation measures are already required to adapt to the effects of climate change being experienced today. As shown in section 1, these risks will increase as worsening climate change affects more people, especially in highly exposed geographical regions and for the most vulnerable members of society.

This section outlines possible and necessary actions to limit the negative impacts and burden on human health, including direct and indirect impacts within and beyond the formal health system. Responses aim to reduce the underlying vulnerability of populations; empower actors to cope or adapt to the impacts; and whenever possible support longer-term development. The health sector has a central part to play in leading climate change adaptation and resilience efforts.[102,103] However, effective adaptation measures must cross multiple societal sectors, identify ways to overcome barriers to achieve co-benefits, and target vulnerable groups and regions.

Early action to address vulnerability allows for more options and flexibility before we face indispensable and involuntary adaptation.[104,105] Panel 2 provides definitions of vulnerability, adaptation, and resilience.

Adaptation to the direct health impacts of climate change

The direct health impacts result from extreme weather events such as storms, floods, droughts, and heatwaves. Many responses centre on the importance of health system strengthening; however, actions in other sectors are also needed.

Early warning systems for extreme events

Approaches to the health management of extreme weather events involve improved early warning systems (EWS), effective contingency planning, and identification of the most vulnerable and exposed communities.[111] They include forecasting, predicting possible health outcomes, triggering effective and timely response plans, targeting vulnerable populations, and communicating prevention responses. Public health authorities need to upgrade existing emergency programmes and conduct exercises to enhance preparedness for anticipated health risks due to new extreme events such as sea level rise, saline water intrusion into drinking water courses, and severe flooding from storm surges. These efforts to improve disaster preparedness must also run in parallel with efforts to strengthen local community resilience.

Actions to reduce burdens of heatwaves

The frequency, intensity, and duration of extreme heat days and heatwaves will increase with climate change, leading to heat stress and increased death rates (see section 1). The effects are worsened by the so-called urban heat island effect, which results from greater heat retention of buildings and paved surfaces, compared with reflective, transpiring, shading, and air-flow-promoting vegetation-covered surfaces. Evidence suggests that effective adaptation measures would reduce the death rates associated with these heat waves. The 2003 European heatwave, which killed up to 70 000 people led France to introduce a heatwave warning system and a national action plan.[111] Health worker training was modified, urban planning altered, and new public health infrastructure developed. The 2006 heatwave suggested that these measures had been effective, with 4400 fewer anticipated deaths.[112]

Adaptation options within health care include training of health-care workers and integrated heatwave early warning systems (HEWS), especially for the most vulnerable populations.[111,113] Adaptation measures also include increasing green infrastructures and urban green spaces, improving the design of social care facilities, schools, other public spaces, and public transport to be more climate-responsive.[113,114] This also entails mitigating effort to reduce air pollutants, which in turn reduces air quality related morbidity and mortality.[115]

Floods and storms

In general, adaptive measures to floods can be classified as structural or non-structural. Infrastructure such as reservoirs, dams, dykes, and floodways can be used to keep flooding away from people and property. In some areas there is also the possibility to incorporate floodable low-lying areas into the urban design that can be temporarily under water during an extreme event. Structural programmes are considered by many flood managers as a priority and are also the principal source of funds for efforts to control floods. However, the construction of flood control works may have a maladaptive effect, encouraging more rapid economic development of the flood plains, and hence ultimately increasing flood losses.[116]

Adaptation to flood risk requires comprehensive approaches (panel 3). Non-structural measures include flood insurance, development policies, zoning laws, flood-plain regulations, building codes, flood proofing, tax incentives, emergency preparedness, flood forecasting, and post-flood recovery.[116,121] Non-structural flood

Panel 2: Vulnerability, adaptation, and resilience

Vulnerability is here defined as the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change.[106] This definition considers demographics, geographical circumstances, effectiveness, and coverage of the health-care system, pre-existing conditions, and socioeconomic factors such as inequity.[107]

Adaptation to climate change is here defined as "the process of adjustment to actual or expected climate and its effects, in human systems in order to moderate harm or exploit beneficial opportunities, and in natural systems human intervention may facilitate adjustment to expected climate".[108]

Resilience is here defined as the capacity of a system to absorb disturbance and reorganise while undergoing change, so as to still retain essentially the same function, structure, identity and feedbacks.[30] Resilience has also been referred to the ability of human communities to withstand external shocks to their social infrastructure.[109] Resilience includes the capacity of a system to not only absorb a disturbance, but to innovate and transform.[110]

Panel 3: Adaptation to floods and storms in Bangladesh

In a mid-range climate-sensitivity projection, the number of people flooded per year globally is expected to increase by 10–25 million per year by 2050.[117] Bangladesh is one of the most vulnerable countries to climate change in south Asia, regularly suffering from events such as flooding, cyclones, or coastal erosion, which cause inundation of farmlands, affect migration, and lead to displacement.[118] More than 5 million Bangladeshis live in areas highly vulnerable to cyclones and storm surges, and more than half the population lives within 100 km of the coast.[119] In 2007, cyclone Sidr killed roughly 4000 people in Bangladesh. By comparison, an equivalent storm in 1970 killed 300 000 people.[120] Bangladesh achieved this reduction in mortality via collaborations between governmental and non-governmental organisations and local communities. Together, these groups improved general disaster reduction, deployed early warning systems, and built a network of cyclone shelters.[31]

adaptation options aim to reduce flood damages and enhance the ecological functions of flood plains. Many opportunities to increase resilience to extreme weather events are found in improved planning, zoning, and the management of land use. These have the additional advantage of providing multiple co-benefits (see ecosystem-based adaptation below).

Action for resilience to indirect impacts

Adaptation to indirect effects poses difficult challenges to policy making due to complex causal chains and limited predictibility.[122] These complex interactions can result in "surprises"—situations in which the behaviour in a system, or across systems, differs qualitatively from expectations or previous experiences. These indirect impacts pose serious obstacles for climate adaptation, especially where health responses require integrated and cross-sectoral interventions.[123]

Food insecurity

Food insecurity and its health impacts play out at the local level, but have clear links to drivers and changes at the national and international level. The compounded impacts of climate change and ocean acidification will affect both agricultural production and fisheries, including food availability and prices.[124–126] Adaptation policies should consider agro-food systems and fisheries and aquaculture alike.

Resilience to increased food insecurity and price volatility is of great importance to human health. Food security could be enhanced while simultaneously ensuring the long-term ability of ecosystems to produce multiple benefits for human wellbeing (panel 4). Issues such as improved local ecosystem stewardship (see section on ecosystem-based adaptation), good governance, and international mechanisms to enhance food security in vulnerable regions are of essence.[130,131] Even though the drivers of increased food prices and price volatilities are contested, investment in improved food security could provide multiple co-benefits and no-regret options.[132,133]

Panel 4: Food security, climate change, and human health

Today, agriculture uses 38% of all ice-free land areas and accounts for 70% of freshwater withdrawals and roughly a third of global greenhouse gas emissions.[127] The provision for global food demand by 2050 cannot assume improved crop yields through sustainable agricultural intensification because of the negative effects on crop growth from an increased frequency of weather extremes. Multifunctional food production systems will prove important in a warmer world. These systems are managed for benefits beyond yield, and provide multiple ecosystem services, support biodiversity, improve nutrition, and can enhance resilience to shocks such as crop failure or pest outbreaks.[128,129]

Important adaptation options for food security action include:

- Enhancement of food security through improved ecosystem based management and ecosystem restoration. Case studies show the benefits of implementing strategies to improve ecosystem management as a means to increase not only food security, but also to achieve other social goals. Examples include collaborative management of mangrove forests to promote conservation, mitigation of climate change and alleviation of poverty among people dependent on the mangroves and adjacent marine ecosystems.[125] Such strategies require supportive institutions, partnerships, collaboration with farmers' innovation networks, and connections from sustainable farms to markets.[129,131] Similar strategies have recently been explored for fisheries and aquaculture.[134]
- Increased investments in agricultural research and human capital are often raised as an important strategy to improve yields and long-term food security.[131] Agricultural research and development (R&D) has proven to have high economic rates of return.[135] Innovative crop insurance mechanisms, new uses of information technology, and improved weather data also hold promise for increased agricultural production.[136] Education in agricultural areas is critical to enhance the diffusion of technologies and crop management, and as a means to increase household incomes and promote gender equality.[131,137]
- Increased investments in rural and water infrastructure. Investment is essential for situations in which underdeveloped infrastructure results in poor supply chains and large food losses. Investments could boost agricultural production, reduce price volatilities, and enhance food security in the long term. The investments required in developing countries to support this expansion in agricultural output have been estimated to be an average annual net investment of US$83 billion (not including public goods such as roads, large scale irrigation projects, and electrification).[131]
- Enhanced international collaboration. International collaboration is critical for food security in food insecure regions. Early warning systems, financial support, emergency food and grain reserves, the ability to scale up safety nets such as child nutrition schemes, and capacity building play a key part in emergency responses to food crises, and can be supported by international organisations.[131,138]

Environmental migration

Changes in human mobility patterns have multiple drivers,[139] and range from large-scale displacement (often in emergency situations), to slow-onset migration (in which people seek new homes and livelihoods over a lengthy period of time as conditions in their home communities worsen).[140] The efficacy of national and international policies, institutions, and humanitarian responses also influence whether people are able to cope with the after-effects of natural hazard in a manner that allows them to recover their homes and livelihoods.[141]

Displacement occurs when choices are limited and movement is more or less forced by land loss, for example due to extreme events.[142] Population displacement can further affect health through increased spread of communicable diseases and malnutrition, resulting from overcrowding and lack of safe water, food, and shelter.[143] Additional impacts on economic development and political instability could develop, generating poverty and civil unrest that will exacerbate the population burden of disease.[1,143]

Existing vulnerabilities will determine the degree to which people are forced to migrate.[144] The availability of alternative livelihoods or other coping capacities in the affected area generally determines the scale and form of migration that may take place. Conflict undermines the capacity of populations to cope with climate change, leading to greater displacement than might have been the case in a more stable environment. Conflicts have also been shown to reduce mobility and trap populations in vulnerable areas, exposing politically marginalised populations to greater environmental risks.[145]

Migration from both slow and rapid-onset crises is likely to be immediately across borders from one poor country into another. Receiving countries could have few resources and poor legal structures or institutional capacity to respond to the needs of the migrants. Destination areas may face similar environmental challenges (eg, drought or desertification) and may offer little respite. In rural areas, drought particularly affects rural to urban migration.[143] Urbanisation can be beneficial for health and livelihood, but also entails many risks.[121,142] The social disruption provoked by migration can lead to a breakdown in traditional institutions and associated coping mechanisms.[146] Furthermore, the lack of mobility and risks entailed by those migrating into areas of direct climate-related risk, such as low-lying coastal deltas, presents a further hazard.[121] The mental health implications of involuntary migration are often downstream effects, seen as a result of multiple interacting social factors (panel 5).

No or low-regret policies to reduce environmental migration

Effective public health and adaptation strategies to reduce environmental migration or reduce the negative impact of environmental migration should entail the coordinated efforts of local institutions, national and international governments and agencies.[100] There are several no or low-regret practices that generate both short-term and long-term benefits if integrated with existing national development, public health and poverty reduction strategies.

1 Slowing down the rate of environmental change, including mitigation policies and reducing land degradation.[121,154]

Panel 5: Mental health impacts and interventions

Climate change affects mental health through various pathways by inflicting natural disasters on human settlements and by causing anxiety-related responses, and later chronic and severe mental health disorders, and implications for mental health systems.[147,148] These effects will fall disproportionately on individuals who are already vulnerable, especially for indigenous people and those living in low-resource settings.[147] Additionally, individuals might feel a distressing sense of loss, known as solastalgia, that people experience when their land is damaged and they lose amenity and opportunity.[149]

Elevated levels of anxiety, depression, and post-traumatic stress disorders have been reported in populations who have experienced flooding and during slow-developing events such as prolonged droughts;[93,96] impacts include chronic distress and increased incidence of suicide.[150,151] Even in high-income regions where the humanitarian crisis might be less, the impact on the local economy, damaged homes, and economic losses can persist for years after natural disasters.[152] Government and agencies now emphasise psychological and psychosocial interventions within disaster response and emergency management. Social adaptation processes can mediate public risk perceptions and understanding, psychological and social impacts, coping responses, and behavioural adaptation.[153]

2 Reducing the impact of environmental change through early warning systems, integrated water management, rehabilitation of degraded coastal and terrestrial ecosystems, and robust building standards.[154,155]
3 Promoting long-term resilience through enhanced livelihoods, increased social protection, and provision of services. These include ecosystem-based investments, and processes that decrease marginalisation of vulnerable groups—eg, by increased access to health services.

Limitations of migration as a means of adaptation

Migration has been proposed as a transformational adaptive strategy or response to climate change. The policy response is often referred to as "managed retreat".[121,156] With changes in climate, resource productivity, population growth, and risks various governments have now, as part of their adaptation strategies, engaged in planning to move settlement.[33] As an example, five indigenous communities in Alaska have planned for relocation with government funding support. Research on experience of migration policy concludes that a greater emphasis on mobility within adaptation policies could be effective.[100,156]

Using migration as a strategy to cope with environmental stress might however create conditions of increased (rather than reduced) vulnerability.[100,144,156] Even though migration is used as a strategy to deal with imminent risks to livelihoods and food security, many vulnerable low-income groups do not have the resources to migrate in order to avoid floods, storms, and droughts.[157] In addition, studies of resettlement programmes demonstrate negative social outcomes, often analysed as breaches in individual human rights.[154] There are significant perceptions of cultural loss and the legitimacy, and success depends on incorporating cultural and psychological factors in the planning processes.[158]

Dynamic infectious disease risks

Interactions and changes in demographics, human connectivity, climate, land use, and biodiversity will substantially alter disease risks at local, national and international scales.[159] For example, vector-borne infectious disease risks are affected by not only changing temperatures, but also sea level rise.[160] The geographical distribution of African trypanosomiasis is predicted to shift due to temperature changes induced by climate change.[161] Biodiversity loss may to lead to an increase in the transmission of infectious diseases such as Lyme disease, schistosomiasis, Hantavirus and West Nile virus.[162] Infectious disease risks are dynamic and subject to multiple and complex drivers. Adaptation responses therefore must consider multiple uncertainties associated with dynamic disease risks, which include a focus on co-benefits, no regrets and resilience.[113,163–165]

Adaptation policy options for infectious disease risks

1 Investing in public health

Determinants of health, such as education, health care, public health prevention efforts, and infrastructure play a major part in vulnerability and resilience.[166] Adapting to climate change will not only be beneficial in reducing climate change impacts, but also have positive effects on public health capacity.[163] Furthermore, health improvements account for 11% of economic growth in low-income and middle-income countries.[167] The UN Framework Convention on Climate Change (UNFCCC) estimates the costs of health-sector adaptation in developing countries to be US$4–12 billion in 2030. However, the health consequences of not investing would be more expensive, and it is clear that there are several health impacts that we will not be able to adapt to.[168]

2 One-health approaches

These approaches involve collaboration across multiple disciplines and geographical territories to protect the health for people, animals and the environment. 70% of emerging infectious diseases are zoonotic[169] and have multiple well-established links to poverty.[170] They also pose considerable global risks (eg, avian influenza, Ebola). Effective responses to emerging infectious diseases require well-functioning national animal and public health systems, reliable diagnostic capacities, and robust long-term funding. Critical gaps are present in existing health systems, including poor reporting, severe institutional fragmentation, and deficient early response capacities.[171,172]

Zoonosis outbreaks are costly: the economic losses from six major outbreaks of highly fatal zoonoses between 1997 and 2009 cost at least US$80 billion.[173] Implementing a one-health approach is, by contrast, economically sensible: the World Bank values its global benefits at $6·7 billion per year.[173] It provides no-regret options because investments will contribute to reduced vulnerability applicable across climate futures, and it enhances resilience by linking government and civil society partners, facilitating early warning and building capacities to respond to multiple disease risks.

3 Surveillance and monitoring

Strengthening the capacity of countries to monitor and respond to disease outbreaks is vital, as shown by the ongoing Ebola epidemic in West Africa. Climate-change adaptation for human health requires a range of data, including on health climate risks or vulnerabilities, and specific diseases related to climate change impacts. Information and data collected from public health surveillance or monitoring systems can be used to determine disease burdens and trends, identify vulnerable people and communities, understand disease patterns, and prepare response plans and public health interventions.[174,175]

Health co-benefits from climate adaptation

Even though many climate-related health effects are beset by uncertainties, policy makers and communities can prepare if they focus on measures that: 1) create multiple societal and environmental benefits; 2) are robust to multiple alternative developments, and 3) enable social actors to respond, adapt and innovate as a response to change. [164,165]

Ecosystem-based adaptation (EbA)–co-benefits for indirect effects

Ecosystem services contribute to human health in multiple ways and can act as buffers, increasing the resilience of natural and human systems to climate change impacts and disasters.[155]

Ecosystem-based Adaptation (EbA) utilises ecosystem services, biodiversity, and sustainable resource management as an adaptation strategy to enhance natural resilience and reduce vulnerability (covered in more detail in a forthcoming *Lancet* Commission on Planetary Health).[176,177] Natural barriers can act as a defence against climatic and non-climatic events—eg, restoration of mangroves for protecting coastal settlements and conservation of forests to regulate water flow for vulnerable communities.[178,179] EbA is considered to be more cost effective than many hard-engineered solutions, and thought to minimise the scope for maladaptation.[155,180] It can be combined with engineered infrastructure or other technological approaches. EbA interventions can be effective in reducing certain climate change vulnerability as it provides both disaster risk reduction functions, and enables improvements in livelihoods and food security, especially in poor and vulnerable settings.[181] However, the scientific evidence about their role in reducing vulnerabilities to disasters is developing, and the limits and timescales of EbA interventions need further evaluation. Drawbacks can include the amount of land they require, uncertainty regarding costs, the long time needed before they become effective, and the cooperation required across institutions and sectors.[180]

Ecosystem-based adaptation in urban areas

EbA also has the potential to yield benefits for highly urban areas, through the development of green infrastructure.[180] The evidence comes mainly from the northern hemisphere, in high-income settings with a dense city core. In many cases enhancement of urban ecosystems provides multiple co-benefits for health such as clean air and temperature regulation.[182] EbA can further create synergies between adaptation and climate-change mitigating measures by assisting in carbon sequestration and storage, and enhancing various ecosystem services considered beneficial for human health.[176,183] Trees are particularly considered to be efficient in reducing concentrations of pollutants, although the capacity can vary by up to 15 times between species.[184]

Green urban design can reduce obesity and improve mental health through increased physical activity and social connectivity.[164] Increased neighbourhood green spaces reduces both morbidity and mortality from many cardiovascular and respiratory diseases and stress-related illnesses.[31] Tree canopies have a higher albedo effect than other hard surfaces and can work to reduce the urban heat island effect, lowering heat mortality by 40–99%.[185] Whilst resulting in improved public health and community resilience, many of these measures will also act to mitigate climate change.

Overcoming adaptation barriers

Globally, relatively few national strategies bring climate change into public health decision-making processes. The health impacts of climate change are often poorly communicated and poorly understood by the public and policy makers. Barriers to health climate adaptation include competing spending priorities, widespread poverty, lack of data to inform adaptation policies, weak institutions, a lack of capital, distorted economic incentives, and poor governance. Here, we elaborate these barriers and discuss some ways to overcome them.

Institutional collaboration

Health-adaptation policies and programmes require engagement of numerous agencies and organisations, including government agencies, non-governmental organisations (NGOs), informal associations, kinship networks, and traditional institutions.[186] At the same time, institutional fragmentation, lack of coordination and communication across levels of government, and conflicts of interest between ministries are overly common.[186,187] Strengthening institutions at multiple levels is vital, and institutional capacity needs-assessment and collaboration are critical for health adaptation to climate change.[188] The support of bridging organisations, as well as partnerships through networks, are critical as a means to overcome fragmentation and improve collaboration, information flows, and learning.[189]

Finance

Lack of finance is commonly cited as a major obstacle to adaptation, especially in the poorest regions and communities. This might result in economic incentives for investment in adaptation appearing small, individuals or firms lowering initial costs by avoiding expensive adaptation technologies or options, and the fact that the long-term benefits of health risk reduction, health improvements, and other societal benefits (reduced public health care costs) are heavily discounted.

Community and informal networks may provide financial support, but regional, national, and international funds as well as private sector funding will be required for adaptation responses at a larger scale.[190] To date, adaptation funding is inadequate compared to the risks and hazards faced. This is covered in more detail, in section 4 of the Commission.

Communication

Public awareness of the health risks of climate change, even from heatwaves and other extreme weather events, is currently low.[191] Innovative media strategies are needed to enhance awareness of such risks and improve public adaptive skills and effectiveness.[192] health professionals, being knowledgeable and trusted, are in a strong position to communicate the risks posed by climate change and the benefits of adaptation.[102]

Monitoring indicators for adaptation to indirect impacts

Several indicators can serve as proxies for investments in adaptation and resilience to the indirect health effects of climate change.

National adaptation programmes of action

National adaptation programmes of action (NAPAs) are designed for low-resource countries to communicate their most urgent adaptation needs to the UNFCCC for funding.[193] Health projects are more often included in the NAPAs and they typically address current disease (eg, malaria) control issues.[168] To this end, there is a need to provide ongoing assessment of the number of countries that integrate health aspects in their NAPA, as well as the extent to which health is integrated. This indicator should assess adaptation for both direct and indirect health impacts.

Early warning systems

This indicator should include the number of countries that have upgraded early warning systems for extreme weather events, climate-change-sensitive diseases, food security, and migration movements. Early warning systems have proved to be a critical and co-beneficial investment and, if matched with response capacities, could help societies adapt more promptly to changing circumstances that affect human health.

Ecosystem-based adaptation

Investments in ecosystem based adaptation for both direct (eg, flood risk) and indirect (eg, food security, disease mitigation) health impacts could create multiple co-benefits and provide no-regret options for several of the indirect effects discussed above.

Conclusion

This section has outlined interventions available to enhance community resilience and adapt to the health effects of climate change. Many of these are no-regret options that could provide co-benefits across several dimensions including food security, disease prevention, and sustainability in general. Adaptation will provide both short-term and long-term benefits beyond human health. Effective adaptation requires institutional collaboration across levels, integrated approaches, appropriate long term funding, and institutions flexible enough to cope with changing circumstances and surprise. Urgent mitigation efforts must accompany the recommendations provided in section 2, a subject covered in section 3 of this Commission.

	Potential mitigation effects
Energy efficiency	
Supply-side efficiency	Save 14% of primary energy supply (121 EJ by 2050)[194]
End-user efficiency	1·5 Gt of CO_2-equivalent in 2020[195]
Carbon sequestration	
Land carbon sequestration	
Afforestation and reforestation	183 Gt of carbon by 2060[196]
Biochar	0·55 Gt of carbon per year[196]
Upstream oil and gas industry methane recovery	570 Mt of CO_2-equivalent in 2020[195]
Ocean carbon-sink enhancement	
Increase ocean alkalinity	0·27 Gt of carbon per year after 100 years[196]
Iron fertilisation	3·5 Gt of carbon per year for first 100 years[196]
Carbon capture and storage	
Carbon capture during energy generation	Can reduce lifecycle CO_2 emission from fossil-fuel combustion at stationary sources by 65–85%[195]
Direct air capture	3·6 Gt CO_2 per year with 10 million units[197]
Carbon intensity reduction	
Renewable energy*	
Geothermal	0·2–5·6 Gt of CO_2 per year by 2050[198]
Bioenergy	2·0–5·3 Gt of CO_2 per year by 2050[198]
Ocean energy (thermal, wave, tidal)	0·0–1·4 Gt of CO_2 per year by 2050[198]
Solar energy	0·4–15·0 Gt of CO_2 per year by 2050[198]
Hydropower	0·6–4·5 Gt of CO_2 per year by 2050[198]
Wind energy	1·2–9·8 Gt of CO_2 per year by 2050[198]
Nuclear energy	1·5–3·0 Gt of CO_2 per year with current capacity[199]

*We obtained the values of CO_2 emission mitigation for renewable energy from figure 10. 20 of the Intergovernmental Panel on Climate Change (IPCC) special report on renewable sources and climate change mitigation.[198] The ranges represented the minimum and maximum values from four future energy scenarios.

Table 2: **List of high-impact technologies for climate mitigation**

Section 3: transition to a low-carbon energy infrastructure

It is technically feasible to transition to a low-carbon infrastructure with new technologies, the use of alternate materials, changing patterns of demand, and by creating additional sinks for GHGs. This requires challenging the deeply entrenched use of fossil fuels. Any significant deployment to meet demanding CO_2 targets will require the reduction of costs of mitigation options, carbon pricing, improvement in the research and development process and the implementation of policies and regulations to act as enabling mechanisms, as well as recognition of the strong near-term and long-term co-benefits to health.

The technologies for reducing GHG emissions related to energy and many energy-related end-uses have been in existence for at least 40 years (table 2), and several key technologies have their roots deep in the 19th century. The technologies are available now. We have a reasonable grasp of their performance, economics and side-effects (unintended impacts). They treat the causes of the problem (fossil fuel GHG emissions) rather than the symptoms (climate change). Other technologies, such as those described under geo-engineering have a high degree of uncertainty as to their effectiveness and also their side effects. We view these technologies as being highly risky but also (at this time) unnecessary, as we have the tools needed to achieve emission targets to avoid catastrophic climate change. Geo-engineering is analogous to using unlicensed drugs to treat Ebola when public health and hygiene could have prevented the problem in the first place. It is also important to recognise that for an energy source to be renewable, it must satisfy a low-carbon requirement, and consider the use of scarce resources such as copper, silicon, and rare earth metals.

Public health has much to gain from the mitigation of short lived climate pollutants (SLCPs) such as methane, black carbon, hydrofluorocarbons, and tropospheric ozone. The benefits for health, climate change, and crop yields are covered in great detail in a report by WHO and the Climate and Clean Air Coalition.[200]

Main sources of GHG emissions

In 2010, annual global GHG emissions were estimated at 49 $GtCO_2e$.[201] The majority (about 70%) of all GHG emissions can be linked back to the burning of fossil fuel for the production of energy services, goods or energy extraction (figure 8).[202] Global emissions from heat and electricity production and transport have tripled and doubled respectively since 1970, whereas the contribution from agriculture and land-use change has slightly reduced from 1990 levels.[203]

When upstream and electricity sector emissions are allocated on an end-use basis, most emissions (about 61%)

are related to the built environment (ie, buildings, transport, and industry). These emissions are related to providing services such as cooling and heat in buildings, power for lights, appliances, electronics and computing, and motive power for moving to and within largely urbanised places, while industrial manufacturing of products feeds into the built environment system through movement of goods, economic activity and employment.

The global energy system

We know that the global energy system is heavily dependent on the extraction, availability, movement, and

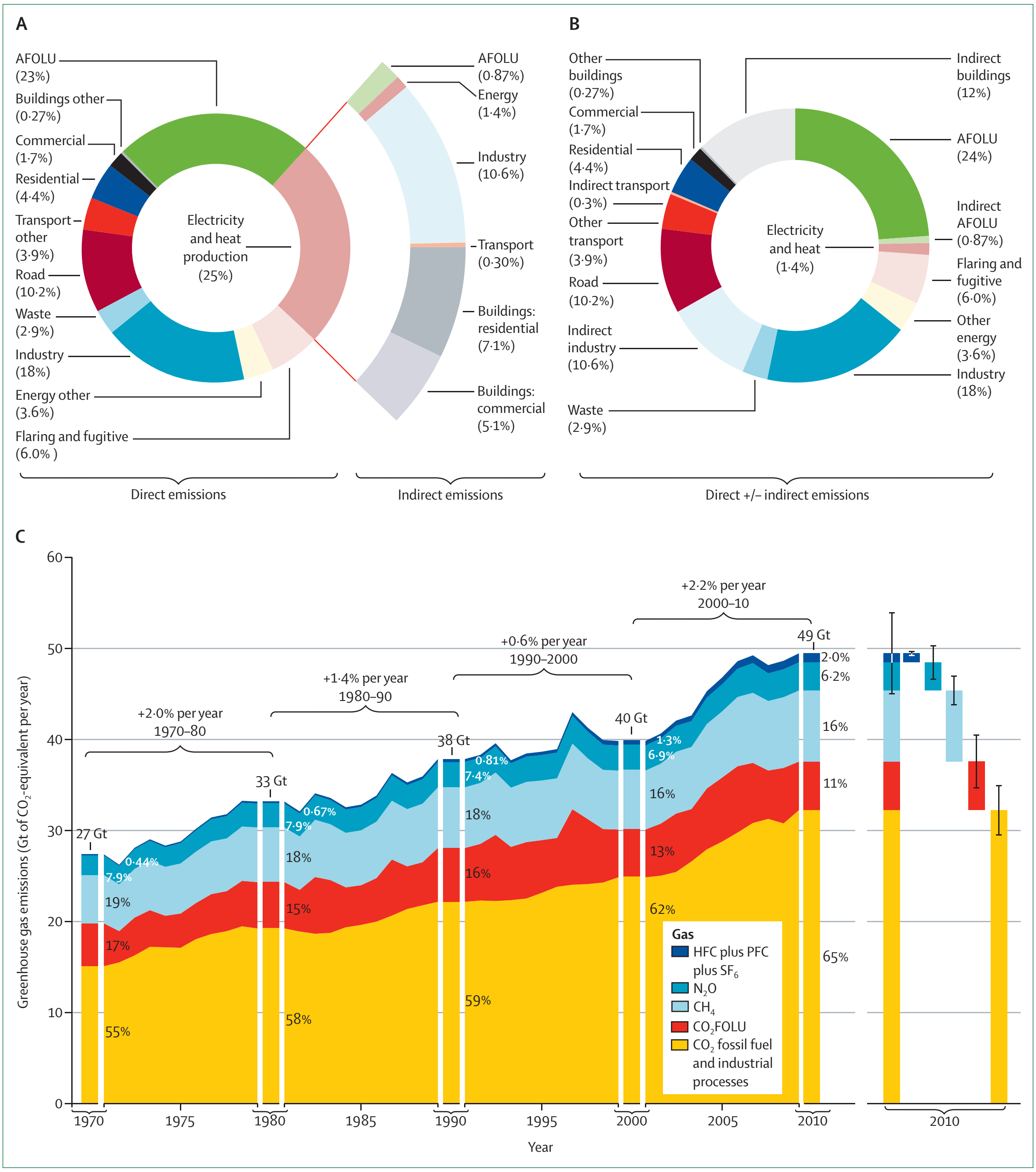

Figure 8: **Sources of greenhouse gas emissions (source: IPCC, 2014[202])**
Allocation of total greenhouse gas emissions in 2010 (49·5 Gt CO_2 equivalent per year) across the five sectors examined in detail in this report (A). The enlarged section of panel A allocates indirect CO_2 emission shares from electricity and heat production in the sectors of final energy use. Panel B allocates total emissions (49·5 Gt of CO_2 equivalent per year) to show how the total from each sector increases or decreases when adjusted for indirect emissions. Total annual greenhouse gas emissions by groups of gases 1970–2010, and estimated uncertainties for 2010 (whiskers; C). The uncertainty ranges are illustrative, given the limited literature in the field.[201] AFOLU=agriculture, forestry, and other land uses. FOLU=forestry, and other land uses.

consumption of fossil fuels, and this system shows vulnerabilities when stressed. For example, the 1972 Organization of the Petroleum Exporting Countries (OPEC) oil embargo (which resulted in a cut of global production by 6·5% over 2 months) or the first Persian Gulf War (which caused a doubling of global oil prices over 3–4 months) each caused major pressure on the access and security of global energy supplies.[204] Furthermore, many of the world's largest actual and potential conventional oil reserves are in areas of historic volatility and civil unrest.[205]

Climate change poses a risk to the existing energy system. Under a changing climate, these vulnerabilities could result in disruption in both supply and production of power under extreme weather events, operations (eg, water availability for cooling towers), viability of infrastructure (eg, location of power lines or hydroelectric systems), impact on transmission (eg, high temperatures or wind damage), and higher demand for cooling and building system performance.[206,207]

The usefulness of fossil fuels relates to their power and energy density, portability, and relative cost compared with other forms of energy. These attributes have acted as challenges to the transition to low-carbon energy sources and vectors, such as renewable and nuclear electricity and hydrogen. Maintaining power supply based on intermittent electricity sources such as wind power is a complex system integration problem.[208] Practical solutions will involve combinations of energy stores (hydroelectric, thermochemical), demand-side management, and the harnessing of geographical diversity with respect to demand and supply. Cross-continental power grids can play a significant part in reducing low-carbon systems costs because greater diversity of demand and supply reduces the need for expensive energy storage.

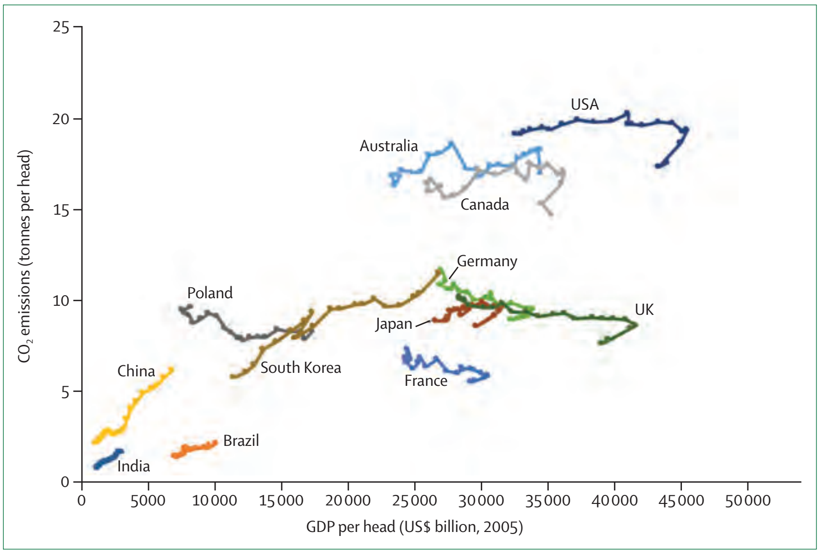

Figure 9: **Per head CO_2 emission trends in relation to income for a selection of countries (1990–2008)[212,213]**
*Based on purchasing power parity.

The growth in energy demand

Global energy demand has grown by 27% from 2001–10, largely concentrated in Asia (79%), the Middle East and Africa (32%), and Latin America (32%), but with near stable but high demand (on a territorial accounting basis) in the 1990 Organisation for Economic cooperation and Development (OECD) group of countries.[203] China doubled its energy demand during this period and represented the single largest proportion of the global increase (44%).[209] Most global growth in energy was in coal (44%) for use in electricity production, a dangerous reality for human health.[210]

Economic productivity has risen alongside global energy demand. Whilst fossil fuel-based energy demand has grown slowly in OECD countries since 1970, gains were made in GDP terms that were largely a result of de-industrialisation of the economy (largely exported to Asia). As a result, Asia has made a significant leap in energy consumption, emissions and GDP. The energy intensity of large global economies (ie, the USA, China, EU, India) have fallen progressively over the period of industrialisation.[211] Figure 9 shows that economic gains need not be strongly coupled to CO_2 emissions, though the association is partly obscured by the export of CO_2 emissions. Moving energy-intensive industries offshore (most of which remain fossil-fuel powered) allows for territorial emissions to fall, but at the cost of increased emissions elsewhere.

Growth in demand for energy will probably continue over the coming 25 years, particularly in lower-middle and low-income economic regions, where most citizens lack access to safe and affordable energy. The growth in global per capita energy demand is linked to improvements in the standard of living in developing regions and directly supports development goals. Expected energy demand in non-OECD countries may double by 2035 (107%) from 2010, while OECD countries may increase by 14% over the same period.[209] However, this growth in demand will continue to directly benefit high-income regions through exported production of goods.

Meeting our future energy needs

Access to energy is a key enabler of economic development and social wellbeing. In recognition of energy being a key determinant of economic and social development, and of health and wellbeing, the UN has declared that 2014–24 is the UN Decade of Sustainable Energy for All. The world's population must be able to access clean forms of energy that can provide these basic needs, which can minimise the health burden from both direct exposure and indirect from future climate change risks. The Sustainable Development Goals (SDGs) have emphasised the role that energy plays in securing a sustainable future for a global 9 billion population by 2050, and has outlined four targets to support, which could act as progress metrics. The indicators measuring progress on the proposed SDGs for securing sustainable energy for all by 2030 include: ensuring universal access to affordable, sustainable, reliable energy services; doubling the share of renewable energy in the global energy mix; doubling the global rate of improvement in energy efficiency; phasing out fossil-fuel production and consumption subsidies that encourage wasteful use, while ensuring secure affordable energy for the poor.[214]

The health burden of the current energy system

Although linked to a historical transformation in health, a fossil-fuel-based energy system also imposes significant health burdens (figure 10). The direct burden occurs through emissions of particulates and solid wastes (coal, oil, gas, biomass), risk of flooding (hydroelectricity), accidents and injuries (all), and emission of radioactive materials (coal, nuclear). But as the main driver of anthropogenic climate change, an energy system based on fossil fuels will also have indirect effects through climate change and the increase in temperatures, extreme weather, heatwaves, and variable precipitation (see section 1).

The immediacy of this burden varies with the inertia built into the emission to exposure pathways and exposure to health-effect pathways. Compared with climate change, the locality and visibility of fossil fuel emissions are more apparent today as poor air quality and toxic discharges, such as smog in Beijing or Delhi. A coal-fired power plant will emit particulates that result in immediate exposure for the local population with consequent increased risk of developing respiratory disease and lung cancer. The exposure to emissions can result in immediate health effects for the local population, such as respiratory tract infections, or take many years or decades to have an effect. A coal-fired station will produce immediate CO_2 emissions, but these emissions do not result in immediate health impact. Instead, GHG emissions that accumulate in the atmosphere over the long term will result in global climate change. The long-term nature of climate change means that these exposures build towards a more dangerous level. Another dimension is locality of the emissions-exposure, exposure-health effect pathways. Locally generated emissions will affect both the population surrounding the point of discharge and in some cases more widely, as in burning coal in north Asia. Climate change, however, will affect all areas to varying degrees.

The global increased use of energy per capita is highly related to considerable improvements in quality of life across much of the world. The majority of this energy use is derived from fossil-fuel use, but mainly coal. Coal's wide availability and economic attractiveness has made it the fuel of choice for use in power generation. The recent expansion of coal use, mainly in the newly industrialising countries, effectively reverses the global pattern through most of the 20th century towards less carbon intensive and less polluting fossil fuels–the progressive displacement of coal by oil, and of both by natural gas. However, the time when fuel switching could decarbonise the global economy sufficiently quickly to avoid dangerous climate change has almost certainly passed. It is increasingly difficult to justify

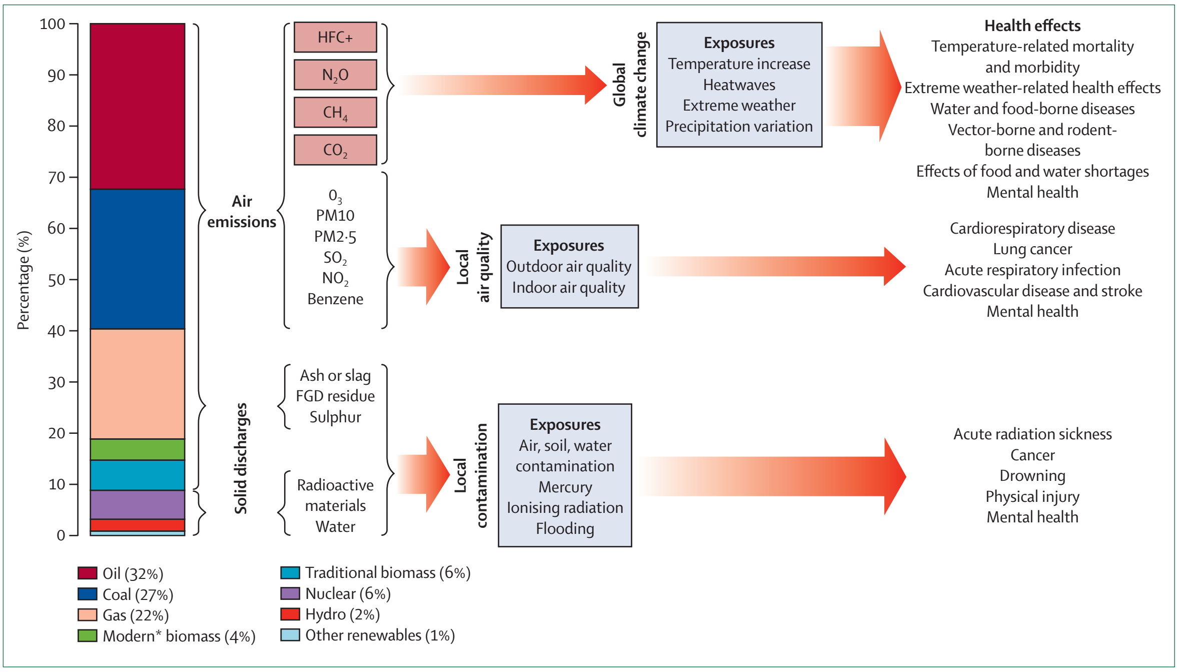

***Figure 10:* Connections between the global energy system and health impacts**
Length of arrows denotes time to impact; width denotes inertia of impact. FDG=flue gas desulphurisation. *Does not include other renewables.

large-scale investment in unabated gas-fired infrastructure. The dangerous impacts of coal on health from exposure to air pollution in the form of noxious particulates and heavy metals, the environmental degradation (eg, contaminating water courses and habitat loss) from the extraction and processing of coal, and the major contribution that burning coal and the release of GHGs has in changing the long-term climate almost certainly undermines the use of coal as a long-term fuel. Although the use of coal as a fuel source for power generation will be linked to economic growth and (sometimes precarious) improvements in quality of life, the risk that coal has on our global health through climate change and habitat loss means that moving to low-emission fuels in areas of high coal demand is a major part of the global low-carbon energy transition. Whilst the use of technologies such as carbon capture and storage (CCS) are consistently cited in reducing the impact of coal-based power generation, at present, these technologies have many major unknowns and are without substantial government investment or the use of carbon pricing.

One important strategy to protect against the health burdens of local and national energy choices, is to ensure that health impact assessments are built in to the planning, costing, and approval phases of a new project. By developing the tools and capacity to enforce this, policy makers can better understand the broader consequences of their decisions.

Actions, technologies, and health outcomes

Actions that seek to mitigate climate change have the potential to be beneficial to health, both directly and indirectly.[1,29] Across a number of sectors, the potential health benefits of switching to low-carbon technologies include a reduction in carbon emissions from power generation,[215,216] improved indoor air quality through clean household cooking technologies in low-income settings and housing thermal efficiency in high-income settings, and lowered particulate-matter exposure from low-emission transport.[217,218]

Decarbonising the power supply sector holds both risks and benefits for health. The direct benefits centre on reducing exposure to air pollutants from fossil-fuel burning.[216] In the UK, the associated burden of air pollution from the power sector is estimated to account for 3800 respiratory related deaths per year.[216] In China, air pollution is thought to result in 7·4 times more premature deaths from PM2.5 than in the EU.[215] It has been estimated that current ambient concentrations of particulate matter led to the loss of about 40 months from the average life expectancy in China, but that this loss could be cut by half by 2050 if climate mitigation strategies were implemented. The risks to health from decarbonisation are more likely to be indirect; if the deployment and adoption of technologies that aim to reduce carbon emissions, reduce energy demand, or switch fuels are not undertaken with care, there are risks of unintended consequences through, for example, poor housing ventilation.[219] Besides air quality, several links between climate mitigation practices and technologies and potential health benefits have been established (figure 11).[220,221] Using active transport as an example, the shift from car driving to walking and cycling not only reduces the air pollutant emissions, but also increases levels of exercise, which in turn can lead to reduced risks of several health outcomes, including cardiovascular diseases, diabetes, and some cancers.[218]

The formal health sector itself also has a role to play in reducing its emissions. Hospitals and health systems, particularly in more industrialised settings, account for around 10% of GDP and have a significant carbon footprint. While the full extent of health care's climate impacts is not known, emerging data confirms its significance and the need for mitigation strategies. For instance, the NHS in England calculated its carbon footprint at more than 18 million tonnes of CO_2 each year—25% of total public sector emissions.[222] 72% of the NHS's carbon footprint is related to procurement and the remaining split between travel and energy use in buildings.[223] In the USA, the health-care sector is responsible for 8% of the country's total GHG emissions.[224] With among the largest sectoral purchasing power globally, the health sector could reduce its impact through the products it purchases and through investment in its infrastructure (ie, hospitals, ambulatory services, and clinics).

By moving toward low-carbon health systems, health care can mitigate its own climate impact, become more resilient to the impacts of climate change, save money, and lead by example. For instance, in South Korea, Yonsei University Health System is targeting reducing GHG emissions by 30% by 2020. Energy efficiency measures saved the system $1·7 million and reduced GHG emissions by 5316 tonnes of CO_2 in 2011 alone.[225] In the USA, Gunderson Health has increased efficiency by 40%, saving $2 million annually, while deploying solar, wind, geothermal, and biomass to significantly reduce its carbon footprint and end its dependence on fossil fuels.[226] In England, the NHS Public Health and Social Care System has similarly committed to reducing their carbon footprint by at least 34% by 2020.[227]

Conversely, accounting for the health co-benefits of climate change mitigation, can help to bring down the overall cost of greenhouse gas mitigation. Jensen and colleagues have shown that the incorporation of health co-benefits of cleaner vehicles and active travel can make those mitigation practices cost effective.[228] The health benefits of reducing methane emission in industrialised nations could exceed costs even under the least aggressive mitigation scenario between 2005 and 2030.[229] For example, in the UK, retrofits aimed at improving energy performance of English dwellings have the potential to

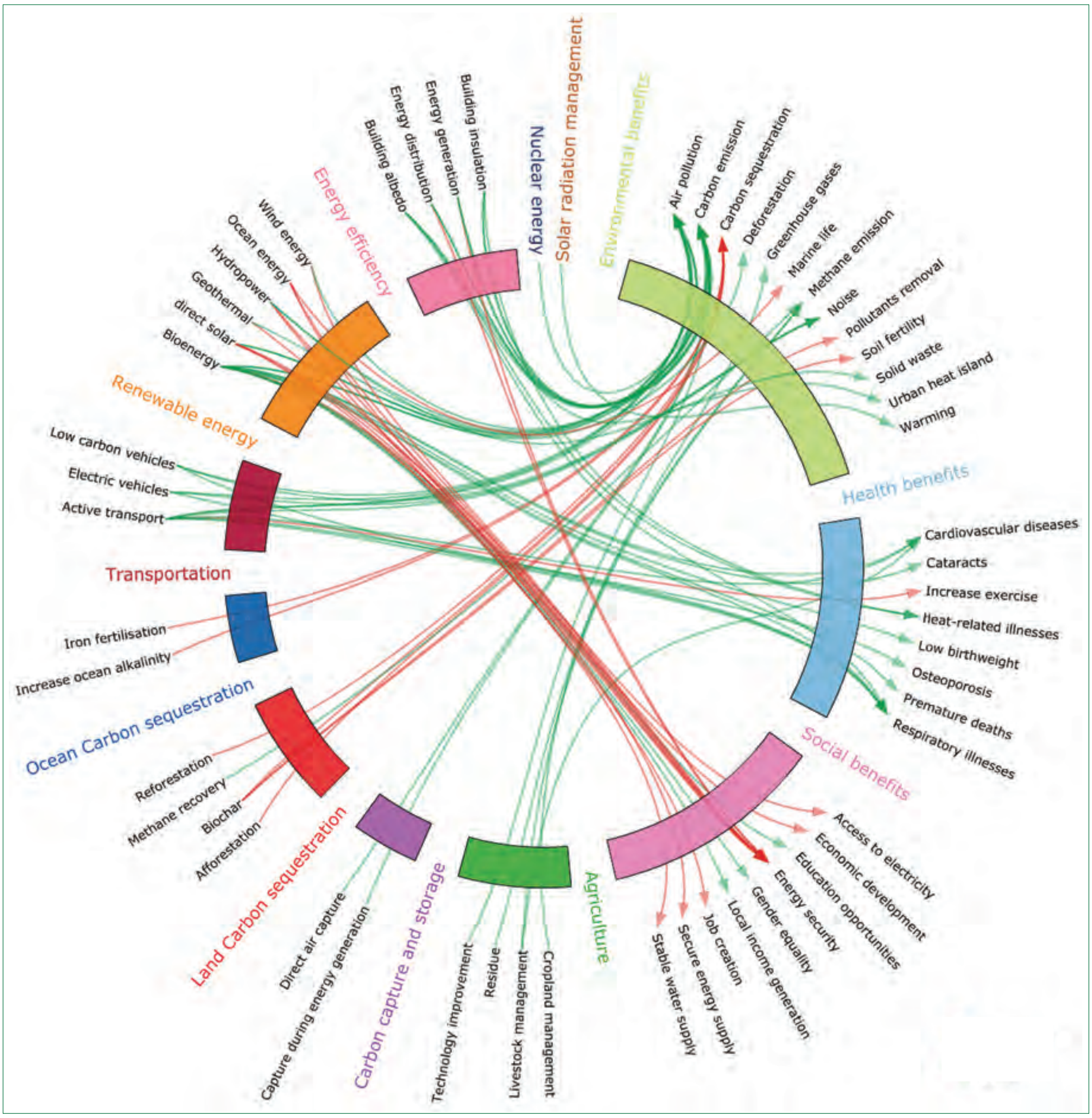

Figure 11: **Frequently cited co-benefits of major mitigation techniques**
Red arrows between a mitigation technology and an effect indicate that the technology will increase the effect; green arrows indicate an opposite trend.

offer substantial health benefit over the long-term, providing ventilation to control indoor pollutants is installed (see appendix 2).

See Online for appendix 2

Pathways to (GHG emissions reduction) pathways

Over the last two centuries, the prevailing pattern of national development has involved dramatic increases in productive capacity, supporting transformations in nutrition and housing, underpinned by development of fossil-fired energy supply, conversion, and distribution systems. Three overlapping stages of development can be identified:

- Stage 1: typically low technology, relatively inefficient and with little regard for damage due to pollution and other externalities.
- Stage 2: locally clean. As countries become wealthier, they can afford to invest in the longer term and deal with the local health problems associated with burning fossil fuels.
- Stage 3: regionally and globally clean. This involves the development of energy systems that address transboundary pollution problems including that of anthropogenic climate change. Stage 3 is generally associated with high GDP and indices of public health.

Importantly, improvements in technology and efficiency have historically accompanied and assisted, but have not been primarily driven by the goal of pollution control. The patterns of development associated with stages 1 and 2 are complex and multi-dimensional, and stage 3 is unlikely to be different. Stages 1 and 2 have historically been associated with increasing income and health.

This pattern of development has resulted in emission of about 1600 $GtCO_2$ since 1870, with a consequent rise in global mean temperature anomaly of +0·85°C (1870–2010). To have a better than 66% probability of keeping the rise in global temperatures to below 2°C, cumulative greenhouse gas emissions from 2011 on would need to be limited to around 630–1180 $GtCO_2$eq.[201,230,231] At the current global emission rate, this budget would be used up in between 13 and 24 years.

The last 30 years of OECD data have shown that significant changes to global energy systems are possible. Indeed, the whole of the 20th century has been characterised by a succession of transitions in energy technologies. However, this process has not been inevitable and decisions on energy systems have been aligned with other national objectives—eg, enhanced security of supply or reduced air pollution. This suggests that the transition to low-carbon energy will need to be predicated on achieving multiple objectives, including climate change, health, equity, and economic prosperity.

Many trajectories that are consistent with such a budget (panel 6 shows those of the UK and China) are in principle possible. Such trajectories necessarily involve emissions in the second half of the century in the region of 90% lower than emissions between 2011–50.[232] All would require an unprecedented global commitment to change, and none appears easy. To stabilise CO_2-equivalent concentrations in the range 450–650 ppm (consistent with 2–4°C of warming) will require the global emission rate to fall by between 3–6% per year, a rate that so far has only been associated with major social upheaval and economic crisis.[25] Postponing deep cuts in emissions may allow for new policies and technologies, but at the cost of significant impacts (eg, for land use and food production) in the second half of the century.

Achieving a 2°C warming target

Many technologies exist or have been proposed to mitigate climate change. But they vary in their potential

Panel 6: Decarbonisation pathways for the UK and China[230]

The Deep Decarbonisation Pathways Project (DDPP) aims to understand and show how major emitting countries can transition to low-carbon economies and, in doing so, move towards the internationally agreed 2°C target by 2050. The project comprises representatives of 15 countries contributing to more than 70% of current global greenhouse gas emissions, and is led by the UN Sustainable Development Solutions Network (SDSN), and the Institute for Sustainable Development and International Relations (IDDRI), Paris.[227]

The project's interim report describes pathways that achieve a 45% decrease of total CO_2-energy emissions over the period (falling to 12·3 Gt by 2050, from 22·3 Gt in 2010). Although the interim pathways do not reach a 50% probability of restricting climate change to 2°C, they provide important insights. Three key pillars of decarbonisation are crucial in all the countries studied: energy efficiency and conservation, a shift to low-carbon electricity, and a switch to lower carbon fuels. However, the balance between these pillars depends on national circumstances.

The UK pathway is characterised by early decarbonisation of the power generation sector, and increased electrification of end-use sectors from 2030, leading to an 83% reduction in CO_2-energy emissions by 2050 (see figures 12A and B). The cumulative investment requirements for such a large-scale decarbonisation are in the region of £200–300 billion, and require a strong policy framework, including electricity market reform. After 2030, radical changes in energy vectors are necessary, with heating switching from gas to heat pumps and district heating, and transport increasingly electrified. Greater-than-marginal reductions in emissions (eg, associated with heating) require sustained strategic vision and interdecadal coordination between energy supply and demand sectors of the economy. Challenges to delivery will probably include the scale of infrastructure investment, and public acceptability across end-use sectors.

The challenge in China is to achieve decarbonisation alongside continued rapid economic growth. The pathway shows GDP per head increasing by six times from 2010 to 2050; this increase is offset by a 72% reduction in energy intensity of GDP—a substantial decoupling. Emissions peak by 2030, and fall by 34% by 2050, driven by falling energy intensity and almost complete decarbonisation of power generation. Despite electricity generation more than doubling by 2050, unabated coal is replaced by renewables, nuclear, and carbon capture and storage (figures 13A and B). In industry, carbon capture and storage and higher efficiency could reduce emissions by 57% by 2050. But growth will continue in the transport sector due to an increase of ten times in mobility, only partly offset by higher efficiency and little penetration of low-carbon vehicles.

Key to the transition of the Chinese energy system is rapid development and deployment of low-carbon technologies, and a shift away from unabated coal use, facilitated by energy market reform and carbon pricing.

The project shows the crucial need for large-scale global technology research, development, demonstration, and deployment, and transfer efforts. A common feature of most pathways is the need to decarbonise freight transport and industry. The final DDPP report will review investment levels and policy frameworks to enable the transition.

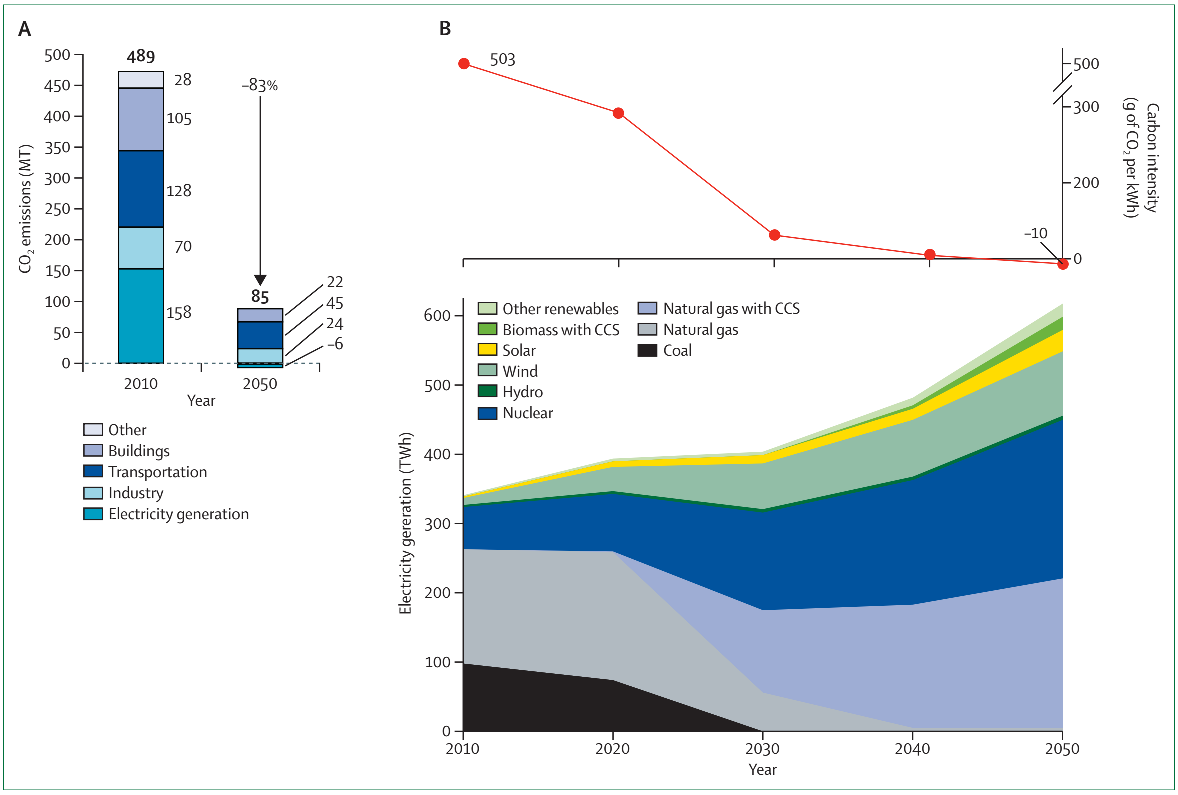

Figure 12: **Energy-related CO_2 emissions pathway for the UK in 2010 and 2050 (A), and energy supply pathway for electricity generation for the UK, 2010–50 (B)**[230]
CCS=carbon capture and storage.

mitigation impacts, stages of development, costs, and potential risks. Table 2 summarises mitigation technologies. Among them are climate engineering approaches such as land and sea sequestration. Although these have significant potential, they carry significant risks, including the possibility of damage to ecosystems. It is currently uncertain that the necessary international consensus to allow the deployment of such technologies could be achieved. Energy efficiency improvement is considered as the least risky of the options, although on its own it is insufficient to achieve the necessary decarbonisation.[233]

Individual behaviour is an important factor that affects the end-user energy efficiency—eg, using high-efficiency heating and cooling systems, adopting more efficient driving practices, routine maintenance of vehicles and building systems, managing temperatures for heating, and hot water for washing.[234,235] But behavioural changes are not so easily achieved and pose considerable risk as a mitigation strategy. The medical professions have decades of experience with attempts to induce mass changes of behaviour through health promotion. The most prominent campaigns have been targeted at alcohol consumption, smoking, diabetes, and obesity. The overarching lesson is that even when behaviour change yields direct personal benefits, amounting in some cases to a decade or more of life expectancy, it is extraordinarily difficult to achieve through persuasion. In practice, different societies favour divergent approaches to influencing behaviour, ranging from the economic, through the physical to the psychological.[236]

Technologies that have the greatest decarbonisation potential include nuclear power, offshore wind, concentrated solar power (CSP), and CCS.[237,238] Solar photovoltaic (PV) and wind systems have been growing exponentially for decades (wind about 12% per year, PV about 35%), with consequent reductions in costs due to learning and increasing scale of production and deployment, while both CSP and CCS have not yet been deployed at any significant scale and so cannot capture significant learning effects. CCS suffers from similar problems to nuclear—ie, large unit sizes, potential regulatory concerns, and long lead times, which means weak and delayed learning once deployment has begun. But CCS's additional disadvantage compared with nuclear and renewables is that while the latter decouple economies from the threat of future rising and volatile fossil fuel costs, CCS magnifies these threats. Even in the absence of carbon pricing, renewables and nuclear can be justified as a hedge against future increases in fossil fuel prices, whereas CCS cannot.

Attempts to understand the adaptation of the whole energy system in the context of rapid transitions to low-carbon emissions have been predominantly from the

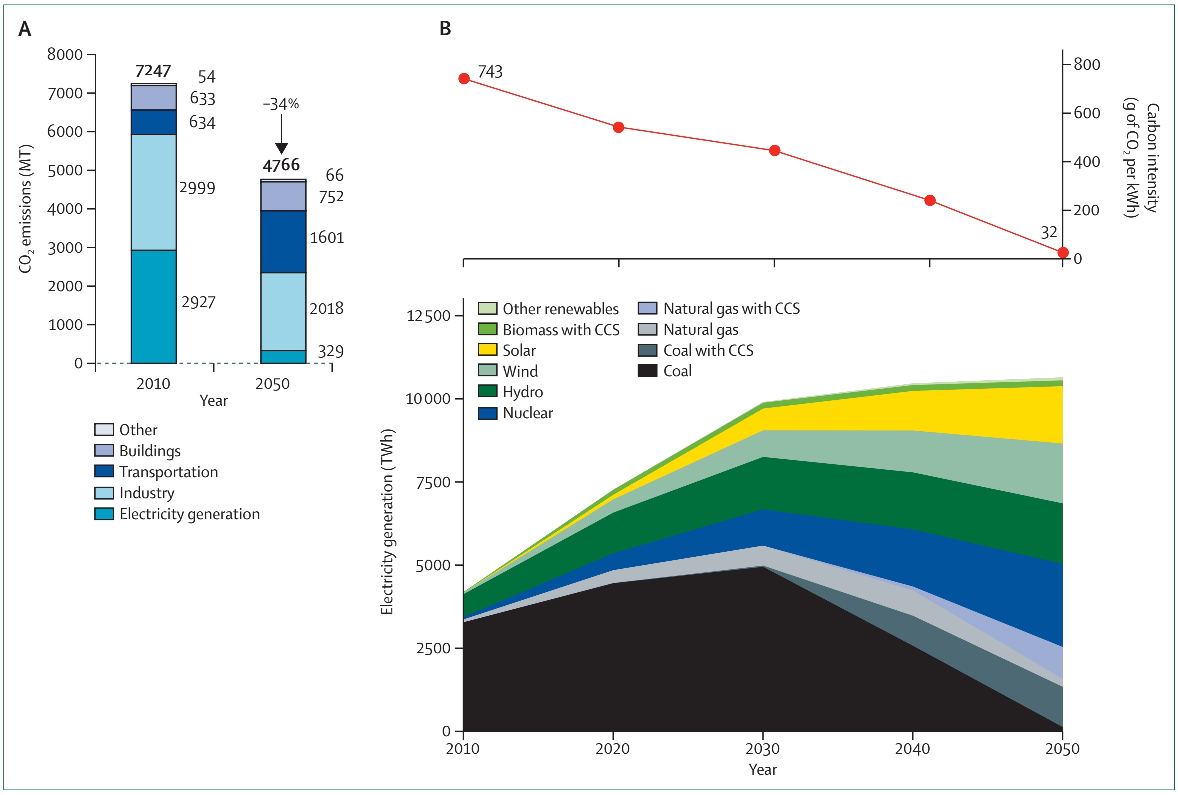

Figure 13: **Energy-related CO_2 emissions pathway for China in 2010 and 2050 (A), and energy supply pathway for electricity generation for China, 2010–50 (B)**[230]
CCS=carbon capture and storage.

discipline of economics. Among these is the Deep Decarbonization Pathways Project (DDPP), which has developed pathways for 15 countries.[230] Panel 6 provides an example of these technology pathways for the UK and China. Transforming the global economy in anything like the timescale implied by the above discussion requires unprecedented action in both industrialised and developing countries. The former will need to embark more-or-less immediately on CO_2 reduction programmes with a high level of ambition. Developing countries will need to move directly from stage 1 to stage 3 (significantly reduced emissions with associated high GDP and indices of public health) probably with both capital and technical support from developed countries. Delayed emission reduction would lower the possibility to control climate change, raise costs and force the uptake of riskier and unproven mitigation technologies with increased risk of unintended consequences for human wellbeing and ecosystems.[239]

The range of unintended consequences when the technologies are administered to different systems is large, complicated, and in some areas poorly understood. Ultimately, rapid mass deployment of low-carbon technologies requires a better understanding of the drivers and barriers to delivery within different economic sectors, the scale and opportunity of deployment, and the setting and its context including the actors and decision makers involved. The application of low-carbon technologies, their impact, deployment, and co-benefits must be maximised by understanding what works, where it works, and why it works. This understanding is particularly important to support emerging technologies that are yet to reach market-scale deployment. Three key drivers are required to support pathways to a low-carbon future: maximising the efficacy of low and zero carbon technologies, maximising the deployment of these technologies, and maximising and internalising the potential health co-benefits of decarbonisation.

Maximising efficacy

Although significant progress has been made in adopting clean technologies, the resulting impact on energy intensities and carbon emissions has been lower than expected. Barriers to adoption and deployment of mitigation technology include a lack of awareness and access to technical knowledge, segmentation and fragmentation within and amongst sectors, and financial disincentives. These barriers will be particularly acute in developing countries where the benefits of energy efficiency are not necessarily recognised and may be a lower priority compared to many other urgent issues, such as poverty eradication, public health improvement, and crime reduction; this may be further affected by a lack of means of communication. Furthermore, due to a lack of quantitative and reliable measurements of energy performance, many stakeholders are not aware of energy savings potential. We propose three actions to improve efficacy:

1 Understanding the direct and indirect impacts of technologies from an integrated technical, economic, social, health and cultural, and political perspective;
2 Gathering, evaluating, and reporting real-world evidence to support and guide development and implementation of mitigation strategy;
3 Put in place policies and regulations (such as reporting schemes, inspections, and benchmarks) to make performance visible within the market.

Maximising uptake

Minimum deployment of low-carbon technologies poses a significant risk to the transition to a low-carbon future. The International Energy Agency (IEA) has stated that nine out of ten low-carbon technologies that are essential for energy efficiency and decarbonisation are failing to meet their deployment objectives. Limited deployment, particularly early in the process, limits learning and constrains subsequent progress.

Inertia in the technology diffusion process within many sectors means that many off-the-shelf technologies today could take 20 years to achieve significant market penetration without incentives to support their uptake. Overcoming such inertia requires clear guidance on technology potential; robust data on technology performance, impact, and costs; detailed information on existing sectors and historic structures; removal of disincentives and perverse incentives; and strong regulations. For certain technologies, regulation can play a major part in accelerating deployment. Criteria for regulations to be effective in this role may be summarised as follows: that the goal of regulation should be unambiguous; that the technical nature of measures which will achieve the goal should be clear, and they should be easy to apply; that the technical nature of these measures should make it easy for the regulator to confirm that they have been implemented; that the total benefits should outweigh costs; and that both benefits and costs should be a small part of some larger economic transaction.[240] Cities offer opportunities and challenges for technology deployment. For appropriate technologies, economies of scale are quickly achieved with population and economic densities supported by larger tax bases, deployment through existing services and a history of operating large scale infrastructure. Density intensifies local environmental problems (particulates, noise, etc), which can in turn make it politically possible to introduce local regulation favouring low-carbon technologies. Resulting niches and learning can then accelerate the development and wider deployment of key mitigation technologies.[241]

Development status is another important driver of deployment. The bulk of technology transfer occurs between developed countries who dominate the invention of technologies for climate mitigation.[242] This does nothing to overcome the low availability of mitigation technologies in developing countries. Major barriers to technology transfer from developed to developing countries include insufficient local human capital and technology support capabilities, lack of capital, trade and policy barriers, lax intellectual property regimes in developing countries, and the potential lack of commercial viability of the technology itself.[243] These barriers need to be overcome to enable countries seeking to achieve a high quality of life to tunnel from stage 1 to stage 3.

Mechanisms to support low-carbon technology uptake should include:

- Enacting policy regulations to improve deployment of technologies (such as incremental minimum performance standards or delivery obligations)
- Developing strong national-level commitments and sources of funds for investment in low-carbon infrastructure that is accessible to local delivery agents.
- Targeting decision makers who can achieve maximum on-the-ground change and uptake of technologies and changes in practices (ie, sector heads, mayors, and councils).

Maximising co-benefits and avoiding unintended consequences

Many low-carbon technologies provide benefits other than reducing greenhouse gas emissions—eg, increased energy security, improved asset values, improved air quality, greater disposable income, and improved health and comfort. Some low-carbon technologies are primarily deployed because of their co-benefits.

Low-carbon technologies inappropriately deployed can hurt the economic and social development of developing countries. The increased use of expensive low-carbon energy sources could delay essential structural changes and slow down the construction of much needed infrastructure. Higher energy prices can affect economic growth and exacerbate poverty and inequality. However, abstaining from mitigation technologies in developing countries carries the risk of lock-in into a high-carbon-intensity economy.[244] In order to avoid such unintended consequences, a balanced strategy focusing on both human development and climate mitigation in developing countries is needed.

Mechanisms to maximise co-benefits should include:

- Developing compelling arguments for action that emphasise co-benefits (ie, health, quality of life, air quality, a creative and resilient economy).
- Putting in place national and international level mechanisms to support and encourage technology adoption (ie, carbon pricing).
- Putting in place policies and economic tools that can facilitate the technology transfer from developed countries to developing countries (ie, the importance of the Green Climate Fund).

***Panel 7*: Total external costs of burning fossil fuels**

The prices of fossil fuels routinely do not account for their global impacts related to climate change, or their local impacts on human health and ecosystems. These external costs of fossil fuels can be expressed by the following formula:

$$TEC_{ff}=C_{cc}+C_{lap}=(C_{cd}+C_{ad}+C_{mg})+(C_{pd}+C_{he}+C_{pc})$$

Where TEC_{ff} are the total external economic costs of burning fossil fuels; C_{cc} are the costs related to climate change, which can in turn be regarded as the sum of C_{cd} (the damage costs of unmitigated climate change), C_{ad} (the costs of adapting to climate change, either present or anticipated), and C_{mg} (the costs of mitigating climate change); and C_{lap}—the costs of local air pollution—which can be regarded as the sum of C_{pd} (the pollution damages to buildings, crops and health of such pollution), C_{he} (the health and other expenditures to remedy this pollution damage) and C_{pc} (the costs of controlling this pollution). There is symmetry in these cost terms relating to climate change and local air pollution, between C_{cd} and C_{pd} (the estimated damage costs), C_{ad} and C_{he} (the actual expenditures in response to the pollution), C_{mg} and C_{pc} and (the costs of reducing the extent of the pollution). The components of this formula are also dependent on each other, in conceptually simple if often practically complex ways, as follows:

- C_{cd} is a function of C_{mg}, such that increased mitigation will reduce the costs of climate damage, with a similar relationship between C_{pd} and C_{pc} for local air pollution.
- C_{ad} is also a function of C_{mg}, such that increased mitigation will reduce the costs of adaptation, with a similar relationship between C_{he} and C_{pc} for local air pollution.
- C_{lap} is also a function of C_{mg}, such that increased mitigation will reduce the costs of air pollution.
- C_{cd} is a function of C_{ad}, such that increased adaptation will reduce the costs of climate damage, with a similar association between C_{he} and C_{pd} for local air pollution.

Notably, in each case, the effects of the different variables on each other might act over widely differing timescales. Furthermore, whereas the above equation has been discussed in terms of the combustion of fossil fuels, which make the major contribution to anthropogenic greenhouse gas emissions, for full cost-effectiveness of climate mitigation the equation should be computed over the full range of greenhouse gas emissions to ensure that relatively cheap abatement measures are not overlooked.

Conclusions

Energy systems comprise some of the largest, most complex and enduring capital structures in modern economies. Decarbonisation and reducing energy demand is not a simple challenge of cleaning up pollutants or installing new equipment, it requires systemic transformations of energy infrastructures and associated systems. We need to put in place mechanisms that support the uptake of technologies in an effective manner (ie, support pathways to impact pathways or pathways to pathways). Finally, it should be noted that the full potential of mitigation technologies will only be achieved if the social and political systems around these technologies co-evolve to deliver carbon targets.

There is a clear and compelling need for the industrialised world to achieve faster and much deeper emission reductions than anything delivered to date. At the same time, industrialisation historically has been accompanied by rising greenhouse gas emissions (particularly CO_2) up to income levels of \$10–15 000 per capita. Some of the major emerging economies are already reaching such levels, with concomitant emissions; helping others to avoid doing so, or helping those (like India) still with huge challenges to lift hundreds of millions of people out of extreme poverty, will require international assistance.

Through a multipronged approach that advocates co-benefits, targets decision makers and puts in effective measures that are understood, it might be possible to make real progress towards meeting our emission reduction goals. These mechanisms represent a public health-style approach to developing and implementing mitigation strategies, with the end goal of many co-benefits.

Section 4: financial and economic action

The total economic cost of fossil-fuel use

Past failures to reduce GHG emissions mean that remaining within the required carbon budget is becoming progressively challenging. We are increasingly committed to a certain level of climate disruption, requiring adaptation measures to reduce the impact this is likely to have. Given that the world is already committed to some degree of climate change, and given too that the combustion of fossil fuels also emits a variety of other pollutants, the total external costs of burning fossil fuels (ie, those costs that are not included in the price of fossil fuels) may be expressed as shown in panel 7.

The optimum outcome of this formula is that which minimises TEC_{ff}, computed over the time horizon of interest. Unfortunately, the state of knowledge now, or at any likely point in time in the future, does not permit such a dynamic optimum to be computed. The purpose of this section is to explore the estimates of these different cost categories that appear in the literature to draw conclusions regarding the extent of climate change adaptation and mitigation that should be attempted, and the policies that might be able to deliver it.

The question of what is optimum in economic terms (GDP or welfare per head) for a given level of carbon emissions and discount rate requires the computation of an optimal time path. What is optimum today (without regard for the future) will not be optimal if the future is to be taken into account. And of course the relation between low prevention costs now means very high treatment costs later, compared with high prevention costs now means lower treatment costs later will be subject to very great uncertainty. Higher uncertainty may mean that high prevention costs would be wasted. On the other hand, with higher uncertainty comes the increased probability that high prevention costs are not high enough. However, whatever the answers to these questions, models reviewed in the IPCC's Working Group III Fifth Assessment Report (AR5) indicate with sufficient certainty that more needs to be spent earlier rather than later if even a moderate value is given to the intermediate and long term future.[201]

The health and related economic benefits of adaptation

There are significant research gaps regarding the scientific evaluation of the health benefits of climate-change adaptation due to its highly diffuse and context-specific nature, with only scattered quantitative or semi-quantitative studies on the health costs and benefits of adaptation options.[245] Monetising these costs and benefits is an even more difficult task. However, the studies that do exist present a strong message. Seven of the eight studies on the effectiveness of heatwave early warning systems reported fewer deaths after the systems were implemented. For example, in the summer of 2006, a heatwave in France produced around 2000 excess deaths—4000 less than anticipated based on previous events.[31] A national assessment attributed this to greater public awareness of the health risks of heat, improved health-care facilities, and the introduction of a heatwave early warning system in 2004.[112] A Climate Forecast Applications Network developed in the USA had successfully forecast three major floods in 2007 and 2008 in Bangladesh 10 days in advance, allowing farmers to harvest crops, shelter animals, store clean water, and secure food before the event.[246] Webster also strongly advocates the establishment of a network between weather and climate forecasters in the developed world, and research and governmental and non-governmental organisations in the less-developed world.[246] According to his estimation, such a network could produce 10–15 day forecasts for south and east Asia for a wide range of hydrometeorological hazards (including slow-rise monsoon floods, droughts, and tropical cyclones) at an annual cost of around $1 million, but with prevention of "billions of dollars of damage and protecting thousands of lives". To support assessments such as these, WHO Europe have prepared an economic analysis tool to enable health systems to calculate the health and adaptation costs of climate change, which was in turn tested in their study of seven European countries.[247,248]

The health and related economic benefits of mitigation

Unmitigated climate change presents serious health risks that could reach potentially catastrophic proportions. Mitigating climate change not only significantly reduces this risk, but can also yield substantial health co-benefits against contemporary circumstances.

Panel 8 illustrates the proportion of national GDP directed to health care increasing with wealth, along with the proportion accounted for by government expenditures. This suggests that governments of high and increasing income countries should give significant priority to mitigating climate change to prevent detrimental health impacts, which could result in the need for significant extra health expenditures, from both governmental and personal finances. Indeed, the direct and indirect cost of existing pollution-induced illnesses alone is significant. The OECD estimates the cost of ambient air pollution in terms of the value of lives lost and ill health in OECD countries, plus India and China, to be more than $3·5 trillion annually (about 5% gross world product [GWP]), with India and China combined accounting for 54% of this total.[251] Globally, and with the addition of indoor air pollution, this value is likely to be substantially higher (appendix 3)

See Online for appendix 3

The European Commission has estimated that in the EU alone, reduced air pollution from policies to mitigate climate change could deliver benefits valued at €38 billion a year by 2050 through reduced mortality. From a broader perspective, the European Commission estimates that moving to a low-carbon economy could reduce the control costs of non-CO_2 air pollutants by €50 billion by 2050.[252] With an increase to 36% renewables in global final energy consumption by 2030 (from 18% in 2010), IRENA calculates up to $230 billion of avoided external health costs annually by 2030.[253] In addition, West and colleagues note that if RCP4.5 is achieved, annual global premature deaths avoided reach 500 000 by 2030, 1·3 million by 2050, and 2·2 million by 2100. Global average marginal benefits of avoided mortality are $50–380 per tCO_2, exceeding marginal abatement costs in 2030 and 2050. The greatest benefit is projected for east Asia, with

Panel 8: Global expenditure on health care

Figure 14 shows the global range of total expenditure on health care as a proportion of GDP in 2011. Total expenditure is 9·1% gross world product (GWP)—about US$6·8 trillion—with geographical variation ranging from 1·65% GDP in South Sudan, to 17·7% in the USA. At a global level, 59% of expenditure is sourced from government budgets (of which 60% is via social security mechanisms), accounting for more than 15% of total expenditure by governments worldwide. The remaining 41% is sourced from the private sector (of which 38% is in the form of health insurance, with 50% out-of-pocket expense). Total average global health expenditure per capita was $1053, in purchasing power parity (PPP) terms.[247]

Figure 15 shows the variation between the economies of different average income levels against these global totals. Total expenditure per head varies between an average of $64 in low-income countries and $4319 in high-income countries in PPP terms. This increase in expenditure proportional to income is accompanied by the increasing use of insurance mechanisms (either private or social security), and decreased reliance on external (international) resources (principally development assistance and funding from non-governmental-organisations), and private expenditure and out-of-pocket expenses (in proportional terms). Whereas private expenditure and out-of-pocket expenses remain a significant component in all groups, external resources decrease rapidly, from 29% in low-income countries to 2·3% in lower middle-income countries, 0·4% in upper middle-income countries, and 0% in high-income countries.

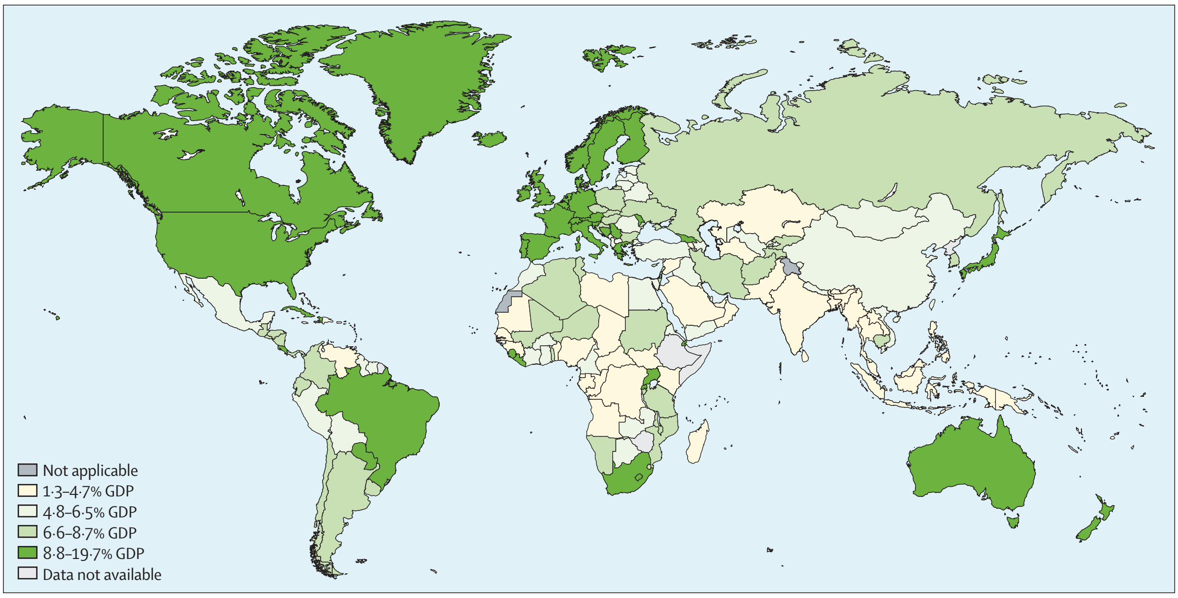

Figure 14: **Total expenditure on health as proportion of GDP (2011)**[249]

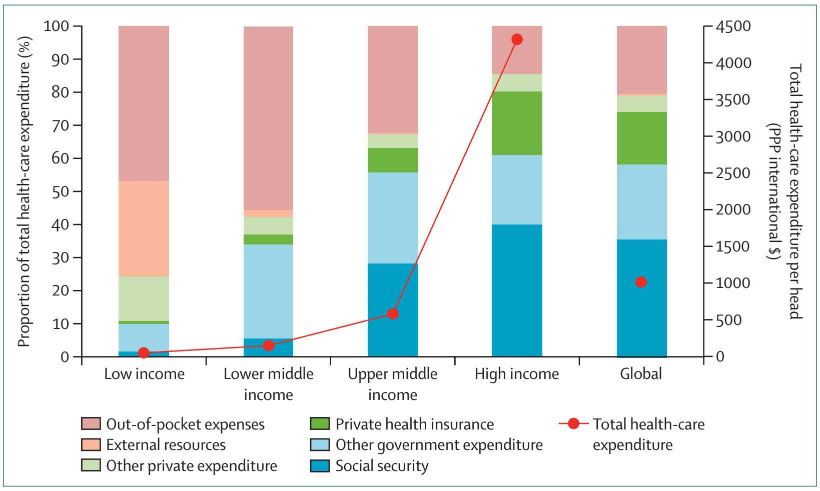

Figure 15: **Global health-care expenditure profile (2011)**[250]
PPP=purchasing power parity.

220 000–470 000 premature deaths avoided per annum by 2030, with marginal benefits of \$70–840/tCO_2—a range 10–70 times that of the projected marginal cost[254] (see appendix 3 for more about the cost of ambient air pollution in China). In the USA, Thompson and colleagues estimate that human health benefits associated with air quality improvements driven by CO_2 mitigation policies can offset the cost of the policies by up to ten times.[255]

See Online for appendix 4

Mitigation actions have other health-related benefits. Policies in the transport sector that encourage active travel (eg, walking and cycling) produce significant reductions in cardiovascular disease, dementia, diabetes, and several cancers, in addition to reduced duration and severity of depressive episodes—all of which are linked to obesity and are costly to treat.[218] For example, increased levels of active travel coupled with increased fuel efficiency in the UK's urban areas could lead to a net saving to public funds cumulatively exceeding £15 billion by 2030, whilst achieving GHG reductions of over 15% in the private transport sector by 2030.[228] Patz and colleagues have comprehensively reviewed the health, environmental, and economic benefits of active travel.[256]

In many countries, climate-change mitigation through increased energy efficiency will have the benefit of reducing fuel poverty (a condition in which low-income households have to spend a high proportion of their income to keep warm or cool), and associated impacts on excess winter mortality, respiratory health of children and infants, and the mental health of adults.[257] Nicol and colleagues estimated that improved housing in England alone could save the UK NHS more than €700 million per year in treatment no longer required.[258] In addition, Copenhagen Economics estimates that improvements in housing energy efficiency in Europe would, alongside the production of direct energy and health-care savings, reduce public subsidies for energy consumption by €9–12 billion per year.[259] Various other health and ancillary benefits exist. Appendix 4 provides information about a recently developed framework to quantity key co-benefits.

It is apparent both that societies spend very large sums on health care and that measures to mitigate climate change would directly reduce existing and projected damages to health from the combustion of fossil fuels, and associated costs. In fact, Markandya and colleagues estimated that in India, if the health benefits of reduced $PM_{2.5}$ emissions alone, resulting from a 50% reduction in CO_2 emissions by 2050 (from 1990 levels) from electricity generation, were valued similarly to the approach used in the EU for air pollution, then they offset the cost of GHG emissions reductions in full.[215] As such, a significant proportion of expenditures for climate-change mitigation (and adaptation) may legitimately be seen as offsetting health expenditures, existing or anticipated, or even put forward itself as expenditure on the treatment and prevention of ill health. If a large part of the costs of climate-change mitigation and adaptation is offset by improved health of the existing population, and if unabated climate change is itself a major health risk, investment in such actions is clearly an attractive and sensible proposition.

Investment required for mitigation and adaptation

In industrialised countries, large-scale investment in energy systems is required simply to maintain existing services as infrastructures age and need to be replaced. Emerging and developing economies will require very large energy system investments to meet growing demand as they develop and to provide increasing proportions of their populations with access to modern energy services. It is estimated that such business-as-usual investments will total around $105 trillion between 2010 and 2050, with average annual investment requirements rising rapidly over time.[260] However, this value excludes the costs of climate damage to the energy system or resilience measures to reduce it. Such costs could be significant.

The IEA estimates that to achieve a trajectory that produces an 80% chance of remaining on a 2°C stabilisation pathway, additional cumulative investment of $36 trillion in the energy system is required by 2050—roughly $1 trillion per year (in the order of 1% GWP under moderate growth assumptions or about 10% of existing expenditure on health care), although recent estimates from the New Climate Economy report suggest that this value may be a much reduced $270 billion per year.[260,261] The insurance premium represented by this additional investment is very modest in relation to the potential costs that are being avoided, even without the offsetting health and other co-benefits such as those described above. To achieve both the requisite level of decarbonisation whilst meeting increasing global demand for energy, the IEA estimates that investments in low-carbon technologies and energy efficiency must account for around 90% of energy system investment by 2035.[262] Currently, this value is around 23%.[262]

Estimates for the investment required for adaptation measures to protect against climate impacts to which the world is already committed are limited. The most comprehensive global estimate thus far was produced by the World Bank (2010), which estimates the annual global cost of adaptation even on a 2°C trajectory to be $70–100 billion by 2050.[171]

Estimating existing expenditure on adaptation actions is not much easier than estimating the possible future costs of adaptation. Buchner and colleagues[263] estimate that in 2012, about $22 billion was invested in activities with an explicit adaptation objective. However, the lack of common agreement on what constitutes an adaptation measure over other investment classifications and objectives mean understanding of existing financial flows to adaptation measures is poor. Even so, whilst the magnitude is difficult to determine, it is reasonable to conclude that existing financial flows for climate change adaptation are not sufficient to match long-term requirements, even for impacts resulting from current and past emissions.

Macroeconomic implications of mitigation and adaptation

The macroeconomic impacts of climate change

Attempts to estimate the marginal social cost of CO_2 emissions in the absence of mitigation or adaptation measures have produced an extremely wide range of results, spanning at least three orders of magnitude.[264] Table 3 illustrates the multifaceted, diverse, and potentially extreme nature of the impacts involved.

The IPCC's AR5 chapter on impacts, adaptation and vulnerability estimates an aggregate loss of up to 2% GDP if global mean temperatures reach 2·5°C above pre-industrial levels.[266] A world of unabated GHG emissions, what might be called a business-as-usual pathway (in which a global mean temperature increase is likely to far exceed 2·5°C, and in which many of the kinds of impacts in the last row and column of table 3 are likely to be experienced) could produce costs equivalent to reducing annual GDP by 5–20% now, and forever, compared with a world with no climate change, according to the Stern Review on the Economics of Climate Change.[267]

It may be noted that these costs are the result of a low discount rate, the validity of which has been questioned.[268] However, the relevant point here is that the physical impacts underlying the upper range of these costs represent a substantial risk to human

	Market	Non-market	Multiple stresses and socially contingent
Projection (trend)	Coastal protection, dry-land loss, energy (heating and cooling)	Heat stress, wet-land loss, ocean acidification, ecosystem, migration and termination	Displacement from coastal zones, regional systemic impacts
Climate variability and (bounded) extremes	Agriculture, water, storms	Loss of life, biodiversity, environmental services	Cascading social effects, environmental migration
System changes and surprises	So-called tipping-point effects on land and resources	High-order social effects, irreversible losses	Regional collapse, famine, war

Adapted from Grubb et al, 2014.[265]

Table 3: **Social cost of CO_2 emissions—assessment framework**

societies—what Weitzmann[269] has called the "fat tails" of climate-risk distributions. The costs of mitigation may be seen to represent a premium paid to reduce these risks and, hopefully, avoid the worst climate outcomes entirely. In any case, even these large costs derive from economic models built upon climate science and impact models, which themselves necessarily cannot fully characterise all processes and interactions known to be of importance.[270]

The macroeconomic impacts of responding to climate change

The theoretical microeconomics position on the balance to be struck between mitigation and adaptation is clear—there should be investment in mitigation up to the point where the marginal cost of further investment is higher than the marginal cost of adaptation plus that of remaining climate damages. In practice, the robust identification of this point is impossible, because of the uncertainty of the costs concerned and how they will develop over time, the difficulties of valuing non-market costs, and the lack of consensus over the appropriate discount rate for such costs, when they are incurred over long and varied time periods.[271] Given that some climate impacts (such as the phenomena in the bottom-right corner of table 3) cannot be adapted to at any computable cost, mitigation-focused investment would seem to be the prudent priority at a global level. In a globally interdependent world, even regions that might be less negatively affected by climate change itself, could expect considerable economic and social disruption from those regions that were thus affected.

The macroeconomic impacts of reducing CO_2 emissions derive from several sources, all of which need to be taken into account if the overall impact is to be properly evaluated. First, there are the impacts of the various kinds of investments discussed above. Investments in energy efficiency measures and technologies are often cost effective at prevailing energy prices, and there is substantial evidence that opportunities for such investments are considerable.[272] Such investments will themselves tend to increase GDP. Investments in low-carbon energy that are redirected from fossil fuel investments will, where the low-carbon energy is more expensive than fossil fuels and leaving out considerations of avoided climate change and co-benefits, tend to reduce GDP. However, if fossil fuel prices increase from their currently relatively low levels and remain volatile, and the capital costs of renewables (especially solar and wind) continue to fall, then at some point renewable electricity may become economically preferable to fossil-fuel derived power, irrespective of other factors.

Investments in low-carbon energy that are additional—such as the extra $1 trillion required annually as identified above—may increase or reduce GDP depending on whether they employ unutilised resources or, in a situation of full employment, crowd out more productive investment, and whether they can build domestic supply chains and new competitive industries that can substitute for imports. Whilst employment in fossil fuel-related and emission-intensive industries would decline over time, low-carbon technology industries would expand and increase employment. IRENA estimate a net global increase of 900 000 jobs in core activities alone (i.e. not including supply chain activities), if the level of renewable energy in global final energy consumption doubles from 18% in 2010 to 36% of by 2030.[253] Advantages may accrue to those countries or industries that begin investment in decarbonisation quickly, by gaining technological leadership through experience and innovation, affording the first mover a competitive edge in a growing market.

For fossil-fuel importing countries, investment in indigenous low-carbon energy sources will reduce the need to import fossil fuels. In the EU, the trade deficit in energy products in 2012 was €421 billion (3·3% EU GDP),[273] and is projected to rise to €600 billion (in 2010 euros) by 2050, as the EU's dependence on foreign fossil fuels increases.[274] Low-carbon investments that reduce the need to import fossil fuels are macroeconomically beneficial, with the value of these trade effects in the future being uncertain and dependent on the price of oil and other fossil fuels. Such uncertainty is itself a cost, which is amplified when allied with price volatility—a common characteristic of fossil-fuel markets.

Possible sources of finance

In the public sector (aside from the extensive resources to be found in local, regional, national, and supranational government budgets), sovereign wealth funds, as of August 2014, held over $6·7 trillion in assets.[275] However, in the private sector, institutional investors held a global total of $75·9 trillion in assets under management in 2013 (this includes $22·8 trillion with pension funds, $24·6 trillion with insurance companies, and $1·5 trillion in foundations and endowments).[276]

Institutional investors are likely to be critical sources of finance for mitigation and adaptation due to the scale of resources available and the presence of long-term investment obligations. However, only 0·1% of institutional investor assets (excluding sovereign wealth funds) are currently invested in low-carbon energy infrastructure projects ($75 billion).[277] Commercial banks are also a key source of finance and are one of the main existing sources of renewable investment capital. The resources held by non-financial companies are also extensive, with the largest 1000 such companies estimated to hold $23 trillion in cash reserves.[278]

International financial institutions (IFIs) such as the Bretton Woods institutions and other multilateral development banks (MDBs), multilateral finance institutions (MFIs), and regional investment banks (RIBs), whilst not holding collective assets to match those above, are also leaders in existing mitigation and adaptation finance, and are likely to be key in building a low-carbon economy in developing countries; their mandates are explicitly focused on development and poverty reduction promoted through low-interest, long-term loans—suitable for large infrastructure projects. Existing dedicated funds for climate-change mitigation and adaptation under the UNFCCC, such as the Green Climate Fund (GCF), are also important resources. The GCF, established by the UNFCCC in 2010 and launched in 2013, aims to raise $100 billion of new and additional funding per annum from industrialised nations, by 2020 (from both public and private finance), to support mitigation and adaptation pathways in developing countries. In 2012, $125·9 billion of official development assistance (ODA) was delivered by donor countries, equivalent to 0·29% of their combined gross national income (GNI). Were states to meet their ODA commitments of 0·7% of GNI, another $174·7 billion would be mobilised.[279]

Enabling architecture and policy instruments

The mobilisation of such financial resources requires robust policy-generated incentive frameworks, underpinned by credible political commitments. By the end of 2013, 66 countries had enacted 487 climate mitigation and adaptation-related laws (or policies of equivalent status), with a rich diversity of approaches.[280] The Stern Review considered that a policy framework for CO_2 abatement should have three elements: carbon pricing, technology policy, and the removal of barriers to behaviour change.[267] This three-part classification maps closely to three policy pillars, which in turn correspond to three different domains of change.[265] Figure 16 illustrates this framework, which can be applied to develop both mitigation and adaptation policy.

Each of the three domains reflects three distinct spheres of economic decision making and development. The first, satisficing, describes the tendency of individuals and organisations to base decisions on habit, assumptions, and rules of thumb, and, to some extent, the presence of psychological distancing (discussed in section 5). Such occurrences are the subject matter of behavioural and organisational economics, which can explain the significant presence of unutilised opportunities for already cost-effective energy efficiency measures. The first pillar of policy, standards and engagement, seeks to address these issues, resulting in firms and individuals making smarter choices. The second domain, optimising, describes the rational approach that reflects traditional assumptions around market behaviour and corresponding theories of neoclassical and welfare economics. The second pillar of policy, markets and pricing, seeks to harness markets, mainly acting through producers rather than consumers, to deliver cleaner products and processes. The final domain, transformation, uses insights from evolutionary and institutional economics to describe the ways in which complex systems develop over time under the influence of strategic choices made by large entities, particularly governments, multinational corporations and institutional investors. The third pillar of policy arising from such analysis seeks to deliver strategic investment in low-carbon innovation and infrastructure.[265]

Each of the three domains and policy pillars, whilst presented as conceptually distinct, interact through numerous channels. For example, as figure 16 illustrates, whilst the impact of each policy pillar is strongest in one domain, each of the pillars of policy have at least some influence on all three domains. All three pillars of policy have an important role in producing a low-carbon global energy system.[265]

Standards and engagement

Energy efficiency standards may take many forms. However, all act to push a market, product or process to higher levels of efficiency (or lower levels of emission intensity), through regulation. Such regulations help to overcome market failures such as split incentives, a prominent example of which is the landlord–tenant problem, when the interests of the landlord and tenants are misaligned. The problem arises because, whilst the installation of energy efficiency measures would benefit the energy bill-paying tenant, savings do not accrue to the landlord who therefore has no incentive to bear the cost of installing such measures. Instead, standards can require their installation, or other measures to induce the same effect.

The main typologies of standards relating to mitigation are CO_2 intensity standards, energy intensity standards and technology standards. The first two specify a target limit for specific CO_2 emissions or energy consumption. Examples are a cap on CO_2

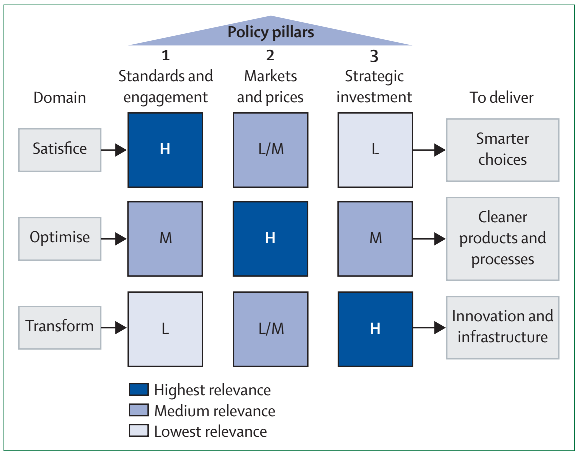

Figure 16: **Three pillars of policy**
Adapted from Grubb et al, 2014.[265]

emissions from passenger cars per kilometre driven (based on the average rating for all cars sold per manufacturer), or on the annual energy consumption of a new building per unit of floor area. Both such policies (and variants) have been successfully implemented in the EU and around the world, and have proven effective. Technology standards may act in a similar manner to CO_2 or energy intensity standards, but may also proscribe the use of certain components in products, or prevent the sale of the least efficient models of a product type. Such standards may be applied with a legal basis, or through the use of voluntary agreements. Standards may also be applied to produce adaptation actions, for example by amending building codes to obligate developers to incorporate resilience measures in new construction.

See Online for appendix 5

Processes and mechanisms for targeted communication and engagement between governments, businesses, other organisations, communities and individuals help to overcome issues of psychological distancing, motivational issues, split incentives and information asymmetry, and act to pull the market towards higher efficiency, lower emissions and greater resilience. Such mechanisms can take many forms and include training and education campaigns, but also labelling and certification, public reporting and other information disclosure and transparency measures. All these approaches act to provide consumers and investors with information surrounding environmental performance of a product, service, process or organisation at the point of use, or across the product lifecycle or organisational operations and supply chain, in order to help them to make informed decisions regarding investments and purchases. This encourages organisations to mitigate risks by reducing organisational (and possibly supply chain) emissions and to invest in adaptation measures to improve resilience, ensuring they retain a strong customer base and remain a safe investment. The introduction of these instruments may also reveal opportunities for efficiency measures that have an economic rationale independent of environmental considerations.

Markets and prices

The Stern Review called the market externality of GHG emissions in the global economy "the greatest and widest-ranging market failure ever seen".[267] Carbon pricing is the economist's preferred means to address this externality. Such pricing may be achieved through national or regional explicit carbon taxes or cap-and-trade emissions trading systems (ETS), which are increasingly present around the world. A carbon tax sets the carbon price directly, but not the level of abatement, whilst an ETS sets the level of abatement, but the price derives from the carbon market. Regardless of the pricing mechanism, market actors may be expected to factor the existing and expected carbon price into short-term operational and long-term investment decisions. Figure 17 summarises the state of pricing mechanisms around the world. As of June 2014, around 40 national and over 20 subnational jurisdictions were engaged in carbon pricing of varied scope and instrument design, covering about 12% of annual global GHG emissions (the Australian ETS was discontinued in July 2014).[281] The largest ETS is the European ETS, established in 2005, and capping more than 40% of annual GHG emissions from power generation and energy-intensive and emission-intensive heavy industry across the EU-28 (plus Norway, Iceland, and Lichtenstein). This is followed in scale by the aggregate of the seven ETS pilot schemes in China, described in appendix 5. As of 2014, the total value of all explicit pricing mechanisms was around $30 billion.[281]

For sectors of the economy for which explicit carbon pricing is infeasible or administratively burdensome, taxes on energy products (such as transport fuels) could be realigned to reflect their carbon content (producing an implicit carbon price) By implementing Environmental Tax Reform (ETR) principles, in which the burden of taxation increases on environmentally damaging activities and is reduced on desired inputs, such as labour, the increase in energy prices can be neutralised from a macroeconomic perspective. Parry and colleagues estimate that corrective taxation that internalises CO_2 emissions, local air pollution, and additional transport-related externalities (such as congestion and accidental injury) arising from coal, natural gas, gasoline, and diesel, could raise additional revenues of 2·6% GDP globally, whilst simultaneously reducing CO_2 emissions by 23% and pollution-related mortality by 63%.[282] If this revenue was used to offset labour taxation (eg, by a reduction in payroll or other corporate taxation), revenue neutrality is achieved whilst producing a double dividend effect of employment, as well as environmental improvement.[283] Alternatively, carbon pricing mechanisms can be used to finance, subsidise, or otherwise incentivise investments into other mitigation and adaptation measures, as discussed below.

In addition to pricing pollution, distorting subsidies for the extraction and consumption of fossil fuels should be removed. For consumers, such subsidies (aimed at providing energy at below market price, and principally applied in developing countries) total around $400 billion annually,[284] whilst producer subsidies (aimed at sustaining otherwise uncompetitive production, principally applied in industrialised countries), are around $100 billion annually.[285]

Both fossil-fuel subsidies and the presence of externalities tend disproportionately to benefit the wealthiest in society (in both national and international contexts), as energy consumption (and associated emissions) increases with prosperity, both directly (eg,

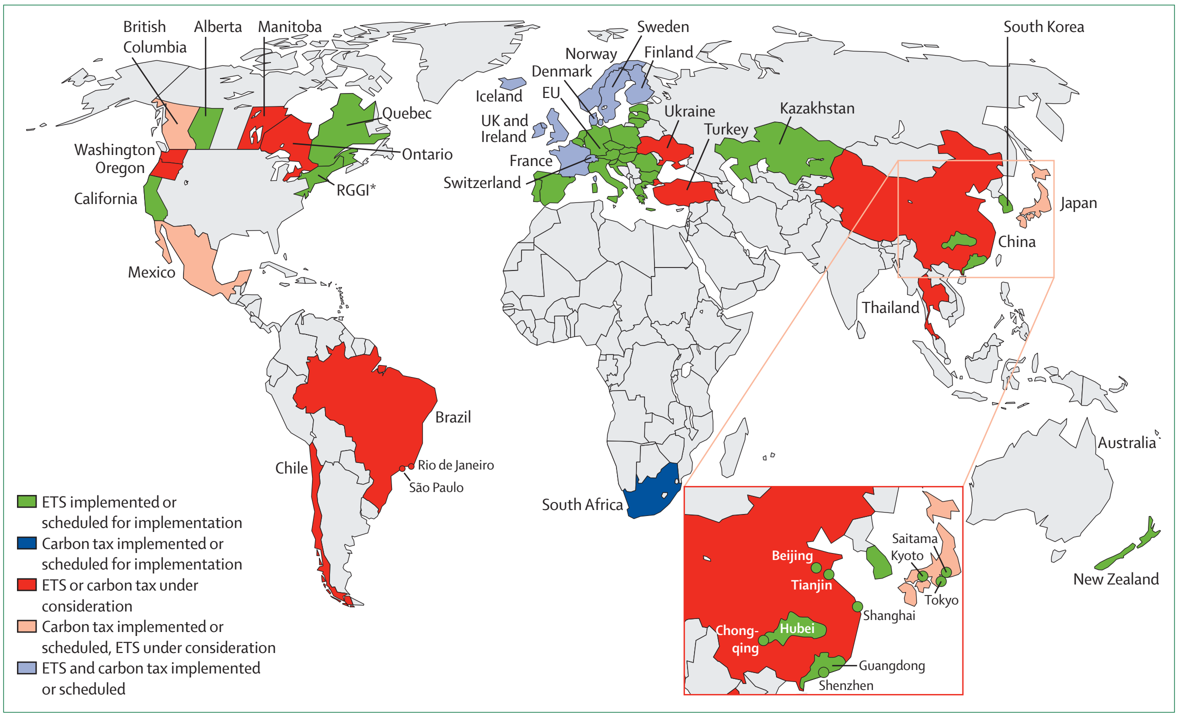

Figure 17: **Existing, emerging, and potential regional, national, and subnational carbon pricing instruments (ETS and tax)**[281]
*The RGGI (Regional Greenhouse Gas Initiative) is a coordinated cap and trade programme, operating between nine Northeastern and Mid-Atlantic States in the USA and Canada. ETS=emissions trading scheme.

via additional travel demand, domestic heating and cooling requirements) and indirectly through additional consumption of energy embodied in products and services. Globally, an estimated 80% of such subsidies actually benefit the wealthiest 40% of the population.[286] However, the introduction of carbon pricing and the removal of fossil fuel subsidies may be regressive, as the poorest in society spend a greater proportion of their disposable income on energy. Reduced taxation of the low paid may partly offset this in industrialised economies, although further targeted support, such as the provision of energy efficiency measures for low-income or vulnerable households (funded by carbon price revenues and foregone subsidy), or the introduction of electricity tariffs differentiated by consumption level, is also likely to be required. In developing countries where most consumer fossil-fuel subsidies are provided, and where a greater proportion of the population is not employed in the formal economy or have no access to electricity, more targeted interventions to remove disproportionate effects on low-income households, such as the expansion of social security, health care, and education provision, will be required.

Strategic investment

Whilst a price on carbon is a key component for mitigation, it is technologically agnostic and mainly encourages the adoption of mature low-carbon technologies. To encourage deployment, improvement and cost-reduction of less mature technologies, direct investment is also required. Although various options exist, Feed-in tariffs (FiTs), used in the electricity sector to provide a guaranteed rate of return to low-carbon generators, have been the most effective policy instrument used for this purpose, and have been responsible for a significant majority of installed global renewable power capacity (appendix 6). A FiT-style instrument may also be used to encourage the deployment of non-electric renewable technologies, including heating and cooling options.

See Online for appendix 6

However, FiTs and comparable instruments only encourage diffusion and incremental improvements for technologies around the end of the innovation chain (market accumulation and diffusion). For technologies in the earlier stages (applied research to demonstration and commercialisation), concerted R&D efforts are required, comparable to public and private pharmaceutical research that has been shown to produce innovative new drugs.[287] Such efforts may be analogous to the Manhattan Project for nuclear technology, or the Apollo Program for space flight, but focused perhaps on energy storage technologies, which are often seen as crucial for the effective decarbonisation of the global energy system.

Public-led strategic investment is also required in urban low-carbon travel infrastructure (eg, segregated cycle lanes), along with investment in electric-car charging points. This also applies to the electricity transmission network, which is under state ownership in most countries. Such investments may be financed in a number of ways, including directly by governments, multilateral organisations, or other public bodies, through the use of carbon pricing revenues or by the issuance of specialised climate bonds (appendix 7).

See Online for appendix 7

Institutional reform and support

Beyond the appropriate selection of policy instruments and timeframes for implementation, investments in decarbonisation and adaptation measures will depend on the existence of effective and supportive governance and well-functioning markets. Good governance requires the well-defined division of responsibilities between government departments, agencies and hierarchies, enforcement of standards and regulations, transparency at key stages of the regulatory process and subsequent monitoring and reporting, and effective communication and stakeholder engagement. Additionally, governments are often the largest consumer in the market, with public spending accounting for 15–30% of GDP in any given country.[288] Sustainable public procurement (SPP) policies act to provide a market for efficient, low-carbon goods and services.

Governments may promote well-functioning markets through the kinds of policies described above, and by reducing institutional barriers to low-carbon investment and innovation. For example, many pension funds across the world are barred from investing in infrastructure, including all in China (except the National Social Security Fund) and many in the EU. Whilst these regulations aim to alleviate legitimate concerns (such as preventing pension funds from becoming an extension of government budgets), they are often excessive and increasingly irrelevant as funds gradually become independent of political interference.[276] Reform of such rules is essential in mobilising capital from institutional investors, irrespective of the policy and incentive mechanisms in place to encourage investment in developing the low-carbon economy.

Section 5: delivering a healthy low-carbon future

Central to this Commission's work is the question of whether human societies can deliver a healthy, low-carbon future. Sections 1 and 2 have explained the scientific basis for concern, the potential health dimensions of impacts, and the adaptation responses required. Sections 3 and 4 have demonstrated the technological and economic feasibility of tackling the problem. Yet over the past decade, global emissions have still risen sharply. The evidence to date of humanity's ability to respond effectively is not encouraging. The difficulty, essentially, is ourselves: the tendency of humans to ignore or discount unpleasant facts or difficult choices (something familiar to doctors); the nature of companies and countries to defend their own rather than collective interests (something familiar to those working in global health); and the narrow, short-term horizons of most human institutions, which feed into the difficulties of global negotiations.

Over the past century, the world has made enormous strides in overcoming similar obstacles in the field of health, with international cooperation on health challenges as a shining example. The problem of anthropogenic climate change is more recent, arguably more complex, and the efforts to tackle it more nascent. But there are some promising developments, and a great deal can be learned by examining the history of efforts to date.

One conclusion evident throughout our report is that much of the technical expertise, technology, and finance required to turn climate change from a public health threat into an opportunity is readily available, but politically restricted. In essence, whether we respond to "the biggest global health threat of the 21st century" is no longer a technical or economic question—it is political. This section analyses the politics of climate change and provides suggestions for action. We examine the international regime (under the UN Framework Convention on Climate Change and its Kyoto Protocol); national policy responses; the role of sub-national governance processes, particularly in major cities; and the importance of individuals and public opinion. Importantly, we stress the need for better synergy between top-down and bottom-up approaches. We seek to draw lessons from global health governance mechanisms, and make suggestions for how health-related issues can inform the climate change negotiation process.

Three phases of response—the international regime

It is almost 30 years since climate change emerged onto political agendas, with three phases of response since then, of roughly a decade each.

First phase: understanding the evidence and establishing institutions and broad goals

The first phase established the institutional basis for responding to climate change, including for scientific input into policy processes. Building on long-held concerns of the scientific community, a series of international workshops in the mid-1980s, hosted by the World Meteorological Organisation and the UN Environment Programme, led governments to establish the IPCC in 1988, as the official channel of scientific advice to the international community. In 1990, the IPCC's first report expressed enough concern for governments to formally launch international negotiations aimed at tackling the problem, and 2 years later to agree on the UNFCCC. The UNFCCC now enjoys almost universal membership.

The UNFCCC established the "ultimate objective" of stabilising GHG concentrations at a level that would prevent dangerous human interference in the climate system (UNFCCC, article 2). This objective has been recently interpreted as implying that global temperatures should not rise more than 2°C above pre-industrial levels, an aim reiterated in frequent statements under the UNFCCC and other international fora, such as the G8. The 2°C goal implies a need to roughly halve global emissions by 2050; stabilising the atmosphere at any level ultimately means bringing net emissions (emissions minus removals from forests, oceans, and other carbon sinks) to zero.

The UNFCCC established that industrialised countries would take the lead in curbing GHG emissions, setting them a non-binding goal of returning their emissions to 1990 levels by 2000. All parties, including developing countries, were given general commitments to address climate change, as well as reporting obligations. The UNFCCC also set up a raft of institutions to monitor implementation and pursue ongoing negotiations, under the auspices of the main decision-making body, the Conference of the Parties (COP).

Health concerns feature, albeit in general terms, in the UNFCCC, which lists impacts on human health and wellbeing as part of the adverse effects of climate change (definitions, article 1). The only other reference requires parties to consider the broader implications of their mitigation and adaptation actions on human health.[289]

Second phase: leading through top-down international commitments

In 1995, governments accepted the findings of the IPCC's second report and launched negotiations to strengthen the UNFCCC's commitments. The working assumption was that the international response would be led by specific, binding emission targets for industrialised countries, which would then be implemented at a national level. This was the approach adopted in the Kyoto Protocol of 1997, which built mainly on designs proposed by the USA under President Clinton.

However, the fact that developing countries were not subject to any such specific commitments weakened the Protocol's short-term impact and undermined its political viability, particularly in the USA, where strong political forces were opposed to any robust action on climate change. The subsequent US repudiation of the Kyoto Protocol made it clear that the Kyoto-type top-down model was unworkable in these circumstances as the principal way forward.

Third phase: bottom-up initiatives

Global negotiations continued, but with widely varying objectives and perceptions. Whilst the EU and developing countries continued to support a Kyoto-style approach with specific targets, few others believed that to be feasible, or even appropriate. Academics and commentators increasingly argued that action happens from the bottom up, not in response to binding top-down commitments, and pointed to a wide range of initiatives, including at state level in the USA, to argue that a fundamentally different approach was needed.

These divergent views came to a head at a summit in Copenhagen in 2009, which collapsed in acrimony save for two pages of unofficial outline text hammered out as a fallback compromise, initially between the USA and major emerging economies. The so-called Copenhagen Accord did register some landmark achievements, notably confirming the 2°C goal, and a promise to raise $100 billion per year of international finance by 2020 to help developing countries deal with climate change. In terms of emission commitments, however, there were no binding targets; instead, the Copenhagen Accord called on countries to declare domestically-generated voluntary pledges of what they might deliver. Since then, almost all major emitters have registered pledges, although based on varying indicators and with very different levels of precision and ambition.

Negotiations in Durban in 2011 saw the launch of a new round of talks aimed at agreeing a universal framework to deal with climate change from 2020. According to the so-called Durban Platform, this new agreement should be applicable to all parties, and "raise the ambition" of the international community.

Patchy progress in the negotiations

If global emission trends are the only indicator of progress, the results of the negotiations to date have been dismal. The 2014 IPCC report warned that global emissions since 2000 have been rising ever faster at around 2% every year, powered largely by spectacular growth in China, and other emerging economies.[201] Viewed more closely, the picture is more nuanced. Taken together, the industrialised countries did meet the UNFCCC's goal of returning their emissions to 1990 levels by 2000 (helped by massive declines in the former Soviet Union and Eastern Bloc). The industrialised countries that accepted targets under the Kyoto Protocol and remained parties to that agreement also all achieved their official goals. There is no question that in the EU, the Protocol provided the legal framework and impetus for strengthening mitigation policies.

The international process has also had successes in other areas. Through the Kyoto Protocol's Clean Development Mechanism (CDM), many developing countries came forward with new projects that generated cheap emission reductions (that could then be sold on to industrialised countries), and by most accounts contributed to the establishment of renewable energy industries and other low-carbon technologies. Through a levy on CDM transactions, the Kyoto Protocol also established a fund to help finance adaptation measures in developing countries.

The UNFCCC also provides a crucial ingredient of transparency. A major achievement has been in establishing a robust system of reporting and review, for both national emissions data and broader policy actions. In 1992, when the UNFCCC was adopted, many countries had very little knowledge of their emissions profile—ie, what GHGs they were emitting and from what sources. The UNFCCC's provisions, building on the IPCC's methodological work, have been crucial in filling that knowledge gap, which lays the foundation for an effective response to climate change.

Despite patchy progress, the global negotiations continue, and indeed are regaining momentum. It is likely that the hybrid course set out in the Copenhagen Accord, and ratified in 2010 by the Cancun Agreements, of domestic aspirations, policies, and objectives will define the primary ingredients of a future global agreement. Perhaps most importantly, it is also now clear that international agreements must run concurrent with (rather than precede) implementation efforts. The future of the international negotiations will inevitably have to combine elements of top-down and bottom-up policies within the global framework.

One indication of both the opportunities and challenges is found in a joint US–China agreement of 2014, in which the US Administration pledged to reduce its emissions by 26–28% below 2005 levels by 2025, and China offered to cap its emissions growth by 2030, or sooner if possible. On the positive side, this is the first time that any major emerging economy has stated it is willing to cap its emission growth in absolute terms, and interactions between the USA and China helped each to a new level of commitment.

On the negative side, it illustrates the scale of the gap between science and action: if viewed in terms of per-capita emissions, it means that the USA is planning to come down somewhat below 15 tCO_2 per capita, whilst China wants headroom to reach potentially 10 tCO_2 per capita by 2030, before declining. This is a far cry from the scientific goals—a 2°C limit implies the need for a global average close to 2 tCO_2 per capita by mid-century. It emphasises that in isolation, such decentralised policy action also seems unlikely in the aggregate to deliver the necessary global mitigation effort effectively, equitably, and efficiently, and points to the risks of abandoning any collective, science-led direction to the global effort.

There are indeed reasons for concern regarding the international regime's ability to deliver on its promise.[290] The international relations literature has tended to assume that regimes start off weak, but as scientific evidence hardens and political will increases, parties agree to ratchet up their commitments and the regime strengthens; this was clearly the assumption of the early climate change negotiators.[291,292] It is difficult to say, however, whether the climate change regime is now getting stronger or weaker. On the one hand, the regime's coverage is expanding and deepening among the developing countries parties. The voluntary approach of the Copenhagen Accord and Cancun Agreements has engaged a much wider group of countries, including all major emitters, into national target-setting. At the same time, the Durban Platform mandate implies that all countries, not just the industrialised ones, are expected to raise their ambition in the new post-2020 regime. On the other hand, the engagement of industrialised countries is weakening compared with in the 1990s and early 2000s, with major emitters, such as Canada, Japan, Russia and, of course, the USA, now operating only under the Copenhagen Accord and Cancun Agreements, whose targets are voluntary and not subject to common metrics.

The outlook for future international negotiations is therefore challenging, to say the least. The rest of this section turns to consider reasons why progress on this issue is so difficult (from both a top-down, and bottom-up perspective), and what can be done to change this.

The generic barriers

The technological, investment, and behavioural changes needed to meet ambitious long-term goals, as illustrated in sections 3 and 4, are, in principle, entirely feasible. But they need to be accomplished in the face of highly diverse social, cultural, economic, and political contexts. Opposing national (and vested) interests, clashing views of what constitutes fair distribution of effort, and a model of economic growth that is currently tied to fossil fuel use, can make progress fraught. There are several key issues, as outlined by Hulme, 2009:[293]

- Uncertainty and complexity. The climate is naturally variable and the science that has identified dangerous, anthropogenic climate change to a very high level of probability is complex. This leaves considerable room for public ignorance or misunderstanding of the nature and severity of the issue. Moreover, climate scientists can be ineffective at communicating the issue to the public.[294]
- Climate change is psychologically distant along four dimensions—temporal, social, geographical, and degree of uncertainty—whereas people tend to connect more easily with issues that are close in time, space and social group, and about which there is little uncertainty. These dimensions interact with each other, all tending to dampen concern and willingness to act.[295]
- There is enormous lock-in to current economic patterns.[296] Fossil-fuel use is at the heart of the industrial economy, often operating through long-lived infrastructure (eg, roads, buildings, and power plants) and enabling valued dimensions of modern lifestyles (eg, travel and temperature control in buildings). It is no exaggeration to say that human societies are addicted to fossil fuels, or at least the services they provide. Providing these valued services

through alternative, lower-carbon means requires systemic change over a long period.

- These three factors can all come together in a fourth: the active promotion of misinformation, motivated by either ideology or vested economic interests. Here, parallels can be drawn between public health efforts to reduce tobacco consumption (appendix 8). It is estimated that US industry spent close to $500 million in its successful campaign against the 2010 House of Representatives proposal to cap US emissions. A major study of the Climate Change Counter Movement in the USA identifies funding of around $900 million annually.[297]

These obstacles are further compounded by the economic characteristics of responses. Low-carbon technologies are generally more capital-intensive than their fossil-fuel alternatives, albeit with much lower running costs. Their implementation therefore requires more upfront investment and a longer time horizon, resulting initially either in higher energy prices or higher taxes, or some combination of the two. The same is true of most adaptation measures; flood protection defences, for example, are capital-intensive investments with uncertain returns.

A large-scale shift to such technologies will require very large investments over a prolonged period of time. This shift in financial flows will need to be incentivised, in the early periods at least, by strong, consistent, and credible public policies, and a change in financial structures. Such policies are far from easy to introduce and sustain, given other political priorities that may be perceived as more pressing, and the political complexities indicated above.

Cities, states, and provinces: progress at the subnational level

Despite all these obstacles, action does continue in varied ways, at many levels. Local issues have long been part of the broader agenda of international environmental politics, and local governments have an increasingly well-documented track record in climate action.

In the past two decades, cities have been pivotal in producing multiple policy-making frameworks and advocacy coalitions. This has fostered a thick texture of para-diplomatic links and policy action around climate change and environmental health.[298,299] The rise and cross-cutting international spread of cities as actors in climate action also evidences a more refined pattern of transnational connections that are not solely bottom up, but rather offer a level of governance from the middle that cuts horizontally across international and national frameworks, involving an expanding variety of public-private structures and offering a distinct variation on civil society models of climate action.[300,301]

The leaders of cities around the world, from major metropolitan hubs like New York and São Paulo, to smaller centres like Rabat or Medellin, are increasingly using the networked reach of their municipal governments to address climate change in ways that are often more flexible and more directly applied than those of the national or international levels. Evermore city leaders have been leveraging their network power through international networks such as the United Cities and Local Governments (UCLG), ICLEI Local Governments for Sustainability, the World Mayors Council on Climate Change and the Climate Leadership Group (or C40).[299]

See Online for appendix 8

These groups are now a well-established presence in the international climate change arena,[302] pointing to the emerging imprint on global environmental governance by city leaders.[303] Their most crucial contribution to climate action is that of leveraging city diplomacy to implement specific actions on the ground via municipal management and multi-city initiatives. In practice, this governance from the middle is about taking advantage of the pooled networked connections of cities to implement a plethora of initiatives aimed at direct and quick implementation, which then injects urban elements in wider international processes.

Among the networks of larger cities, there is an emerging pattern of their local policy priorities becoming aggregated under a single strategic issue, as seen in integrated planning, climate, and sustainability plans such as Sustainable Sydney 2030. Concurrently, climate action has taken place on municipal purview areas such as energy regulation, transport and mobility, building retrofit, or waste management. Major centres like New York or Tokyo, for instance, have implemented building energy retrofit schemes across their city infrastructures.

Taken together, such a two-headed agency can enable cities to collectively attract and therefore release investment capital to execute wide-ranging policy programmes (such as C40's Energy Efficiency Building Retrofit programme). This ability to leverage global capital by effectively generating a large single market can be highly influential insofar as the cities are able to act quickly, often within the space of a year, and increasingly represent a significant proportion of the world's population and energy generation. This stands by contrast with national governments, where climate policy is often subsumed within other priorities rather than as an organising aim across government.

City-level governance may also provide the flexibility and scope to include health in actions on climate change, with city leaders becoming key actors in recognising and responding to the health co-benefits of doing so. It is important that the UN-led international negotiations process takes account of this dimension of multi-level governance, which operates in both formal and informal ways.

Public opinion and behaviour

Ultimately, effective actions by local and national governments, and by businesses, are unsustainable without supportive public opinion. Public support for stronger action on climate change is a necessary, albeit far from sufficient, factor, and is essential if behavioural change is to contribute to solving the problem. In this respect, the evidence is somewhat mixed. Cross-national studies, such as the 2013 survey presented in figure 18, suggest that most people view climate change as a threat, although with some significant variation within regions.[304]

Public understandings of climate change are shaped by broader knowledge and belief systems, including religious convictions and political beliefs.[294] There is evidence that the public recognises that climate change is complex, and interconnected with other environmental and social challenges.[305] Effective communication about climate change requires trust.[306] The most trusted sources vary across time and place,

Figure 18: **Perceptions of the threat of climate change, 2013[304]**

and can include family and friends, environmental groups, scientists, and the media; local and city-level authorities may provide an important conduit for communicating information from trusted sources. For scientists to engage effectively with the public, however, they need to seek a greater understanding of prior knowledge and belief systems, and communication skills radically different from those of academia. They must move beyond traditional scientific discourse to convey a big picture of climate change with which members of the public can engage; this can then provide a context and framing for the discussion of new scientific results and their consequences.[294]

Public responses to climate change

The causes of climate change lie ultimately in human behaviour, in particular in the economies and lifestyles of rich societies.[307] However, it has been science, rather than social science, that has underpinned climate change communication and policy development.[308] There is as yet little evidence on how to change behaviours that contribute to climate change,[309] but taking broader evidence on the determinants of behaviour and behavioural change, four themes stand out.

First, knowledge deficits are not the primary barrier to action; knowing about the causes and consequences of climate change does not, on its own, motivate people to change their lifestyles.[310] Instead, it is emotions—the feelings that accompany thinking—that are central.[311] Negative emotions, including fear, pessimism, and guilt, can produce passive and defensive responses, and do little to encourage individuals to change their behaviour and to press for wider social action. So-called fear appeals only work if accompanied by equally strong messages about how to address the problem.[312] Representations of climate change as inexorably heading for catastrophe close off the possibility that individual and collective action can make a difference.[294]

Second, climate change is best represented in ways that anchor it in positive emotions,[313] by framing action in ways that connect with people's core values and identities. Examples include framing climate change as: an ethical and intergenerational issue; about safeguarding ancestral lands and the sanctity of the natural world; or an appreciation of the global injustice of anthropogenic climate change driven by rich countries but paid for by poorer ones.[107,314] Aligning climate change to a range of ethical positions and a core set of identities can offer a way of appealing to diverse social groups, and thus securing a broad and inclusive platform of public support for action. This could be facilitated by avoiding the rhetoric of climate catastrophe, and emphasising, instead, human capacity to steer a way to a sustainable future, including lifting the burdens that unmitigated climate change would otherwise impose on future generations.[313,315]

Third, integral to such an ethical framing of climate change is the implied duty on national and international organisations to take action. A recurrent finding is that the public sees the main responsibility for action lying with governments and other powerful institutions, not least because the options open to individuals to take radical action to cut their own GHG emissions are often sorely limited by cost or availability (eg, poor public transport provision). Public willingness to take action is also contingent on those considered responsible for climate change taking action themselves.[316] The majority of the public in cross-national surveys believe that their country has a responsibility to take action on climate change, and that their government is not doing enough.[317]

Fourth, many climate-affecting behaviours are habitual and resistant to change. Everyday domestic energy use (eg, cooking, heating the home), travel behaviour, and eating patterns are undertaken as part of a daily routine and without conscious thought. Such behaviours are resistant to change, even if alternative options are available, and interventions relying on increasing knowledge have limited effect.[318]

Conclusions

It is clear that in isolation, a top-down approach (international agreement followed by national legislation with which individuals and business must comply) to managing climate change is no longer a sufficient response. Other actors are already taking steps independent of any agreement to reduce their emissions, and a voluntary transformation to a low-carbon economy may already be underway. At the same time, as indicated throughout this report, these bottom-up initiatives have hardly, as yet, taken us any closer to the scale of global action required to protect human health against the risks of climate change, than has the decade of targets under the Kyoto Protocol.

Section 1 has underlined the way in which the continued acceleration of GHG emissions and atmospheric concentrations, mapped on to changing global demographics, is making climate change an increasingly severe risk to global health. Despite the threat that climate change poses to human development, it remains but one of many factors influencing decision makers, and rarely the most important one. Precautionary adaptation is clearly inadequate and prevailing patterns of energy production and consumption are still driving the world towards a dangerous climatic future. Current economic drivers of growth lock communities into patterns of energy use which no amount of reframing can change unless coordinated realignment of these drivers takes place. And the argument that others should be doing more to tackle climate change, because they are more to blame, remains one of the most politically potent excuses for inadequate action.

Thus the challenge, and the crucial test of the international process, will be finding a synthesis of top-down and bottom-up forces. An effective international agreement will be one that supports stronger efforts everywhere and at every level. The diverse worlds of bottom-up initiatives in cities, companies and many others should in turn help overcome the obstacles that impede the ability or willingness of national governments to commit to stronger national actions. To be truly effective, any future agreement will thus need not only to agree goals and aspirations, but also identify what is necessary at the international and national levels to achieve them. This may also require a mechanism, such as a feedback loop, that will motivate increased national ambitions over time. A system of review will be a crucial component, with regular assessments of the effectiveness of national policies, actions, and targets.

Section 6: bringing the health voice to climate change

Our studies point to multiple ways in which the health agenda may help accelerate the response to climate change. First are the positive lessons for international cooperation. No-one would suggest that national action to protect health should depend on a global, all-encompassing treaty. Yet few would deny that WHO and numerous other fora of international cooperation are important in accelerating, coordinating, and deepening responses to health challenges—particularly, but not exclusively, those with transboundary dimensions. The health experience neatly illustrates the falsity of the dichotomy between top-down and bottom-up: one measure of success is how each can reinforce the other. Learning from the health experience may illuminate the most effective actions at a particular level or levels of governance, and how the multi-level governance framework and international negotiation process can mutually reinforce actions at different levels.

Second, political lessons from health have particular, and largely encouraging, resonance for a climate dialogue increasingly characterised by pessimism about the ability to control the problem. The denialism of HIV, responsible for perhaps a million deaths, did eventually give way to global acceptance of the science. 50 years of tobacco industry resistance and obfuscation of the science on lung cancer has to a large extent been overcome, including with recognition embodied in WHO's Framework Convention on Tobacco Control, that governments have a duty to resist such lobbying forces.

Third, the health implications could and should be more effectively harnessed in efforts to build support for a stronger response to climate change. The health impacts of climate change discussed in this Commission are not well represented in global negotiations, but they are a critical factor to be considered in mitigation and adaptation actions. A better understanding of the health impacts of climate change can help to drive top-down negotiations and bottom-up action in many realms. A sophisticated approach is needed, which draws on the universal desire to tackle threats to health and wellbeing (without any particular philosophical slant), in order to motivate rapid action, and a policy framing that is more human than purely environment, technology, or economy focused. This requires making the impact of climate change on people explicit, rather than implicit. By considering directly how climate change will impact on human health, we are naturally drawn to the human component of climate impacts, rather than the environmental (flooding, forest fires) or more abstract effects (the economy, the climate). This supports a human framing of climate change, putting it in terms that may be more readily understood by the public. Fostering such public resonance can act as a powerful policy driver: public pressure is, of course, a crucial factor motivating both national governments and their negotiators in the international arena.

Fourth, local health benefits could in themselves help to drive key adaptation and mitigation actions. The numerous health co-benefits of many adaptation measures were emphasised in section 2, whilst section 3 noted substantial health co-benefits of many mitigation measures. Examples of the latter include the reduced health risks and costs when populations live in well-insulated buildings, and the reduction in air pollution (and other health) damages associated with fossil fuel use, which, as noted, even in strictly economic terms typically amount to several percent of GDP, as well as adding directly to the strain on limited health-care resources. With the direct costs of deep cuts in emissions estimated at around 10% of global expenditure on health, both the direct and indirect health dimensions should be a major driver for mitigation efforts. It is also commonly seen that responding to climate change from a public health perspective brings together both mitigation and adaptation interventions, yielding powerful synergies.

Fifth, analogies in health responses can also help to underline that there is rarely a single solution to complex problems: different and complementary measures are required to tackle different dimensions, and pursuing both prevention (mitigation) and treatment (adaptation) is crucial:

With severely ill or vulnerable patients, the first step is to stabilise the patient and tackle the immediate symptoms. Helping poor countries particularly to adapt to the impacts of climate change is similarly a priority. But as noted in section 2, adaptation cannot indefinitely protect human health in the face of continuing and accumulating degrees of climate change, any more than tackling the symptoms will cure a serious underlying disease.

- For infectious diseases, antimicrobials and a functioning health system to produce, distribute, and administer drugs effectively are essential components. The obvious analogy here is with specific greenhouse

gas mitigation policies, such as energy efficiency programmes and technology programmes that span the full spectrum from R&D through to policies to support industrial scale deployment and related infrastructure.
- Deeply-ingrained patterns of behaviour are best addressed by comprehensive approaches and the use of multiple policy levers. Evidence from studies of health behaviour change suggests that, to be sustained, changes in the individual's everyday environments are required. Structural levers are also important for addressing social inequalities in harmful behaviours. Such evidence could be harnessed to inform policies to address climate change—eg, the behaviour change checklists developed to guide policy to reduce tobacco use and tackle harmful alcohol consumption may be particularly useful. Applying lessons from health behaviour change may help to accelerate policy development, building an evidence platform for interventions to promote mitigative and adaptive behaviours.
- As with the evolution of drug-resistant bacteria, the challenges of drug addiction, or the rising health problems of obesity, medical fixes cannot solve all health problems. Similarly, in our energy systems, specific mitigation policies and projects are constantly faced with the ingenuity of the fossil fuel industry in finding and driving down the costs of extracting new fossil fuel resources and marketing them. The long-term antidote is more analogous to programmes of sustained immunisation, education, incentives, and enforcement, all oriented towards supporting healthier lives.

The single most powerful strategic instrument to inoculate human health against the risks of climate change would be for governments to introduce strong and sustained carbon pricing, in ways pledged to strengthen over time until the problem is brought under control. Like tobacco taxation, it would send powerful signals throughout the system, to producers and users, that the time has come to wean our economies off fossil fuels, starting with the most carbon intensive and damaging like coal. In addition to the direct incentives, the revenues could be directed to measures across the spectrum of adaptation, low-carbon innovation, and the global diffusion of better technologies and practices. As outlined in section 4, carbon pricing thus has immense potential, particularly when embedded in comprehensive policy packages. This most powerful antidote, however, still faces many political obstacles.

The crux of the matter is that stabilising the atmosphere at any level ultimately requires reducing net emissions to zero. A healthy patient cannot continue with indefinitely rising levels of a toxin in the blood; even nutrients essential to a healthy body (like salt) can become damaging if not stabilised. The climate-change analogy is obvious and focuses global attention on the need to stabilise atmospheric concentrations, which in climate terms, means getting net emissions (that is, emissions minus removals by forests, oceans, and other sinks) to zero. On most scientific indicators, it means getting to zero during the second half of this century. A unifying goal, therefore may be a commitment to achieve zero emissions based on multiple partnerships involving different actors. If any region can achieve net zero, there is no fundamental reason why that should not become global. Getting to net zero also focuses us on a common task: how to get there, which is potentially harder for the societies that have become more dependent on fossil fuels, whilst in developing countries, it sends a clear signal that the sooner their emissions can peak, the better for their own path towards that common goal. If the goal is net zero, all actors in all societies have a sense of the direction of the international framework for action in order to protect everyone's health against the risks posed by continual increases in the global concentration of heat-trapping gases.

A Countdown to 2030: global health and climate action

If we are to minimise the health impacts of climate change, we must monitor and hold governments accountable for progress and action on emissions reduction and adaptation. One might argue that action on climate change is already effectively addressed by the IPCC, World Bank, UNFCCC, WHO, and the G20. We believe, however, that the health dimension of the climate change crisis has been neglected. There are four reasons why an independent accountability and review process is warranted:

1. The size of the health threat from climate change is on a scale quite different from localised epidemics or specific diseases. On current emissions trajectories there could be serious population health impacts in every region of the world within the next 50 years.
2. There is a widespread lack of awareness of climate change as a health issue.[191]
3. Several independent accountability groups have brought energy, new ideas and advocacy to other global health issues. For example, the Institute of Health Metrics and Evaluation in Seattle have led analyses of the Global Burden of Disease, the Countdown to 2015 child survival group has monitored global progress since 2003, and the Global Health 2035 group have stimulated new ideas about global health financing.
4. Perhaps the paramount reason for an independent review is the authority of health professional voices with policy makers and communities. Doctors and nurses may be trusted more than environmentalists. They also bring experience of collating evidence and conducting advocacy to cut deaths as a result of tobacco, road traffic accidents, infectious disease, and lifestyle-related non-communicable diseases.

Panel 9: Framework of indicators for monitoring progress in three critical areas

Health impacts

An updated review of evidence on the health impacts of climate change:

- Heat stress and heatwaves
- Climate-sensitive dynamic infectious diseases
- Air pollution and allergy
- Climate-related migration
- Food insecurity and crop yields
- Extreme weather events
- Ecosystem service damage

Actions to reduce greenhouse gas emissions that improve public health

International progress and compliance with:

- A strong and equitable international agreement
- Low-carbon and climate-resilient technology innovation and investment
- Climate governance (finance, decision making, coordination, legislation)

Regional and national progress and successes with:

- Phasing out of coal-fired power generation and removal of fossil-fuel subsidies
- Urban planning, spatial infrastructure, and liveable cities
- Government incentives capital for low-carbon, resilient buildings and infrastructure

Adaptation, resilience, and climate-smart health systems

Progress and successes with:

- Poverty reduction and reductions in inequities
- Vulnerability and exposure reduction in high-risk populations
- Food security in poor countries
- Communication of climate risks and community engagement for local solutions
- Development of climate resilient, low-carbon health systems; scale up of renewables and combined heat and power generation in health facilities; use of climate finance for health infrastructure; decentralisation of care

We propose the formation of an independent international Countdown to 2030: global health and climate action coalition, along the same lines as other successful global health monitoring groups. We recommend that a broad international coalition of experts across disciplines from health to the environment, energy, economics, and policy, together with lay observers, drawn from every region of the world, should monitor and report every 2 years. The report would provide a summary of evidence on the health impacts of climate change; progress in mitigation policies and the extent to which they consider and take advantage of the health co-benefits; and progress with broader adaptation action to reduce population vulnerability and to build climate resilience and to implement low-carbon, sustainable health systems.

A Countdown process would complement rather than replace existing IPCC and other UN reports. UN reports understandably seek cautious consensus. An independent review of progress would add the full weight and voice of the health community and valuable metrics to this critical population health challenge. A Countdown to 2030: global health and climate action coalition would independently decide the structure of their reports and the sentinel indicators they would choose to monitor progress towards key outcomes, policies and practice. Panel 9 outlines one possible framework for monitoring progress in three critical areas: health impacts; progress with action to reduce GHG emissions; and progress with actions to support adaptation, and the resilience of both populations and health systems, to climate change.

Optimism

We should draw considerable strength in the face of the challenges of climate change from the way in which the global community has addressed numerous other threats to health in the recent past. Although the threats are great and time is short, we have an opportunity for social transformation that will link solutions to climate change with a progressive green global economy, reductions in social inequalities, the end of poverty, and a reversal of the pandemic of non-communicable disease.

There are huge opportunities for social and technological innovation. We have modern communications to share successful local learning. At the highest levels of state, there are opportunities for political leaders to grasp the global challenge with transformative climate initiatives of a scale and ambition to match the Marshall plan, the Apollo and Soyuz space programmes, and the commercial success of mobile telephony. Scalable, low-carbon, and renewable energy technologies require billions of dollars of new investment and ideas. In cities, municipal governments are already bringing energy and innovation to create connected, compact urban communities, better buildings, managed growth, and more efficient transport systems. In local communities transformative action creates greater environmental awareness and facilitates low-carbon transition. And within local government, civil society, and business, many people aim to bring about social and economic transformation. All of us can help cut GHG emissions and reduce the threat of climate change to our environment and health. At every level, health must find its voice. In health systems we can set an example with scale up of renewables, combined heat and power generation in health facilities, decentralisation of care and promotion of active transport, and low-carbon healthy lifestyles. But time is limited. Immediate action is needed. The Countdown to 2030 coalition must begin its work immediately.

Contributors

The 2015 *Lancet* Commission on Health and Climate Change is an international collaboration led by University College London, Tsinghua University, the University of Exeter, the Stockholm Resilience Centre, and Umeå University. The Commission undertook its work within five central working groups, which were responsible for the design, drafting, and review of their individual sections. All commissioners contributed to the overall report structure and concepts, and provided input and expertise in facilitating integration between the five core sections. *Members of Working Group 1 (climate change and exposure to health risks)*: W Neil Adger, Mat Collins, Peter M Cox, Andy Haines, Alasdair Hunter, Xujia Jiang, Mark Maslin, Tara Quinn, Sergey Venevsky, Qiang Zhang. *Members of Working Group 2 (action for resilience and adaptation)*: Victor Galaz, Delia Grace, Moxuan Li, Georgina Mace, My Svensdotter, Koko Warner, Yongyuan Yin, Chaoqing Yu, Bing Xu. *Members of Working Group 3 (transition to a low-carbon energy infrastructure)*: Ian Hamilton, Lu Liang, Robert Lowe, Tadj Oreszczyn, Steve Pye, Jun Yang. *Members of Working Group 4 (financial and economic action)*: Wenjia Cai, Paul Drummond, Paul Ekins, Paolo Agnolucci, Melissa Lott. *Members of Working Group 5 (delivering a healthy low-carbon future)*: Jason Blackstock, Sarah Chaytor, Adam Cooper, Joanna Depledge, Hilary Graham, Michael Grubb, Yong Luo.

Michael Grubb acted as the integrating editor for mitigation (working across Working Groups 3, 4, and 5), and Maria Nilsson acted as the integrating editor for health (working across all working groups). Peter Byass, Ilan Kelman, and Tim Colbourn provided global health expertise for a number of working groups, and contributed to the Commission's overall direction. Nick Watts, Anthony Costello, Hugh Montgomery, and Peng Gong were responsible for the strategic direction, integration, and editing of the Commission.

Declaration of interests

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References

1 Costello A, Abbas M, Allen A, et al. Managing the health effects of climate change: *Lancet* and University College London Institute for Global Health Commission. *Lancet* 2009; **373:** 1693–733.

2 IPCC. Summary for policymakers. In: Field CB, Barros VR, Dokken DJ, et al, eds. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Cambridge, UK, and New York, NY, USA: Cambridge University Press, 2014: 1–32.

3 Cubasch U, Wuebbles D, Chen D, et al. Introduction. In: Stocker TF, Qin D, Plattner G-K, et al, eds. Climate change 2013: the physical science basis contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2013: 119–58.

4 British Petroleum. BP statistical review of world energy June 2014. London: BP, 2014.

5 Ciais P, Sabine C, Bala G, et al. Carbon and Other Biogeochemical Cycles. In: Stocker TF, Qin D, Plattner G-K, et al, eds. Climate change 2013: the physical science basis contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2013: 465–570.

6 National Oceanic and Atmospheric Administration. Trends in atmospheric carbon dioxide. 2014. http://www.esrl.noaa.gov/gmd/ccgg/trends/weekly.html (accessed Dec 22, 2014).

7 Balla G. Digesting 400 ppm for global mean CO_2 concentration. *Curr Sci* 2013; **104:** 1471–72.

8 IPCC. Summary for Policymakers. In: Stocker TF, Qin D, Plattner G-K, et al, eds. Climate change 2013: the physical science basis contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2013: 1–30.

9 McMillan M, Shepherd A, Sundal A, et al. Increased ice losses from Antarctica detected by CryoSat-2. *Geophys Res Lett* 2014; **41:** 3899–905.

10 Riahi K, Rao S, Krey V, et al. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. *Clim Change* 2011; **109:** 33–57.

11 Stott PA, Stone DA, Allen MR. Human contribution to the European heatwave of 2003. *Nature* 2004; **432:** 610–14.

12 Rahmstorf S, Coumou D. Increase of extreme events in a warming world. *Proc Natl Acad Sci USA* 2011; **108:** 17905–09.

13 Otto F, Massey N. Oldenborgh Gv, Jones R, Allen M. Reconciling two approaches to attribution of the 2010 Russian heat wave. *Geophys Res Lett* 2012; **39:** L04702.

14 Peterson T, Hoerling M, Stott P, Herring S. Explaining extreme events of 2012 from a climate perspective. *Bull Am Meteor Soc* 2013; **94:** S1–106.

15 Herring S, Hoerling M, Peterson T, Stott P. Explaining extreme events of 2013 from a climate perspective. *Bull Am Meteor Soc* 2014; **95:** S1–96.

16 Peterson T, Stott P, Herring S. Explaining extreme events of 2011 from a climate perspective. *Bull Am Meteor Soc* 2012; **93:** 1041–67.

17 Pall P, Aina T, Stone DA, et al. Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature* 2011; **470:** 382–85.

18 World Bank. Turn down the heat: why a 4°C warmer world must be avoided. 2012. https://openknowledge.worldbank.org/handle/10986/11860 (accessed May 10, 2015).

19 Silver N. The signal and the noise: the art and science of prediction. London: Penguin UK, 2012.

20 McMaster R, Baber C. Multi-agency operations: cooperation during flooding. *Appl Ergon* 2012; **43:** 38–47.

21 Overview and Scrutiny Management Committee. Scrutiny inquiry into the summery emergency 2007. Gloucestershire: Gloucestershire County Council, 2007.

22 Rockström J, Steffen W, Noone K, et al. Planetary boundaries: exploring the safe operating space for humanity. *Ecol Soc* 2009; **14:** 32.

23 Lenton TM, Held H, Kriegler E, et al. Tipping elements in the Earth's climate system. *Proc Natl Acad Sci USA* 2008; **105:** 1786–93.

24 Haines A, Ebi KL, Smith KR, Woodward A. Health risks of climate change: act now or pay later. *Lancet* 2014; **384:** 1073–75.

25 Anderson K, Bows A. Beyond 'dangerous' climate change: emission scenarios for a new world. *Philos Trans A Math Phys. Eng Sci* 1934; **2011:** 20–44.

26 WHO. Health in the Green Economy. Geneva: World Health Organisation, 2011.

27 Watts G. The health benefits of tackling climate change: an Executive Summary for the *Lancet* Series. Nov 25, 2009. http://www.thelancet.com/pb/assets/raw/Lancet/stories/series/health-and-climate-change.pdf (accessed May 10, 2015).

28 WHO, World Bank. Access to modern energy services for health facilities in resource-constrained settings. Geneva: World Health Organization, 2015.

29 Haines A, McMichael AJ, Smith KR, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. *Lancet* 2009; **374:** 2104–14.

30 Walker BH, Gunderson LH, Kinzig AP, Folke C, Carpenter SR, Schultz L. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecol Soc* 2006; **11:** 13.

31 Smith KR, Woodward A, Campell-Lendrum D, et al. Human health—impacts adaptation and co-benefits. Climate change 2014: impacts, adaptation, and vulnerability Working Group II contribution to the IPCC 5th Assessment Report. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2014.

32 Hales S, Kovats S, Lloyd S, Campbell-Lendrum D. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva: World Health Organization, 2014.

33 Adger WN, Pulhin JM, Barnett J, et al. Human security. In: Field CB, Barros VR, Dokken DJ, et al, eds. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press; 2014: 755–91.

34 Barrett CB. Food security and sociopolitical stability. Oxford: Oxford University Press, 2013.

35 Bradshaw S, Fordham M. Women, girls and disasters: a review for DFID. London: Department for International Development (DFID), 2013.

36 Jonkman SN, Kelman I. An analysis of the causes and circumstances of flood disaster deaths. *Disasters* 2005; **29:** 75–97.

37 WHO. Gender, climate change and health. Geneva: World Health Organization, 2014.

38 Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. Impact of regional climate change on human health. *Nature* 2005; **438:** 310–17.

39 Aström C, Orru H, Rocklöv J, Strandberg G, Ebi KL, Forsberg B. Heat-related respiratory hospital admissions in Europe in a changing climate: a health impact assessment. *BMJ Open* 2013; **3:** e001842.

40 Russo S, Dosio A, Graversen RG, et al. Magnitude of extreme heat waves in present climate and their projection in a warming world. *J Geophys Res D Atmospheres* 2014; **199:** 12 500–512.

41 Coumou D, Robinson A. Historic and future increase in the global land area affected by monthly heat extremes. *Environ Res Lett* 2013; **8:** 034018.

42 Ryazantzev S. Demographic and socio-economic consequences of heat wave and forest fires of 2010 in European Russia. *Ecol Life* 2011; **5:** 80–85.

43 van Donkelaar A, Martin RV, Levy RC, et al. Satellite-based estimates of ground-level fine particulate matter during extreme events: a case study of the Moscow fires in 2010. *Atmos Environ* 2011; **45:** 6225–32.

44 Revitch B, Shaposhnikov D. Climate change, heat and cold waves as risk factors of increased mortality in Russia. *Ecoforum* 2012; **2:** 122–38.

45 Barriopedro D, Fischer EM, Luterbacher J, Trigo RM, García-Herrera R. The hot summer of 2010: redrawing the temperature record map of Europe. *Science* 2011; **332:** 220–24.

46 Ebi K, Mills D. Winter mortality in a warming climate: a reassessment. *Wiley Interdiscip Rev Clim Change* 2013; **4:** 203–12.

47 Healy JD. Excess winter mortality in Europe: a cross country analysis identifying key risk factors. *J Epidemiol Community Health* 2003; **57:** 784–89.

48 Woodward A. Heat, cold and climate change. *J Epidemiol Community Health* 2014; **68:** 595–96.

49 Staddon P, Montgomery H, Depledge M. Climate warming will not decrease winter mortality. *Nature Clim Change* 2014; **4:** 190–94.

50 Seto KC, Güneralp B, Hutyra LR. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc Natl Acad Sci USA* 2012; **109:** 16083–88.

51 O'Neill B, Kriegler E, Ebi K, et al. The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century. *Glob Environ Change* 2015; published online Feb 12. DOI:10.1016/j.gloenvcha.2015.01.004.

52 Samir K, Lutz W. The human core of the shared socioeconomic pathways: population scenarios by age, sex and level of education for all countries to 2100. *Glob Environ Change* 2014; published online July 4. DOI:10.1016/j.gloenvcha.2014.06.004.

53 Kriegler E, O'Neill BC, Hallegatte S, et al. The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. *Glob Environ Change* 2012; **22:** 807–22.

54 Bhatt S, Gething PW, Brady OJ, et al. The global distribution and burden of dengue. *Nature* 2013; **496:** 504–07.

55 Kovats RS, Hajat S. Heat stress and public health: a critical review. *Annu Rev Public Health* 2008; **29:** 41–55.

56 Quinn T, Adger N. Climate change when you are getting on in life. *Environ Plann A* 2011; **43:** 2257–60.

57 Lutz W, Muttarak R, Striessnig E. Environment and development. Universal education is key to enhanced climate adaptation. *Science* 2014; **346:** 1061–62.

58 Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity—an increasing challenge for low and middle-income countries during climate change. *Global Health Action* 2009; **2:** 10.3402/gha.v2i0.2047.

59 Parsons K. Human thermal environment: the effects of hot, moderate and cold temperatures on human health, comfort and performance, 3rd edn. New York: CRC Press, 2014.

60 Hémon D, Jougla E. Surmortalité liée à la Canicule d'Août 2003: Rapport d'Étape. Estimation de la Surmortalite et Principales Caracteristiques Epidemiologiques. Rapport remis au Ministre de la Santé, de la Famille et des Personnes Handicapées. Paris: Institut National de la Santé et de la Recherche Médicale (INSERM), 2003.

61 Centers for Disease Control and Prevention (CDC). Heat-related deaths among crop workers—United States, 1992–2006. *MMWR Morb Mortal Wkly Rep* 2008; **57:** 649–53.

62 Wesseling C, Crowe J, Hogstedt C, Jakobsson K, Lucas R, Wegman DH, and the First International Research Workshop on the Mesoamerican Nephropathy. Resolving the enigma of the mesoamerican nephropathy: a research workshop summary. *Am J Kidney Dis* 2014; **63:** 396–404.
63 DARA and the Climate Vulnerability Forum. Climate vulnerability monitor 2012: a guide to the cold calculus of a hot planets. Barcelona: Fundacion DARA Internacional, 2012.
64 United Nations Development Programme (UNDP). Human development report 2011. Sustainability and equity: a better future for all. London: UNDP, 2011.
65 Dunne JP, Stouffer RJ, John JG. Reductions in labour capacity from heat stress under climate warming. *Nature Clim Change* 2013; **3:** 563–66.
66 Porter JR, Xie L, Challinor AJ, et al. Food security and food production systems. In: Field CB, Barros VR, Dokken DJ, et al. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2014: 485–533.
67 Sherwood SC, Huber M. An adaptability limit to climate change due to heat stress. *Proc Natl Acad Sci USA* 2010; **107:** 9552–55.
68 WHO. World malaria report. Geneva: World Health Organization, 2012.
69 Ndyomugyenyi R, Magnussen P. Trends in malaria-attributable morbidity and mortality among young children admitted to Ugandan hospitals, for the period 1990–2001. *Ann Trop Med Parasitol* 2004; **98:** 315–27.
70 Siraj AS, Santos-Vega M, Bouma MJ, Yadeta D, Ruiz Carrascal D, Pascual M. Altitudinal changes in malaria incidence in highlands of Ethiopia and Colombia. *Science* 2014; **343:** 1154–58.
71 Sutherst RW. Global change and human vulnerability to vector-borne diseases. *Clin Microbiol Rev* 2004; **17:** 136–73.
72 WHO, World Meteorological Organisation. Atlas of health and climate. Geneva: World Health Organization, 2012.
73 Hopp J, Foley J. Worldwide fluctuations in dengue fever case related to climate variability. *Clim Res* 2003; **25:** 85–94.
74 Lipp EK, Huq A, Colwell RR. Effects of global climate on infectious disease: the cholera model. *Clin Microbiol Rev* 2002; **15:** 757–70.
75 WHO. Burden on disease from air pollution in 2012. 2014. http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf (accessed Oct 7, 2014).
76 Jacob DJ, Winner DA. Effect of climate change on air quality. *Atmos Environ* 2009; **43:** 51–63.
77 Giorgi F, Meleux F. Modelling the regional effects of climate change on air quality. *C R Geosci* 2007; **339:** 721–33.
78 Schär C, Vidale PL, Lüthi D, et al. The role of increasing temperature variability in European summer heatwaves. *Nature* 2004; **427:** 332–36.
79 Wu S, Mickley LJ, Leibensperger EM, Jacob DJ, Rind D, Streets DG. Effects of 2000–2050 global change on ozone air quality in the United States. *J Geophys Res, D, Atmospheres* 2008; **113:** D06302.
80 Tagaris E, Manomaiphiboon K, Liao K-J, et al. Impacts of global climate change and emissions on regional ozone and fine particulate matter concentrations over the United States. *J Geophys Res, D, Atmospheres* 2007; **112:** D14312.
81 Murazaki K, Hess P. How does climate change contribute to surface ozone change over the United States? *J Geophys Res, D, Atmospheres* 2006; **111:** D05301.
82 Mickley LJ, Jacob DJ, Field BD, Rind D. Effects of future climate change on regional air pollution episodes in the United States. *Geophys Res Lett* 2004; **31:** L24103.
83 Knowlton K, Rosenthal JE, Hogrefe C, et al. Assessing ozone-related health impacts under a changing climate. *Environ Health Perspect* 2004; **112:** 1557–63.
84 Jiang H, Liao H, Pye HOT, et al. Projected effect of 2000–2050 changes in climate and emissions on aerosol levels in China and associated transboundary transport. *Atmos Chem Phys* 2013; **13:** 7937–60.
85 Wang Y, Shen L, Wu S, Mickley L, He J, Hao J. Sensitivity of surface ozone over China to 2000–2050 global changes of climate and emissions. *Atmos Environ* 2013; **75:** 374–82.
86 Jiang Z, Zhang X, Wang J. Projection of climate change in China in the 21st century by IPCC-AR4 models. *Geograph Res* 2008; **27:** 787–99.
87 Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380:** 2224–60.
88 Lobell DB, Banziger M, Magorokosho C, Vivek B. Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature Clim Change* 2011; **1:** 42–45.
89 Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. *Science* 2011; **333:** 616–20.
90 Grace K, Davenport F, Funk C, Lerner AM. Child malnutrition and climate in Sub-Saharan Africa: An analysis of recent trends in Kenya. *Appl Geogr* 2012; **35:** 405–13.
91 Taylor RG, Scanlon B, Doll P, et al. Ground water and climate change. *Nature Clim Change* 2013; **3:** 322–29.
92 Schewe J, Heinke J, Gerten D, et al. Multimodel assessment of water scarcity under climate change. *Proc Natl Acad Sci USA* 2014; **111:** 3245–50.
93 Ahern M, Kovats RS, Wilkinson P, Few R, Matthies F. Global health impacts of floods: epidemiologic evidence. *Epidemiol Rev* 2005; **27:** 36–46.
94 Dasgupta S, Laplante B, Meisner C, Wheeler D, Yan J. The impact of sea level rise on developing countries: a comparative analysis. *Clim Change* 2009; **93:** 379–88.
95 Nicholls R, Marinova N, Lowe J, et al. Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. *Philos Trans R Soc A* 1934; **2011:** 161–81.
96 Paranjothy S, Gallacher J, Amlôt R, et al. Psychosocial impact of the summer 2007 floods in England. *BMC Public Health* 2011; **11:** 145.
97 Jongman B, Ward PJ, Aerts JCJH. Global exposure to river and coastal flooding: Long term trends and changes. *Glob Environ Change* 2012; **22:** 823–35.
98 Olsson L, Opondo M, Tschakert P, et al. Livelihoods and poverty. In: Field CB, Barros VR, Dokken DR, et al, eds. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press, 2014: 793–832.
99 Gleditsch NP. Whither the weather? Climate change and conflict. *J Peace Res* 2012; **49:** 3–9.
100 McMichael C, Barnett J, McMichael AJ. An ill wind? Climate change, migration, and health. *Environ Health Perspect* 2012; **120:** 646–54.
101 Black R, Arnell NW, Adger WN, Thomas D, Geddes A. Migration, immobility and displacement outcomes following extreme events. *Environ Sci Pol* 2013; **27** (suppl 1): S32–43.
102 Frumkin H, McMichael AJ. Climate change and public health: thinking, communicating, acting. *Am J Prev Med* 2008; **35:** 403–10.
103 Frumkin H, Hess J, Luber G, Malilay J, McGeehin M. Climate change: the public health response. *Am J Public Health* 2008; **98:** 435–45.
104 O'Brien K. Global environmental change II: From adaptation to deliberate transformation. *Prog Hum Geogr* 2012; **36:** 667–76.
105 Pelling M. Adaptation to climate change: from resilience to transformation. London: Routledge, 2011.
106 Adger WN. Vulnerability. *Glob Environ Change* 2006; **16:** 268–81.
107 Patz J, Gibbs H, Foley J, Rogers J, Smith K. Climate change and global health: quantifying a growing ethical crisis. *EcoHealth* 2007; **4:** 397–405.
108 IPCC. Glossary of terms. In: Field CB, Stocker TF, Qin D, eds. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. London, UK and New York, NY: Cambridge University Press, 2012: 555–64.
109 Adger WN. Social and ecological resilience: are they related? *Prog Hum Geogr* 2000; **24:** 347–64.
110 Hackmann H, St Clair AL. Transformative cornerstones of social science research for global change. Paris: International Social Science Council, 2012.
111 Pascal M, Laaidi K, Ledrans M, et al. France's heat health watch warning system. *Int J Biometeorol* 2006; **50:** 144–53.

112 Fouillet A, Rey G, Wagner V, et al. Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? A study of the 2006 heat wave. *Int J Epidemiol* 2008; **37:** 309–17.
113 Ebi KL, Burton I. Identifying practical adaptation options: an approach to address climate change-related health risks. *Environ Sci Policy* 2008; **11:** 359–69.
114 Matthies F, Bickler G, Marin NC, Hales S. Heat-health action plans: guidance. Copenhagen: World Health Organization Regional Office for Europe, 2008.
115 Pugh TAM, Mackenzie AR, Whyatt JD, Hewitt CN. Effectiveness of green infrastructure for improvement of air quality in urban street canyons. *Environ Sci Technol* 2012; **46:** 7692–99.
116 UN Economic and Social Commission for Asia and the Pacific, UN Office for Disaster Risk Reduction. Reducing vulnerability and exposure to disasters. The Asia-Pacific disaster report 2012. Bangkok: ESCAP and UNISDR, 2012.
117 Nicholls RJ, Lowe JA. Benefits of mitigation of climate change for coastal areas. *Glob Environ Change* 2004; **14:** 229–44.
118 Etzold B, Ahmed AU, Hassan SR, Neelormi S. Clouds gather in the sky, but no rain falls. Vulnerability to rainfall variability and food insecurity in Northern Bangladesh and its effects on migration. *Clim Dev* 2013; **6:** 18–27.
119 McGranahan G, Balk D, Anderson B. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environ Urban* 2007; **19:** 17–37.
120 Foresight. Migration and global environmental change: future challenges and opportunities. London: UK Government Office for Science, 2011.
121 Michel-Kerjan E. Catastrophe economics: the national flood insurance program. *J Econ Perspect* 2010; **24:** 165–86.
122 Lafferty KD. Calling for an ecological approach to studying climate change and infectious diseases. *Ecology* 2009; **90:** 932–33.
123 Zinsstag J, Schelling E, Wyss K, Mahamat MB. Potential of cooperation between human and animal health to strengthen health systems. *Lancet* 2005; **366:** 2142–45.
124 Allison EH, Perry AL, Badjeck M-C, et al. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish Fish* 2009; **10:** 173–96.
125 Dulvy N, Allison E. A place at the table? *Nature Rep Clim Change* 2009; **3:** 68–70.
126 Gephart J, Pace M, D'Odorico P. Freshwater savings from marine protein consumption. *Environ Res Lett* 2014; **9:** 014005.
127 Foley JA, Ramankutty N, Brauman KA, et al. Solutions for a cultivated planet. *Nature* 2011; **478:** 337–42.
128 Bajželj B, Richards K, Allwood J, et al. Importance of food-demand management for climate mitigation. *Nature Clim Change* 2014; **4:** 924–29.
129 UN Environment Programme (UNEP). Avoiding future famines: strengthening the ecological foundation of food security through sustainable food systems. Nairobi: UNEP, 2012.
130 Food and Agricultural Organization (FAO), International Fund for Agricultural Development, World Food Programme. The state of food insecurity in the world: how does international price volatility affect domestic economies and food security? Rome: FAO, 2011.
131 Food and Agricultural Organization (FAO), Organization for Economic Cooperation and Development. Price volatility in food and agricultural markets: policy responses. Rome: FAO, 2011.
132 Gilbert CL, Morgan CW. Food price volatility. *Phil Trans R Soc B* 2010; **365:** 3023–34.
133 UN Conference on Trade and Development (UNCTAD). Promoting low-carbon investment. New York and Geneva: UNCTAD, 2013.
134 Cochrane K, Young C, De Soto D, Bahri T. Climate change implications for fisheries and aquaculture - overview of current scientific knowledge. Rome: Food and Agricultural Organization, 2009.
135 Alston J, Marra M, Pardey P, Wyatt T. Research returns redux: a meta-analysis of the returns to agricultural R&D. *Aust J Agric Resour Econ* 2000; **44:** 185–215.
136 von Braun J, Ahmed A, Asenso-Okyere K, et al. High food prices: the what, who, and how of proposed policy actions. Washington DC: International Food Policy Research Institute, 2008.
137 Rosegrant MW, Cline SA. Global food security: challenges and policies. *Science* 2003; **302:** 1917–19.
138 UN High Level Task Force on the Global Food Security Crisis. Scaling up nutrition: a framework for action. 2010. http://siteresources.worldbank.org/NUTRITION/Resources/281846-1131636806329/PolicyBriefNutrition.pdf (accessed May 10, 2015).
139 Hugo G. Future demographic change and its interactions with migration and climate change. *Glob Environ Change* 2011; **21:** S21–33.
140 Martin SF, Warner K. Climate change, migration, and development. In: Omelaniuk I, ed. Global perspectives on migration and development. New York: Springer Books, 2012: 153–72.
141 Collinson S. Developing adequate humanitarian responses. Background papers of the study team on climate change and migration. Washington DC: The German Marshall Fund of the United States, 2010.
142 Oppenheimer M, Campos M, Warren R, et al. Emergent risks and key vulnerabilities. Climate change 2014: impacts, adaptation, and vulnerability Working Group II Contribution to the IPCC 5th Assessment Report. Cambridge, UK and New York, NY: Cambridge University Press; 2014. 1039–99.
143 Confalonieri U, Menne B, Akhtar R, et al. Human health. In: Parry MC, Palutikof OF, van der Linden JP, et al, eds. Climate change 2007: impacts, adaptation and vulnerability contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2007: 391–431.
144 Warner K, Afifi T, Kälin W, et al. Changing climate, moving people: framing migration, displacement and planned relocation. Policy brief no 8. Bonn: UN University Institute for Environment and Human Security, 2013.
145 Raleigh C. The search for safety: The effects of conflict, poverty and ecological influences on migration in the developing world. *Glob Environ Change* 2011; **21** (suppl 1)**:** S82–93.
146 O'Brien K, Pelling M, Patwardhan A, et al. Toward a sustainable and resilient future. In: Field CB, Stocker TF, Qin D, et al, eds. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press, 2012: 437–86.
147 Berry HL, Bowen K, Kjellstrom T. Climate change and mental health: a causal pathways framework. *Int J Public Health* 2010; **55:** 123–32.
148 Fritze JG, Blashki GA, Burke S, Wiseman J. Hope, despair and transformation: climate change and the promotion of mental health and wellbeing. *Int J Ment Health Syst* 2008; **2:** 13.
149 Albrecht G, Sartore GM, Connor L, et al. Solastalgia: the distress caused by environmental change. *Australas Psychiatry* 2007; **15** (suppl 1)**:** S95–98.
150 Hanigan IC, Butler CD, Kokic PN, Hutchinson MF. Suicide and drought in New South Wales, Australia, 1970-2007. *Proc Natl Acad Sci USA* 2012; **109:** 13950–55.
151 Keshavarz M, Karami E, Vanclay F. The social experience of drought in rural Iran. *Land Use Policy* 2013; **30:** 120–29.
152 Kessler RC, Galea S, Gruber MJ, Sampson NA, Ursano RJ, Wessely S. Trends in mental illness and suicidality after Hurricane Katrina. *Mol Psychiatry* 2008; **13:** 374–84.
153 Reser JP, Swim JK. Adapting to and coping with the threat and impacts of climate change. *Am Psychol* 2011; **66:** 277–89.
154 Johnson CA. Governing climate displacement: the ethics and politics of human resettlement. *Env Polit* 2012; **21:** 308–28.
155 Lal PN, Mitchell T, Aldunce P, et al. National systems for managing the risks from climate extremes and disasters. In: Field CB, Stocker TF, Qin D, et al, eds. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press; 2012: 339–92.
156 Barnett J, Webber M. Migration as adaptation: opportunities and limits. In: McAdam J, ed. Climate change and displacement: multidisciplinary perspectives. Oxford: Hart Publishing, 2010: 55.
157 Warner K, Afifi T. Where the rain falls: evidence from 8 countries on how vulnerable households use migration to manage the risk of rainfall variability and food insecurity. *Clim Devel* 2014; **6:** 1–17.
158 Bronen R, Chapin FS 3rd. Adaptive governance and institutional strategies for climate-induced community relocations in Alaska. *Proc Natl Acad Sci USA* 2013; **110:** 9320–25.

159 Shuman EK. Global climate change and infectious diseases. *N Engl J Med* 2010; **362:** 1061–63.
160 Ramasamy R, Surendran SN. Possible impact of rising sea levels on vector-borne infectious diseases. *BMC Infect Dis* 2011; **11:** 18.
161 Moore S, Shrestha S, Tomlinson KW, Vuong H. Predicting the effect of climate change on African trypanosomiasis: integrating epidemiology with parasite and vector biology. *J R Soc Interface* 2012; **9:** 817–30.
162 Keesing F, Belden LK, Daszak P, et al. Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature* 2010; **468:** 647–52.
163 Ebi K, Berry P, Campbell-Lendrum D, et al. Protecting health from climate change: vulnerability and adaptation assessment. Geneva: World Health Organization and Pan American Health Organization, 2012.
164 Cheng JJ, Berry P. Health co-benefits and risks of public health adaptation strategies to climate change: a review of current literature. *Int J Public Health* 2013; **58:** 305–11.
165 Heltberg R, Siegel PB, Jorgensen SL. Addressing human vulnerability to climate change: toward a 'no-regrets' approach. *Glob Environ Change* 2009; **19:** 89–99.
166 Keim ME. Building human resilience: the role of public health preparedness and response as an adaptation to climate change. *Am J Prev Med* 2008; **35:** 508–16.
167 Jamison DT, Summers LH, Alleyne G, et al. Global health 2035: a world converging within a generation. *Lancet* 2013; **382:** 1898–955.
168 Parry M, Arnell N, Berry P, et al. Assessing the costs of adaptation to climate change: a review of the UNFCCC and other recent estimates. London: Imperial College London and International Institute for Environment and Development, 2009.
169 Jones KE, Patel NG, Levy MA, et al. Global trends in emerging infectious diseases. *Nature* 2008; **451:** 990–93.
170 Grace D, Mutua F, Ochungo P, Kruska R. Mapping of poverty and likely zoonoses hotspots. London: International Livestock Research Institute, 2012.
171 World Bank. The costs to developing countries of adapting to climate change: new methods and estimates. Washington DC: World Bank, 2010.
172 Dye C. After 2015: infectious diseases in a new era of health and development. *Philos Trans R Soc Lond B Biol Sci* 2014; **369:** 20130426.
173 World Bank. People, pathogens and our planet: the economics of one health. Washington DC: World Bank, 2012.
174 Semenza JC, Suk JE, Estevez V, Ebi KL, Lindgren E. Mapping climate change vulnerabilities to infectious diseases in Europe. *Environ Health Perspect* 2012; **120:** 385–92.
175 Teutsch SM, Churchill RE. Principles and practice of public health surveillance, 2nd edn. New York, NY: Oxford University Press, 2000.
176 Colls A, Ash N, Ikkala N. Ecosystem-based adaptation: a natural response to climate change. Switzerland: International Union for Conservation of Nature, 2009.
177 Pramova E, Locatelli B, Brockhaus M, Fohlmeister S. Ecosystem services in the national adaptation programmes of action. *Clim Pol* 2012; **12:** 393–409.
178 Pramova E, Locatelli B, Djoudi H, Somorin OA. Forests and trees for social adaptation to climate variability and change. *Wiley Interdiscip Rev Clim Chang* 2012; **3:** 581–96.
179 Spalding MD, Ruffo S, Lacambra C, et al. The role of ecosystems in coastal protection: adapting to climate change and coastal hazards. *Ocean Coast Manage* 2014; **90:** 50–57.
180 Mimura N, Pulwarty R, Duc D, et al. Adaptation planning and implementation. Climate change 2014: impacts, adaptation, and vulnerability Working Group II Contribution to the IPCC 5th Assessment Report. Cambridge, UK and New York, NY: Cambridge University Press, 2014.
181 The Royal Society. Resilience to extreme weather. London: The Royal Society Science Policy Centre, 2014.
182 Gill SE, Handley JF, Ennos AR, Pauleit S. Adapting cities for climate change: the role of the green infrastructure. *Built Environ* 2007; **33:** 115–33.
183 Munang R, Thiaw I, Alverson K, Mumba M, Liu J, Rivington M. Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. *Curr Opin Environ Sustain* 2013; **5:** 67–71.
184 Drewniak B, Snyder P, Steiner A, Twine T, Wuebbles D. Simulated changes in biogenic VOC emissions and ozone formation from habitat expansion of Acer Rubrum (red maple). *Environ Res* 2014; **9:** 014006.
185 Stone B Jr, Vargo J, Liu P, et al. Avoided heat-related mortality through climate adaptation strategies in three US cities. *PLoS One* 2014; **9:** e100852.
186 Huang C, Vaneckova P, Wang X, Fitzgerald G, Guo Y, Tong S. Constraints and barriers to public health adaptation to climate change: a review of the literature. *Am J Prev Med* 2011; **40:** 183–90.
187 Wilbanks T, Leiby P, Perlack R, Ensminger JT, Wright S. Toward an integrated analysis of mitigation and adaptation: some preliminary findings. *Mitig Adapt Strategies Glob Change* 2007; **12:** 713–25.
188 California Natural Resources Agency. 2009 California climate adaptation strategy: a report to the Governor of the state of California in response to Executive Order S-13-2008. Sacramento: California Natural Resources Agency, 2009.
189 Feiock RC. Metropolitan Governance and Institutional Collective Action. *Urban Aff Rev* 2008; **44:** 356–77.
190 UNFCCC. Third synthesis report on technology needs identified by Parties not included in Annex I to the Convention. Document FCCC/SBSTA/2013/Inf7 Subsidiary Body for Scientific and Technological Advice, thirty-ninth session. Warsaw: UNFCCC, 2013.
191 Leiserowitz A, Maibach E, Roser-Renouf C, Feinberg G, Rosenthal S, Marlon J. Public perceptions of the health consequences of global warming. New Haven: Yale University and George Mason University, 2014.
192 Moser SC, Dilling L. Creating a climate for change: communicating climate change and facilitating social change. Cambridge: Cambridge University Press, 2007.
193 Noble I, Huq S, Ayers J, et al. Adaptation needs and options. Climate change 2014: impacts, adaptation, and vulnerability Working Group II Contribution to the IPCC 5th Assessment Report. Cambridge, UK and New York, NY: Cambridge University Press, 2014.
194 Graus W, Blomen E, Worrell E. Global energy efficiency improvement in the long term: a demand-and supply-side perspective. *Energy Efficiency* 2011; **4:** 435–63.
195 International Energy Agency (IEA). Redrawing the energy-climate map. World energy outlook special report. Paris: IEA, 2013.
196 Vaughan N, Lenton T. A review of climate geoengineering proposals. *Clim Change* 2011; **109:** 745–90.
197 Lackner KS, Brennan S, Matter JM, Park AH, Wright A, van der Zwaan B. The urgency of the development of CO2 capture from ambient air. *Proc Natl Acad Sci USA* 2012; **109:** 13156–62.
198 Fischedick M, Schaeffer R, Adedoyin A, et al. Mitigation potential and costs. In: Edenhofer O, Pichs-Madruga R, Sokona Y, et al, eds. IPCC special report on renewable energy sources and climate change mitigation. Cambridge, UK and New York, NY: Cambridge University Press, 2011.
199 Bvd Z. The role of nuclear power in mitigating emissions from electricity generation. *Energy Strat Rev* 2013; **1:** 296–301.
200 Scovronick N, Adair-Rohani H, Borgford-Parnell N, et al. Reducing global health risks through mitigation of short-lived climate pollutants: scoping report for policymakers. Geneva: World Health Organization and Climate and Clean Air Coalition, 2015.
201 Summary for policymakers. In: Edenhofer O, Pichs-Madruga R, Sokona Y, et al, eds. Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press, 2014.
202 Victor D, Zhou D, Ahmed E, et al. Introductory Chapter. In: Edenhofer O, Pichs-Madruga R, Sokona Y, et al, eds. Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press, 2014.
203 Bruckner T, Bashmakov I, Mulugetta Y, et al. Energy Systems. In: Edenhofer O, Pichs-Madruga R, Sokona Y, et al, eds. Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press, 2014.

204 Stafford Smith M, Horrocks L, Harvey A, Hamilton C. Rethinking adaptation for a 4°C world. *Philos Trans A Math Phys Eng Sci* 2011; **369:** 196–216.

205 Basedau M, Lay J. Resource curse or rentier peace? The ambiguous effects of oil wealth and oil dependence on violent conflict. *J Peace Res* 2009; **46:** 757–76.

206 Schaeffer R, Szkloa A, Pereira-de-Lucena A, et al. Energy sector vulnerability to climate change: a review. *Energy* 2012; **38:** 1–12.

207 Schaeffer M, Hare W, Rahmstorf S, Vermeer M. Long-term sea-level rise implied by 1·5°C and 2°C warming levels. *Nature Clim Change* 2012; **2:** 867–70.

208 Czisch G. Scenarios for a future electricity supply: cost-optimised variations on supplying Europe and its neighbours with electricity from renewable energies. Stevenage: Institution of Engineering and Technology, 2011.

209 International Energy Agency (IEA). World energy outlook 2013. Paris: IEA, 2013.

210 Barrett J, Le Quéré, Lenzen M, Peters G, Roelich K, Wiedmann T. Consumption-based emissions reporting. Memorandum submitted by UKERC (CON 19). 2011. http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/writev/consumpt/con20.htm (accessed May 10, 2015).

211 Blanco G, Gerlagh R, Suh S, et al. Drivers, trends and mitigation. In: Edenhofer O, Pichs-Madruga R, Sokona Y, et al, eds. Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press, 2014.

212 World Bank. World development indicators—GDP per capita (constant 2005 US$). Washington, DC: World Bank, 2015.

213 World Bank. World development indicators—CO_2 emissions (metric tons per capita). Tennessee: World Bank, 2015.

214 Open Working Group proposal for Sustainable Development Goals. New York: UN Department of Economic and Social Affairs, Division for Sustainable Development, 2014.

215 Markandya A, Armstrong BG, Hales S, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: low-carbon electricity generation. *Lancet* 2009; **374:** 2006–15.

216 Markandya A, Wilkinson P. Electricity generation and health. *Lancet* 2007; **370:** 979–90.

217 Wilkinson P, Smith KR, Davies M, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. *Lancet* 2009; **374:** 1917–29.

218 Woodcock J, Edwards P, Tonne C, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *Lancet* 2009; **374:** 1930–43.

219 Davies M, Oreszczyn T. The unintended consequences of decarbonising the built environment: a UK case study. *Energy Build* 2012; **46:** 80–85.

220 Proust K, Newell B, Brown H, et al. Human health and climate change: leverage points for adaptation in urban environments. *Int J Environ Res Public Health* 2012; **9:** 2134–58.

221 Shaw MR, Overpeck JT, Midgley GF. Cross-chapter box on ecosystem based approaches to adaptation—emerging opportunities. In: Field CB, Barros VR, Dokken DJ, et al, eds. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2014: 101–03.

222 NHS Sustainable Development Unit. Saving carbon, improving health: NHS carbon reduction strategy. Cambridge: Sustainable Development Unit, 2009.

223 Public Health England and NHS England. Module: carbon hotspots. Sustainable development strategy for the health and care system 2014–2020. London: Sustainable Development Unit, 2014.

224 US Environmental Protection Agency (EPA). Inventory of US greenhouse gas emissions and sinks: 1990–2009. Washington, DC: EPA, 2011.

225 Global Green and Healthy Hospitals Network. Greenhouse Gas Emissions Reduction and Availability of Energy-Saving Practices in the Special Context of a Hospital Environment: Yonsei University Health System. 2014. http://greenhospitals.net/en/case-studies/ (accessed Dec 7, 2014).

226 Health G. Gundersen reaches first days of energy independence: first health system in nation to achieve this distinction. 2014. http://www.gundersenenvision.org/gundersen-reaches-first-days-of-energy-independence (accessed Dec 7, 2014).

227 Sustainable Development Unit. NHS, Public Health and Social Care. A cross England health system statement for the UN Climate Summit. Cambridge: Sustainable Development Unit, 2014.

228 Jensen HT, Keogh-Brown MR, Smith RD, et al. The importance of health co-benefits in macroeconomic assessments of UK greenhouse gas emission reduction strategies. *Clim Change* 2013; **121:** 223–37.

229 West J, Fiore A, Horowitz L. Scenarios of methane emission reductions to 2030: abatement costs and co-benefits to ozone air quality and human mortality. *Clim Change* 2012; **114:** 441–61.

230 Institute for Sustainable Development and International Relations, Sustainable Development Solutions Network. Pathways to deep decarbonization: interim 2014 report. Washington, DC: SDSN and IDDRI, 2014.

231 Clarke L, Jiang K, Akimoto K, et al. Assessing transformation pathways. In: Edenhofer O, Pichs-Madruga R, Sokona Y, et al, eds. Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2014.

232 Krey V, Masera G, Blanford T, et al. Annex II: metrics & methodology. In: Edenhofer O, Pichs-Madruga R, Sokona Y, et al, eds. Climate change 2014: mitigation of climate change contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2014.

233 Mills B, Schleich J. Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: an analysis of European countries. *Energy Pol* 2012; **49:** 616–28.

234 Gilligan J, Dietz T, Gardner G, Stern P, Vandenbergh M. The behavioural wedge. *Significance* 2010; **7:** 17–20.

235 Mohareb E, Kennedy C. Scenarios of technology adoption towards low-carbon cities. *Energy Pol* 2014; **66:** 685–93.

236 Verbeek P. Ethiek en technologie: moreel actorschap en subjectiviteit in een technologische cultuur. *Ethische Perspectiven* 2006; **16:** 267–89.

237 International Energy Agency. Energy technology perspectives 2012. Paris: IEA, 2012.

238 International Energy Agency. Coal medium-term market report 2012. Paris: IEA, 2012.

239 Mills E. Weighing the risks of climate change mitigation strategies. *Bull At Sci* 2012; **68:** 67–78.

240 Lowe R. Defining and meeting the carbon constraints of the 21st Century. *Build Res Inform* 2000; **28:** 159–75.

241 Geels F. Technological transitions and system innovations: a co-evolutionary and socio-technical analysis. Cheltenham: Edward Elgar, 2005.

242 Dechezlepretre A, Glachant M, Hascic I, Johnstone N, Meniere Y. Invention and transfer of climate change-mitigation technologies: a global analysis. *Rev Environ Econ Pol* 2011; **5:** 109–30.

243 Karakosta C, Doukas H, Psarras J. Technology transfer through climate change: setting a sustainable energy pattern. *Renew Sustain Energy Rev* 2010; **14:** 1546–57.

244 Jakob M, Steckel J. How climate change mitigation could harm development in poor countries. *Wiley Interdiscip Rev Clim Change* 2014; **5:** 161–68.

245 Chambwera M, Heal G, Dubeux C, et al. Economics of adaptation. In: Field CB, Barros VR, Dokken DJ, et al, eds. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2014: 945–77.

246 Webster PJ. Meteorology: improve weather forecasts for the developing world. *Nature* 2013; **493:** 17–19.

247 WHO Regional Office for Europe. Climate change and health: a tool to estimate health and adaptation costs. Copenhagen: World Health Organization, 2013.

248 WHO Regional Office for Europe. Climate, environment and health action plan and information system: policy monitoring and assessment. Copenhagen: World Health Organzation, 2011.

249 WHO. Global health expenditure database. 2014. http://apps.who.int/nha/database/World_Map/Index/en?id=REPORT_4_WORLD_MAPS&mapType=3&ws=0 (accessed Dec 22, 2014).
250 WHO. World health statistics 2014. http://www.who.int/mediacentre/news/releases/2014/world-health-statistics-2014/en/ (accessed Sept 7, 2014).
251 Organisation of Economic Co-operation and Development. The cost of air pollution: health impacts of road transport. Paris: OECD, 2014.
252 European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: a roadmap for moving to a competitive low carbon economy in 2050. Brussels: European Commission, 2011.
253 International Renewable Energy Agency. REmap 2030: a renewable energy roadmap. Abu Dhabi: IRENA, 2014.
254 West JJ, Smith SJ, Silva RA, et al. Co-benefits of global greenhouse gas mitigation for future air quality and human health. *Nature Clim Chang* 2013; **3:** 885–89.
255 Thompson T, Rausch S, Saari R, Selin N. A systems approach to evaluating the air quality co-benefits of US carbon policies. *Nature Clim Change* 2014; **4:** 917–23.
256 Patz JA, Frumkin H, Holloway T, Vimont DJ, Haines A. Climate change: challenges and opportunities for global health. *JAMA* 2014; **312:** 1565–80.
257 Liddell C, Morris C. Fuel poverty and human health: A review of recent evidence. *Energy Pol* 2010; **38:** 2987–97.
258 Nicol S, Roys M, Davidson M, Ormandy D, Ambrose P. Quantifying the economic cost of unhealthy housing—a case study from England. In: Braubach M, Jacobs DE, Ormandy D, eds. Environmental burden of disease associated with inadequate housing: a method guide to the quantification of health effects of selected housing risks in the WHO European Region. Copenhagen: World Health Organization Regional Office for Europe, 2011: 197–208.
259 Copenhagen Economics. Multiple benefits of investing in energy efficient renovation of buildings: impact on public finances. Copenhagen: Renovate Europe, 2012.
260 International Energy Agency. World energy outlook. Paris: IEA, 2012.
261 The New Climate Economy. Better growth, better climate. New York: The Global Commission on the Economy and Climate, 2014.
262 International Energy Agency. World energy investment outlook. Paris: IEA, 2014.
263 Buchner B, Herve-Mignucci M, Trabacchi C, et al. The global landscape of climate finance. San Francisco: Climate Policy Initiative, 2013.
264 Watkiss P, Downing T. The social cost of carbon: valuation estimates and their use in UK policy. *Integr Assess J* 2008; **8:** 85–105.
265 Grubb M. Planetary economics: energy, climate change and the three domains of sustainable development. London: Routledge, 2014.
266 Arent DJ, Tol RSJ, Faust E, et al. Key economic sectors and services. In: Field CB, Barros VR, Dokken DJ, et al, eds. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2014: 659–708.
267 Stern N. Stern Review on the economics of climate change. London: HM Treasury, 2006.
268 Nordhaus W. A review of the Stern Review on the economics of climate change. *J Econ Lit* 2007; **XLV:** 703–724.
269 Weitzmann M. Fat-tailed uncertainty in the economics of catastrophic climate change. *Rev Environ Econ Policy* 2011; **5:** 275–92.
270 Stern N. The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models. *J Econ Lit* 2013; **51:** 838–59.
271 Goulder L, Williams R. The choice of discount rate for climate change policy evaluation. *Clim Change Econ* 2012; **3:** 18.
272 International Energy Agency. Mind the gap: quantifying principal-agent problems in energy efficiency. Paris: IEA, 2007.
273 European Commission. Energy economic developments in Europe: European economy. Brussels: European Commission, 2014.
274 Capros P, De Vita A, Tasios D, et al. EU Energy, transport and GHG emissions: trends to 2050–reference scenario. Luxembourg: European Commission, 2013.
275 Sovereign Wealth Funds Institute. Fund rankings 2013. http://www.swfinstitute.org/fund-rankings/ (accessed Aug 25, 2014).
276 Fulton M, Capalino R. Investing in the clean trillion: closing the clean energy investment gap. Boston: Ceres, 2014.
277 Kaminker C, Kawanishi O, Stewart F, Caldecott B, Howarth N. Institutional investors and green infrastructure investments: selected case studies. Paris: Organization for Economic Co-operation and Development, 2013.
278 Macmillan I, Prakash I, Shoult R. The cash paradox: how record cash reserves are influencing corporate behaviour. July, 2014. http://dupress.com/articles/excess-cash-growth-strategies/ (accessed Dec 20, 2014).
279 UN. Millennium Development Goal 8, the challenge we face: MDG Gap Task Force Report 2013. New York: United Nations, 2013.
280 Nachmany M, Fankhauser S, Townshend T, et al. The GLOBE climate legislation study: a review of climate legislation study: a review of climate change legislation in 66 countries. London: GLOBE International and the Grantham Research Institute, London School of Economics, 2014.
281 World Bank Group. State and trends of carbon pricing. Washington, DC: World Bank, 2014.
282 Parry IWH, Heine D, Lis E. Getting the prices right: from principle to practice. Washington, DC: International Monetary Fund, 2014.
283 Schöb R. The Double Dividend Hypothesis of Environmental Taxes. Working Paper no.946. Munich: Centre for Economic Studies & the ifo Group, 2003.
284 International Energy Agency. World Energy Outlook. Paris; 2010.
285 Victor D. The politics of fossil-fuel subsidies: global subsidies initiative & the international institute for sustainable development. Geneva: Global Subsidies Initiative, International Institute for Sustainable Development, 2009.
286 International Monetary Fund. World economic outlook. Washington, DC: IMF, 2010.
287 Mazzucato M. The entrepreneurial state: debunking public *vs* private sector myths. London: Anthem Press, 2013.
288 Ravenel P, Brites J, Dichamp G, Monteillet C, Yaker MF, Enmanuel CA. The impacts of sustainable public procurement: eight illustrative case studies. Paris: UNEP Sustainable Consumption and Production Branch, 2012.
289 UN Framework Convention on Climate Change (UNFCCC). United Nations Framework Convention on Climate Change. Geneva: IUCC, 1992.
290 Depledge J. The global climate change regime. In: Ekins P, Bradshaw M, Watson J, eds. Global energy: issues, potentials and policy implications. Oxford: Oxford University Press, 2015.
291 Bodansky D. The United Nations Framework Convention on Climate Change: a commentary. *Yale J Int Law* 1993; **18:** 451–558.
292 Susskind L. Environmental diplomacy, negotiating more effective global agreements. New York: Oxford University Press, 1994.
293 Hulme M. Why we disagree about climate change: understanding controversy, inaction and opportunity. Cambridge: Cambridge University Press, 2009.
294 Rapley CG, de Meyer K, Carney J, et al. Time for change? climate science reconsidered. Report of the UCL Policy Commission on Communicating Climate Science. London: UCL, 2014.
295 Spence A, Poortinga W, Pidgeon N. The psychological distance of climate change. *Risk Anal* 2012; **32:** 957–72.
296 Unruh GC. Understanding carbon lock-in. *Energy Pol* 2000; **28:** 817–30.
297 Brulle R. Institutionalizing delay: foundation funding and the creation of US climate change counter-movement organizations. *Clim Change* 2014; **122:** 681–94.
298 Bulkeley H. Betsill. M. Cities and climate change: urban sustainability and global environmental governance. New York: Routledge, 2003.
299 Boutiligier S. Cities, networks, and global environmental governance. London: Routledge, 2013.
300 Roman M. Governing from the middle: the C40 Cities Leadership Group. *Corp Gov* 2010; **10:** 73–84.
301 Curtis S. Global Cities and the Transformation of the International System. *Rev Int Stud* 2011; **37:** 1923–47.

302 Gordon DJ. Between local innovation and global impact: cities, networks, and the governance of climate change. *Can Foreign Pol J* 2013; **19:** 288–307.
303 Rvd P Melissen J. City diplomacy: the expanding role of cities in international politics. The Hague: Netherlands Institute of International Relations, 2007.
304 Center PR. Climate change and financial instability seen as top global threats. Washington, DC: Pew Research Center, 2013.
305 Darier É, Schüle R. 'Think globally, act locally'? Climate change and public participation in Manchester and Frankfurt. *Local Environ* 1999; **4:** 317–29.
306 Poortinga W, Pidgeon NF. Exploring the dimensionality of trust in risk regulation. *Risk Anal* 2003; **23:** 961–72.
307 Pretty J. The consumption of a finite planet: well-being, convergence, divergence and the nascent green economy. *Environ Resour Econ* 2013; **55:** 475–99.
308 Hulme M. Reducing the future to climate: a story of climate determinism and reductionism. *Osiris* 2011a; **26:** 245–66.
309 Webb J. Climate change and society: the chimera of behaviour change technologies. *Sociology* 2012; **46:** 109–25.
310 Wolf J, Moser SC. Individual understandings, perceptions, and engagement with climate change: insights from in–depth studies across the world. *Wiley Interdiscip Rev Clim Chang* 2011; **2:** 547–69.
311 Höijer B. Emotional anchoring and objectification in the media reporting on climate change. *Public Underst Sci* 2010; **19:** 717–31.
312 Witte K, Allen M. A meta-analysis of fear appeals: implications for effective public health campaigns. *Health Educ Behav* 2000; **27:** 591–615.
313 Markowitz EM, Shariff AF. Climate change and moral judgement. *Nature Climate Change* 2012; **2:** 243–47.
314 Green D, Billy J, Tapim A. Indigenous Australians' knowledge of weather and climate. *Clim Change* 2010; **100:** 337–54.
315 Giddens A. The politics of climate change. Cambridge: John Wiley and Sons, 2009.
316 Vignola R, Klinsky S, Tam J, McDaniels T. Public perception, knowledge and policy support for mitigation and adaption to climate change in Costa Rica: comparisons with North American and European studies. *Mitig Adapt Strategies Glob Change* 2013; **18:** 303–23.
317 World Bank Group. Public attitudes toward climate change: findings from a multi-country poll. Background note to the world development report 2010. Washington, DC: World Bank, 2009.
318 Marteau TM, Hollands GJ, Fletcher PC. Changing human behavior to prevent disease: the importance of targeting automatic processes. *Science* 2012; **337:** 1492–95.

This is Exhibit "E" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018

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A Commissioner for taking Affidavits within British Columbia

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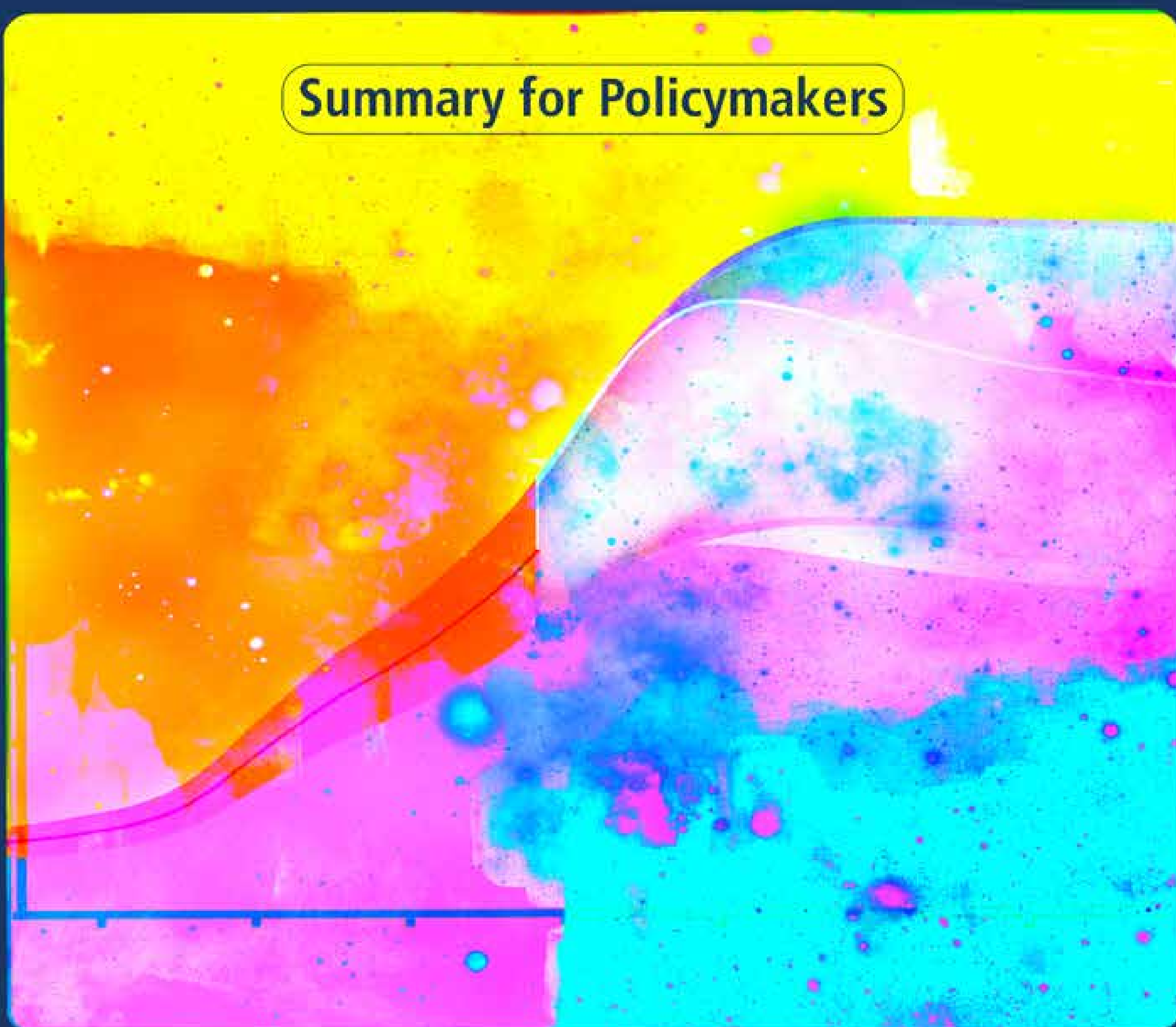
INTERGOVERNMENTAL PANEL ON climate change

Global Warming of 1.5°C

An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty



WG I WG II WG III

WMO UNEP

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Summary for Policymakers

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Summary for Policymakers

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Introduction

This Report responds to the invitation for IPCC '... to provide a Special Report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways' contained in the Decision of the 21st Conference of Parties of the United Nations Framework Convention on Climate Change to adopt the Paris Agreement.[1]

The IPCC accepted the invitation in April 2016, deciding to prepare this Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

This Summary for Policymakers (SPM) presents the key findings of the Special Report, based on the assessment of the available scientific, technical and socio-economic literature[2] relevant to global warming of 1.5°C and for the comparison between global warming of 1.5°C and 2°C above pre-industrial levels. The level of confidence associated with each key finding is reported using the IPCC calibrated language.[3] The underlying scientific basis of each key finding is indicated by references provided to chapter elements. In the SPM, knowledge gaps are identified associated with the underlying chapters of the Report.

A. Understanding Global Warming of 1.5°C[4]

A.1 Human activities are estimated to have caused approximately 1.0°C of global warming[5] above pre-industrial levels, with a *likely* range of 0.8°C to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*) (Figure SPM.1) {1.2}

A.1.1 Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (*likely* between 0.75°C and 0.99°C)[6] higher than the average over the 1850–1900 period (*very high confidence*). Estimated anthropogenic global warming matches the level of observed warming to within ±20% (*likely range*). Estimated anthropogenic global warming is currently increasing at 0.2°C (*likely* between 0.1°C and 0.3°C) per decade due to past and ongoing emissions (*high confidence*). {1.2.1, Table 1.1, 1.2.4}

A.1.2 Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic. Warming is generally higher over land than over the ocean. (*high confidence*) {1.2.1, 1.2.2, Figure 1.1, Figure 1.3, 3.3.1, 3.3.2}

A.1.3 Trends in intensity and frequency of some climate and weather extremes have been detected over time spans during which about 0.5°C of global warming occurred (*medium confidence*). This assessment is based on several lines of evidence, including attribution studies for changes in extremes since 1950. {3.3.1, 3.3.2, 3.3.3}

1 Decision 1/CP.21, paragraph 21.

2 The assessment covers literature accepted for publication by 15 May 2018.

3 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with AR5.

4 See also Box SPM.1: Core Concepts Central to this Special Report.

5 Present level of global warming is defined as the average of a 30-year period centred on 2017 assuming the recent rate of warming continues.

6 This range spans the four available peer-reviewed estimates of the observed GMST change and also accounts for additional uncertainty due to possible short-term natural variability. {1.2.1, Table 1.1}

A.2 Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (*high confidence*), but these emissions alone are *unlikely* to cause global warming of 1.5°C (*medium confidence*). (Figure SPM.1) {1.2, 3.3, Figure 1.5}

A.2.1 Anthropogenic emissions (including greenhouse gases, aerosols and their precursors) up to the present are *unlikely* to cause further warming of more than 0.5°C over the next two to three decades (*high confidence*) or on a century time scale (*medium confidence*). {1.2.4, Figure 1.5}

A.2.2 Reaching and sustaining net zero global anthropogenic CO_2 emissions and declining net non-CO_2 radiative forcing would halt anthropogenic global warming on multi-decadal time scales (*high confidence*). The maximum temperature reached is then determined by cumulative net global anthropogenic CO_2 emissions up to the time of net zero CO_2 emissions (*high confidence*) and the level of non-CO_2 radiative forcing in the decades prior to the time that maximum temperatures are reached (*medium confidence*). On longer time scales, sustained net negative global anthropogenic CO_2 emissions and/or further reductions in non-CO_2 radiative forcing may still be required to prevent further warming due to Earth system feedbacks and to reverse ocean acidification (*medium confidence*) and will be required to minimize sea level rise (*high confidence*). {Cross-Chapter Box 2 in Chapter 1, 1.2.3, 1.2.4, Figure 1.4, 2.2.1, 2.2.2, 3.4.4.8, 3.4.5.1, 3.6.3.2}

A.3 Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (*high confidence*). These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (*high confidence*). (Figure SPM.2) {1.3, 3.3, 3.4, 5.6}

A.3.1 Impacts on natural and human systems from global warming have already been observed (*high confidence*). Many land and ocean ecosystems and some of the services they provide have already changed due to global warming (*high confidence*). (Figure SPM.2) {1.4, 3.4, 3.5}

A.3.2 Future climate-related risks depend on the rate, peak and duration of warming. In the aggregate, they are larger if global warming exceeds 1.5°C before returning to that level by 2100 than if global warming gradually stabilizes at 1.5°C, especially if the peak temperature is high (e.g., about 2°C) (*high confidence*). Some impacts may be long-lasting or irreversible, such as the loss of some ecosystems (*high confidence*). {3.2, 3.4.4, 3.6.3, Cross-Chapter Box 8 in Chapter 3}

A.3.3 Adaptation and mitigation are already occurring (*high confidence*). Future climate-related risks would be reduced by the upscaling and acceleration of far-reaching, multilevel and cross-sectoral climate mitigation and by both incremental and transformational adaptation (*high confidence*). {1.2, 1.3, Table 3.5, 4.2.2, Cross-Chapter Box 9 in Chapter 4, Box 4.2, Box 4.3, Box 4.6, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.4.1, 4.4.4, 4.4.5, 4.5.3}

SPM

Cumulative emissions of CO_2 and future non-CO_2 radiative forcing determine the probability of limiting warming to 1.5°C

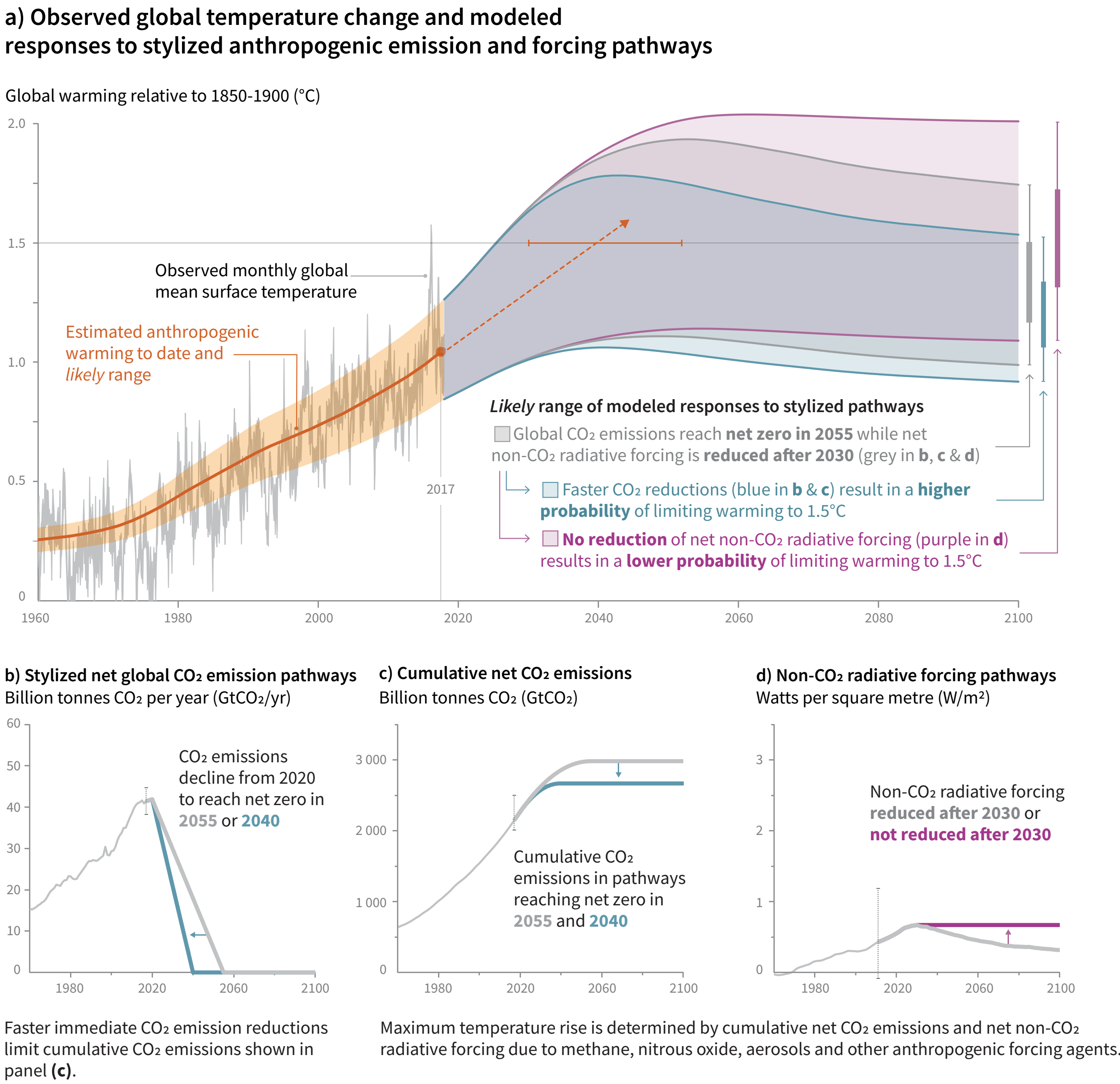

Figure SPM.1 | Panel a: Observed monthly global mean surface temperature (GMST, grey line up to 2017, from the HadCRUT4, GISTEMP, Cowtan–Way, and NOAA datasets) change and estimated anthropogenic global warming (solid orange line up to 2017, with orange shading indicating assessed *likely* range). Orange dashed arrow and horizontal orange error bar show respectively the central estimate and *likely* range of the time at which 1.5°C is reached if the current rate of warming continues. The grey plume on the right of panel a shows the *likely* range of warming responses, computed with a simple climate model, to a stylized pathway (hypothetical future) in which net CO_2 emissions (grey line in panels b and c) decline in a straight line from 2020 to reach net zero in 2055 and net non-CO_2 radiative forcing (grey line in panel d) increases to 2030 and then declines. The blue plume in panel a) shows the response to faster CO_2 emissions reductions (blue line in panel b), reaching net zero in 2040, reducing cumulative CO_2 emissions (panel c). The purple plume shows the response to net CO_2 emissions declining to zero in 2055, with net non-CO_2 forcing remaining constant after 2030. The vertical error bars on right of panel a) show the *likely* ranges (thin lines) and central terciles (33rd – 66th percentiles, thick lines) of the estimated distribution of warming in 2100 under these three stylized pathways. Vertical dotted error bars in panels b, c and d show the *likely* range of historical annual and cumulative global net CO_2 emissions in 2017 (data from the Global Carbon Project) and of net non-CO_2 radiative forcing in 2011 from AR5, respectively. Vertical axes in panels c and d are scaled to represent approximately equal effects on GMST. {1.2.1, 1.2.3, 1.2.4, 2.3, Figure 1.2 and Chapter 1 Supplementary Material, Cross-Chapter Box 2 in Chapter 1}

B. Projected Climate Change, Potential Impacts and Associated Risks

B.1 Climate models project robust[7] differences in regional climate characteristics between present-day and global warming of 1.5°C,[8] and between 1.5°C and 2°C.[8] These differences include increases in: mean temperature in most land and ocean regions (*high confidence*), hot extremes in most inhabited regions (*high confidence*), heavy precipitation in several regions (*medium confidence*), and the probability of drought and precipitation deficits in some regions (*medium confidence*). {3.3}

B.1.1 Evidence from attributed changes in some climate and weather extremes for a global warming of about 0.5°C supports the assessment that an additional 0.5°C of warming compared to present is associated with further detectable changes in these extremes (*medium confidence*). Several regional changes in climate are assessed to occur with global warming up to 1.5°C compared to pre-industrial levels, including warming of extreme temperatures in many regions (*high confidence*), increases in frequency, intensity, and/or amount of heavy precipitation in several regions (*high confidence*), and an increase in intensity or frequency of droughts in some regions (*medium confidence*). {3.2, 3.3.1, 3.3.2, 3.3.3, 3.3.4, Table 3.2}

B.1.2 Temperature extremes on land are projected to warm more than GMST (*high confidence*): extreme hot days in mid-latitudes warm by up to about 3°C at global warming of 1.5°C and about 4°C at 2°C, and extreme cold nights in high latitudes warm by up to about 4.5°C at 1.5°C and about 6°C at 2°C (*high confidence*). The number of hot days is projected to increase in most land regions, with highest increases in the tropics (*high confidence*). {3.3.1, 3.3.2, Cross-Chapter Box 8 in Chapter 3}

B.1.3 Risks from droughts and precipitation deficits are projected to be higher at 2°C compared to 1.5°C of global warming in some regions (*medium confidence*). Risks from heavy precipitation events are projected to be higher at 2°C compared to 1.5°C of global warming in several northern hemisphere high-latitude and/or high-elevation regions, eastern Asia and eastern North America (*medium confidence)*. Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C global warming (*medium confidence*). There is generally *low confidence* in projected changes in heavy precipitation at 2°C compared to 1.5°C in other regions. Heavy precipitation when aggregated at global scale is projected to be higher at 2°C than at 1.5°C of global warming (*medium confidence*). As a consequence of heavy precipitation, the fraction of the global land area affected by flood hazards is projected to be larger at 2°C compared to 1.5°C of global warming (*medium confidence*). {3.3.1, 3.3.3, 3.3.4, 3.3.5, 3.3.6}

B.2 By 2100, global mean sea level rise is projected to be around 0.1 metre lower with global warming of 1.5°C compared to 2°C (*medium confidence*). Sea level will continue to rise well beyond 2100 (*high confidence*), and the magnitude and rate of this rise depend on future emission pathways. A slower rate of sea level rise enables greater opportunities for adaptation in the human and ecological systems of small islands, low-lying coastal areas and deltas (*medium confidence*). {3.3, 3.4, 3.6}

B.2.1 Model-based projections of global mean sea level rise (relative to 1986–2005) suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5°C of global warming, 0.1 m (0.04–0.16 m) less than for a global warming of 2°C (*medium confidence*). A reduction of 0.1 m in global sea level rise implies that up to 10 million fewer people would be exposed to related risks, based on population in the year 2010 and assuming no adaptation (*medium confidence*). {3.4.4, 3.4.5, 4.3.2}

B.2.2 Sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century (*high confidence*). Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-metre rise in sea level over hundreds to thousands of years. These instabilities could be triggered at around 1.5°C to 2°C of global warming (*medium confidence*). (Figure SPM.2) {3.3.9, 3.4.5, 3.5.2, 3.6.3, Box 3.3}

7 Robust is here used to mean that at least two thirds of climate models show the same sign of changes at the grid point scale, and that differences in large regions are statistically significant.

8 Projected changes in impacts between different levels of global warming are determined with respect to changes in global mean surface air temperature.

B.2.3 Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems, including increased saltwater intrusion, flooding and damage to infrastructure (*high confidence*). Risks associated with sea level rise are higher at 2°C compared to 1.5°C. The slower rate of sea level rise at global warming of 1.5°C reduces these risks, enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems and infrastructure reinforcement (*medium confidence*). (Figure SPM.2) {3.4.5, Box 3.5}

B.3 On land, impacts on biodiversity and ecosystems, including species loss and extinction, are projected to be lower at 1.5°C of global warming compared to 2°C. Limiting global warming to 1.5°C compared to 2°C is projected to lower the impacts on terrestrial, freshwater and coastal ecosystems and to retain more of their services to humans (*high confidence*). (Figure SPM.2) {3.4, 3.5, Box 3.4, Box 4.2, Cross-Chapter Box 8 in Chapter 3}

B.3.1 Of 105,000 species studied,[9] 6% of insects, 8% of plants and 4% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 1.5°C, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2°C (*medium confidence*). Impacts associated with other biodiversity-related risks such as forest fires and the spread of invasive species are lower at 1.5°C compared to 2°C of global warming (*high confidence*). {3.4.3, 3.5.2}

B.3.2 Approximately 4% (interquartile range 2–7%) of the global terrestrial land area is projected to undergo a transformation of ecosystems from one type to another at 1ºC of global warming, compared with 13% (interquartile range 8–20%) at 2°C (*medium confidence*). This indicates that the area at risk is projected to be approximately 50% lower at 1.5°C compared to 2°C (*medium confidence*). {3.4.3.1, 3.4.3.5}

B.3.3 High-latitude tundra and boreal forests are particularly at risk of climate change-induced degradation and loss, with woody shrubs already encroaching into the tundra (*high confidence*) and this will proceed with further warming. Limiting global warming to 1.5°C rather than 2°C is projected to prevent the thawing over centuries of a permafrost area in the range of 1.5 to 2.5 million km^2 (*medium confidence*). {3.3.2, 3.4.3, 3.5.5}

B.4 Limiting global warming to 1.5°C compared to 2ºC is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (*high confidence*). Consequently, limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans, as illustrated by recent changes to Arctic sea ice and warm-water coral reef ecosystems (*high confidence*). {3.3, 3.4, 3.5, Box 3.4, Box 3.5}

B.4.1 There is *high confidence* that the probability of a sea ice-free Arctic Ocean during summer is substantially lower at global warming of 1.5°C when compared to 2°C. With 1.5°C of global warming, one sea ice-free Arctic summer is projected per century. This likelihood is increased to at least one per decade with 2°C global warming. Effects of a temperature overshoot are reversible for Arctic sea ice cover on decadal time scales (*high confidence*). {3.3.8, 3.4.4.7}

B.4.2 Global warming of 1.5°C is projected to shift the ranges of many marine species to higher latitudes as well as increase the amount of damage to many ecosystems. It is also expected to drive the loss of coastal resources and reduce the productivity of fisheries and aquaculture (especially at low latitudes). The risks of climate-induced impacts are projected to be higher at 2°C than those at global warming of 1.5°C (*high confidence*). Coral reefs, for example, are projected to decline by a further 70–90% at 1.5°C (*high confidence*) with larger losses (>99%) at 2ºC (*very high confidence*). The risk of irreversible loss of many marine and coastal ecosystems increases with global warming, especially at 2°C or more (*high confidence*). {3.4.4, Box 3.4}

9 Consistent with earlier studies, illustrative numbers were adopted from one recent meta-study.

This is Exhibit "F" referred to in the
Affidavit of Paul Kershaw, sworn before me at
North Vancouver this 18th day of December,
2018.

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A Commissioner for taking Affidavits
within British Columbia

PERSPECTIVE

Trajectories of the Earth System in the Anthropocene

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We explore the risk that self-reinforcing feedbacks could push the Earth System toward a planetary threshold that, if crossed, could prevent stabilization of the climate at intermediate temperature rises and cause continued warming on a "Hothouse Earth" pathway even as human emissions are reduced. Crossing the threshold would lead to a much higher global average temperature than any interglacial in the past 1.2 million years and to sea levels significantly higher than at any time in the Holocene. We examine the evidence that such a threshold might exist and where it might be. If the threshold is crossed, the resulting trajectory would likely cause serious disruptions to ecosystems, society, and economies. Collective human action is required to steer the Earth System away from a potential threshold and stabilize it in a habitable interglacial-like state. Such action entails stewardship of the entire Earth System—biosphere, climate, and societies—and could include decarbonization of the global economy, enhancement of biosphere carbon sinks, behavioral changes, technological innovations, new governance arrangements, and transformed social values.

Earth System trajectories | climate change | Anthropocene | biosphere feedbacks | tipping elements

The Anthropocene is a proposed new geological epoch (1) based on the observation that human impacts on essential planetary processes have become so profound (2) that they have driven the Earth out of the Holocene epoch in which agriculture, sedentary communities, and eventually, socially and technologically complex human societies developed. The formalization of the Anthropocene as a new geological epoch is being considered by the stratigraphic community (3), but regardless of the outcome of that process, it is becoming apparent that Anthropocene conditions transgress Holocene conditions in several respects (2). The knowledge that human activity now rivals geological forces in influencing the trajectory of the Earth System has important implications for both Earth System science and societal decision making. While recognizing that different societies around the world have contributed differently and unequally to pressures on the Earth System and will have varied capabilities to alter future trajectories (4), the sum total of human impacts on the system needs to be taken into account for analyzing future trajectories of the Earth System.

Here, we explore potential future trajectories of the Earth System by addressing the following questions.

> Is there a planetary threshold in the trajectory of the Earth System that, if crossed, could prevent stabilization in a range of intermediate temperature rises?
>
> Given our understanding of geophysical and biosphere feedbacks intrinsic to the Earth System, where might such a threshold be?

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If a threshold is crossed, what are the implications, especially for the wellbeing of human societies?

What human actions could create a pathway that would steer the Earth System away from the potential threshold and toward the maintenance of interglacial-like conditions?

Addressing these questions requires a deep integration of knowledge from biogeophysical Earth System science with that from the social sciences and humanities on the development and functioning of human societies (5). Integrating the requisite knowledge can be difficult, especially in light of the formidable range of timescales involved. Increasingly, concepts from complex systems analysis provide a framework that unites the diverse fields of inquiry relevant to the Anthropocene (6). Earth System dynamics can be described, studied, and understood in terms of trajectories between alternate states separated by thresholds that are controlled by nonlinear processes, interactions, and feedbacks. Based on this framework, we argue that social and technological trends and decisions occurring over the next decade or two could significantly influence the trajectory of the Earth System for tens to hundreds of thousands of years and potentially lead to conditions that resemble planetary states that were last seen several millions of years ago, conditions that would be inhospitable to current human societies and to many other contemporary species.

Risk of a Hothouse Earth Pathway

Limit Cycles and Planetary Thresholds. The trajectory of the Earth System through the Late Quaternary, particularly the Holocene, provides the context for exploring the human-driven changes of the Anthropocene and the future trajectories of the system (*SI Appendix* has more detail). Fig. 1 shows a simplified representation of complex Earth System dynamics, where the physical climate system is subjected to the effects of slow changes in Earth's orbit and inclination. Over the Late Quaternary (past 1.2 million years), the system has remained bounded between glacial and interglacial extremes. Not every glacial–interglacial cycle of the past million years follows precisely the same trajectory (7), but the cycles follow the same overall pathway (a term that we use to refer to a family of broadly similar trajectories). The full glacial and interglacial states and the ca. 100,000-years oscillations between them in the Late Quaternary loosely constitute limit cycles (technically, the asymptotic dynamics of ice ages are best modeled as pullback attractors in a nonautonomous dynamical system). This limit cycle is shown in a schematic fashion in blue in Fig. 1, *Lower Left* using temperature and sea level as the axes. The Holocene is represented by the top of the limit cycle loop near the label A.

The current position of the Earth System in the Anthropocene is shown in Fig. 1, *Upper Right* by the small ball on the pathway that leads away from the glacial–interglacial limit cycle. In Fig. 2, a stability landscape, the current position of the Earth System is represented by the globe at the end of the solid arrow in the deepening Anthropocene basin of attraction.

The Anthropocene represents the beginning of a very rapid human-driven trajectory of the Earth System away from the glacial–interglacial limit cycle toward new, hotter climatic conditions and a profoundly different biosphere (2, 8, 9) (*SI Appendix*). The current position, at over 1 °C above a preindustrial baseline (10), is nearing the upper envelope of interglacial conditions over the past 1.2 million years (*SI Appendix*, Table S1). More importantly, the rapid trajectory of the climate system over the past half-century along with technological lock in and socioeconomic

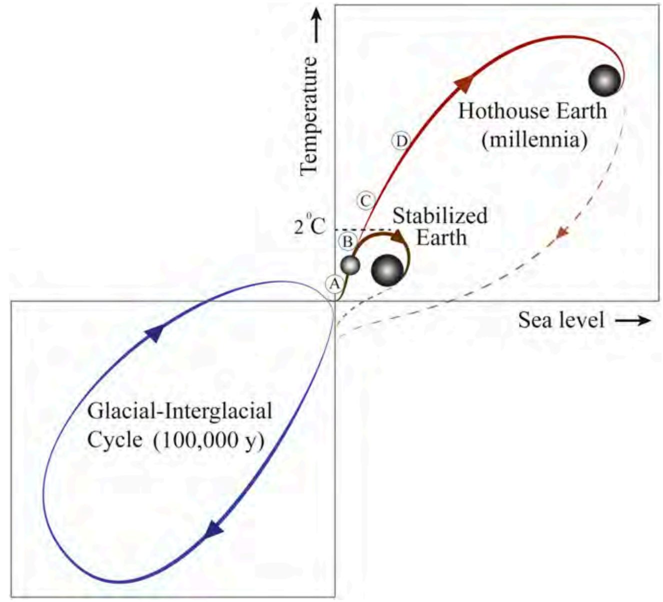

Fig. 1. **A schematic illustration of possible future pathways of the climate against the background of the typical glacial–interglacial cycles (*Lower Left*). The interglacial state of the Earth System is at the top of the glacial–interglacial cycle, while the glacial state is at the bottom. Sea level follows temperature change relatively slowly through thermal expansion and the melting of glaciers and ice caps. The horizontal line in the middle of the figure represents the preindustrial temperature level, and the current position of the Earth System is shown by the small sphere on the red line close to the divergence between the Stabilized Earth and Hothouse Earth pathways. The proposed planetary threshold at ∼2 °C above the preindustrial level is also shown. The letters along the Stabilized Earth/Hothouse Earth pathways represent four time periods in Earth's recent past that may give insights into positions along these pathways (*SI Appendix*): A, Mid-Holocene; B, Eemian; C, Mid-Pliocene; and D, Mid-Miocene. Their positions on the pathway are approximate only. Their temperature ranges relative to preindustrial are given in *SI Appendix*, Table S1.**

inertia in human systems commit the climate system to conditions beyond the envelope of past interglacial conditions. We, therefore, suggest that the Earth System may already have passed one "fork in the road" of potential pathways, a bifurcation (near A in Fig. 1) taking the Earth System out of the next glaciation cycle (11).

In the future, the Earth System could potentially follow many trajectories (12, 13), often represented by the large range of global temperature rises simulated by climate models (14). In most analyses, these trajectories are largely driven by the amount of greenhouse gases that human activities have already emitted and will continue to emit into the atmosphere over the rest of this century and beyond—with a presumed quasilinear relationship between cumulative carbon dioxide emissions and global temperature rise (14). However, here we suggest that biogeophysical feedback processes within the Earth System coupled with direct human degradation of the biosphere may play a more important role than normally assumed, limiting the range of potential future trajectories and potentially eliminating the possibility of the intermediate trajectories. We argue that there is a significant risk that these internal dynamics, especially strong nonlinearities in feedback processes, could become an important or perhaps, even dominant factor in steering the trajectory that the Earth System actually follows over coming centuries.

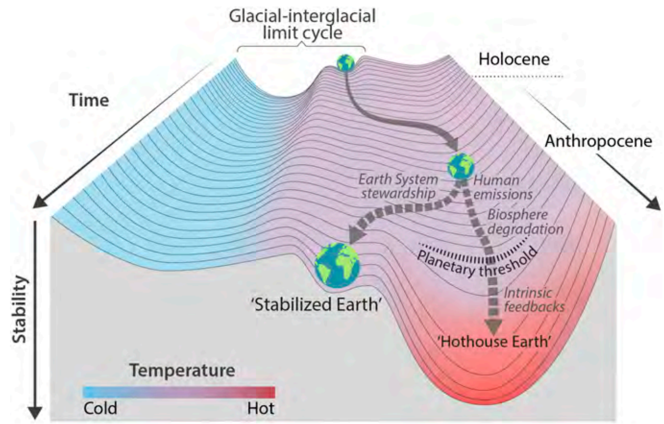

Fig. 2. Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene. The fork in the road in Fig. 1 is shown here as the two divergent pathways of the Earth System in the future (broken arrows). Currently, the Earth System is on a Hothouse Earth pathway driven by human emissions of greenhouse gases and biosphere degradation toward a planetary threshold at ∼2 °C (horizontal broken line at 2 °C in Fig. 1), beyond which the system follows an essentially irreversible pathway driven by intrinsic biogeophysical feedbacks. The other pathway leads to Stabilized Earth, a pathway of Earth System stewardship guided by human-created feedbacks to a quasistable, human-maintained basin of attraction. "Stability" (vertical axis) is defined here as the inverse of the potential energy of the system. Systems in a highly stable state (deep valley) have low potential energy, and considerable energy is required to move them out of this stable state. Systems in an unstable state (top of a hill) have high potential energy, and they require only a little additional energy to push them off the hill and down toward a valley of lower potential energy.

This risk is represented in Figs. 1 and 2 by a planetary threshold (horizontal broken line in Fig. 1 on the Hothouse Earth pathway around 2 °C above preindustrial temperature). Beyond this threshold, intrinsic biogeophysical feedbacks in the Earth System (*Biogeophysical Feedbacks*) could become the dominant processes controlling the system's trajectory. Precisely where a potential planetary threshold might be is uncertain (15, 16). We suggest 2 °C because of the risk that a 2 °C warming could activate important tipping elements (12, 17), raising the temperature further to activate other tipping elements in a domino-like cascade that could take the Earth System to even higher temperatures (*Tipping Cascades*). Such cascades comprise, in essence, the dynamical process that leads to thresholds in complex systems (section 4.2 in ref. 18).

This analysis implies that, even if the Paris Accord target of a 1.5 °C to 2.0 °C rise in temperature is met, we cannot exclude the risk that a cascade of feedbacks could push the Earth System irreversibly onto a "Hothouse Earth" pathway. The challenge that humanity faces is to create a "Stabilized Earth" pathway that steers the Earth System away from its current trajectory toward the threshold beyond which is Hothouse Earth (Fig. 2). The human-created Stabilized Earth pathway leads to a basin of attraction that is not likely to exist in the Earth System's stability landscape without human stewardship to create and maintain it. Creating such a pathway and basin of attraction requires a fundamental change in the role of humans on the planet. This stewardship role requires deliberate and sustained action to become an integral, adaptive part of Earth System dynamics, creating feedbacks that keep the system on a Stabilized Earth pathway (*Alternative Stabilized Earth Pathway*).

We now explore this critical question in more detail by considering the relevant biogeophysical feedbacks (*Biogeophysical Feedbacks*) and the risk of tipping cascades (*Tipping Cascades*).

Biogeophysical Feedbacks. The trajectory of the Earth System is influenced by biogeophysical feedbacks within the system that can maintain it in a given state (negative feedbacks) and those that can amplify a perturbation and drive a transition to a different state (positive feedbacks). Some of the key negative feedbacks that could maintain the Earth System in Holocene-like conditions—notably, carbon uptake by land and ocean systems—are weakening relative to human forcing (19), increasing the risk that positive feedbacks could play an important role in determining the Earth System's trajectory. Table 1 summarizes carbon cycle feedbacks that could accelerate warming, while *SI Appendix*, Table S2 describes in detail a more complete set of biogeophysical feedbacks that can be triggered by forcing levels likely to be reached within the rest of the century.

Most of the feedbacks can show both continuous responses and tipping point behavior in which the feedback process becomes self-perpetuating after a critical threshold is crossed; subsystems exhibiting this behavior are often called "tipping elements" (17). The type of behavior—continuous response or tipping point/abrupt change—can depend on the magnitude or the rate of forcing, or both. Many feedbacks will show some gradual change before the tipping point is reached.

A few of the changes associated with the feedbacks are reversible on short timeframes of 50–100 years (e.g., change in Arctic sea ice extent with a warming or cooling of the climate; Antarctic sea ice may be less reversible because of heat accumulation in the Southern Ocean), but most changes are largely irreversible on timeframes that matter to contemporary societies (e.g., loss of permafrost carbon). A few of the feedbacks do not have apparent thresholds (e.g., change in the land and ocean physiological carbon sinks, such as increasing carbon uptake due

Table 1. Carbon cycle feedbacks in the Earth System that could accelerate global warming

Feedback	Strength of feedback by 2100,* °C	Refs. (*SI Appendix*, Table S2 has more details)
Permafrost thawing	0.09 (0.04–0.16)	20–23
Relative weakening of land and ocean physiological C sinks	0.25 (0.13–0.37)	24
Increased bacterial respiration in the ocean	0.02	25, 26
Amazon forest dieback	0.05 (0.03–0.11)	27
Boreal forest dieback	0.06 (0.02–0.10)	28
Total	0.47 (0.24–0.66)	

The strength of the feedback is estimated at 2100 for an ∼2 °C warming.
*The additional temperature rise (degrees Celsius) by 2100 arising from the feedback.

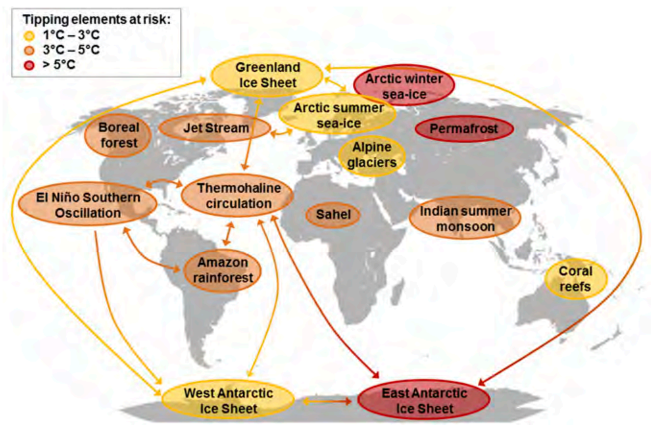

Fig. 3. Global map of potential tipping cascades. The individual tipping elements are color- coded according to estimated thresholds in global average surface temperature (tipping points) (12, 34). Arrows show the potential interactions among the tipping elements based on expert elicitation that could generate cascades. Note that, although the risk for tipping (loss of) the East Antarctic Ice Sheet is proposed at >5 °C, some marine-based sectors in East Antarctica may be vulnerable at lower temperatures (35–38).

to the CO_2 fertilization effect or decreasing uptake due to a decrease in rainfall). For some of the tipping elements, crossing the tipping point could trigger an abrupt, nonlinear response (e.g., conversion of large areas of the Amazon rainforest to a savanna or seasonally dry forest), while for others, crossing the tipping point would lead to a more gradual but self-perpetuating response (large-scale loss of permafrost). There could also be considerable lags after the crossing of a threshold, particularly for those tipping elements that involve the melting of large masses of ice. However, in some cases, ice loss can be very rapid when occurring as massive iceberg outbreaks (e.g., Heinrich Events).

For some feedback processes, the magnitude—and even the direction—depend on the rate of climate change. If the rate of climate change is small, the shift in biomes can track the change in temperature/moisture, and the biomes may shift gradually, potentially taking up carbon from the atmosphere as the climate warms and atmospheric CO_2 concentration increases. However, if the rate of climate change is too large or too fast, a tipping point can be crossed, and a rapid biome shift may occur via extensive disturbances (e.g., wildfires, insect attacks, droughts) that can abruptly remove an existing biome. In some terrestrial cases, such as widespread wildfires, there could be a pulse of carbon to the atmosphere, which if large enough, could influence the trajectory of the Earth System (29).

Varying response rates to a changing climate could lead to complex biosphere dynamics with implications for feedback processes. For example, delays in permafrost thawing would most likely delay the projected northward migration of boreal forests (30), while warming of the southern areas of these forests could result in their conversion to steppe grasslands of significantly lower carbon storage capacity. The overall result would be a positive feedback to the climate system.

The so-called "greening" of the planet, caused by enhanced plant growth due to increasing atmospheric CO_2 concentration (31), has increased the land carbon sink in recent decades (32). However, increasing atmospheric CO_2 raises temperature, and hotter leaves photosynthesize less well. Other feedbacks are also involved—for instance, warming the soil increases microbial respiration, releasing CO_2 back into the atmosphere.

Our analysis focuses on the strength of the feedback between now and 2100. However, several of the feedbacks that show negligible or very small magnitude by 2100 could nevertheless be triggered well before then, and they could eventually generate significant feedback strength over longer timeframes—centuries and even millennia—and thus, influence the long-term trajectory of the Earth System. These feedback processes include permafrost thawing, decomposition of ocean methane hydrates, increased marine bacterial respiration, and loss of polar ice sheets accompanied by a rise in sea levels and potential amplification of temperature rise through changes in ocean circulation (33).

Tipping Cascades. Fig. 3 shows a global map of some potential tipping cascades. The tipping elements fall into three clusters based on their estimated threshold temperature (12, 17, 39). Cascades could be formed when a rise in global temperature reaches the level of the lower-temperature cluster, activating tipping elements, such as loss of the Greenland Ice Sheet or Arctic sea ice. These tipping elements, along with some of the non-tipping element feedbacks (e.g., gradual weakening of land and ocean physiological carbon sinks), could push the global average temperature even higher, inducing tipping in mid- and higher-temperature clusters. For example, tipping (loss) of the Greenland Ice Sheet could trigger a critical transition in the Atlantic Meridional Ocean Circulation (AMOC), which could together, by causing sea-level rise and Southern Ocean heat accumulation, accelerate ice loss from the East Antarctic Ice Sheet (32, 40) on timescales of centuries (41).

Observations of past behavior support an important contribution of changes in ocean circulation to such feedback cascades. During previous glaciations, the climate system flickered between two states that seem to reflect changes in convective activity in the Nordic seas and changes in the activity of the AMOC. These variations caused typical temperature response patterns called the "bipolar seesaw" (42–44). During extremely cold conditions in the north, heat accumulated in the Southern Ocean, and Antarctica warmed. Eventually, the heat made its way north and generated subsurface warming that may have been instrumental in destabilizing the edges of the Northern Hemisphere ice sheets (45).

If Greenland and the West Antarctic Ice Sheet melt in the future, the freshening and cooling of nearby surface waters will have significant effects on the ocean circulation. While the probability of significant circulation changes is difficult to quantify, climate model simulations suggest that freshwater inputs compatible with current rates of Greenland melting are sufficient to have measurable effects on ocean temperature and circulation (46, 47). Sustained warming of the northern high latitudes as a result of this process could accelerate feedbacks or activate tipping elements in that region, such as permafrost degradation, loss of Arctic sea ice, and boreal forest dieback.

While this may seem to be an extreme scenario, it illustrates that a warming into the range of even the lower-temperature cluster (i.e., the Paris targets) could lead to tipping in the mid- and higher-temperature clusters via cascade effects. Based on this analysis of tipping cascades and taking a risk-averse approach, we suggest that a potential planetary threshold could occur at a temperature rise as low as ~2.0 °C above preindustrial (Fig. 1).

Alternative Stabilized Earth Pathway

If the world's societies want to avoid crossing a potential threshold that locks the Earth System into the Hothouse Earth pathway, then it is critical that they make deliberate decisions to avoid this risk and maintain the Earth System in Holocene-like conditions. This human-created pathway is represented in Figs. 1 and 2 by what we call Stabilized Earth (small loop at the bottom of Fig. 1, *Upper Right*), in which the Earth System is maintained in a state with a temperature rise no greater than 2 °C above preindustrial (a "super-Holocene" state) (11). Stabilized Earth would require deep cuts in greenhouse gas emissions, protection and enhancement of biosphere carbon sinks, efforts to remove CO_2 from the atmosphere, possibly solar radiation management, and adaptation to unavoidable impacts of the warming already occurring (48). The short broken red line beyond Stabilized Earth in Fig. 1, *Upper Right* represents a potential return to interglacial-like conditions in the longer term.

In essence, the Stabilized Earth pathway could be conceptualized as a regime of the Earth System in which humanity plays an active planetary stewardship role in maintaining a state intermediate between the glacial–interglacial limit cycle of the Late Quaternary and a Hothouse Earth (Fig. 2). We emphasize that Stabilized Earth is not an intrinsic state of the Earth System but rather, one in which humanity commits to a pathway of ongoing management of its relationship with the rest of the Earth System.

A critical issue is that, if a planetary threshold is crossed toward the Hothouse Earth pathway, accessing the Stabilized Earth pathway would become very difficult no matter what actions human societies might take. Beyond the threshold, positive (reinforcing) feedbacks within the Earth System—outside of human influence or control—could become the dominant driver of the system's pathway, as individual tipping elements create linked cascades through time and with rising temperature (Fig. 3). In other words, after the Earth System is committed to the Hothouse Earth pathway, the alternative Stabilized Earth pathway would very likely become inaccessible as illustrated in Fig. 2.

What Is at Stake? Hothouse Earth is likely to be uncontrollable and dangerous to many, particularly if we transition into it in only a century or two, and it poses severe risks for health, economies, political stability (12, 39, 49, 50) (especially for the most climate vulnerable), and ultimately, the habitability of the planet for humans.

Insights into the risks posed by the rapid climatic changes emerging in the Anthropocene can be obtained not only from contemporary observations (51–55) but also, from interactions in the past between human societies and regional and seasonal hydroclimate variability. This variability was often much more pronounced than global, longer-term Holocene variability (*SI Appendix*). Agricultural production and water supplies are especially vulnerable to changes in the hydroclimate, leading to hot/dry or cool/wet extremes. Societal declines, collapses, migrations/resettlements, reorganizations, and cultural changes were often associated with severe regional droughts and with the global megadrought at 4.2–3.9 thousand years before present, all occurring within the relative stability of the narrow global Holocene temperature range of approximately ±1 °C (56).

SI Appendix, Table S4 summarizes biomes and regional biosphere–physical climate subsystems critical for human wellbeing and the resultant risks if the Earth System follows a Hothouse Earth pathway. While most of these biomes or regional systems may be retained in a Stabilized Earth pathway, most or all of them would likely be substantially changed or degraded in a Hothouse Earth pathway, with serious challenges for the viability of human societies.

For example, agricultural systems are particularly vulnerable, because they are spatially organized around the relatively stable Holocene patterns of terrestrial primary productivity, which depend on a well-established and predictable spatial distribution of temperature and precipitation in relation to the location of fertile soils as well as on a particular atmospheric CO_2 concentration. Current understanding suggests that, while a Stabilized Earth pathway could result in an approximate balance between increases and decreases in regional production as human systems adapt, a Hothouse Earth trajectory will likely exceed the limits of adaptation and result in a substantial overall decrease in agricultural production, increased prices, and even more disparity between wealthy and poor countries (57).

The world's coastal zones, especially low-lying deltas and the adjacent coastal seas and ecosystems, are particularly important for human wellbeing. These areas are home to much of the world's population, most of the emerging megacities, and a significant amount of infrastructure vital for both national economies and international trade. A Hothouse Earth trajectory would almost certainly flood deltaic environments, increase the risk of damage from coastal storms, and eliminate coral reefs (and all of the benefits that they provide for societies) by the end of this century or earlier (58).

Human Feedbacks in the Earth System. In the dominant climate change narrative, humans are an external force driving change to the Earth System in a largely linear, deterministic way; the higher the forcing in terms of anthropogenic greenhouse gas emissions, the higher the global average temperature. However, our analysis argues that human societies and our activities need to be recast as an integral, interacting component of a complex, adaptive Earth System. This framing puts the focus not only on human system dynamics that reduce greenhouse gas emissions but also, on those that create or enhance negative feedbacks that reduce the risk that the Earth System will cross a planetary threshold and lock into a Hothouse Earth pathway.

Humanity's challenge then is to influence the dynamical properties of the Earth System in such a way that the emerging unstable conditions in the zone between the Holocene and a very hot state become a de facto stable intermediate state (Stabilized Earth) (Fig. 2). This requires that humans take deliberate, integral, and adaptive steps to reduce dangerous impacts on the Earth System, effectively monitoring and changing behavior to form feedback loops that stabilize this intermediate state.

There is much uncertainty and debate about how this can be done—technically, ethically, equitably, and economically—and there is no doubt that the normative, policy, and institutional aspects are highly challenging. However, societies could take a wide range of actions that constitute negative feedbacks, summarized in *SI Appendix*, Table S5, to steer the Earth System toward Stabilized Earth. Some of these actions are already altering emission trajectories. The negative feedback actions fall into three broad categories: (*i*) reducing greenhouse gas emissions, (*ii*) enhancing or creating carbon sinks (e.g., protecting and enhancing biosphere carbon sinks and creating new types of sinks) (59), and (*iii*) modifying Earth's energy balance (for example, via solar radiation management, although that particular feedback entails very large risks of destabilization or degradation of several key processes in the Earth System) (60, 61). While reducing emissions is a priority, much more could be done to reduce direct human pressures on critical biomes that contribute to the regulation of the state of the Earth System through carbon sinks and moisture feedbacks, such as the Amazon and boreal forests (Table 1), and to build much more effective stewardship of the marine and terrestrial biospheres in general.

The present dominant socioeconomic system, however, is based on high-carbon economic growth and exploitative resource use (9). Attempts to modify this system have met with some success locally but little success globally in reducing greenhouse gas emissions or building more effective stewardship of the biosphere. Incremental linear changes to the present socioeconomic system are not enough to stabilize the Earth System. Widespread, rapid, and fundamental transformations will likely be required to reduce the risk of crossing the threshold and locking in the Hothouse Earth pathway; these include changes in behavior, technology and innovation, governance, and values (48, 62, 63).

International efforts to reduce human impacts on the Earth System while improving wellbeing include the United Nations Sustainable Development Goals and the commitment in the Paris agreement to keep warming below 2 °C. These international governance initiatives are matched by carbon reduction commitments by countries, cities, businesses, and individuals (64–66) , but as yet, these are not enough to meet the Paris target. Enhanced ambition will need new collectively shared values, principles, and frameworks as well as education to support such changes (67, 68). In essence, effective Earth System stewardship is an essential precondition for the prosperous development of human societies in a Stabilized Earth pathway (69, 70).

In addition to institutional and social innovation at the global governance level, changes in demographics, consumption, behavior, attitudes, education, institutions, and socially embedded technologies are all important to maximize the chances of achieving a Stabilized Earth pathway (71). Many of the needed shifts may take decades to have a globally aggregated impact (*SI Appendix*, Table S5), but there are indications that society may be reaching some important societal tipping points. For example, there has been relatively rapid progress toward slowing or reversing population growth through declining fertility resulting from the empowerment of women, access to birth control technologies, expansion of educational opportunities, and rising income levels (72, 73). These demographic changes must be complemented by sustainable per capita consumption patterns, especially among the higher per capita consumers. Some changes in consumer behavior have been observed (74, 75), and opportunities for consequent major transitions in social norms over broad scales may arise (76). Technological innovation is contributing to more rapid decarbonization and the possibility for removing CO_2 from the atmosphere (48).

Ultimately, the transformations necessary to achieve the Stabilized Earth pathway require a fundamental reorientation and restructuring of national and international institutions toward more effective governance at the Earth System level (77), with a much stronger emphasis on planetary concerns in economic governance, global trade, investments and finance, and technological development (78).

Building Resilience in a Rapidly Changing Earth System. Even if a Stabilized Earth pathway is achieved, humanity will face a turbulent road of rapid and profound changes and uncertainties on route to it—politically, socially, and environmentally—that challenge the resilience of human societies (79–82). Stabilized Earth will likely be warmer than any other time over the last 800,000 years at least (83) (that is, warmer than at any other time in which fully modern humans have existed).

In addition, the Stabilized Earth trajectory will almost surely be characterized by the activation of some tipping elements (*Tipping Cascades* and Fig. 3) and by nonlinear dynamics and abrupt shifts at the level of critical biomes that support humanity (*SI Appendix*, Table S4). Current rates of change of important features of the Earth System already match or exceed those of abrupt geophysical events in the past (*SI Appendix*). With these trends likely to continue for the next several decades at least, the contemporary way of guiding development founded on theories, tools, and beliefs of gradual or incremental change, with a focus on economy efficiency, will likely not be adequate to cope with this trajectory. Thus, in addition to adaptation, increasing resilience will become a key strategy for navigating the future.

Generic resilience-building strategies include developing insurance, buffers, redundancy, diversity, and other features of resilience that are critical for transforming human systems in the face of warming and possible surprise associated with tipping points (84). Features of such a strategy include (*i*) maintenance of diversity, modularity, and redundancy; (*ii*) management of connectivity, openness, slow variables, and feedbacks; (*iii*) understanding social–ecological systems as complex adaptive systems, especially at the level of the Earth System as a whole (85); (*iv*) encouraging learning and experimentation; and (*v*) broadening of participation and building of trust to promote polycentric governance systems (86, 87).

Conclusions

Our systems approach, focusing on feedbacks, tipping points, and nonlinear dynamics, has addressed the four questions posed in the Introduction.

Our analysis suggests that the Earth System may be approaching a planetary threshold that could lock in a continuing rapid pathway toward much hotter conditions—Hothouse Earth. This pathway would be propelled by strong, intrinsic, biogeophysical feedbacks difficult to influence by human actions, a pathway that could not be reversed, steered, or substantially slowed.

Where such a threshold might be is uncertain, but it could be only decades ahead at a temperature rise of ~2.0 °C above preindustrial, and thus, it could be within the range of the Paris Accord temperature targets.

The impacts of a Hothouse Earth pathway on human societies would likely be massive, sometimes abrupt, and undoubtedly disruptive.

Avoiding this threshold by creating a Stabilized Earth pathway can only be achieved and maintained by a coordinated, deliberate effort by human societies to manage our relationship with the rest of the Earth System, recognizing that humanity is an integral, interacting component of the system. Humanity is now facing the need for critical decisions and actions that could influence our future for centuries, if not millennia (88).

How credible is this analysis? There is significant evidence from a number of sources that the risk of a planetary threshold and thus, the need to create a divergent pathway should be taken seriously:

First, the complex system behavior of the Earth System in the Late Quaternary is well-documented and understood. The two bounding states of the system—glacial and interglacial—are reasonably well-defined, the ca. 100,000-years periodicity of the limit cycle is established, and internal (carbon cycle and ice albedo feedbacks) and external (changes in insolation caused by changes in Earth's orbital parameters) driving processes are generally well-known. Furthermore, we know with high confidence that the progressive disintegration of ice sheets and the transgression of other tipping elements are difficult to reverse after critical levels of warming are reached.

Second, insights from Earth's recent geological past (*SI Appendix*) suggest that conditions consistent with the Hothouse Earth pathway are accessible with levels of atmospheric CO_2 concentration and temperature rise either already realized or projected for this century (*SI Appendix*, Table S1).

Third, the tipping elements and feedback processes that operated over Quaternary glacial–interglacial cycles are the same as several of those proposed as critical for the future trajectory of the Earth System (*Biogeophysical Feedbacks*, *Tipping Cascades*, Fig. 3, Table 1, and *SI Appendix*, Table S2).

Fourth, contemporary observations (29, 38) (*SI Appendix*) of tipping element behavior at an observed temperature anomaly of about 1 °C above preindustrial suggest that some of these elements are vulnerable to tipping within just a 1 °C to 3 °C increase in global temperature, with many more of them vulnerable at higher temperatures (*Biogeophysical Feedbacks* and *Tipping Cascades*) (12, 17, 39). This suggests that the risk of tipping cascades could be significant at a 2 °C temperature rise and could increase sharply beyond that point. We argue that a planetary threshold in the Earth System could exist at a temperature rise as low as 2 °C above preindustrial.

The Stabilized Earth trajectory requires deliberate management of humanity's relationship with the rest of the Earth System if the world is to avoid crossing a planetary threshold. We suggest that a deep transformation based on a fundamental reorientation of human values, equity, behavior, institutions, economies, and technologies is required. Even so, the pathway toward Stabilized Earth will involve considerable changes to the structure and functioning of the Earth System, suggesting that resilience-building strategies be given much higher priority than at present in decision making. Some signs are emerging that societies are initiating some of the necessary transformations. However, these transformations are still in initial stages, and the social/political tipping points that definitively move the current trajectory away from Hothouse Earth have not yet been crossed, while the door to the Stabilized Earth pathway may be rapidly closing.

Our initial analysis here needs to be underpinned by more in-depth, quantitative Earth System analysis and modeling studies to address three critical questions. (*i*) Is humanity at risk for pushing the system across a planetary threshold and irreversibly down a Hothouse Earth pathway? (*ii*) What other pathways might be possible in the complex stability landscape of the Earth System, and what risks might they entail? (*iii*) What planetary stewardship strategies are required to maintain the Earth System in a manageable Stabilized Earth state?

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1 Crutzen PJ (2002) Geology of mankind. *Nature* 415:23.
2 Steffen W, Broadgate W, Deutsch L, Gaffney O, Ludwig C (2015) The trajectory of the Anthropocene: The great acceleration. *Anthropocene Rev* 2:81–98.
3 Waters CN, et al. (2016) The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* 351:aad2622.
4 Malm A, Hornborg A (2014) The geology of mankind? A critique of the Anthropocene narrative. *Anthropocene Rev* 1:62–69.
5 Donges JF, et al. (2017) Closing the loop: Reconnecting human dynamics to Earth System science. *Anthropocene Rev* 4:151–157.
6 Levin SA (2003) Complex adaptive systems: Exploring the known, the unknown and the unknowable. *Bull Am Math Soc* 40:3–20.
7 Past Interglacial Working Group of PAGES (2016) Interglacials of the last 800,000 years. *Rev Geophys* 54:162–219.
8 Williams M, et al. (2015) The Anthropocene biosphere. *Anthropocene Rev* 2:196–219.
9 McNeill JR, Engelke P (2016) *The Great Acceleration* (Harvard Univ Press, Cambridge, MA).
10 Hawkins E, et al. (2017) Estimating changes in global temperature since the pre-industrial period. *Bull Am Meteorol Soc* 98:1841–1856.
11 Ganopolski A, Winkelmann R, Schellnhuber HJ (2016) Critical insolation-CO_2 relation for diagnosing past and future glacial inception. *Nature* 529:200–203.
12 Schellnhuber HJ, Rahmstorf S, Winkelmann R (2016) Why the right climate target was agreed in Paris. *Nat Clim Change* 6:649–653.
13 Schellnhuber HJ (1999) 'Earth system' analysis and the second Copernican revolution. *Nature* 402(Suppl):C19–C23.
14 IPCC (2013) Summary for policymakers. *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds Stocker TF, et al. (Cambridge Univ Press, Cambridge, UK), pp 3–29.
15 Drijfhout S, et al. (2015) Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. *Proc Natl Acad Sci USA* 112:E5777–E5786.
16 Stocker TF, et al. (2013) Technical summary. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds Stocker TF, et al. (Cambridge Univ Press, Cambridge, UK).
17 Lenton TM, et al. (2008) Tipping elements in the Earth's climate system. *Proc Natl Acad Sci USA* 105:1786–1793.
18 Scheffer M (2009) *Critical Transitions in Nature and Society* (Princeton Univ Press, Princeton).
19 Raupach MR, et al. (2014) The declining uptake rate of atmospheric CO_2 by land and ocean sinks. *Biogeosciences* 11:3453–3475.
20 Schaefer K, Lantuit H, Romanovsky VE, Schuur EAG, Witt R (2014) The impact of the permafrost carbon feedback on global climate. *Environ Res Lett* 9:085003.
21 Schneider von Deimling T, et al. (2015) Observation-based modelling of permafrost carbon fluxes with accounting for deep carbon deposits and thermokarst activity. *Biogeosciences* 12:3469–3488.
22 Koven CD, et al. (2015) A simplified, data-constrained approach to estimate the permafrost carbon-climate feedback. *Philos Trans A Math Phys Eng Sci* 373:20140423.
23 Chadburn SE, et al. (2017) An observation-based constraint on permafrost loss as a function of global warming. *Nat Clim Change* 7:340–344.
24 Ciais P, et al. (2013) Carbon and other biogeochemical cycles. *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds Stocker TF, et al. (Cambridge Univ Press, Cambridge, UK), pp 465–570.
25 Segschneider J, Bendtsen J (2013) Temperature-dependent remineralization in a warming ocean increases surface pCO_2 through changes in marine ecosystem composition. *Global Biogeochem Cycles* 27:1214–1225.
26 Bendtsen J, Hilligsøe KM, Hansen J, Richardson K (2015) Analysis of remineralisation, lability, temperature sensitivity and structural composition of organic matter from the upper ocean. *Prog Oceanogr* 130:125–145.
27 Jones C, Lowe J, Liddicoat S, Betts R (2009) Committed terrestrial ecosystem changes due to climate change. *Nat Geosci* 2:484–487.
28 Kurz WA, Apps MJ (1999) A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. *Ecol Appl* 9:526–547.
29 Lewis SL, Brando PM, Phillips OL, van der Heijden GMF, Nepstad D (2011) The 2010 Amazon drought. *Science* 331:554.
30 Herzschuh U, et al. (2016) Glacial legacies on interglacial vegetation at the Pliocene-Pleistocene transition in NE Asia. *Nature Commun* 7:11967.

31 Mao J, et al. (2016) Human-induced greening of the northern extratropical land surface. *Nat Clim Change* 6:959–963.
32 Keenan TF, et al. (2016) Recent pause in the growth rate of atmospheric CO_2 due to enhanced terrestrial carbon uptake. *Nature Commun* 7:13428, and erratum (2017) 8:16137.
33 Hansen J, et al. (2016) Ice melt, sea level rise and superstorms: Evidence from paleoclimatedata, climate modeling, and modern observations that 2 °C global warming could be dangerous. *Atmos Chem Phys* 16:3761–3812.
34 Kriegler E, Hall JW, Held H, Dawson R, Schellnhuber HJ (2009) Imprecise probability assessment of tipping points in the climate system. *Proc Natl Acad Sci USA* 106:5041–5046.
35 Pollard D, DeConto RM (2009) Modelling West Antarctic ice sheet growth and collapse through the past five million years. *Nature* 458:329–332.
36 Pollard D, DeConto RM, Alley RB (2015) Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure. *Earth Planet Sci Lett* 412:112–121.
37 DeConto RM, Pollard D (2016) Contribution of Antarctica to past and future sea-level rise. *Nature* 531:591–597.
38 Rintoul SR, et al. (2016) Ocean heat drives rapid basal melt of the Totten Ice Shelf. *Sci Adv* 2:e1601610.
39 US Department of Defense (2015) National security implications of climate-related risks and a changing climate. Available at archive.defense.gov/pubs/150724-congressional-report-on-national-implications-of-climate-change.pdf?source=govdelivery. Accessed February 7, 2018.
40 Mengel M, Levermann A (2014) Ice plug prevents irreversible discharge from East Antarctica. *Nat Clim Change* 4:451–455.
41 Armour KC, et al. (2016) Southern Ocean warming delayed by circumpolar upwelling and equatorward transport. *Nat Geosci* 9:549–554.
42 Stocker TF, Johnsen SJ (2003) A minimum thermodynamic model for the bipolar seesaw. *Paleoceanography* 18:1087.
43 Rahmstorf S (2002) Ocean circulation and climate during the past 120,000 years. *Nature* 419:207–214.
44 Hemming SR (2004) Heinrich events: Massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint. *Rev Geophys* 42:1–43.
45 Alvarez-Solas J, et al. (2010) Link between ocean temperature and iceberg discharge during Heinrich events. *Nat Geosci* 3:122–126.
46 Stouffer RJ, et al. (2006) Investigating the causes of the response of the thermohaline circulation to past and future climate changes. *J Clim* 19:1365–1387.
47 Swingedow D, et al. (2013) Decadal fingerprints of freshwater discharge around Greenland in a multi-model ensemble. *Clim Dyn* 41:695–720.
48 Rockström J, et al. (2017) A roadmap for rapid decarbonization. *Science* 355:1269–1271.
49 Schleussner C-F, Donges JF, Donner RV, Schellnhuber HJ (2016) Armed-conflict risks enhanced by climate-related disasters in ethnically fractionalized countries. *Proc Natl Acad Sci USA* 113:9216–9221.
50 McMichael AJ, et al., eds (2003) *Climate Change and Human Health: Risks and Responses* (WHO, Geneva).
51 Udmale PD, et al. (2015) How did the 2012 drought affect rural livelihoods in vulnerable areas? Empirical evidence from India. *Int J Disaster Risk Reduct* 13:454–469.
52 Maldonado JK, Shearer C, Bronen R, Peterson K, Lazrus H (2013) The impact of climate change on tribal communities in the US: Displacement, relocation, and human rights. *Clim Change* 120:601–614.
53 Warner K, Afifi T (2014) Where the rain falls: Evidence from 8 countries on how vulnerable households use migration to manage the risk of rainfall variability and food insecurity. *Clim Dev* 6:1–17.
54 Cheung WW, Watson R, Pauly D (2013) Signature of ocean warming in global fisheries catch. *Nature* 497:365–368.
55 Nakano K (2017) Screening of climatic impacts on a country's international supply chains: Japan as a case study. *Mitig Adapt Strategies Glob Change* 22:651–667.
56 Latorre C, Wilmshurst J, von Gunten L, eds (2016) Climate change and cultural evolution. *PAGES (Past Global Changes) Magazine* 24:1–32.
57 IPCC (2014) Summary for policymakers. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds Field CB, et al. (Cambridge Univ Press, Cambridge, UK), pp 1–32.
58 Schleussner C-F, et al. (2016) Science and policy characteristics of the Paris Agreement temperature goal. *Nat Clim Change* 6:827–835.
59 Griscom BW, et al. (2017) Natural climate solutions. *Proc Natl Acad Sci USA* 114:11645–11650.
60 Barrett S, et al. (2014) Climate engineering reconsidered. *Nat Clim Change* 4:527–529.
61 Mathesius S, Hofmann M, Calderia K, Schellnhuber HJ (2015) Long-term response of oceans to CO_2 removal from the atmosphere. *Nat Clim Change* 5:1107–1113.
62 Geels FW, Sovacool BK, Schwanen T, Sorrell S (2017) Sociotechnical transitions for deep decarbonization. *Science* 357:1242–1244.
63 O'Brien K (2018) Is the 1.5 °C target possible? Exploring the three spheres of transformation. *Curr Opin Environ Sustain* 31:153–160.
64 Young OR, et al. (2006) The globalization of socioecological systems: An agenda for scientific research. *Glob Environ Change* 16:304–316.
65 Adger NW, Eakin H, Winkels A (2009) Nested and teleconnected vulnerabilities to environmental change. *Front Ecol Environ* 7:150–157.
66 UN General Assembly (2015) *Transforming Our World: The 2030 Agenda for Sustainable Development*, A/RES/70/1. Available at https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf. Accessed July 18, 2018.
67 Wals AE, Brody M, Dillon J, Stevenson RB (2014) Science education. Convergence between science and environmental education. *Science* 344:583–584.
68 O'Brien K, et al. (2013) You say you want a revolution? Transforming education and capacity building in response to global change. *Environ Sci Policy* 28:48–59.
69 Chapin FS, III, et al. (2011) Earth stewardship: A strategy for social–ecological transformation to reverse planetary degradation. *J Environ Stud Sci* 1:44–53.
70 Folke C, Biggs R, Norström AV, Reyers B, Rockström J (2016) Social-ecological resilience and biosphere-based sustainability science. *Ecol Soc* 21:41.
71 Westley F, et al. (2011) Tipping toward sustainability: Emerging pathways of transformation. *Ambio* 40:762–780.
72 Lutz W, Muttarak R, Striessnig E (2014) Environment and development. Universal education is key to enhanced climate adaptation. *Science* 346:1061–1062.
73 Bongaarts J (2016) Development: Slow down population growth. *Nature* 530:409–412.
74 Defila R, Di Giulio A, Kaufmann-Hayoz R, eds (2012) *The Nature of Sustainable Consumption and How to Achieve It: Results from the Focal Topic "From Knowledge to Action–New Paths Towards Sustainable Consumption"* (Oakum, Munich).
75 Cohen MJ, Szejnwald Brown H, Vergragt P, eds (2013) *Innovations in Sustainable Consumption: New Economics, Socio-Technical Transitions and Social Practices* (Edward Elgar, Cheltenham, UK).
76 Nyborg K, et al. (2016) Social norms as solutions. *Science* 354:42–43.
77 Biermann F, et al. (2012) Science and government. Navigating the anthropocene: Improving Earth system governance. *Science* 335:1306–1307.
78 Galaz V (2014) *Global Environmental Governance, Technology and Politics: The Anthropocene Gap* (Edward Elgar, Cheltenham, UK).
79 Peters DPC, et al. (2004) Cross-scale interactions, nonlinearities, and forecasting catastrophic events. *Proc Natl Acad Sci USA* 101:15130–15135.
80 Walker B, et al. (2009) Environment. Looming global-scale failures and missing institutions. *Science* 325:1345–1346.
81 Hansen J, Sato M, Ruedy R (2012) Perception of climate change. *Proc Natl Acad Sci USA* 109:E2415–E2423.
82 Galaz V, et al. (2017) Global governance dimensions of globally networked risks: The state of the art in social science research. *Risks Hazards Crisis Public Policy* 8:4–27.
83 Augustin L, et al.; EPICA community members (2004) Eight glacial cycles from an Antarctic ice core. *Nature* 429:623–628.
84 Polasky S, Carpenter SR, Folke C, Keeler B (2011) Decision-making under great uncertainty: Environmental management in an era of global change. *Trends Ecol Evol* 26:398–404.
85 Capra F, Luisi PL (2014) *The Systems View of Life; A Unifying Vision* (Cambridge Univ Press, Cambridge, UK).
86 Carpenter SR, et al. (2012) General resilience to cope with extreme events. *Sustainability* 4:3248–3259.
87 Biggs R, et al. (2012) Toward principles for enhancing the resilience of ecosystem services. *Annu Rev Environ Resour* 37:421–448.
88 Figueres C, et al. (2017) Three years to safeguard our climate. *Nature* 546:593–595.

This is Exhibit "G" referred to in the
Affidavit of Paul Kershaw, sworn before me
at North Vancouver this 18th day of
December, 2018.

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A Commissioner for taking Affidavits
within British Columbia

ACTING ON CLIMATE CHANGE

Solutions from Canadian Scholars

Sustainable Canada Dialogues

United Nations Educational, Scientific and Cultural Organization · UNESCO Chair for Dialogues on Sustainability · McGill

Trottier ISPP — Institute for Science and Public Policy / Institut pour la science et les politiques publiques

Réseau Environnement

Association francophone pour le savoir — Acfas

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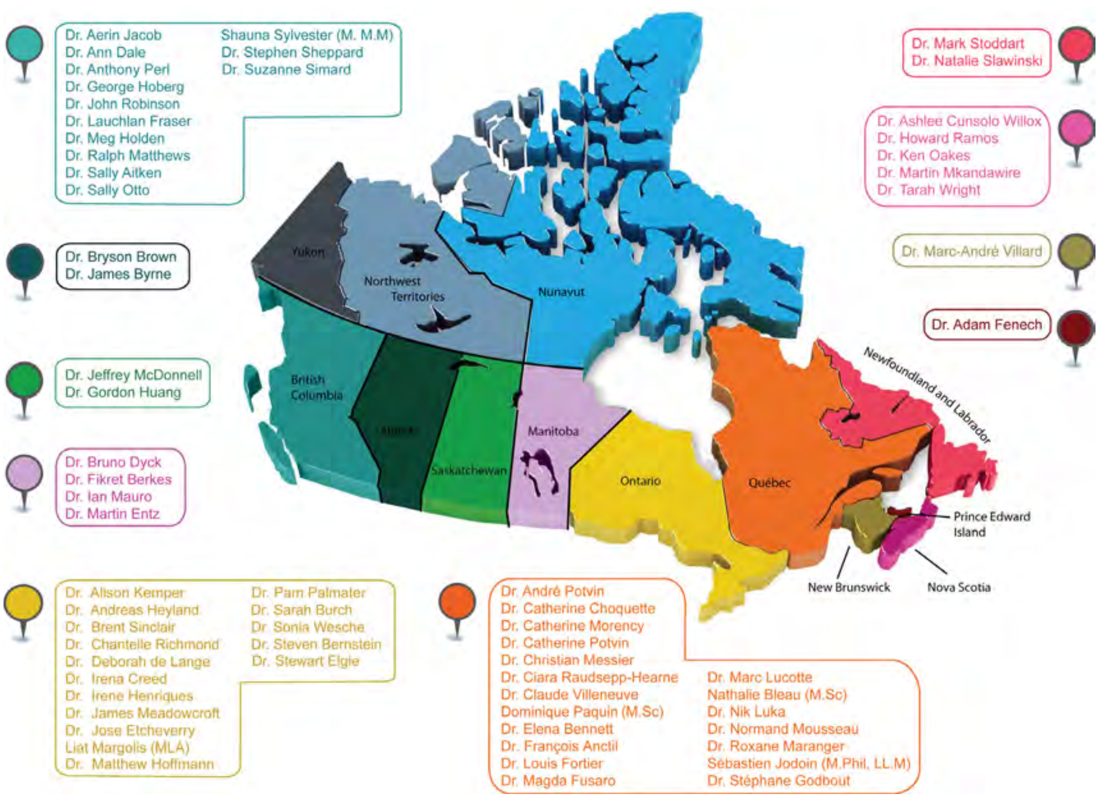
Sustainable Canada Dialogues

ACTING ON CLIMATE CHANGE:
Solutions from Canadian Scholars

A scholarly consensus on science-based, viable solutions for greenhouse gas reduction. Produced by *Sustainable Canada Dialogues*, an initiative under the *UNESCO–McGill Chair for Dialogues on Sustainability* and the *Trottier Institute for Science and Public Policy*. *Sustainable Canada Dialogues* has mobilized over 60 Canadian scholars from every province, representing climate change expertise in areas from engineering to sociology.

Map of SCD Scholars



EXECUTIVE **SUMMARY**

In fall 2014, United Nations Secretary Ban Ki-moon exhorted all countries in the world to raise the ambitions of their climate change policies to avoid a global temperature increase of more than 2°C during this century. Answering this call, the scholars of *Sustainable Canada Dialogues*[1] (SCD), an initiative that mobilizes over 60 researchers from every province, worked collectively to identify a possible pathway to a low carbon economy in Canada. Our network of scholars represents disciplines across engineering, sciences and social sciences, with sustainability at the heart of our research programs.

Acting on Climate Change: Solutions from Canadian Scholars identifies ten policy orientations illustrated by actions that could be immediately adopted to kick-start Canada's necessary transition toward a low carbon economy and sustainable society. **We unanimously recommend putting a price on carbon.**

The Sustainable Canada Dialogues benefited from collaboration with the Consortium OURANOS[2] that carried out climate simulations for the position paper. The simulations, based on the greenhouse gas mitigation scenarios of the Intergovernmental Panel on Climate Change (IPCC)[3], show that immediate global actions to reduce greenhouse gas emissions would successfully limit temperature increases in Canada. We must act today to ensure tomorrow.

Besides putting a price on carbon *Acting on Climate Change: Solutions from Canadian Scholars* examines how Canada can reduce its greenhouse gas emissions (GHG) by: 1) producing electricity with low carbon emissions sources; 2) modifying energy consumption through evolving urban design and a transportation revolution; and 3) linking transition to a low-carbon economy with a broader sustainability agenda, through creation of participatory and open governance institutions that engage the Canadian public. Our proposals take into account Canada's assets and are based on the well-accepted "polluter pays" principle. They are presented in details in the core document that can be downloaded from the SCD website.

In the short term, policy orientations that could trigger climate action include:

- Implementing either a national carbon tax or a national economy-wide cap and trade program;
- Eliminating subsidies to the fossil fuel industry and fully integrating the oil and gas production sector in climate policies;
- Integrating sustainability and climate change into landscape planning at the regional and city levels to ensure that, amongst other goals, new and maintenance infrastructure investments are consistent with the long-term goal of decarbonizing.

1 http://www.sustainablecanadadialogues.ca/en/scd
2 http://www.ouranos.ca/
3 http://ipcc.ch/home_languages_main_french.shtml

In the short- to middle-terms, the transition could be facilitated by:

- East-West intelligent grid connections that allow provinces producing hydroelectricity to sell electricity to their neighbors while taking full advantage of Canada's low carbon energy potential;
- Well-managed energy efficiency programs that produce significant positive economic returns across the board, through cost savings as well as job creation. Energy efficiency programs could target the building sector as well as businesses and industries.

In the short- to long-terms, the transition could support a transportation "revolution":

- Transportation strategies that move the sector away from its dependence on fossil fuel could rest on the implementation of a basket of options, ranging from electrification of transport to collective and active transportation.

Because renewable energy resources are plentiful, we believe that Canada could reach **100% reliance on low carbon electricity by 2035**. This makes it possible, in turn, to adopt a long-term target of at least **80% reduction in emissions by the middle of the century**, consistent with Canada's international climate mitigation responsibility. In the short-term, we think Canada, in keeping with its historical position of aligning with United States' targets, could adopt a **2025 target of 26-28% GES reductions relative to our 2005 levels**.

We envision climate policy as the ongoing, long-term project of making the *transition* to a low-carbon society and economy. This notion of transition has many advantages: the 80% target establishes the direction of change, allowing Canada to plan for the future while recognizing that goals will take time to accomplish. It permits governments, businesses and citizens to situate their activities within a dynamic context. As with other past and future major transitions, e.g. industrialization or electrification, there will be controversies and setbacks. Some economic sectors will contract as others expand. The most important aspect of Canadian climate policies is to build a sustainable future *starting today*.

Recognition that certain forms of economic development were causing environmental damage led to the notion of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." We have adopted a more recent definition of sustainability that emphasizes the importance of desired futures. We propose that the specific transition pathways to a low carbon economy in Canada could rest on the hopes of Canadians for social and environmental well-being and help articulate a vision for the country.

The transition to a low carbon sustainable society will usher in great opportunities for innovation by developing new technologies, businesses and employment. The international landscape has changed substantively since Canada withdrew from the Kyoto Protocol in December 2011. Canada's major trade partner, the USA, doubled their GHG emissions reduction target in 2014. In 2011, the International Energy Agency (IEA) estimated that investments for energy efficiency were worth USD 310-360 billion[4]. A clear climate policy framework would reduce uncertainty in the business environment, encouraging companies to invest in low-carbon technologies.

We have identified policy orientations designed to deliver viable, large impacts based on our expertise and on dialogue among our members. We do not claim to offer all possible policies or incentives to achieve sustainability, and we understand that further analyses, debate and refinement will be required. However, in virtually all cases, our proposals are in line with a number of international and national analyses of viable policy options to decarbonize.

We believe that putting options on the table is long overdue in Canada and hope that our input will help governments at all levels to make ambitious and thoughtful commitments to emission reductions before December 2015 and the *2015 Paris-Climate Conference*. We wish for an intense period of consultation and policy development to identify the policy instruments, regulations and incentives best suited to Canada. We offer our full cooperation to all levels of government in this challenging, but exciting, period. The time is now ripe to initiate ambitious climate change mitigation efforts.

4 http://www.iea.org/bookshop/463-Energy_Efficiency_Market_Report_2014

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*To **Adèle** (2 months), **Alice** (4 years), **Arthur** (17 months), **Avery** (2 years),*
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*and **all other children.***

Your future is our inspiration.

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5 http://normandmousseau.com/-A-common-energy-policy-for-Eastern-.html?lang=en

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Chapter 2

CANADA'S TRANSITION TO A LOW-CARBON SOCIETY

Canada needs an integrated climate action plan. The most important aspect of the plan is to get going today.

This Chapter identifies policy orientations *(in blue)*, illustrated by a number of actions *(in green)* that could allow Canada to adopt new emissions reduction targets before the *2015 Paris-Climate Conference*. Transitioning to a low-carbon society could be facilitated by climate policies designed with the following characteristics:

Environmentally effective
Policies meeting GHG reduction targets without causing other excessive environmental impacts;

Cost-effective
Policies achieving the necessary GHG reductions at the least possible cost;

Administratively feasible
Complexity of policies being within the governance capacity of the implementing jurisdictions;

Equitable
Policies that are not placing unjustified burdens on any region, sector, or income group;

Politically feasible
Policies acceptable to Canadian publics and their elected representatives[46].

Climate policies could rest on the "polluter pays" principle. Canadians are accustomed to this notion: for instance, taxes on cigarettes are justified in part by generating the income necessary to cover the health-related costs of smoking.

In addition, meaningful climate policies require three elements:

1. An objective (clear target and timeline);
2. A choice of policy instruments (subsidies or tax incentives, regulation, carbon tax or cap and trade, research and development); and
3. The design of policy instruments to achieve the stated objective.

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46 Adapted from Jaccard, M., and Rivers, N. (2008). Canadian Policies for Deep Greenhouse Reduction. A Canadian Priorities Agenda: Policy Choices to Improve Economic and Social Well-Being. Jeremy Leonard, Christopher Ragan and France St-Hilaire, eds. Ottawa: IRPP. http://irpp.org/research-studies/jaccard-rivers-2007-10-29/

Because energy, transport, and building infrastructure last several decades, and they lock in development along specific pathways[47], we believe that a **long-term target of 80% emissions reduction**, aligned with IPCC's recommendation for developed countries[48], should be adopted immediately to inform current decision making. Failure to do so would imprison Canada in a high-carbon development pathway.

A medium-term target is needed for 2025 that will raise the ambition of Canada's emissions reduction effort beginning now. To maintain past consistency with US objectives, Canada could adopt the recently announced US target of **26-28% below 2005 levels by 2025**.

2.1 KEY ENABLING POLICY

KEY POLICY ORIENTATION # 1 : Put a price on carbon

Challenging trade-offs among different policy options means there is no mechanism for reducing GHG emissions that fully meets all desired characteristics of climate policies. For example, a basket of regulations can be effective, and more politically palatable to some, but could be less cost-effective than a carbon tax or cap and trade[49]. It could however be a tremendous administrative challenge to regulate non-industrial sources of GHG emissions that collectively account for a significant share of Canada's emissions.

Widespread agreement nevertheless exists among climate policy analysts that carbon pricing should be a key component of any comprehensive climate change policy. There is less agreement on which carbon pricing mechanism (a carbon tax, or cap and trade) provides the best balance.

2.1.1 Carbon Tax or Cap and trade ?

Carbon taxes have been the preferred instrument of economists for decades because of their cost-effectiveness and administrative simplicity. British Columbia implemented an effective model of a revenue-neutral carbon tax in 2008 that is receiving increasing recognition around the world[50]. In the contemporary political climate, however, carbon taxes come with special political baggage.

Cap and trade, when designed effectively, can be virtually as cost-effective as a carbon tax, although its administrative complexity likely makes it more costly than a tax. The basic feature of a cap and trade system is that the government establishes an absolute cap on emissions designed to decline over time, allowing it to meet a GHG reduction target. The government issues allowances or permits to emitters, and emitters can trade their allowances in a regulated market. This approach has the advantage of directly controlling the quantity of emissions, as well as providing greater certainty and accountability that targets will be met. However, cap and trade poses special administrative challenges because the market in permits must be regulated to avoid manipulation. A cap and trade system has been in place in the European Union for eight years, and is also operating in California and Québec[51]. However, overall, we find more advantages to a national approach.

The choice between carbon tax or cap and trade depends on the weight placed upon different criteria and consequences. If price certainty and administrative simplicity are valued most, then carbon tax is the better instrument. If avoiding new types of taxes and greater certainty over emission control are most important, then cap and trade is the better instrument. Either a carbon tax or a cap and trade system could work effectively, efficiently, and fairly to enable Canada to meet a ambitious GHG reduction targets.

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47 Lecocq, F. and Shalizi, Z. (2014). The economics of targeted mitigation in infrastructure. Climate Policy, 14(2), 187-208.

48 http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_SPMcorr1.pdf

49 Nordhaus, W. (2013). The Climate Casino : Risk, Uncertainty, and Economics for a Warming World. New Haven : Yale University Press. Part IV.

50 Harrison, K. (2013). The Political Economy of British Columbia's Carbon Tax. OECD Environmental Working Paper 63. http://www.oecd-ilibrary.org/docserver/download/5k3z04gkkhkg.pdf ?expires=1394731610&id=id&accname=guest&checksum=D7C2C9BF73AFC-88901C793F4A343698D

51 Newell, R., et al. (2013). Carbon markets 15 years after Kyoto : Lessons learned, new challenges. The Journal of Economic Perspectives, 123-146.

2.1.2 National or Provincial ?

Persistent concerns about regional equity suggest that to be politically feasible, climate policies should not result in significant regional redistribution. The relatively decentralized nature of Canada's federation raises questions about which is more desirable : a national plan or a differentiated province-led approach like the one Canada has today.

From a cost-effectiveness standpoint, a national GHG reduction plan has advantages. There would be concerns about fairness and competitiveness if emitters in one province paid a significantly different carbon price than emitters elsewhere in Canada. A cap and trade system would realize economic benefits from being applied to a larger and more diverse area. Moreover, a national approach would avoid the challenging question about how to allocate emission reduction targets to provinces, because in either the carbon tax approach or a cap and trade system, provincial emission levels would be responses to market signals, not established in advance. But a national approach would be politically challenging, especially given the diverse policy instruments currently in use by different provinces and various political sensitivities within the country.

In the short term, adopt either a national carbon tax or a national cap and trade program.

National Carbon Tax
A national revenue-neutral carbon tax could be built on the British Columbia model and apply to all fuel use. The tax would need to increase over time for Canada to meets its emission reduction targets.

National Cap and Trade
A national cap and trade could be modeled on the basic design of the Québec system. Since it is linked to the much larger California system, some of the risks of administrative complexity are reduced.

2.1.3 National Carbon Tax

With a national carbon tax, one approach to adjusting the price over time would be to link the tax to the social cost of carbon (currently $40/tonne CO_2 or higher[52] and estimated to increase annually by $1/ tonne CO_2). To improve equity, carbon tax revenues could be distributed back to the provinces of origin. Adjustments to the tax system could be made (as is the case in British Columbia) to ensure the carbon tax does not disadvantage low-income groups. Any national system would require provinces with different policy instruments already in place to adapt. If Québec wanted to keep its cap and trade system, for example, it could either negotiate an equivalency agreement that ensures its carbon price levels are similar to the rest of the country, or comply with a province-specific emission cap.

2.1.4 National Cap and Trade

A national cap and trade program would benefit from building on an existing system. Careful design, guided by the following questions, could help smooth the transition :

- What sources are covered ? Our proposal would cover industrial and utility emissions and fuel distributors.
- Are allowances auctioned or issued for free ("grandparenting") ? Québec-California's Cap and Trade system provides free allowances to certain industries. Our proposal would begin by providing free allowances but then increase the fraction of allowances auctioned over time. While this approach would slow the flow of new revenues to governments, it would ease the transition to the new climate policy and allow emitters time to adjust.
- Are prices regulated with price floors, caps, or both ? Our proposal would establish a price floor that would increase over time, and a mechanism to minimize permit price volatility.

52 Hope C, Hope M. (2013) The social cost of CO_2 in a low-growth world. Nature Climate Change 3, 722-724. and Howarth RB, Gerst MD, Borsuk ME. (2013) Risk mitigation and the social cost of carbon. Global Environmental Change 24,123-131.

- How are actions linked with other jurisdictions ? There are some important tensions between different policy instruments, so introducing a national cap and trade program will pose some challenges for provinces, like British Columbia and Alberta, that have pursued alternative instruments. There would be considerable benefits in cost-effectiveness for having a national system. But provisions could be made for equivalency agreements, if provinces wanted an option to continue relying on their existing policy instruments. However, it would be important to develop a legally-binding, province-specific reduction target in that case.
- How should revenues be allocated from auctions ? To address regional equity concerns, as auction revenues increase, they could be returned to the province of origin, and that province of origin could decide how to use those revenues. To address the differential impact of implementing the system on different income groups, income taxes could be adjusted accordingly.
- Should offsets be allowed from non-regulated emitters ? Offsets can increase flexibility and reduce compliance costs, but need to be carefully regulated to ensure their legitimacy. We recommend following the practice of California, Québec, and the EU, and allow well-regulated offsets but limit them to a maximum of 8 % of emitters' compliance obligations.

A carbon pricing mechanism is an essential first step, but more will be required from governments at all levels over coming decades to accelerate the transition to a low-carbon society. Increased funding for research, development and deployment of low-carbon technologies, stronger regulatory standards, measures to encourage citizen initiatives and public education are all important. By strengthening green and low-carbon innovations we can address the challenge of climate change and increase opportunities for prosperity and sustainable development.

2.2 FURTHER ELEMENTS OF THE TRANSITION TO A LOW-CARBON ECONOMY AND SOCIETY

Energy is the main source of GHG emissions and thus at the heart of climate change mitigation. According to Canada's latest GHG inventory (1990-2012)[53], energy accounts for 81 percent of all human-related GHG emissions. Canada's economy relies heavily upon natural resource extraction, including oil and gas, which is highly energy intensive and is largely targeted for export[54]. Over the last decade, the Canadian government has resisted efforts to reduce GHG emissions largely due to concerns over the international competitiveness of emission-intensive commodities[55]. Yet in Canada, emission-intensive industries and extraction sectors, including oil, gas, potash and mining, represent about 35 percent of all GHG emissions. Above and beyond industrial usage, which includes natural resource extraction and transformation, the average Canadian still produces 30 percent more emissions than the total per person in Europe, leaving plenty of space to undertake positive actions on energy-related GHG emissions.

2.2.1 Energy Production : Electricity

With vast, already installed hydropower capacity and rich potential in undeveloped renewable energy sources that could be harnessed to produce electricity (*Figure 4*), Canada could rapidly move away from fossil fuels in the electricity sector[56]. This transformation, which would put Canada at the forefront of green electricity internationally, could also provide significant cost-savings and give leverage to a number of Canadian industrial sectors.

KEY POLICY ORIENTATION # 2 :
Include aggressive goals for low-carbon electricity production in federal and provincial climate action plans.

53 http://www.ec.gc.ca/ges-ghg/default.asp ?lang=En&n=83A34A7A-1

54 In 2012, for example, 74 % of crude oil, 57 % of marketable natural gas and 23 % of refined petroleum products produced in Canada were exported. See Report on Energy Supply and Demand in Canada 2012 preliminary, Statistics Canada, 2014. (57-003-X).

55 Rivers N. (2010) Impacts of climate policy on the competitiveness of Canadian industry : How big and how to mitigate ? Energy Economics, 32(5), 1092-1104.

56 Barrington-Leigh, C. and Ouliaris, M. (2014) The renewable energy landscape in Canada : a spatial analysis (March 2014) http://wellbeing.research.mcgill.ca/publications/Barrington-Leigh-Ouliaris-DRAFT2014.pdf

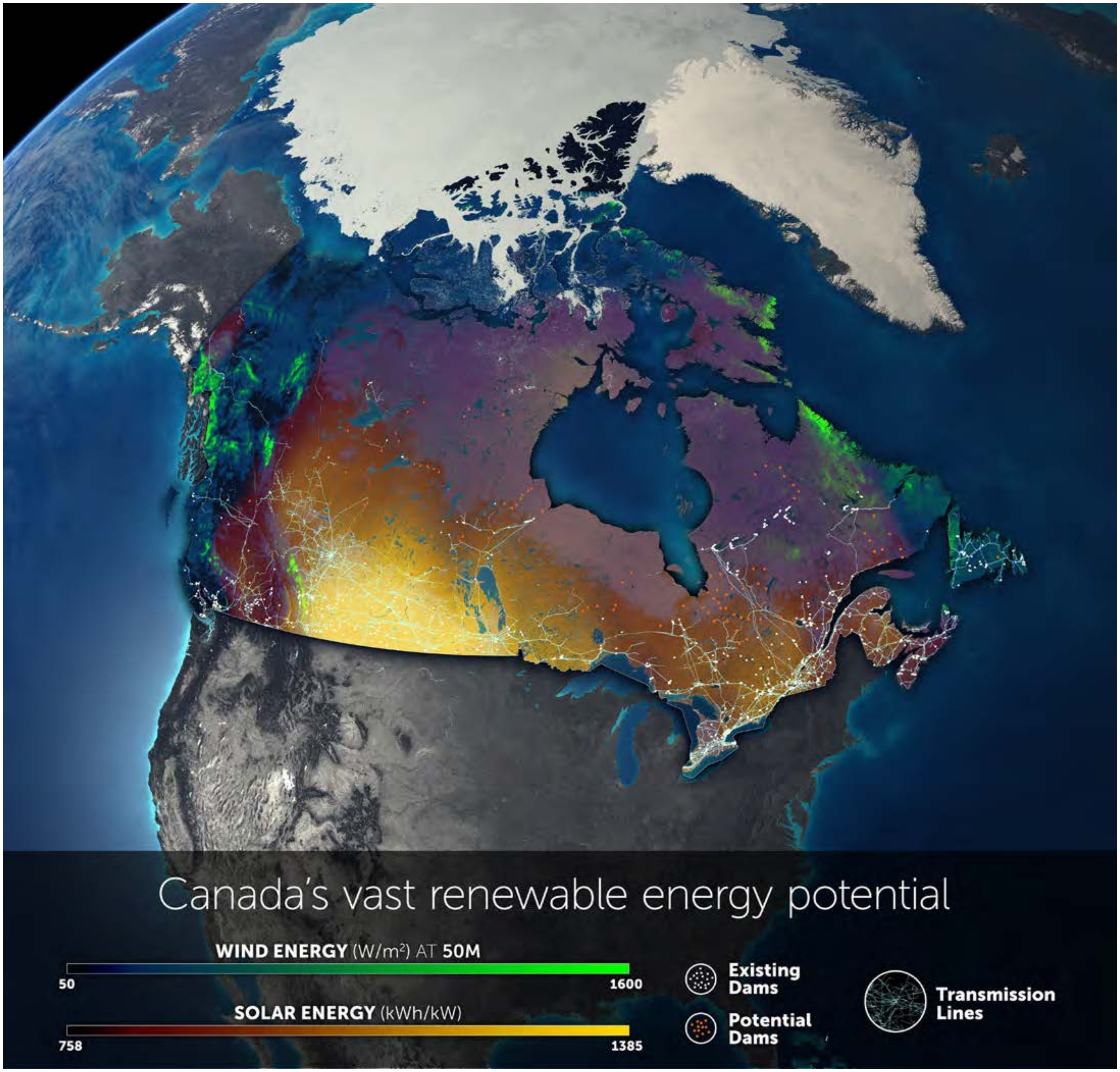

FIGURE 4: MAP OF NATIONAL RENEWABLE ENERGY

East-west interconnections of the electrical grid between provinces could rely on the large-scale hydroelectric infrastructures developed over the past half-century across Canada, dominated by British Columbia, Manitoba, Québec and Newfoundland-and-Labrador. Hydroelectricity could then be combined with intermittent renewables such as wind and solar energy across the country.

Wind energy resources are abundant in the southern prairies, near the Great Lakes, across much of northern British Columbia, Yukon, Nunavut, Quebec and Newfoundland. West and east coast offshore wind development also have substantial potential. Solar energy resources are viable across much of southern Canada, most notably on the southern prairies.

DATA: **Solar Energy:** Published by Natural Resources Canada and Environment Canada. Reproduced with the permission of Natural Resources Canada © Her Majesty the Queen in Right of Canada, 2007. **Wind Energy:** Images downloaded from http://pv.nrcan.gc.ca/ on February 1 2015. **Tranmission Lines:** Government of Canada; Natural Resources Canada; Earth Sciences Sector; Canada Centre for Mapping and Earth Observation. **Existing Dams:** Natural Resources Canada, Atlas of Canada 1,000,000 National Frameworks Data, Hydrology – Dams (V6.0), 2010. **Potential Dams:** Global Forest Watch Canada, Hydropower Developments in Canada: Number, Size and Jurisdictional and Ecological Distribution, 2012. **Earth:** NASA, Globaïa.
DESIGN: Félix Pharand-Deschênes, Globaïa.

Among the number of possible actions to support this first step toward a low-carbon Canada, two appear especially promising :

In the short-term, adopt ambitious sectorial targets for low-carbon electricity production.

Seventy-seven percent of Canada's electricity is already produced from low-carbon emission sources. Combining current hydroelectric production capacity with plentiful untapped renewable energy resources and east-west intelligent grid connections[57] between provinces (see next action bullet), could allow Canada to adopt a target of 100 percent low-carbon electricity production by 2035. While this might seem very ambitious, it is in fact coherent with lowering prices for renewable technologies[58] and the current international context. Norway, for example, already generates 100 percent of its electricity using renewable energy while a number of European countries and regions[59 60 61 62] have adopted, above and beyond low-carbon electricity, a 100 percent renewable energy target. A number of studies and reports[63] propose pathways to achieve such ambitious targets.

Fully developing Canada's low-carbon energy potential however would have to be done taking into account broader sustainability issues, since energy infrastructure can have important environmental and social costs[64]. In addition, the potential of new technologies (such as carbon capture and storage) for reaching 100 percent low-carbon electricity needs to be evaluated[65]. Finally there are technical, political, social and economic barriers to adoption of low-carbon energy solutions that need to be identified and eliminated in a systematic manner to reach the 100 percent low-carbon energy target and meet the multiple needs of local communities while protecting ecosystems. Many of the technical barriers appear in fact to be barriers of information[66] and seem easier to surpass at the municipal level than at higher level of governments[67].

In the short to mid-term, support interprovincial electricity transportation infrastructure.

High-voltage east-west electricity transportation infrastructure between adjacent provinces would allow provinces that produce hydroelectricity (British Columbia, Manitoba, Newfoundland-Labrador and Québec) to sell it to their neighbors. This infrastructure development could be in part supported by the Federal government. Simulations by CESAR., at University of Calgary, show that importing hydro power from BC could lower Alberta's electricity emissions (although this would require development of untapped hydro reserve and a framework for interprovincial cooperation[68]). Similarly, modelling[69 70], done at the University of Regina indicates that importing hydroelectricity from Manitoba would allow Saskatchewan to lower emissions from electricity production, pointing out that once hydro and wind capacities have reached maximum available levels, the least-cost option would then be electricity import. It is noteworthy that Québec and Ontario have recently signed an agreement to expand electricity trading

57 The Deep Decarbonization Canada chapter emphasizes the importance of an "enhanced transmission grid flexibility and energy storage technologies to allow more electricity generation from intermittent renewables" (p. 14).

58 Prices for wind energy, for example, are quickly falling. On December 16, 2014, Hydro-Québec announced that it has accepted three submissions for 450 MW at an average price of 7.6 ¢/kWh including 1.3 ¢/kWh for transport. http://nouvelles.hydroquebec.com/fr/communiques-de-presse/697/appel-doffres-visant-lachat-de-450-mw-denergie-eolienne-hydro-quebec-distribution-retient-3-soumissions-totalisant-4464-mw/

59 http://www.umweltbundesamt.de/en/publikationen/germany-2050-a-greenhouse-gas-neutral-country

60 http://www.nytimes.com/2014/11/11/science/earth/denmark-aims-for-100-percent-renewable-energy.html ?_r=0

61 http://www.scotland.gov.uk/Topics/archive/National-Planning-Policy/themes/renewables

62 http://www.esv.or.at/english/energy-in-upper-austria/

63 http://go100re.net/e-library/studies-and-reports/ and The New Climate Economy Report to "raise ambition for zero-carbon electricity (NCE -Energy, p 27-28)". and https ://web.stanford.edu/group/efmh/jacobson/Articles/I/susenergy2030.html

64 Shaw, K. (2011). Climate deadlocks : the environmental politics of energy systems. Environmental Politics, 20(5), 743-763.

65 Van Alphen, K., et al. (2010). Accelerating the deployment of carbon capture and storage technologies by strengthening the innovation system. International Journal of Greenhouse Gas Control, 4(2), 396-409.

66 Richards, G., et al. (2012). Barriers to renewable energy development : A case study of large-scale wind energy in Saskatchewan, Canada. Energy Policy, 42, 691-698.

67 St-Denis, G. and Parker, P. (2009). Community energy planning in Canada : The role of renewable energy. Renewable and Sustainable Energy Reviews, 13(8), 2088-2095.

68 Transforming Alberta's power sector to address barriers to oil sands production and export, David B. Layzell, CESAR Initiative, University of Alberta, Presentation at the Conoco Phillips IRIS Seminar Series (June 4th, 2014). http://www.cesarnet.ca/research/exploring-strategies-transforming-alberta-s-electrical-systems

69 Lin, Q. G., et al. (2005). An energy systems modelling approach for the planning of power generation : a North American case study. International journal of computer applications in technology (International Network of Centres for Computer Applications), 22(2), 151-159.

70 Lin, Q. G., et al. (2010) The Optimization of Energy Systems under Changing Policies of Greenhouse-gas Emission Control—A Study for the Province of Saskatchewan, Canada. Energy Sources, Part A : Recovery, Utilization, and Environmental Effects, 32(17), 1587-1602.

and cooperate on climate change[71].

2.2.2 Energy Production : Oil and Gas

In 2012, according to Environment Canada[72], oil and gas production was responsible for about 160 Mt CO_2 eq. ; more than three times the GHG emissions associated with energy consumed by the rest of Canada's industry (Figure 3). As such, the oil and gas extraction and transformation sector comes just after transportation for national GHG emissions and could surpass it, if growth continues.

KEY POLICY ORIENTATION # 3 :
Integrate the oil and gas production sector in climate policies

In a continental energy market, Canadian energy producers and exporters in energy intensive industries will face pressure to harmonize with the US. A strong regulatory framework incorporating carbon pricing could favor the development and deployment of innovations[73].

In the short-term, eliminate all direct and indirect subsidies to the fossil fuel industry[74].

In addition, federal and provincial governments could orient the industry.

In the short- to mid- terms, develop a clear regulatory framework coherent with the transition to a low-carbon society and economy.

2.3 ENERGY CONSUMPTION

It is important to understand that reducing GHG emissions demands limiting negative environmental impacts of energy use through energy switching, energy efficiency and some form of energy conservation[75]. Energy efficiency, in particular, is crucial to avoiding unnecessary expansion of energy infrastructure[76], and serves as a focus for innovation and increased competitiveness. It was shown almost twenty years ago that the earlier energy efficiency measures would be adopted in Canada, the lower the cost of GHG emission reduction[77].

KEY POLICY ORIENTATION # 4 :
Adopt a multi-level energy policy with energy efficiency and cooperation in electrification at its core.

Following the lead of the USA, Canada has positioned itself as a leader in efficiency standards in a few sectors, such as industrial electric motors. However, Canada's Energy Efficiency Act[78] lags behind current best practices. The following considerations could be addressed by a national energy efficiency policy elaborated jointly by the federal and provincial governments.

In the short-term, develop a national energy policy with long-term plans for transitioning to low-carbon energy.

Currently decision-making is made in a fragmented way disconnecting energy production, transport and consumption, as well as jurisdiction. A multi-level energy policy could incorporate the following elements :

1. Update norms and standards of energy efficiency across the economic sectors to the highest possible levels, with automatic increments planned ahead ;

71 http://www.cbc.ca/news/business/ontario-quebec-sign-deals-on-electricity-climate-change-1.2844837

72 http://www.ec.gc.ca/ges-ghg/default.asp ?lang=En&n=83A34A7A-1

73 Van Alphen, K., et al. (2010). Accelerating the deployment of carbon capture and storage technologies by strengthening the innovation system. International Journal of Greenhouse Gas Control, 4(2), 396-409.

74 According to the New Climate Economy Report : "With oil-producing country governments facing the greatest asset stranding risk, there will be a need to address and manage the budgetary consequences of reduced demand and the falling oil prices that would result. This should include more rapid phasing out of current fossil fuel subsidies" (NCE - Finance Chapter p. 35-37 http://newclimateeconomy.report/).

75 See for recent overview : Richards, G., et al. (2012). Barriers to renewable energy development : A case study of large-scale wind energy in Saskatchewan, Canada. Energy Policy, 42, 691-698.

76 Shaw, K. (2011). Climate deadlocks : the environmental politics of energy systems. Environmental Politics, 20(5), 743-763.

77 Harvey, L.D.D., et al. (1997). Achieving ecologically-motivated reductions of Canadian CO_2 emissions. Energy, 22(7), 705-724.

78 http://www.nrcan.gc.ca/energy/regulations-codes-standards/6861

2. Favour low- or zero-carbon energy sources whenever possible;
3. Adopt a lifecycle integrated approach to energy projects;
4. Limit energy losses by favouring energy reuse.

In the short-term, ensure government efficiency standards and procurement.

Government leadership for climate action could be shown by ensuring that government purchases at federal, provincial and municipal levels should be "smart" (i.e. secure, sustainable). Governments are big purchasers, and their practices can influence private industry to follow, especially since private industry supplies government entities[79].

In the mid- to long-term, implement efficiency targets for energy use in the extractive industry.

An energy framework could be designed to improve energy efficiency in all natural resource extraction. Extractive industries, which are generally energy intensive, are often located far away from connected electricity grids. It is important to encourage these industries toward maximizing low-carbon energy and moving to low-carbon electricity production, even for the most remote sites. The mining industry is directly affected by climate change and already identifying mitigation options[80 81].

2.4 ENERGY CONSUMPTION : TRANSPORTATION

Canada's transportation system will need to undergo a major revision in the context of the transformation of the energy sector proposed above. Realistic visions for a sustainable Canada mean advancing sustainable ways to transport people and goods over long and short distances[82]. Given the long turnaround time associated with transportation because of vehicle and infrastructure lifespans, it is essential that industry, public sector and consumer investments start to be guided by the need to achieve a reduction of 80 percent in emissions within 35 years.

Governments' investment orientations need to consider that infrastructures built today must foster and sustain a transition to a low-carbon society[83]. This is essential to ensure Canadians have the most cost-effective transportation alternatives in the future. Federal money could support the transformation of transport through development of necessary infrastructure.

KEY POLICY ORIENTATION # 5 :
Throughout Canada, rapidly adopt low-carbon transportation strategies.

Given the complexity of the transportation sector[84], a range of actions might be needed and remain to be fully evaluated in terms of cost/benefit returns:

In the short term, update emissions standards for vehicles and support fuel diversification.

National emission standards could match regions with "best practices" (European or Californian standards within North America), not only for cars, but also for sport utility vehicles and trucks. In addition, the use of natural gas hybrids, biodiesel and the development of electric alternatives for the cars and the heavy trucking industry can contribute to the transition. The production of biodiesel fuel should be strictly controlled to avoid creating adverse effects on biodiversity or water quality.

In the mid- to long-terms, electrify road transport.

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79 Brammer, S. and Walker, H. (2011). Sustainable procurement in the public sector : an international comparative study. International Journal of Operations & Production Management, 31(4), 452-476.

80 Ford, J. D., et al. (2010). Perceptions of climate change risks in primary resource use industries : a survey of the Canadian mining sector. Regional Environmental Change, 10(1), 65-81.

81 Ford, J. D., et al. (2011). Canary in a coal mine : perceptions of climate change risks and response options among Canadian mine operations. Climatic change, 109(3-4), 399-415.

82 Richard, G. and Perl, A. (2010). Transport Revolutions : Moving People and Freight Without Oil. Gabriola Island, BC : New Society Publishers, 433 pp.

83 Lecocq, F. and Shalizi, Z. (2014). The economics of targeted mitigation in infrastructure. Climate Policy, 14(2), 187-208. and Nilsson, M. and Eckerberg, K. (2007). Environmental Policy Integration in Practice : Shaping Institutions for Learning, London : Earthscan.

84 Kennedy, C., et al. (2005). The four pillars of sustainable urban transportation. Transport Reviews, 25(4), 393-414.

The IPCC Fifth Assessment Report (Working Group III[85]) stresses the importance of electrification in the historical evolution of energy production and consumption, emphasising substituting fossil fuel with electricity in transportation, as much as possible.

Urban transport offers a good place to start, for example by electrifying all public (taxi, municipal cars, etc.) and freight fleets[86]. Car-sharing fleets (e.g. Communauto[87] in Montréal) could help showcase electric cars and facilitate their adoption[88]. Electrification of vehicles may be the key element of the transition to low-carbon pathways in jurisdictions like Québec[89], where transport represents 78.4 percent of GHG emissions and electricity is already low in carbon.

In the short- to mid-terms, support new models of transportation.

An array of alternatives to privately owned cars could be made available and plans of access for public transportation could be developed in all Canadian cities. These could include buses, car sharing, taxi-buses[90] and electric trolley-buses[91]. Federal or provincial funding could be made available to establish electric trolley-buses or rapid transit networks conditional upon municipalities removing all on-street parking along these corridors or other disincentives to driving. A range of policies, from tolls to parking fees, have been proposed to stimulate such changes. Across 36 metropolitan areas in Canada, on average only 8 percent of workers commuted to work by public transit in 2011[92]. Setting ambitious targets could help orient investments.

In the short-term, favor active transportation.

The environmental and health benefits of active transportation, such as bicycling and walking, could be taken into account in infrastructure planning. Bicycle paths and streets, wide sidewalks and bicycle parking spaces are needed, while bike-sharing systems (for example, Toronto's Bike Share[93]) could expand the range of bicycle users. Given the length of the winter season, efforts can also be deployed to promote four-season bicycling[94]. Regulations need to be modified to reflect the needs of active transportation (for example vis-à-vis stop signs), and to ensure the safety of cyclists.

In the mid-term, improve and increase intercity rail and intermodal transportation.

Improve rail infrastructure to increase the proportion of freight transport by train, and to provide high-speed passenger train alternative(s) to personal vehicle use. Three times more fuel efficient than trucks, intermodal shipping reduces energy consumption, contributing to improved air quality and environmental conditions. In the USA, shifting 10 % of long-haul freight from truck to rail would save nearly one billion gallons of fuel annually, according to a study by the Federal Railroad Administration. And replacing over the road shipping with intermodal transportation for shipments of more than 1,000 miles would reduce GHG by 65 %, according to the Environmental Protection Agency (EPA)[95].

In addition, high-speed electric train projects (e.g. Vancouver-Seattle-Portland, Calgary-Edmonton, Montréal-Ottawa-Toronto) could be completed in the middle term, provided there are shifts in priority from government spending on road and airport infrastructure expansion to electric train deployment projects. High-speed train networks could then expand in other areas, including suburban and rural zones, along with measures to handle the last-kilometer hurdle. The impact of such projects on emissions reductions, and their economic viability, depends upon their success in decreasing air and car travel between target destinations.

85 http://mitigation2014.org/report/publication

86 http://www.aqtr.qc.ca/images/stories/Activites/2013/mobilite/castonguay.pdf

87 http://communauto.com/index_eng.html

88 Struben, J. and Sterman, J. D. (2008). Transition challenges for alternative fuel vehicle and transportation systems. Environment and Planning B : Planning and Design, 35(6), 1070-1097.

89 http://www.mddelcc.gouv.qc.ca/changements/ges/2010/inventaire1990-2010.pdf

90 http://www.ville.victoriaville.qc.ca/content/fr-CA/s2f_taxibus.aspx

91 Unruh, G. C. (2002). Escaping carbon lock-in. Energy policy, 30(4), 317-325.

92 http://www12.statcan.gc.ca/nhs-enm/2011/as-sa/99-012-x/2011003/tbl/tbl1a-eng.cfm

93 http://www.bikesharetoronto.com/

94 http://www.ledevoir.com/documents/pdf/rapportveloquebec16nov.pdf

95 http://www.fhwa.dot.gov/environment/air_quality/cmaq/reference/intermodal_freight_transportation/

2.5 ENERGY CONSUMPTION : CITIES AND BUILDINGS

Cities are home to 81 percent of Canadians[96]. They concentrate wealth, innovation, education, consumption, and GHG emissions, as well as poverty and vulnerability. SCD's vision of cities is articulated at three interconnected levels : landscape, city and building.

KEY POLICY ORIENTATION # 6 :
Integrate landscape, land use, transportation and energy infrastructure planning policies at multiple scales to ensure climate change mitigation.

In 2011, 52 percent of Canada's metropolitan population lived in medium- and high-density neighbourhoods, and 48 percent lived within 9 km of a city centre[97]. However, throughout Canada, cities are increasing urban density, mixed land uses and non-automobile transportation options, while encouraging climate-friendly buildings and reduction of energy consumption. Strategic landscape planning can provide environmental, economic and social benefits to both rural and urban areas, including resilience to the effects of climate extremes and protection of agriculture, as well as improving cultural, recreational, public health, social equity and education benefits.

In the short-term, integrate climate change into the heart of territorial and urban planning and identify new avenues for financing.

New "smart" urban development projects such as providing incentives to build-in ecological resilience and reduce reliance on cars will require considerable investment. Land value tax financing is probably neither sufficient nor adequate since it incentivizes developer-led. New financing approaches, such as divesting from currently planned road and highway expenses, could be considered. Valuation of natural and constructed landscapes for their ecosystem functioning and environmental management benefits, for example climate change mitigation via thermal cooling[98], represents a critical paradigm shift in municipal and provincial planning.

In the short-term, acknowledge the importance of, and support, green infrastructure and " smart growth[99]" city planning.

Landscape and open-space planning is tied to mobility because "smart" city planning reduces the need to travel and creates space for active mobility, such as walking and bicycling. " Smart growth[100] " cities are designed for high amenity, mixed land use and medium to high dwelling density, with all systems (water, waste, energy, transportation, buildings, etc.) made sustainable, clean, accessible, integrated and connected using advanced technologies. In this context, the " green infrastructure " of urban regions becomes an important component of public infrastructure irrespective of the size of the urban area[101].

Canada has a harsh climate and heating is a considerable energy expense. In total, building heating is responsible for about 80 Mt CO_2 eq[102]. Heating across the country is mostly done by natural gas and oil, except in Québec and Manitoba where renewable electricity provides a considerable proportion of heat for residential, commercial and institutional buildings. Urban densities and designs that allow access to sunshine are critical for implementation of passive and active solar heating strategies. The building sector should be a leader in reducing energy use and GHG emissions.

96 Statistics Canada, 2011. "Population, urban and rural, by province and territory." http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/demo62a-eng.htm

97 Statistics Canada, 2011. "Population, urban and rural, by province and territory." http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/demo62a-eng.htm

98 Hough, M. (2004). Cities and natural process : a basis for sustainability. Routledge.

99 "Smart growth" cities are designed for high amenity, mixed land use and medium to high dwelling density, with all systems (water, waste, energy, transportation, buildings, etc.) made sustainable, clean, accessible, integrated, and connected using advanced technologies.

100 http://www.epa.gov/smartgrowth/tisg.htm

101 Green infrastructure is defined as spatially and functionally integrated networks of natural and constructed vegetative systems and green technologies that leverage the functions of natural ecosystems to provide environmental, social and economic benefits http://www.asla.org/greeninfrastructure.aspx

102 http://www.ec.gc.ca/ges-ghg/default.asp ?lang=En&n=83A34A7A-1

KEY POLICY ORIENTATION # 7 :
Support evolution of the building sector toward a carbon neutral or carbon-positive sector[103].

While energy efficiency in the residential sector improved 29 percent from 1990-2007, overall energy use in this sector increased 7 percent[104]. Between 1990 and 2007, the number of households increased 31 percent while the average Canadian home became 10 percent larger leading to an increase in the number of dwellings and more energy consumed.

In the short-term, adopt ambitious targets for energy demand and efficiency of buildings and include climate change mitigation in national building codes.

By 2035, nearly three- quarters of Canada's buildings will be new or renovated. A new building code, improving energy efficiency of the housing sector to support Architecture 2030[105] targets, could be developed. Such a code could incorporate stringent performance standards such as PassivHaus[106] and consider post-occupancy evaluation in green building projects[107].

A range of actions could help the building sector become carbon neutral or net-positive[108] : energy demand could be cut significantly through proper siting, building and urban density, and by incorporating daylighting, solar heating and natural ventilation. The energy efficiency of environmental control systems could increase and the remaining energy demand could be met by active low-carbon energy.

However tighter building regulations represent additional costs to the developers, and extra labor and work hours for the workers. Changing industry practices could be supported through improved training in the workforce, financing by governments, financial incentives to build better, more sustainable and efficient buildings and disincentives to developers that don't follow best practice guidelines.

In the short- to mid-term, invest in renewable and ambient energy for new and existing buildings.

Design and technology are available to create more climate-friendly buildings at little or no additional cost through cutting demand, increasing efficiency, and shifting to low-carbon energy sources[109]. Options for 100 percent heating transfer to renewable energy include hydroelectricity, solar, biomass and geothermal heat. As with the transportation sector, evolution of the building sector is slow and requires considerable investments. Including requirements for natural lighting, passive heating and cooling and use of active renewable energy in new urban developments is one of the possible ways forward.

Existing buildings could be renovated to the highest possible technical standards for energy efficiency[110]. This could be facilitated by funding from the federal and/or provincial governments. The " pay as you save " policy developed in the UK for building energy efficiency[111] is an interesting model that could be considered for buildings already in place. Electric heat pumps and new insulation can reduce the GHG emissions of old buildings.

2.6 TRANSITIONING TO A LOW-CARBON SOCIETY

Understanding GHG reduction as part of a medium- to long-term transition to a low-carbon society has many advantages.

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103 Kolokotsa, D., et al. (2011). A roadmap towards intelligent net zero-and positive-energy buildings. Solar Energy, 85(12), 3067-3084. and Reed, W. (2007). Shifting from 'sustainability'to regeneration. Building Research & Information, 35(6), 674-680.

104 http://oee.nrcan.gc.ca/publications/statistics/trends09/chapter3.cfm ?attr=0

105 http://architecture2030.org/

106 http://www.passivhaus.org.uk/

107 e.g. UK's CarbonBuzz initiative http://www.carbonbuzz.org/

108 See section 3.5 for definition and example.

109 Cole, R. (2013). Shifting Performance Expectations : Net Positive Buildings. Retrieved from http://www.cesb.cz/cesb13/proceedings/0_keynote/CESB13-Key_Cole.pdf ; Building Performance Institute Europe : http://bpie.eu/eusew_2014.html#.VMpn1ryON8U ; Dekay, M. and Brown, G. Z. (2014). Sun, wind, and light : Architectural design strategies. John Wiley & Sons. : New-York, 413 p.

110 Harvey LDD. (2014) Global climate-oriented building energy use scenarios, Energy Policy, 67, 473-487

111 http://www.ukgbc.org/content/pay-you-save-task-group

- It establishes the direction of change, allowing Canada to plan for the future while recognizing goals take time to accomplish (Figure 5);
- It permits governments, businesses and citizens to situate their activities within the context of expected changes;
- It provides historical references allowing Canadians to understand the transition to a low-carbon economy and society in the light of past social and technical changes, such as industrialization, electrification, the rise of information and communications technologies or democratization.

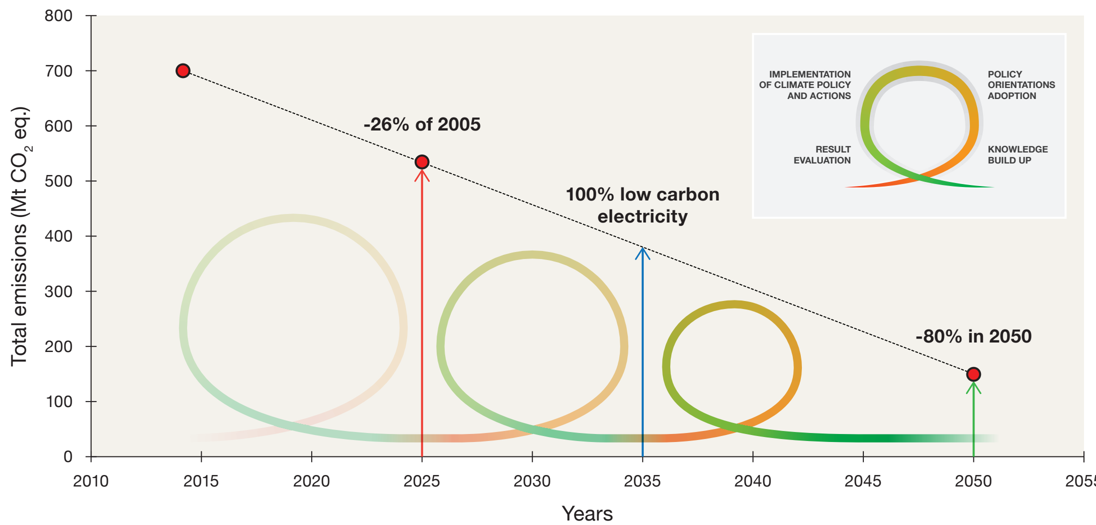

FIGURE 5: TRANSITION TOWARDS A LOW CARBON ECONOMY
Emissions reduction targets as well as target for the production of electricity from renewable sources will flag the road for the transition to a low carbon economy. Progress should be monitored periodically and, at each time, the most appropriate policies and actions, according to the current state of knowledge, should be implemented.

As with other past and future major transitions, there will be controversies and setbacks. Some economic sectors will contract as others expand and adjustment policies may be required. But it will also usher in great opportunities for developing new technologies, businesses and employment.

There are many different routes and pathways consistent with a low-carbon future in Canada. Carbon emissions from transport can be cut by encouraging people to walk, ride a bike, take public transit or drive a low-emission vehicle. Probably we will do more of all of these—but how they will be combined into the future we choose to build remains to be seen. Similarly, we can generate low-carbon electricity with hydro, wind, solar and other renewable energies, but also with nuclear power or fossil sources equipped with carbon capture and storage.

Different regions will opt for different combinations of these and other technologies depending on their vision, energy mixes[112] and emissions sectors[113]. Decarbonisation priorities in Québec, with its hydro-based electricity system, will look different from those in Alberta, which relies substantially on coal and has a developed a hydrocarbon extraction sector. Different realities exist in the other provinces as well. Determining decarbonisation pathways necessarily involves choices about what is acceptable and desirable in the low-carbon world we want to build.

Viewed from the standpoint of the country as a whole, this diversity is complicated. However, it can also be seen as an advantage because different regions can explore different routes, drawing on different technologies, industries and practices. There is room for creativity and cooperation as different provincial and city governments develop transition pathways suitable to their particular circumstances, mobilizing local resources, business interests, technological prowess and cultural norms to encourage movement toward low-carbon emission solutions.

112 http://www.cesarnet.ca/background-energy-systems

113 http://www.cesarnet.ca/blog/dividing-big-picture-visualizing-provincial-diversity

Above all, it should be recognized that no one knows in advance which technologies or institutional solutions will ultimately prove most effective, cost-efficient and socially acceptable. We do not know exactly what the world will look like in thirty or fifty years' time. However, Canada will not be travelling solo on this road to transformation. Nations around the globe engage with the challenge of defining low-carbon development trajectories. Indeed, almost every carbon reduction method advanced in this position paper has already been taken up by decision-makers in one or another developed States. And many countries—including Germany, Sweden, Denmark and the United Kingdom—have already begun to set their policies within the framework of a deliberate transition to a low-carbon emission society. Advancing this transition means getting going now, applying policies that are most appropriate according to the current state of knowledge, then systematically monitoring progress and adjusting our efforts over time on the basis of lessons learned (Figure 6).

This is Exhibit "H" referred to in the
Affidavit of Paul Kershaw, sworn before me
at North Vancouver this 18th day of
December, 2018.

....

A Commissioner for taking Affidavits
within British Columbia

Acting on Climate Change: **Extending the Dialogue Among Canadians**

A collection of texts in response to

Acting on Climate Change: Solutions from Canadian Scholars,

a consensus document released in March 2015

Sustainable Canada Dialogues

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GENERATION | squeeze

ABOUT THE ORGANIZATION

GENERATION SQUEEZE

PAUL KERSHAW

Generation Squeeze is a uniquely positioned, national, non-partisan organization that speaks up for Canadians in their 20s, 30s, 40s and younger who are squeezed by lower incomes, higher costs, less time, and a deteriorating environment. Because governments are less willing to adapt for younger Canadians than others, we're squeezing back so Canada works for all generations.

A CARP for Younger Canada: our enterprise takes inspiration from the model of generational organizing implemented by the Canadian Association of Retired Persons (CARP), which lobbies on behalf of Canadians age 50+.

Our theory of change is simple: if younger Canadians had an organization with political and market clout that matched that of CARP, governments would be more likely to adapt policies to address the squeeze on their generation with the same conviction they do for the aging population. Presently, Canadian governments combine to spend $33 000 to $40 000 annually per person age 65 and older, compared to less than $12 000 per person under age 45; and governments leave younger generations larger fiscal and environmental debts than were inherited by today's aging population when they were young adults.

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RESEARCH SHOWS THAT CANADIANS IN THEIR 20S, 30S, 40S AND THE CHILDREN THEY RAISE ARE SQUEEZED BY LOWER INCOMES, HIGHER COSTS, LESS TIME AND A DETERIORATING ENVIRONMENT COMPARED TO A GENERATION AGO.

Contributed by

GENERATION SQUEEZE

Building Political Will

for a Low-carbon, High Prosperity Canada

Endorsing the Report.
Adopting its Recommendations.

Generation Squeeze[1] applauds the time, expertise and process used to produce the Sustainable Canada Dialogues 2015 report *Acting on Climate Change: Solutions from Canadian Scholars*. We are inspired by the vision for Canada presented in the report, and enthusiastically embrace its recommendations to move toward a sustainable, low-carbon, high prosperity Canada that works for all generations. The recommendations are powerful in part because they reflect a consensus among more than 60 scholars representing every region in the country, and also because they articulate science-based, viable solutions for greenhouse gas (GHG) reductions that will ensure Canadians successfully meet our international obligations, along with our domestic commitments to intergenerational fairness.

Generation Squeeze has integrated the *Acting on Climate Change: Solutions from Canadian Scholars* recommendations to inform our vision for a *Better Generational Deal*[2]: one that gives all Canadians a chance to live up to our potential, enough time and money to enjoy life, and the opportunity to work together to leave our country and planet better off than we found them. To this end, we pursue policy adaptations that enhance the ability of younger Canadians to:

- Pay off student debt
- Find a good job
- Reduce the time it takes to save and pay for a home
- Afford a family
- Save for retirement
- **All while leaving at least as much as we inherited**
- **Using and collecting tax dollars better**

In pursuit of the final two components of a Better Generational Deal, we formally endorse recommendations from *Acting on Climate Change: Solutions from Canadian Scholars*.

1 http://www.gensqueeze.ca

2 http://www.gensqueeze.ca/policies

Specifically, in order to leave at least as much as we inherit, Generation Squeeze endorses the recommendations to:

- Build East-West intelligent grid connections that allow provinces producing hydroelectricity to sell electricity to their neighbours while taking full advantage of Canada's low-carbon energy potential. Hydroelectricity could then be combined with intermittent renewables such as wind and solar energy across the country so Canada relies 100% on low-carbon electricity production by 2035.

- Well-managed energy efficiency programs that produce significant positive economic returns across the board, through cost savings as well as job creation. Energy efficiency programs could target the building sector, businesses and industries, and especially transportation.

- Support evolution of the building sector toward a carbon neutral or carbon-positive sector, including investment in renewable and ambient energy for new and existing buildings. Integrate sustainability and climate change into landscape planning at the regional and city levels to ensure that, amongst other goals, new and maintenance infrastructure investments are consistent with the long-term goal of decarbonizing.

- Support sustainable fisheries, forestry and agriculture practices, offering opportunities not only to limit GHG emissions but also, where possible, to enhance carbon sequestration, protect biological diversity and water quality.

To ensure we collect and use tax dollars better, Generation Squeeze recommends that Canada:

- Eliminate subsidies for fossil fuel industries, and fully integrate the oil and gas production sector in climate policies.

- Price pollution. This requires the introduction of either a national carbon tax or a national economy-wide cap-and-trade program. Revenue from pricing pollution can be used to reduce other taxes and/or invest in other components of a Better Generational Deal.

Building Political Will for a Low-carbon, High Prosperity Canada

While numerous research networks across the country deliver scientific expertise on climate change and sustainability, the *Acting on Climate Change: Solutions from Canadian Scholars* report acknowledges that "information alone is not enough to trigger leadership on climate change and more effective climate change governance. It is clear that decisions are made more on the basis of intuition and values than on rational, careful consideration of costs and benefits of action" (p. 47).

As experts about the large gap between scientific evidence and public policy decisions, Generation Squeeze affirms this conclusion. We believe that this component of the report could be strengthened by adding that **government decisions respond to those who organize and show up**.

Although all Canadians over age 18 have political entitlements, generational cohorts vary significantly in the way they exercise these liberties. Data show that citizens over the age of 45 are much more likely to cast a ballot than are citizens under age 45[3]; and the latter group consists frequently of parents of minors who have no voting rights. Similarly, with over 300 000 members, the Canadian Association of Retired Persons (CARP) has built political clout for its constituency that is age 50+. By contrast, until Generation Squeeze began first as an awareness-raising campaign in 2011, and developed into a campaign to build political power for Canadians in their 20s, 30s, 40s and their children, there had been no pan-Canadian, big-tent generational organization to speak up for younger Canada. We still have considerable distance to travel to catch up to CARP's membership and associated political clout.

This age pattern in voting and political organizing poses a major barrier to the translation of research about climate change into government budgets and policy adaptations, because the risks of inaction to reduce GHGs are borne primarily by younger stakeholders, and the families they will be raising in the middle of this century. So long as Canadians under 45 are less likely to vote and organize in between elections, all political parties are less likely to design platforms that adapt for younger generations. This pattern is evident not only in regards to Canada's tepid commitment to climate change policy in comparison to international leaders, but also in regards to other policy areas related to population health. For instance, groups like Global AgeWatch[4] rank Canada among the top countries worldwide for aging because of spending on medical care, Old Age Security and the Canada Public Pension Plan. By contrast, groups like UNICEF[5] rank Canada among the least generous Organisation for Economic Co-operation and Development (OECD) countries for investments in the generation raising young children, judging that our parental leave and childcare services fall below international standards.

In order for Canada to implement *Acting on Climate Change: Solutions from Canadian Scholars*' recommendations, Generation Squeeze recommends that the authors urge **greater attention be paid to the implementation of interventions designed to increase the power of younger generations in the world of politics**. Certainly, they have the most to lose.

Our organization is at the forefront of one such intervention, and is enthusiastic about the opportunities to partner with authors from Sustainable Canada Dialogues to scale it up.

Consistent with the report's emphasis on the "need to establish organizations focused on the transition to low-carbon pathways" (p. 47), we are building a non-profit lobby designed to grow one million Generation Squeeze supporters by the medium-term. As our network grows, we will bring to the world of politics the one commodity that can out-compete money in a democracy — genuine person power.

To do this, we are organizing allies in part according to their residence in electoral districts. Once our membership is sufficiently large, we intend to approach all candidates running for office, particularly in districts that historically have close election results. In a strictly non-partisan way, we will share with all parties that: 1) the last election was won or lost by less than, for example, 1500 votes;

3 Uppal, S. and LaRochelle-Côté, S. (2012). Factors associated with voting. Perspectives on Labour and Income, 1-15.

4 Global AgeWatch (2013). Global AgeWatch Index 2013, http://www.helpage.org/global-agewatch/, accessed on March 25th, 2014.

5 UNICEF (2008). The child care transition: A league table of early childhood education and care in economically advanced countries. In Innocenti Report Card 8, UNICEF Innocenti Research Centre, Florence, http://www.unicef-irc.org/publications/pdf/rc8_eng.pdf, accessed on July 31st, 2009.

that 2) Generation Squeeze has thousands of allies in their district; and that 3) we only need to move a fraction of those allies to make the difference between winning and losing their local election. As we operationalize this strategy in upwards of 20 ridings, we will build an organization that can make the difference between winning and losing a majority government provincially and/or federally. We will use the resulting influence to transform existing priorities articulated by political parties across the political spectrum in ways that ensure their platforms embrace components of a Better Generational Deal so that Canada works for all generations.

By adopting the recommendations from *Acting on Climate Change: Solutions from Canadian Scholars* as part of our vision for a Better Generational Deal, Generation Squeeze is an intervention designed to grow political will in support of the scholarly consensus articulated in that report. This is a variation on the report's emphasis regarding "social mobilisation" (p. 48) – one that not only focuses on behaviour change to promote sustainability at the individual level, but also to increase our collective capacity to promote sustainability at the population level.

In keeping with the authors' focus on "the importance of triggering a values shift in response to climate change" (p. 47), Generation Squeeze recommends that Sustainable Canada Dialogues contribute to telling a **broader narrative about generational prosperity and intergenerational fairness.**

Generation Squeeze organizes its political mobilization activity around a communications narrative that has been expertly shaped in the light of Canadian values about intergenerational fairness, and emerging concerns that younger Canadians are inheriting a socioeconomic and environmental standard of living that is deteriorating compared to the one their parents inherited a generation ago in Canada. Accordingly, we purposefully link interests and values related to sustainability with concerns that people feel immediately in their wallets as a result of stagnant wages, high housing costs, less time and larger government debts. This innovative communication frame marries the environmental and economic, often in deeply personal ways for people, and can complement existing communication strategies within green environmental movements. Specifically, our plan to build political will in support of a low-carbon, high prosperity Canada makes available a unique opportunity to attract the interest, time, and eventually clout, of a broader constituency of Canadians who have not yet connected the dots between the risks of climate change with other components of the time, money and service squeeze they are feeling more immediately in their lives.

In sum, Sustainable Canada Dialogues has identified the policy adaptations that will put Canada on a secure path to a low-carbon, high prosperity future. It is time to embed these recommendations in interventions designed to grow the political will required to achieve their implementation. Building a national lobby for those in their 20s, 30s and 40s, along with the children they parent – one that is organized around a broad narrative of generational prosperity and fairness – can be a major contributor to building this political will. Generation Squeeze therefore welcomes the opportunity to work in collaboration with Sustainable Canada Dialogues partners in support of their inspiring vision for Canada.

ABOUT THE INITIATIVE

SUSTAINABLE CANADA DIALOGUES

This contribution is part of a collection of texts, *Acting on Climate Change: Extending the Dialogue Among Canadians*, stemming from interactions between Sustainable Canada Dialogues, an initiative of the UNESCO-McGill Chair for Dialogues on Sustainability, and business associations, First Nations, non-governmental organizations, labour groups, institutions, organizations and private citizens.

Sustainable Canada Dialogues is a voluntary initiative that mobilizes over 60 researchers from every province in Canada, representing disciplines across engineering, sciences and social sciences. We are motivated by a shared view that putting options on the table will stimulate action and is long overdue in Canada.

Together, the contributions enrich the scope of possible solutions and show that Canada is brimming with ideas, possibilities and the will to act. The views expressed in *Acting on Climate Change: Extending the Dialogue Among Canadians* are those of the contributors, and are not necessarily endorsed by Sustainable Canada Dialogues.

We thank all contributors for engaging in this dialogue with us to help reach a collective vision of desired pathways to our futures.

FOR MORE INFORMATION, VISIT OUR WEBSITE

sustainablecanadadialogues.ca/en/scd/acting-on-climate-change

American Economic Review 2015, 105(4): 1339–1370
http://dx.doi.org/10.1257/aer.15000001

This is Exhibit "I" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

A Commissioner for taking Affidavits within British Columbia

Climate Clubs: Overcoming Free-riding in International Climate Policy†

By William Nordhaus*

Notwithstanding great progress in scientific and economic understanding of climate change, it has proven difficult to forge international agreements because of free-riding, as seen in the defunct Kyoto Protocol. This study examines the club as a model for international climate policy. Based on economic theory and empirical modeling, it finds that without sanctions against non-participants there are no stable coalitions other than those with minimal abatement. By contrast, a regime with small trade penalties on non-participants, a Climate Club, can induce a large stable coalition with high levels of abatement. (*JEL* Q54, Q58, K32, K33)

I. Bargaining and Climate Coalitions

A. *Free-riding and the Westphalian System*

Subject to many deep uncertainties, scientists and economists have developed an extensive understanding of the science, technologies, and policies involved in climate change and reducing emissions. Much analysis of the impact of national policies such as cap-and-trade or carbon taxes, along with regulatory options, has been undertaken.

Notwithstanding this progress, it has up to now proven difficult to induce countries to join in an international agreement with significant reductions in emissions. The fundamental reason is the strong incentives for free-riding in current international climate agreements. *Free-riding* occurs when a party receives the benefits of a public good without contributing to the costs. In the case of the international climate-change policy, countries have an incentive to rely on the emissions reductions of others without taking proportionate domestic abatement. To this is added temporal free-riding when the present generation benefits from enjoying the consumption benefits of high carbon emissions, while future generations pay for those emissions in lower consumption or a degraded environment. The result

* Sterling Professor of Economics, Yale University (e-mail: william.nordhaus@yale.edu). I would like to thank the many scholars whose research has contributed to the analysis underlying this study as well as people who have commented on early drafts and presentations. Paul Sztorc of the Yale Department of Economics contributed to the modeling, particularly of the international trade module. The research has been supported by the US National Science Foundation and the US Department of Energy. The author declares no relevant conflicts of interest.

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of free-riding is the failure of the only significant international climate treaty, the Kyoto Protocol, and the difficulties of forging effective follow-up regimes.

While free-riding is pervasive, it is particularly difficult to overcome for global public goods. Global public goods differ from national market failures because no mechanisms—either market or governmental—can deal with them effectively. Arrangements to secure an international climate treaty are hampered by the Westphalian dilemma. The 1648 Treaty of Westphalia established the central principles of modern international law. First, nations are sovereign and have the fundamental right of political self-determination; second, states are legally equal; and third, states are free to manage their internal affairs without the intervention of other states. The current Westphalian system requires that countries consent to joining international agreements, and all agreements are therefore essentially voluntary (Treaty of Vienna 1969, article 34).

B. *Clubs as a Mechanism to Overcome Free-riding*

Notwithstanding the Westphalian dilemma, nations have overcome many transnational conflicts and spillovers through international agreements. There are over 200,000 UN-registered treaties and actions, which are presumptive attempts to improve the participants' welfare. Countries enter into agreements because joint action can take into account the spillover effects among the participants.

How have countries overcome the tendency toward free-riding associated with the Westphalian system? Consider the many important international agreements in international trade and finance as well as alliances that have reduced the lethality of interstate military conflicts. These have often been accomplished through the mechanism of "clubs." A club is a voluntary group deriving mutual benefits from sharing the costs of producing an activity that has public-good characteristics. The gains from a successful club are sufficiently large that members will pay dues and adhere to club rules in order to gain the benefits of membership.

The theory of clubs is a little-known but important corner of the social sciences. (For an early analysis, see Buchanan 1965, while for a fine survey, see Sandler and Tschirhart 1980.) The major conditions for a successful club include the following: (i) that there is a public-good-type resource that can be shared (whether the benefits from a military alliance or the enjoyment of a golf course); (ii) that the cooperative arrangement, including the dues, is beneficial for each of the members; (iii) that nonmembers can be excluded or penalized at relatively low cost to members; and (iv) that the membership is stable in the sense that no one wants to leave. For the current international-trade system, the advantages are the access to other countries' markets with low trade barriers. For military alliances, the benefits are peace and survival. In all cases, countries must contribute dues—these being low trade barriers for trade or burden sharing in defense treaties. If we look at successful international clubs, we might see the seeds of an effective international system to deal with climate change.

The organization of this paper is as follows. After a sketch of the proposal, I begin with a discussion of the issues of free-riding and previous analyses of potential solutions. I examine potential approaches to internalizing the transnational spillovers and conclude that a Climate Club with penalties for nonmembers is the most fruitful mechanism. The following sections develop a model of coalition formation with climate economics (the Coalition-DICE or C-DICE model) and show the results of illustrative calculations. The bottom line—that clubs with penalties or sanctions on nonparticipants can support a strong international climate agreement—is summarized at the end of the paper.

C. *A Sketch of the Climate Club*

The idea of a Climate Club should be viewed as an idealized solution of the free-riding problem that prevents the efficient provision of global public goods. Like free trade or physics in a vacuum, it will never exist in its pure form. Rather, it is a blueprint that can be used to understand the basic forces at work and sketch a system that can overcome free-riding.

Here is a brief description of the proposed Climate Club: the club is an agreement by participating countries to undertake harmonized emissions reductions. The agreement envisioned here centers on an "international target carbon price" that is the focal provision of an international agreement. For example, countries might agree that each country will implement policies that produce a minimum domestic carbon price of $25 per ton of carbon dioxide (CO_2). Countries could meet the international target price requirement using whatever mechanism they choose—carbon tax, cap-and-trade, or a hybrid.

A key part of the club mechanism (and the major difference from all current proposals) is that nonparticipants are penalized. The penalty analyzed here is uniform percentage tariffs on the imports of nonparticipants into the club region. Calculations suggest that a relatively low tariff rate will induce high participation as long as the international target carbon price is up to $50 per ton.

An important aspect of the club is that it creates a strategic situation in which countries acting in their self-interest will choose to enter the club and undertake high levels of emissions reductions because of the structure of the incentives. The balance of this study examines the club structure more carefully and provides an empirical model to calculate its effectiveness.

II. Background on International Agreements on Climate Change

A. *Basic Free-riding Equilibrium*

There is a large literature on the strategic aspects of international environmental agreements, including those focused on climate change. One important strand is the analytical work on global public goods. The clear message is that without special features the outcome will be a prisoners' dilemma or tragedy of the commons in which there is too little abatement. This point is illustrated with a simple model that will form the backbone of the empirical model below.

I begin by analyzing the costs and benefits of national climate policies in a noncooperative (NC) framework (Nash 1950). In the NC framework, countries act individually and are neither rewarded nor penalized by other countries for their policies. The analysis assumes that countries maximize their national economic welfare and ignores partisan, ideological, myopic, and other nonoptimizing behaviors. While history is full of wooden-headed actions of countries and their leaders, as well as policies that are farsighted and attend to global welfare, attempting to incorporate these features is beyond the scope of this study of climate regimes.

B. *Noncooperative Equilibrium in a One-shot Decision*

Begin by assuming that countries choose their policies once and for all in a single decision. I take a highly stylized structure, but the most complex models extant have virtually identical results.

For this example, I assume that the emissions-intensities (σ) and the damage-output ratios are identical for all countries and that countries only differ in their sizes. In what follows, $W =$ total economic welfare, $A =$ abatement cost, $D =$ damages, $Q =$ output, $E =$ actual emissions, $\overline{E} =$ uncontrolled emissions, and $\mu =$ emissions control rate $[= (\overline{E} - E)/\overline{E}]$. A key variable is the social cost of carbon (SCC), which is the marginal damage from a unit of emissions. The global SCC is denoted by γ, while θ is the country share of world output and other variables. This first analysis excludes trade.

The basic identity for country i is that welfare equals output minus abatement cost minus damages. Abatement costs are assumed to be quadratic in the emissions reduction rate, $A_i = \alpha\mu_i^2 Q_i = \alpha\mu_i^2\theta_i Q_w$, where α is the identical abatement-cost parameter and Q_w is world output. Damages are proportional to global emissions. All these imply for region i:

$$W_i = Q_i - A_i - D_i = \theta_i Q_w - \alpha\mu_i^2\theta_i Q_w - \gamma\theta_i(E_i + \sum_{j\neq i} E_j). \tag{1}$$

The potential for free riding occurs because most of the damages originate outside the country. This is captured in the last term of equation (1), which in practice means that for all countries the preponderance of damages originate outside, while the preponderance of damages caused by a country's emissions falls on other countries.

Maximizing each country's welfare in a one-shot game, assuming no cooperation or strategic interactions, yields (as shown in the online Appendix) the noncooperative emissions-control rate and domestic carbon price $\left(\tau_i^{NC}\right)$:

$$\mu_i^{NC} = \theta_i[\gamma\sigma/2\alpha] \tag{2}$$

$$\tau_i^{NC} = \theta_i\gamma. \tag{3}$$

The most intuitive result shown in (3) is that a country's noncooperative carbon price is equal to the country share of output times the global social cost of carbon. A less intuitive result in (2) is that a country's noncooperative control rate $\left(\mu_i^{NC}\right)$ is proportional to the country share of world output, to the global SCC, to the emissions-output ratio, and inverse to the abatement-cost parameter. Equation (3) survives alternative specifications of the abatement-cost function, while (2) is sensitive to parameters such as the exponent in the cost function.

Under the simplified assumptions, calculate the global average NC control rate and carbon price as functions of the cooperative levels $\left(\overline{\mu}^C \text{ and } \overline{\tau}^C\right)$;

$$\overline{\mu}^{NC} = \sum_i \theta_i\mu_i = \sum_i \theta_i^2[\gamma\sigma/2\alpha] = (\gamma\sigma/2\alpha)H(\theta) = \overline{\mu}^C H(\theta) \tag{4}$$

$$\overline{\tau}^{NC} = \sum_i \theta_i\tau_i = \sum_i \gamma\theta_i^2 = \gamma H(\theta) = \overline{\tau}^C H(\theta). \tag{5}$$

In these equations, $H(\theta)=\sum_i \theta_i^2$ is the Herfindahl index of country size.

Equations (4) and (5) show the basic free-riding equilibrium for a global public good with the simplified structure. The globally averaged noncooperative carbon price and control rate are equal to the Herfindahl index times the cooperative values. For example, if there are ten equally sized countries, the Herfindahl index is 10 percent, and the global carbon tax and emissions-control rates are 10 percent of the efficient levels.

The Herfindahl index for country gross domestic products (GDPs) is about 12 percent, indicating that (when emissions-intensities and damage ratios are equal for each country) the noncooperative control rate and carbon price are about 12 percent of the cooperative values. This figure is close to calculations that have been made in more complete models (see Nordhaus and Yang 1996; Nordhaus 2010; Bosetti et al. 2012). For example in the multiperiod RICE-2010 model with 12 regions, the noncooperative price is estimated to be is 11 percent of the efficient price (Nordhaus 2010, supplemental materials).

C. *Outcomes with Repeated Decisions*

A more complete treatment of country interactions in climate-change policy views interactions in a dynamic framework with decisions over time. The standard analysis uses the framework of a repeated prisoners' dilemma (RPD) game. For simplicity, assume that the structure above is repeated every few years with identical parameters. One equilibrium of a RPD is just the iterated inefficient one-shot equilibrium with minimal abatement as described above. However, because players can reward and punish other players for good and bad behavior, RPD games generally have multiple equilibria; these might include more efficient outcomes if country discount rates are low (these being the generalized results of various folk theorems). The efficient RPD equilibrium with large numbers of countries will be hampered by free-riding and inability to construct renegotiation-proof strategies in situations with large number of agents.

The strategic significance of the analysis of NC behavior is threefold. First, the overall level of abatement in the noncooperative equilibrium will be much lower than in the efficient (cooperative) strategy. A second and less evident point is that countries will have strong incentives to free-ride by not participating in strong climate-change agreements. Finally, the difficulty of escaping from a low-level, noncooperative equilibrium is amplified by the intertemporal trade-off because the current generation pays for the abatement while future generations are the beneficiaries of lower damages. But to a first approximation, the noncooperative analysis in this section describes international climate policy as of 2015.

III. Climate Coalitions and International Environmental Treaties

A. *Key Definitions on Sanctions and Coalitions*

Might coalitions of countries form cooperative arrangements or treaties that improve on noncooperative arrangements? Questions involving the formation, value, and stability of coalitions have a long history in game theory, oligopoly theory, as well as in environmental economics. In this section, I analyze coalitions without external penalties, that is, ones that have self-contained payoffs and cannot be enforced by third parties or be linked to other arrangements.

Begin with some definitions. The formal difference between "external" and "internal" penalties is the following. If countries are playing a repeated game, then *internal penalties* maintain the payoff structure of the game, but countries can penalize or reward others by selecting different combinations of strategies. Tit-for-tat is a game with internal penalties because it has a reward structure given by the payoffs of the stage games. In the end, however, the rewards must be some combination of the payoffs of the original game. By contrast, *external penalties* change the payoff structure of the game. A standard external penalty comes when a player imposes a sanction that derives from a trading relationship that is unconnected to the payoffs of the original game. For example, in a treaty to preserve whales, a player might punish an uncooperative party by imposing a duty on the imports of related products. The tariffs are unrelated to the public-goods nature of the decline of the whale population and are therefore external.

Before turning to the analysis of coalitions, it will be useful to distinguish between "bottom-up" and "top-down" coalitions. The standard approach in environmental economics, reviewed in the next section, focuses on a bottom-up approach in which coalitions optimize their own self-interest and evolve into larger or smaller coalitions. Regional trade agreements are examples of this approach.

The Climate Club approach is instead a top-down approach. Here, the regime is optimized to attract large numbers of participants and attain high levels of abatement, and then countries decide whether or not to join. The Bretton Woods institutions such as the International Monetary Fund or the World Trade Organization are examples of the top-down model.

B. *Bottom-up Coalitions and the Small Coalition Paradox*

In the context of climate change, coalitions of countries can form treaties that potentially improve the welfare of their members by taking concerted action. If several countries maximize their joint welfare, the optimized level of abatement will rise relative to the noncooperative equilibrium because more countries will benefit. In the algebraic example described above, the coalition's optimal control rate shown in equation (2) will equal the global optimum times the coalition's share of world output. As the coalition increases to include all countries, the global level of abatement will tend toward the efficient rate. This result might form the basis for hopes that arrangements like the Kyoto Protocol will lead to deep emissions reductions.

In fact, theoretical and empirical studies indicate that bottom-up coalitions for cartels and global public goods tend to be small, fragile, and unstable. Work on coalition stability by Hart and Kurz (1983) found that coalitions are generally not stable, and their structure will depend upon the structure of the payoffs and the stability concept. Studies of the structure of cartels in oligopoly theory (see, e.g., D'Aspremont et al. 1983 and Donsimoni, Economides, and Polemarchakis 1986) found that cartels are likely to be small, unstable, or of vanishingly small importance as the number of firms grows.

Studies in environmental economics and climate change find virtually universally that coalitions tend to be either small or shallow, a result I will call the "small coalition paradox." The paradigm for understanding the small coalition paradox is well discussed in Barrett's (2003) book on international environmental agreements.

His analysis emphasizes credible or "self-enforcing" treaties (Barrett 1994). These are ones that combine individual rationality (for each player individually) and collective rationality (for all players together). This concept is weaker than the concept of coalition stability discussed later, which adds rationality for each subset of the players. Barrett emphasizes the difficulties of reaching agreements on global public goods with large numbers of participants because of free-riding. Similar to the results for cartels, Barrett and others find that stable climate coalitions tend to have few members; therefore, as the number of countries rises, the fraction of global emissions covered by the agreement declines. He further argues, based on a comprehensive review of existing treaties, that there are very few treaties for global public goods that succeed in inducing countries to increase their investments significantly above the noncooperative levels. Moreover, the ones that do succeed include external penalties.

How can we understand the small coalition paradox? Here is the intuition for climate change: clearly, two countries can improve their welfare by combining and raising their carbon price to the level that equals the sum of their SCCs. Either country is worse off by dropping out. The 2014 agreement between China and the United States to join forces in climate policy might be interpreted as an example of a small bottom-up coalition.

Does it follow that, by increasing the number of countries in the treaty, this process would accumulate into a grand coalition of all countries with efficient abatement? That conclusion is generally wrong. The problem arises because, as more countries join, the cooperative carbon price becomes ever higher, and ever further from the NC price. The discrepancy gives incentives for individual countries to defect. When a country defects from an agreement with m countries, the remainder coalition (of $m - 1$ countries) would reoptimize its levels of abatement. The revised levels of abatement would still be well above the NC levels for the remainder coalition, while the defector free-rides on the abatement of the remainder coalition. The exact size of the coalitions would depend upon the cost and damage structure as well as the number of countries.

The online Appendix provides a simple analysis of the bottom-up coalition equilibrium for identical countries with the cost and damage structure shown in equations (1)–(5). The only stable coalitions have two or three countries. (For simplicity, assume the lower number holds in the case of ties.) The size of the stable coalition is independent of the number of countries, the social cost of carbon, output, emissions, and the emissions intensity. If there are ten identical countries, there will be five coalitions of two countries each. The global average carbon price is twice that of the NC equilibrium. This result is clear because each country-pair has a joint SCC that is the sum of the two countries' SCCs. The globally averaged carbon price will be one-fifth of the efficient level. With countries of different sizes but equal intensities, countries will group together in stable coalitions of size two, with the countries of similar sizes grouped together in pairs (i.e., largest with second-largest, and so on).

The key result is that bottom-up coalitions perform only slightly better than the noncooperative equilibrium.

C. *Modeling Results for Bottom-up Coalitions*

The coalition theories described above generally use highly stylized structures and assumptions, so it is useful to examine empirical models of climate-policy coalitions with more realistic assumptions. Several empirical studies have examined the structure of coalitions or international agreements using a variety of alternative cooperative structures and coalition assumptions. A brief description of key studies is contained in the online Appendix.

The central results of existing studies reproduce the finding of the small coalition paradox. Without penalties on nonparticipants, stable coalitions tend to be small and have emissions reductions that are close to the noncooperative level. In addition, many studies find that coalitions tend to be unstable, particularly if transfers among regions are included.

IV. Sanctions on Nonparticipants to Promote an Effective Climate Club

As noted above, the syndrome of free-riding along with the international norm of voluntary participation appears to doom international climate agreements like the Kyoto Protocol. The suggestion in this paper is that a club structure—where external sanctions are imposed on nonmembers—will be necessary to induce effective agreements. I analyze in depth a specific model of sanctions (tariffs on nonparticipants), but the model illustrates the more general point that external sanctions are necessary to promote participation in effective agreements to provide global public goods.

A. *Stable Coalitions*

While it is easy to design potential international climate agreements, the reality is that it is difficult to construct ones that are effective and stable. Effective means abatement approaching the global optimum. The concept of stability used here is denoted as a *coalition Nash equilibrium*. Under this definition, a coalition is stable if no group (sub-coalition) among the countries can improve its welfare by changing its status. That is, it combines individual rationality (for each player individually), collective rationality (for all players together), and coalition rationality (for each subset of the players). This is a natural extension of a Nash equilibrium, which applies to single countries. The concept is widely used in different fields and was originally called strong equilibrium in Aumann (1959); also see Bernheim, Peleg, and Whinston (1987). The term coalition Nash is more intuitive and is used here.

The small coalition paradox motivates the current approach. The goal here is to find a structure that is stable and effective for a wide variety of country preferences, technologies, and strategies. The most appealing structure is one that does not depend on sophisticated and fragile repeated-game strategies and instead has an efficient equilibrium for every period (in the stage games) in a repeated game. I therefore focus on one-shot games that have efficient and unique equilibria. If these are then turned into a repeated game, each of the one-shot games will be a sub-game-perfect coalition Nash equilibrium, and the repeated game will have an efficient coalition-Nash equilibrium.

B. *Transfers Undermine Coalition Stability*

The present study assumes that there is no sharing of the gains from cooperation among members of the coalition. In some cases, particularly those with asymmetric

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Table 3—Country Preferred International Target Carbon Prices
(*For global SCC of $25*)

Region	Global target carbon price that maximizes domestic welfare for SCC \$25/t CO_2 and penalty tariff of 5 percent
South Africa	9
China	14
Eurasia	14
Southeast Asia	17
Russia	19
ROW	24
United States	28
Brazil	29
Latin America	31
India*	31
Canada*	34
Japan	38
European Union*	38
Sub-Saharan Africa	39
Mideast	40
Memorandum items (*\$ per ton* CO_2)	
Global SCC	25
Average preferred price	
GDP weights	28
Population weights	27
Median preferred price	
GDP weights	28
Population weights	29

Notes: What international target carbon price would regions prefer when the global SCC is $25 per ton? For example, the US national welfare is highest when the target price is $28 per ton. Countries with high damages and low abatement costs such as the EU prefer high target prices. The table shows the optima without trade effects. The optima with trade effects have higher country-preferred target carbon prices.

*Countries with multiple local optima.

damages. There will be second-order effects through cost-of-capital factors, GDP, and other economic variables. But a changed discount rate will affect the outcome primarily through changes in the SCC.

VIII. Conclusion

The present study analyzes the syndrome of free-riding in climate agreements such as the Kyoto Protocol and considers potential structures for overcoming free-riding. This concluding section summarizes the basic approach and conclusions.

A. *The Climate Club*

The structure of climate change as a global public good makes it particularly susceptible to free-riding. The costs of abatement are national, while the benefits are global and independent of where emissions take place. An additional complication is that the abatement costs are paid today while most of the benefits of abatement come in the distant future. The present study shows, in a stylized model of costs and damages, that the global noncooperative carbon price and abatement rate are proportional to the Herfindahl index of country size. This implies, given realistic data, that the global noncooperative carbon price and control rate will be in the order of one-tenth of the efficient cooperative levels.

Next consider possible mechanisms to combat free-riding and focus on a Climate Club. It is generally assumed that the most effective approach will be to impose trade sanctions on nonparticipants, and this is the route followed here. Most trade sanctions rely on duties on carbon-intensive goods. For strategic, economic, and technical reasons, this paper instead considers penalties that take the form of uniform ad valorem tariffs levied by club participants on nonparticipants. In the analysis, the tariff rates vary from 0 percent to 10 percent. It is further assumed that a climate treaty will amend trade rules so that a penalty tariff conforms with international trade law and retaliation by nonparticipants is prohibited.

This study assumes that countries adopt an international carbon-price target rather than a quantity target as the policy instrument. The assumed target price ranges from \$12.5–\$100 per ton CO_2. In the experiments, the international target carbon price is always set equal to the global social cost of carbon.

Individual countries are assumed to adopt climate policies that maximize their national economic welfare. Welfare equals standard income less damages less abatement costs less the costs of trade sanctions. I assume a one-shot static game, but this can be interpreted as the stage game of a repeated game. The equilibrium, described as a coalition Nash equilibrium, is a coalition of countries that is stable against any combination of joiners and defectors. The equilibrium is calculated by an evolutionary algorithm that tests each coalition against a random collection of countries that can defect and join.

The study introduces a new approach called the C-DICE model (Coalition DICE, or Coalition Dynamic Integrated Model of Climate and the Economy). It is a 15-region model with abatement, damages, international trade, and the economic impacts of tariffs. Using an evolutionary algorithm, the model can be used to find stable coalition Nash equilibria.

B. *Qualifications*

I begin with qualifications on the results that relate to the data and structural parameters. The data on output, CO_2 emissions, and trade are relatively well measured. The global SCC is uncertain but can be varied as shown in the different experiments. The national SCCs are also uncertain, but since they are all small relative to the global SCC, their exact magnitudes are not critical for the findings. Other structural uncertainties relate to the abatement cost function and the optimal tariff rate.

A related question is whether a trade-penalty-plus-carbon-price regime can operate in the future with the rising carbon prices that are generally associated with an efficient climate-change program. Answering this question requires a multiperiod coalition model and is on the agenda for future research.

These results are presented in the spirit of an extended example used to clarify the free-riding in international agreements rather than as a specific proposal for a climate treaty. A Climate Club of the kind analyzed here raises central issues about the purpose of the global trading system, about the goals for slowing climate change, about the justice of a system that puts all countries on the same footing, and about how countries would actually negotiate such a regime. The dangers to the world trading system of such a proposal are so important that they must be reiterated. Today's open trading system is the result of decades of negotiations to combat protectionism. It has undoubtedly produced large gains to living standards around the world. A regime that ties a climate-change agreement to the trading system should be embraced only if the benefits to slowing climate change are clear and the dangers to the trading system are worth the benefits.

C. *Results*

One major result is to confirm that a regime without trade sanctions will dissipate to the low-abatement, noncooperative (NC) equilibrium. This is true starting from a random selection of participating countries. More interestingly, starting from the Kyoto coalition (Annex I countries as defined by the Kyoto treaty) with no sanctions, the coalition always degenerates to the NC structure with minimal abatement.

A surprising result is that the Climate Club structure generates stable coalitions for virtually all sets of parameters. A few regimes produce quasi-stable coalitions with similar numbers of participants.

A next set of results concerns the impact of different Climate Club parameters on the participation structure. The participation rate and the average global carbon price rise with the tariff rate. For the lowest target carbon prices ($12.5 and $25 per ton), full participation and efficiency are achieved with relatively low tariffs (2 percent or more). However, as the target carbon price rises, it becomes increasingly difficult to attain the cooperative equilibrium. For a $50 per ton target carbon price, the Club can attain 90+ percent efficiency with a tariff rate of 5 percent or more. However, for a target carbon price of $100 per ton, it is difficult to induce more than the noncooperative level of abatement.

Why is it so difficult to attain efficient abatement with high social costs of carbon even with high penalty tariffs? The reason is that the gap between the cooperative and the noncooperative equilibrium rises sharply as the global SCC increases. Take the case of a large country like China or the United States. For these countries the national SCC might be 10 percent of the global SCC. For a global SCC and target price of $25 per ton, participation would require increasing the domestic carbon price from $2.5 to $25, while a global SCC of $100 would require increasing from $10 to $100. Because abatement costs are sharply increasing in the target carbon price, this implies that the costs of cooperation become much larger as the target carbon price rises. On the other hand, the costs of trade penalties associated with nonparticipation are independent of the global SCC. So the national cost-benefit trade-off tilts toward nonparticipation as the international target carbon price rises.

Next examine the patterns of gains and losses. Here, measure the impact relative to the noncooperative equilibrium. Note as well that these results assume no transfers among countries. The benefits are widely distributed among countries. The only regions showing losses across several regimes are Eurasia and South Africa; however, the losses are small relative to gains for other regions. There are no regimes with aggregate losses.

Look at the distribution of gains and losses to determine whether a Climate Club would be attractive to most countries relative to existing arrangements. All regions would prefer a regime with penalties and modest carbon prices to a regime with no penalties. Paradoxically, this is the case even for countries that do not participate. The reason is that the gains from strong mitigation measures of participants outweigh the losses from the tariffs for nonparticipants as long as the tariff rate is not too high. This powerful result indicates that a regime with sanctions should be attractive to most regions.

D. *Bottom Line*

Here is the bottom line: the present study finds that without sanctions there is no stable climate coalition other than the noncooperative, low-abatement coalition. This conclusion is soundly based on public-goods theory, on C-DICE model simulations, on the history of international agreements, and on the experience of the Kyoto Protocol.

The analysis shows how an international climate treaty that combines target carbon pricing and trade sanctions can induce substantial abatement. The modeling results indicate that modest trade penalties on nonparticipants can induce a coalition that approaches the optimal level of abatement as long as the target carbon price is up to $50 per ton at current income and emission levels. The attractiveness of a Climate Club must be judged relative to the current approaches, where international climate treaties are essentially voluntary and have little prospect of slowing climate change.

REFERENCES

Aumann, R. J. 1959. "Acceptable Points in General Cooperative N-Person Games." *Contributions to the Theory of Games IV,* edited by A. W. Tucker and R. D. Luce, 287–324. Princeton, NJ: Princeton University Press.

Barrett, Scott. 1994. "Self-Enforcing International Environmental Agreements." *Oxford Economic Papers* 46 (0): 878–94.

Barrett, Scott. 2003. *Environment and Statecraft: The Strategy of Environmental Treaty-Making.* Oxford and New York: Oxford University Press.

Bernheim, B. Douglas, Bezalel Peleg, and Michael D. Whinston. 1987. "Coalition-Proof Nash Equilibria: Concepts." *Journal of Economic Theory* 42 (1): 1–12.

Bordoff, Jason E. 2009. "International Trade Law and the Economics of Climate Policy: Evaluating the Legality and Effectiveness of Proposals to Address Competitiveness and Leakage Concerns." In *Climate Change, Trade, and Competitiveness: Is a Collision Inevitable?* edited by Lael Brainard and Isaac Sorkin, 35–68. Washington, DC: Brookings Institution.

Bosetti, Valentina, Carlo Carraro, Enrica DeCian, Emanuele Massetti, and Massimo Tavoni. 2012. "Incentives and Stability of International Climate Coalitions: An Integrated Assessment." *Energy Policy* 55: 44–56.

Brainard, Lael, and Isaac Sorkin (eds.). 2009. *Climate Change, Trade, and Competitiveness: Is a Collision Inevitable?* Washington, DC: Brookings Institution Press.

Buchanan, J. M. 1965. "An Economic Theory of Clubs." *Economica* NS 32 (0): 1–14.

Carraro, Carlo, and Domenico Siniscalco. 1993. "Strategies for the International Protection of the Environment." *Journal of Public Economics* 52 (3): 309–28.

CDIAC. 2014. Carbon Dioxide Infromation Analysis Center. http://cdiac.ornl.gov/.

This is Exhibit "J" referred to in the
Affidavit of Paul Kershaw, sworn before
me at North Vancouver this 18th day of
December, 2018.

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within British Columbia

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Executive summary

This is the 9th edition of the UN Environment Emissions Gap Report. It assesses the latest scientific studies on current and estimated future greenhouse gas emissions and compares these with the emission levels permissible for the world to progress on a least-cost pathway to achieve the goals of the Paris Agreement. This difference between "where we are likely to be and where we need to be" is known as the 'emissions gap'. As in previous years, the report explores some of the most important options available for countries to bridge the gap.

The political context this year is provided by several processes and events:

- The Talanoa Dialogue – an inclusive, participatory and transparent dialogue about ambitions and actions, conducted under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC) and designed to help build momentum for new or updated Nationally Determined Contributions (NDCs) to be submitted by 2020.
- The Global Climate Action Summit in September 2018 – bringing together many non-state and subnational actors (NSAs) that are actively involved in climate issues.
- The Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C – focusing on "the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty". The Emissions Gap Report has benefited significantly from the IPCC Special Report and its underlying studies.

This Emissions Gap Report has been prepared by an international team of leading scientists, assessing all available information, including that published in the context of the IPCC Special Report, as well as in other recent scientific studies. The assessment production process has been transparent and participatory. The assessment methodology and preliminary findings were made available to the governments of the countries specifically mentioned in the report to provide them with the opportunity to comment on the findings.

1. **Current commitments expressed in the NDCs are inadequate to bridge the emissions gap in 2030. Technically, it is still possible to bridge the gap to ensure global warming stays well below 2°C and 1.5°C, but if NDC ambitions are not increased before 2030, exceeding the 1.5°C goal can no longer be avoided. Now more than ever, unprecedented and urgent action is required by all nations. The assessment of actions by the G20 countries indicates that this is yet to happen; in fact, global CO_2 emissions increased in 2017 after three years of stagnation.**

This year's report presents the newest assessment of the emissions gap in 2030 between emission levels under full implementation of the unconditional and conditional NDCs and those consistent with least-cost pathways to stay below 2°C and 1.5°C respectively.

- With the results of the new global studies prepared for the IPCC report, the emissions gap – especially to stay below 1.5°C warming – has increased significantly in comparison with previous estimates, as new studies explore more variations and make more cautious assumptions about the possibility of global carbon dioxide-removal deployment.
- Pathways reflecting current NDCs imply global warming of about 3°C by 2100, with warming continuing afterwards. If the emissions gap is not closed by 2030, it is very plausible that the goal of a well-below 2°C temperature increase is also out of reach.

- The assessment of country action for this Emissions Gap Report concludes that while most G20 countries are on track to meet their Cancun pledges for 2020, the majority are not yet on a path that will lead them to fulfilling their NDCs for 2030.
- Concerns about the current level of both ambition and action are thus amplified compared to previous Emissions Gap Reports. According to the current policy and NDC scenarios, global emissions are not estimated to peak by 2030, let alone by 2020. The current NDCs are estimated to lower global emissions in 2030 by up to 6 $GtCO_2e$ compared to a continuation of current policies. As the emissions gap assessment shows, this original level of ambition needs to be roughly tripled for the 2°C scenario and increased around fivefold for the 1.5°C scenario.
- Action by non-state and subnational actors (NSAs), including regional and local governments and businesses, is key to implementing the NDCs. The strong engagement by NSAs demonstrated at the recent Global Climate Action Summit is promising and can help governments deliver on their NDCs, but the impact of current individual NSA pledges on reducing the gap is extremely limited. Chapter 5 of this Emissions Gap Report was pre-released at the Summit, and documents that if international cooperative initiatives succeed in increasing their membership and ambition, substantially greater potential can be realized. The chapter emphasizes that enhanced monitoring and reporting of actions and resulting emissions reductions will be essential for the credibility of NSA action.
- Countries therefore need to move rapidly on the implementation of their current NDCs; at the same time, more ambitious NDCs are necessary by 2020 to meet the jointly agreed goals. This report summarizes the different approaches countries can take to build enhanced ambition and enhance the scale, scope and effectiveness of their domestic policy.
- The policies and measures chapters in this year's report address two key aspects for the longer-term transition to a zero-emission economy and society. Fiscal policies provide a key opportunity for reducing future emissions, and there are options to design them in such a way that they deliver the desired results without creating economic and social problems. Several countries have demonstrated that it is possible to overcome social resistance, but few have gone far enough to have the necessary emissions reduction impact. Innovation policy and market creation also offer significant mitigation potential and governments should play a key role in ensuring the development and market introduction of new and emerging low-carbon technologies and practices.

The key messages from the 2018 Emissions Gap Report send strong signals to national governments and to the political part of the Talanoa Dialogue at the 24th session of the Conference of the Parties (COP 24). Along with the recent IPCC Special Report, these messages provide the scientific underpinning for the UN 2019 Climate Summit, which will convene on the theme of 'A Race We Can Win. A Race We Must Win'. By way of the summit, the United Nations Secretary-General will seek to challenge States, regions, cities, companies, investors and citizens to step up action in six key areas: energy transition, climate finance and carbon pricing, industry transition, nature-based solutions, cities and local action, and resilience.

2. **Global greenhouse gas emissions show no signs of peaking. Global CO_2 emissions from energy and industry increased in 2017, following a three-year period of stabilization. Total annual greenhouse gases emissions, including from land-use change, reached a record high of 53.5 $GtCO_2e$ in 2017, an increase of 0.7 $GtCO_2e$ compared with 2016. In contrast, global GHG emissions in 2030 need to be approximately 25 percent and 55 percent lower than in 2017 to put the world on a least-cost pathway to limiting global warming to 2°C and 1.5°C respectively.**

In 2017 greenhouse gas (GHG) emissions - excluding emissions from land-use change - reached a record 49.2 $GtCO_2e$. This is an increase of 1.1 percent on the previous year. Emissions from land-use change, which vary from year to year because of weather conditions, added another 4.2 $GtCO_2$, bringing the total to 53.5 $GtCO_2e$.

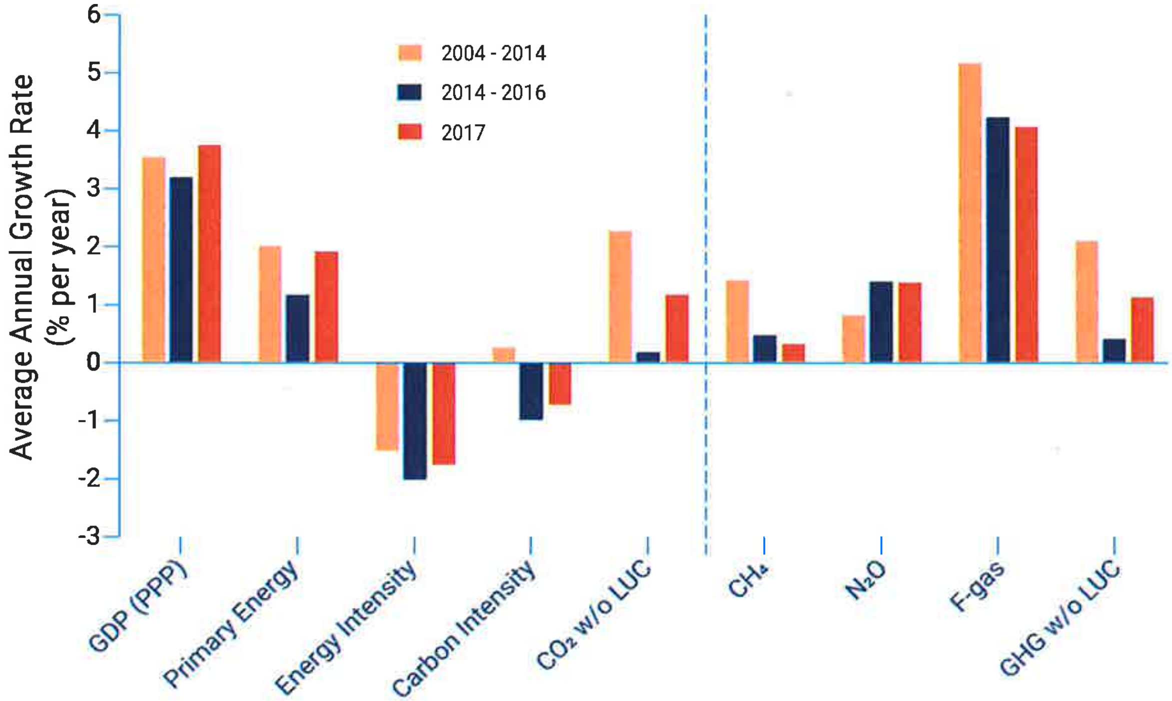
Despite modest growth in the world economy, CO_2 emissions from fossil fuel combustion, cement production and other industrial processes remained relatively stable from 2014 to 2016. This brought optimism to climate policy discussions, indicating that global GHG emissions might show signs of peaking. However, preliminary estimates of global CO_2 emissions from fossil fuels, industry and cement for 2017 suggest an increase of 1.2 percent (figure ES.1). The main drivers of the increase are higher gross domestic product (GDP) growth (about 3.7 percent) and slower declines in energy, and especially carbon, intensity, compared with the 2014–2016 period. The 2017 increase leaves considerable uncertainty as to whether the 2014–2016 slowdown was driven primarily by short-term economic factors.

Since CO_2 emissions from fossil fuels, industry and cement dominate total GHG emissions, the changes in CO_2 emissions had the largest influence on GHG emissions from 2014 to 2017. Land-use change emissions have remained relatively flat, despite large annual variations driven by weather patterns and uncertainty in input data.

Global peaking of emissions by 2020 is crucial for achieving the temperature targets of the Paris Agreement, but the scale and pace of current mitigation action remains insufficient. Following on from the Talanoa Dialogue, which has raised confidence in implementation efforts and has shown that increased ambition is possible, national governments have the opportunity to strengthen their current policies and their NDCs by 2020.

Global peaking of GHG emissions is determined by the aggregate emissions from all countries. While there has been steady progress in the number of countries that

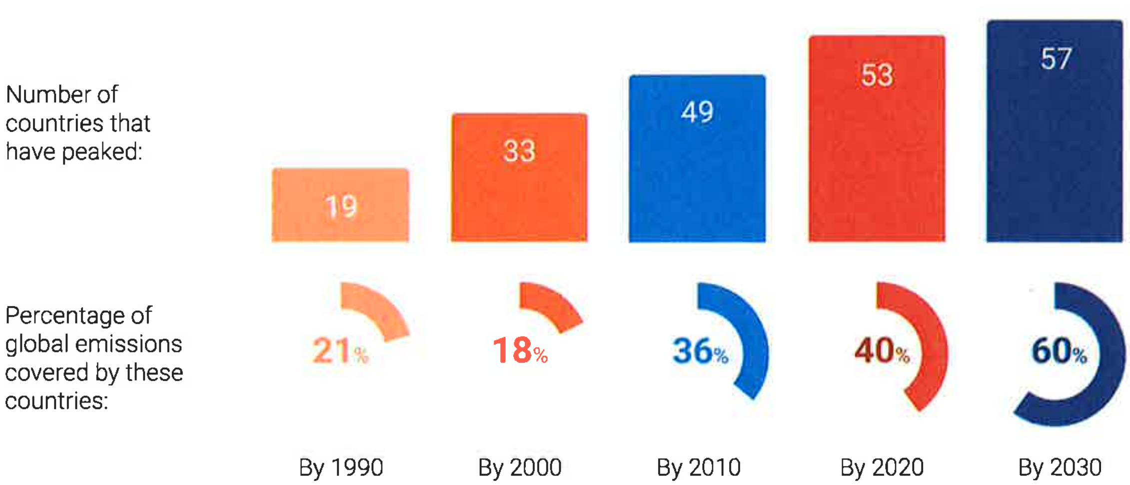
Figure ES.1: Average annual growth rates of key drivers of global CO_2 emissions (left of dotted line) and components of GHG emissions (right of dotted line).



Note: Land-use change emissions are not included due to large inter-annual variability. Leap-year adjustments are not included in the growth rates.

have peaked their GHG emissions or have pledged to do so in the future (figure ES.2), the 49 countries that have so far done so, and the 36 percent share of global emissions they represent, is not large enough to enable the world's emissions to peak in the near term. By 2030, up to 57 countries, representing 60 percent of global emissions, will have peaked, if commitments are fulfilled.

Figure ES.2: Number of countries that have peaked or are committed to peaking their emissions, by decade (aggregate) and percentage of global emissions covered (aggregate).



Source: Levin and Rich (2017).

Countries that have already peaked have a critical role to play in determining the timing and level of global emissions peaking, as each country's decarbonization rate after peaking will be a defining factor in global cumulative emissions. However, it is clear that countries that have peaked their GHG emissions have not reduced their emissions at a fast-enough rate since the peak year.

Collectively, G20 members are projected to achieve the Cancun pledges by 2020, but they are not yet on track to realize their NDCs for 2030. Consistent with past Emissions Gap Reports, this report finds that the GHG emissions of the G20 countries, as a group, will not have peaked by 2030 unless there is a rapid increase in ambition and action within the next few years.

While G20 members collectively are on track to achieving the target emission levels in 2020 implied by the Cancun pledges, some countries (Canada, Indonesia, Mexico, the Republic of Korea, South Africa and the USA) are either not projected to achieve their Cancun pledges, or there is uncertainty on whether they will achieve them.

At present, the G20 countries are collectively not on track to meet their unconditional NDCs for 2030. Around half of the G20 members' GHG emissions trajectories fall short of achieving their unconditional NDCs (Argentina, Australia, Canada, EU28, the Republic of Korea, Saudi Arabia, South Africa and the USA). Three G20 members (Brazil, China and Japan) are on track to meeting their NDC targets under current policies, while emissions under current policies of three additional countries (India, Russia and Turkey) are projected to be more than 10 percent below their unconditional NDC targets. This may, in some cases, reflect relatively low ambition in the NDCs. It is uncertain whether two countries (Indonesia and Mexico) are on track to meeting their NDC targets in 2030 under current policies.

G20 members will need to implement additional policies to reduce their annual GHG emissions further by about 2.5 $GtCO_2e$ to achieve their unconditional NDCs and by about 3.5 $GtCO_2e$ to achieve their conditional NDCs by 2030. These additional reductions needed have gone down by approximately 1 $GtCO_2e$ compared with 2017, due to lower projections of emissions under current policies in China, the EU28 and the USA.

Table ES.1: Total global greenhouse gas emissions in 2030 under different scenarios (median and 10th to 90th percentile range), temperature implications and the resulting emissions gap.

Scenario (rounded to the nearest gigatonne)	Number of scenarios in set	Global total emissions in 2030 [$GtCO_2e$]	Estimated temperature outcomes			Emissions Gap in 2030 [$GtCO_2e$]		
			50% chance	66% chance	90% chance	Below 2°C	Below 1.8°C	Below 1.5°C in 2100
No-policy baseline	179	65 (60–70)						
Current policy	4	59 (56–60)				18 (16–20)	24 (22–25)	35 (32–36)
Unconditional NDCs	12	56 (52–58)				15 (12–17)	21 (17–23)	32 (28–34)
Conditional NDCs	10	53 (49–55)				13 (9–15)	19 (15–20)	29 (26–31)
Below 2.0°C (66% chance)	29	40 (38–45)	Peak: 1.7–1.8°C In 2100: 1.6–1.7°C	**Peak: 1.9–2.0°C** **In 2100: 1.8–1.9°C**	Peak: 2.4–2.6°C In 2100: 2.3–2.5°C			
Below 1.8°C (66% chance)	43	34 (30–40)	Peak: 1.6–1.7°C In 2100: 1.3–1.6°C	**Peak: 1.7–1.8°C** **In 2100: 1.5–1.7°C**	Peak: 2.1–2.3°C In 2100: 1.9–2.2°C			
Below 1.5°C in 2100 (66% chance)	13	24 (22–30)	Peak: 1.5–1.6°C In 2100: 1.2–1.3°C	**Peak: 1.6–1.7°C** **In 2100: 1.4–1.5°C**	Peak: 2.0–2.1°C In 2100: 1.8–1.9°C			

Note: The gap numbers and ranges are calculated based on the original numbers (without rounding), which may differ from the rounded numbers (third column) in the table. Numbers are rounded to full $GtCO_2e$. GHG emissions have been aggregated with 100-year global warming potential (GWP) values of the IPCC Second Assessment Report. The NDC and current policy emission projections may differ slightly from the presented numbers in Cross-Chapter Box 11 of the IPCC Special Report (Bertoldi *et al.*, 2018) due to the inclusion of new studies after the literature cut-off date set by the IPCC. Pathways were grouped in three categories depending on whether their maximum cumulative CO_2 emissions were less than 600 $GtCO_2$, between 600 and 900 $GtCO_2$, or between 900 and 1,300 $GtCO_2$ from 2018 onwards until net zero CO_2 emissions are reached, or until the end of the century if net zero is not reached before. Pathways assume limited action until 2020 and cost-optimal mitigation thereafter. Estimated temperature outcomes are based on the method used in the IPCC 5th Assessment Report.

percent of the total GHG emissions over the last decade when excluding LUC, the top 7 (including Russia, Japan and international transport) account for more than 66 percent, while G20 members contribute 78 percent. Aggregated GHG emissions from G20 countries grew at 2.1 percent/year from 2004 to 2014, remained relatively steady from 2014 to 2016 and are estimated to grow 0.9 percent in 2017. Even though emission reductions are needed from all countries, the top emitters are responsible for most of the changes in global emissions.

China emits more than one quarter (27 percent) of global GHG emissions (excluding LUC), and the ups and downs of Chinese emissions leave an important signature on global emissions growth. From 2004 to 2014, Chinese GHG emissions grew at an annual rate of 6 percent (accounting for two thirds of global emissions growth), before declining slightly from 2014 to 2016. The slowdown during the 2014–2016 period was across all GHGs, though CO_2 dominated the trend due to a marked decline in coal consumption. Some reports have speculated that Chinese emissions, more specifically coal consumption, may have peaked (Qi *et al.*, 2016). However, the increase of 1.2 percent in global CO_2 emissions in 2017, due to renewed growth of emissions at a rate of 0.9 percent, suggests that it may be too soon to consider Chinese emissions to have peaked.

The European Union (EU) and USA play key strategic roles in global climate policy due to their historical responsibility, and together account for more than 20 percent of global GHG emissions (13 percent for the USA and 9 percent for the EU, excluding LUC). Emissions in the USA likely peaked in 2007 and decreased at an annual rate of 0.4 percent from 2004 to 2014. The rate of reductions increased from 2014 to 2016 (annual declines of 2 percent), with significant drops in 2015 and 2016 due to less coal-powered electricity generation. Emissions decreased slightly in 2017 by 0.3 percent. Reductions have been strongest for CO_2 emissions, but there has been strong growth in fluorinated gas emissions. This indicates that the USA made considerable contributions to the observed slowdown in global GHG emissions growth for the 2014–2016 period.

The EU has had steady declines in GHG emissions since 1990, with accelerated reductions of 2 percent/year from 2004 to 2014. However, EU emissions have been increasing since 2014 (on average 1 percent/year), reversing the long-term trend. Increases in CO_2 emissions due to strong growth in oil and gas use are largely responsible for the overall rise, though N_2O emissions have also increased and the growth of fluorinated gas emissions has also remained strong. CH_4 emissions continued to decline but at a slower rate.

Due to its large population, India's GHG emissions represent 7.1 percent of the global total, despite its low per capita emissions and large parts of the population needing better living standards. Indian emissions grew strongly in the 2004–2014 period, at an annual rate of 5 percent, with only a slight respite during the 2014–2016 period, when the annual rate dropped to 3 percent. India's GHG emissions are estimated to grow at a rate of 3 percent in 2017 due to the demonetization process (removal of some rupees from circulation) and the introduction of a goods and services tax.[14]

Although the top 4 countries represent 56 percent of global GHG emissions (excluding LUC), this does not downplay the importance of the remaining countries. GHG emissions in the Russian Federation are 4.6 percent of the global total and since 2014 have continued to grow by about 1 percent/year (excluding LUC). In Japan, GHG emissions (2.9 percent of the global total) have declined on average 1 percent/year since 2014, despite significant fluctuations following the Fukushima Daiichi nuclear disaster. Emissions from international aviation and marine transport, which represent 2.5 percent of global GHG emissions, have grown strongly at an annual rate of over 2 percent since 2014.

Despite a distinct slowdown in emissions growth from 2014 to 2016, initial data for 2017 indicates GHG emissions have started to increase, both globally and in key countries. It is unclear whether the 2017 growth trend will be sustained in the next few years or whether 2017 will just be an anomalous year as global emissions reach a plateau. While it seemed that global GHG emissions could peak in the near future, recent changes have now delayed this.

2.4 Assessment of current policies: are G20 members on track to meet the Cancun pledges for 2020 and NDC targets for 2030, and to peak their emissions?

2.4.1 Overview and comparison of G20 members

As G20 members currently account for around 78 percent of global emissions, they will greatly influence the achievement of the Paris Agreement climate goal. This section provides an update of the extent to which G20 members are putting in place and implementing policies that enable them to meet the Cancun pledges and NDCs. In addition, it offers an overview of G20 members' respective shares of global emissions, the implications of their unconditional NDCs for per capita emissions and where they stand with respect to peaking of emissions and decarbonization rates. Table 2.1 provides a comparative overview of this information for all G20 members (with the EU28 represented collectively instead of as the four Member States that are also individual G20 members).

Collective progress towards the Cancun pledges and NDCs

G20 members are collectively projected to achieve the conditional end of the Cancun pledges for 2020 under current policies. However, as table 2.1 indicates, six G20

14 https://www.carbonbrief.org/guest-post-why-indias-co2-emissions-grew-strongly-in-2017.

members (Canada, Indonesia, Mexico, the Republic of Korea, South Africa, the USA) are either not projected to achieve their Cancun pledges, or have uncertainty on whether they will achieve it.

At present, G20 countries are collectively not on track to meet their unconditional NDCs for 2030. Based on an assessment of current policies, around half of G20 members fall short of achieving their unconditional NDCs (Argentina, Australia, Canada, EU28, the Republic of Korea, Saudi Arabia, South Africa and the USA) (table 2.1 and figure 2.4). Under current policies, three G20 members (Brazil, China and Japan) are on track to meet their NDC targets, while emissions under current policies of three additional countries (India, Russia and Turkey) are projected to be more than 10 percent below their unconditional NDC targets. It is uncertain whether two countries (Indonesia and Mexico) are on track to meet their NDC targets in 2030 under current policies.

It is estimated that G20 members will need to implement additional policies to reduce GHG emissions further by about 2.5 $GtCO_2e$/year to achieve their unconditional NDCs and 3.5 $GtCO_2e$/year to achieve their conditional NDCs by 2030. The estimate of additional reductions needed has decreased by approximately 1 $GtCO_2e$ compared with 2017, due to lower projections of emission reductions under current policies in China, the EU28 and the USA.

It is important to note that a country likely to meet or exceed its NDCs based on current policies is not necessarily undertaking more stringent mitigation action than a country that is not on track. It can also indicate that the ambition of the current NDC could be enhanced. According to the Paris Agreement, countries are obliged to regularly update and strengthen their NDCs. The assessment conducted in this section is based on current NDCs, recognizing that they are to be revised and should be strengthened considerably by 2020 to reduce global emissions to levels consistent with limiting global warming to below 2°C or 1.5°C by 2030 (see chapter 3).

Peaking of emissions and decarbonization rates

Countries that have historically peaked have a critical role to play in determining the timing and level of global emissions peaking, as each country's decarbonization rate after peaking will be a defining factor for global cumulative emissions. Countries that have already peaked their GHG emissions have not reduced their emissions at fast enough rates since the peak year. For example, an 80 percent reduction of emissions between 2005 and 2050 requires a constant annual reduction rate of 3.5 percent/year for the period. By contrast, the G20 members that have peaked show constant annual emission reduction rates ranging between 0.6 percent/year (Canada) and 2.5 percent/year (Russia) up to 2016 for all GHG emissions, including land use, land-use change and forestry (LULUCF) (table 2.1). Brazil, the only non-Annex I member of the G20 that has peaked its GHG emissions to date, showed an average reduction rate of 12 percent/year between 2004 and 2012 due to the large reductions in emissions from LULUCF. Brazil's GHG emissions from non-LULUCF sectors have increased by 2.4 percent/year on average (table 2.1).

Table 2.1: Overview of the status and progress of G20 members, including on Cancun pledges and NDC targets.

Country	Share of global GHG emissions in 2017[a]	On track to meet the targets with current policies?		Unconditional NDC: per capita[b] GHG emissions		Emission peaking	
		Cancun pledges	Unconditional NDC	tCO_2e/cap in 2030[c]	versus 2015 levels	Peaking year[d]	Average annual growth after peaking[e]
Argentina	0.8%	No pledge	No	9.8	-6%	No commitment to peak	—
Australia	1.2%	Yes	No	15.4	-29%	2006	-1.6%/year
Brazil	2.3%	Yes	Yes	5.3	-22%	2004	(2006–2016) -12.0%/year (2004–2012) (+2.4%/year excluding LULUCF)
Canada	1.6%	No	No	12.9	-33%	2007	-0.6%/year (2007–2016)
China	26.8%	Yes	Yes	10.0	+17%	By 2030 (CO_2 only)	—
EU28	9.0%	Yes	No	6.1	-23%	1990 or earlier	-1.1%/year (1990–2016)
India	7.0%	Yes	Yes*	3.5	+67%	No commitment to peak	—
Indonesia	1.7%	Uncertain	Uncertain	6.9	+15%	No commitment to peak	—
Japan	3.0%	Yes	Yes	8.6	-13%	By 2020	—
Mexico	1.5%	Uncertain	Uncertain	5.1	-2%	By 2030	—
Republic of Korea	1.6%	No	No	10.1	-21%	By 2020	—
Russian Federation	4.6%	Yes	Yes*	18.9	+33%	1990 or earlier (former Soviet republic)	-2.5%/year (1990–2016) +0.5%/year (2000–2016)
Saudi Arabia	1.5%	No pledge	No	23.1	+19%	No commitment to peak	—
South Africa	1.1%	Uncertain	No	9.5	0%	No commitment to peak	—
Turkey	1.2%	No pledge	Yes*	10.5	+102%	No commitment to peak	—
United States of America	13.1%	Uncertain	No	14.0 (2025)	-25% (2025)	2007	-1.5%/year (2007–2016)

Notes:

a Olivier *et al.* (2018), excluding LULUCF.

b Population projections are based on the medium fertility variant of the United Nations World Population Prospects 2017 edition (UN DESA, 2017).

c The G20 average in 2015 was 7.5 tCO_2e/cap (based on national GHG inventories and using the EDGAR GHG trend if emissions for the latest years were missing). Using EDGAR estimates only, the G20 average in 2015 was 8.0 tCO_2e/cap (Olivier *et al.*, 2017).

d Given the unconditional pledges. Expected peak years are based only on commitments that countries have made and assume the achievement of such commitments.

e Authors' calculations based on UNFCCC (2018) data (including LULUCF). For Australia and Canada, the peak years based on 2018 GHG inventories were 2007 and 2004 respectively, which differs from those assessed by Levin and Rich (2017), since they used older inventory data. Peak years reported by Levin and Rich (2017) are used here for the calculations. The average emission growth rates were -1.8 percent/year for Australia with 2007 as the peak year and -0.5 percent/year for Canada with 2004 as the peak year.

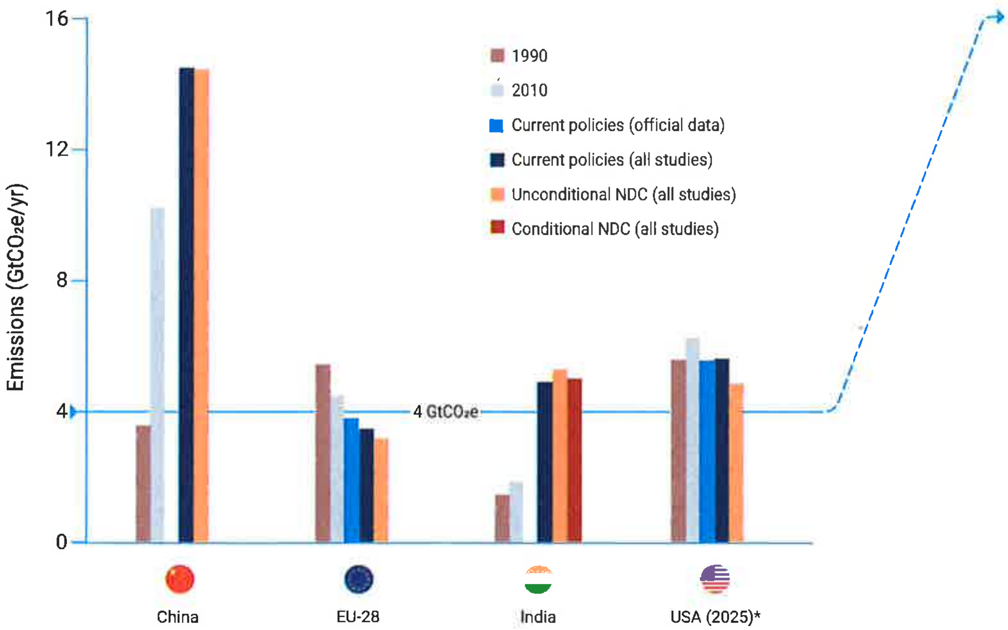
* Denotes that the current policy trajectory is more than 10 percent below the NDC target.

To assess whether the changes in emission-related indicators as a result of NDCs are both ambitious and fair (in line with the long-term goal of the Paris Agreement) would require a thorough evaluation of normative indicators of burden-sharing indicators, which is beyond the scope of this report. However, a number of recent peer-reviewed studies attempt this task, based on various effort-sharing considerations (Höhne *et al.*, 2014; Pan *et al.*, 2017; Robiou du Pont *et al.*, 2017; CAT, 2018a; Holz *et al.*, 2018).

Figure 2.4 provides a detailed comparison of estimated emissions under current policies and the full implementation of NDCs for all G20 members, mapping these against 1990 and 2010 emissions. For each of the G20 members, median GHG emission projections have been calculated for current policies and full implementation of the NDC, using information from a recently published study (den Elzen *et al.*, forthcoming), which updates and expands the data sources covered in the 2017 Emissions Gap Report (UNEP, 2017), using the most up-to-date data from countries' recently published National Communications, 3rd biennial reports of 7 G20 members, and several other new national studies for policies and NDC projections. The estimates draw on official country data and independent sources (see den Elzen *et al.* 2018 for further details). GHG emission projections under current policies from independent analyses presented in this chapter cover main energy and climate policies implemented by a recent cut-off date and do not consider prospective policies that are being debated or planned. Similarly, current policy and NDC estimates only partially cover commitments and actions made by non-state and subnational actors to date and do not fully reflect the implications of recent significant declines in the cost of renewable energy sources. The role and potential of non-state and subnational actors is assessed in chapter 5, while chapter 7 discusses the role of innovation policy and market creation.

Figure 2.4: Greenhouse gas emissions (all gases and sectors) of the G20 and its individual members by 2030 under different scenarios and compared with historical emissions.

Figure 2.4a.



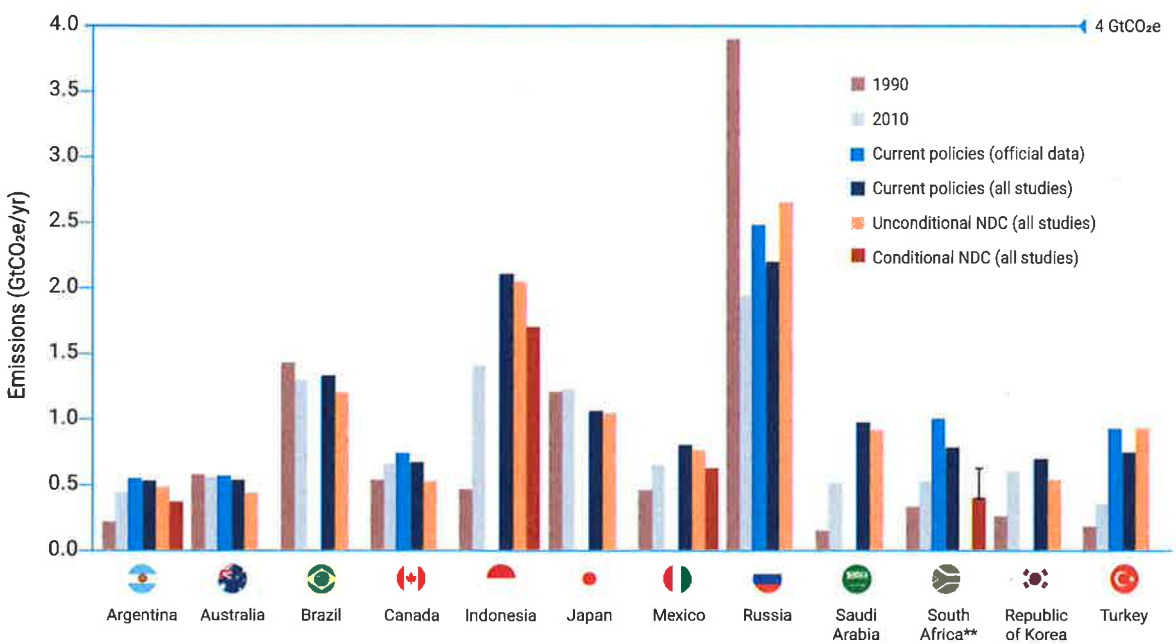
Notes:
For reporting reasons, the emission projections for China, the EU, India and the USA are shown in figure 2.4a with and the other countries shown in figure 2.4b, using 2 different vertical axes.
As a conservative assumption, South Africa is not considered as having a firm commitment to peak, since there is no guarantee that the conditions upon which they made the pledge will be met.
* For the USA, the unconditional NDC is for 2025.

2.4.2 Emissions trends and targets of individual G20 members[15]

Argentina's revised NDC introduced at COP 22 in 2016 presents an unconditional GHG emissions target of 483 $MtCO_2e$/year by 2030 and a further conditional target of 369 $MtCO_2e$/year (Government of Argentina, 2016). If the unconditional target is met, emissions would increase by 19 percent above 2010 levels in 2030. The current policies scenario projected by Climate Action Tracker for 2030 (CAT, 2018b) was lowered by about 5 percent from its projection in 2016. Nevertheless, Argentina is likely to miss its NDC targets if it does not change its current policies (Ministry of the Environment and Sustainable Development Argentina, 2015).

To help achieve its NDC targets, the Government of Argentina established a National Cabinet for Climate Change to facilitate discussions and agreements between 17 ministries on policies and measures to be implemented relating to the targets. These discussions have resulted in the development of mitigation action plans for the energy, forestry and transport sectors, with plans for industry, infrastructure and agriculture to be introduced shortly. The action on implementing renewable energy in Argentina's energy mix is particularly notable and is supported by 2 laws, one promoting renewable energy and implemented primarily through the RenovAr programme (which auctions renewable power capacity) and the other introducing distributed generation (though implementation is pending detailed ruling). The entire package of unconditional actions in sectoral plans is expected to reduce emissions by approximately 110 $MtCO_2e$/year by 2030 compared with the baseline. The success of these mitigation actions in achieving the 2030 unconditional NDC target depends on several factors, including the opposition of civil society to the construction of two mega hydroelectric dams in Patagonia and to two new nuclear power plants, and the country's recurrent financial constraints to sustain the implementation of some actions, such as the RenovAr program.

Figure 2.4b.



** South Africa's Intended Nationally Determined Contribution (INDC) is based on an emissions trajectory with an emissions range of 398–614 $MtCO_2e$ including LULUCF over the 2025–2030 period.

15 For a more comprehensive assessment of climate change mitigation policies including sector- and technology-specific policies in G20 countries, see, for example, Climate Transparency (2017).

Under its Cancun pledge, **Australia** proposed 3 targets for 2020 with different conditions: 5 percent, 15 percent and 25 percent below emission levels in 2000. The goal of 5 percent currently stands as Australia's unconditional pledge. In accordance with the Kyoto Protocol, Australia uses a carbon budget approach that accounts for cumulative emissions between 2013 and 2020 in order to assess progress against its pledge. For the budget period, Australia is on track to overachieve its 2020 target by 166 $MtCO_2e$ without including carry-over from the Kyoto Protocol's 1st commitment period and by 294 $MtCO_2e$ with carry-over (Department of the Environment and Energy, 2017b). Independent studies consider the year 2020 in isolation and find Australia's current policy trajectory close to achieving its target.

In its NDC, Australia announced a 26–28 percent reduction below 2005 levels of GHG emissions by 2030 (UNFCCC, 2016). There has been no improvement in Australia's climate policy since 2017 and emission levels for 2030 are projected to be well above the NDC target. The latest projection published by the government shows that emissions would remain at high levels rather than reducing in line with the 2030 target (Department of the Environment and Energy, 2017a; CAT, 2018c). The Emissions Reduction Fund, which aims to purchase emissions reductions at the lowest available cost through auctions, and its safeguard mechanism are the main existing policies.

Brazil's Cancun pledge aims to reduce GHG emissions in 2020 by 36.1–38.9 percent compared with business as usual and its NDC target aims to reduce emissions to 1.3 $GtCO_2e$/year by 2025 with the emission level dropping to 1.2 $GtCO_2e$/year by 2030 (37 percent and 43 percent below 2005 levels respectively). Recent independent studies suggest that current policy scenario projections are well below the Cancun pledge level and in line with the NDC targets (Kitous *et al.*, 2017; Kuramochi *et al.*, 2017a; CAT, 2018d). GHG emission projections have been revised downward compared with previous year's (referenced in the 2017 Emissions Gap Report). Uncertainty remains about the future of the country's GHG emissions growth. For example, emissions from LULUCF reduced by 86 percent between 2005 and 2012 (Ministry of Science, Technology and Innovation, 2016), but recent data and analyses suggest that the decreasing trend for deforestation and the resulting reductions in GHG emissions have slowed down or even stopped (Azevedo *et al.*, 2018). In fact, the recent political crisis in the country has forced a weak government to concede reversals in environmental regulation as a bargaining chip to maintain power, which may potentially impact GHG emissions from land use as well as Brazil's contribution towards global climate targets (Rochedo *et al.*, 2018). The newly elected president of Brazil has indicated that he wants to limit environmental constraints on agriculture.

In February 2018, the National Congress approved the National Biofuels Policy (RenovaBio – Decree No. 9.308), which seeks to boost the use of renewable fuels and expand its share in the energy mix. Recent electricity auctions have targeted solar energy, signalling a potential increase in solar capacity in the country in the coming years. Existing contracts for solar electricity in operation and under construction total around 4 GW nominal capacity (CCEE, 2018).

Canada pledged to reduce its economy-wide GHG emissions by 17 percent below 2005 levels by 2020 and 30 percent by 2030 (UNFCCC, 2014; UNFCCC, 2016). Canada could achieve its 2020 target under a low economic growth scenario, but it is not likely to achieve its NDC target (Government of Canada, 2017; CAT, 2018e). However, recent analysis suggests that Canada's emissions will be 4–6 percent lower in 2030 than projected in 2016, suggesting that progress is being made towards the target (Kitous *et al.*, 2017; Kuramochi *et al.*, 2017a; PBL, 2017; CAT, 2018e). In October 2017, Canada published regulations to phase down the production and consumption of HFCs in accordance with the Kigali Amendment. Canada is also planning a federal carbon pricing backstop system to enforce carbon pricing in provinces that have not implemented a provincial system by the end of 2018 (Government of Canada, 2017).

China pledged to reduce the intensity of CO_2 emissions by 40–45 percent by 2020 and its NDC includes 4 major targets for 2030: (1) peak CO_2 emissions around 2030, making best efforts to peak earlier; (2) reduce the carbon intensity of Gross Domestic Product (GDP) by 60–65 percent from 2005 levels; (3) increase the share of non-fossil fuels in primary energy consumption to around 20 percent; and (4) increase the forest stock volume by around 4.5 billion m^3 from 2005 levels. Independent studies, including those recently published (Sha *et al.*, 2015; den Elzen *et al.*, 2016; IEA, 2017; CAT, 2018f), suggest that China will likely achieve emission level targets in line with its Cancun pledges and NDC targets.

Recent independent studies (Kitous *et al.*, 2017; Kuramochi *et al.*, 2017a; CAT, 2018f) have revised their emissions projections down compared with previous years (UNEP, 2017), but do not strongly suggest that CO_2 emissions will peak before 2030. Contrastingly, other recent studies argue that recent structural shifts in the economy are likely to result in much steeper reductions in CO_2 intensity of Gross Domestic Product (GDP). Green and Stern (2017) provide an illustrative pathway in which intensity is halved from 2005 to 2020, resulting in peaked CO_2 emissions between 2020 and 2025. Guan *et al.* (2018) also conclude that the decline of CO_2 emissions in China is structural and is likely to be sustained if recently started transitions of industrial and energy systems continue.

China announced a new national emissions trading system in December 2017, which is expected to be fully operational by 2020. Initially, the system will apply only to the power sector, but may be expanded to other sectors in the future. The system's overall impact on CO_2 emissions is currently unclear, as many operational details are yet to be shared, including the start date and the level and distribution of emissions allowances. It is estimated that the full scheme will cover 5 $GtCO_2$/year when it includes both the power and industrial sectors, and 3–3.5 $GtCO_2$/year when only applied to the power sector as planned for the first few years (NewClimate

SPHA
SASKATCHEWAN
Public Health Association

This is Exhibit "K" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

....

A Commissioner for taking Affidavits within British Columbia

Via Email

December 17, 2018

Generation Squeeze
Attn: Dr. Paul Kershaw
17280 Ford Road
Pitt Meadows, BC

Dear Dr. Kershaw:

Re: Court of Appeal for Ontario, File No. C65807, a reference respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018*, No. 1, SC 2018, c. 12 (the "Reference Case")

I write on behalf of the Saskatchewan Public Health Association ("SPHA") to confirm our support for and membership in the coalition of organizations joining Generation Squeeze in applying for leave to intervene in the Reference Case. We share your commitment to intergenerational justice in climate policy and we believe this application is an important opportunity to protect the interests of young Canadians and future generations in a healthy and sustainable climate.

SPHA is a non-profit, non-governmental organization founded in 1952, with the mission to promote the health of Saskatchewan people and their environment through education, advocacy and empowerment.

We are a volunteer organization with approximately 80 members. Our membership includes community health nurses, health educators, public health inspectors, medical health officers, epidemiologists, educational psychologists, nutritionists, podiatrists, environmental health officers, health researchers, dentists, community program planners, project coordinators, health administrators and community health directors, as well as concerned citizens.

SPHA is concerned with the social and ecological determinants of health, which include natural resources and ecological processes, such as a reasonably stable climate. Among other things, PHAS works to promote equitable access to those basic conditions for health across and within generations of Saskatchewan residents.

Again, SPHA is proud to be a member of the intergenerational climate coalition applying for leave to intervene in the Reference Case.

Sincerely,

Fleur Macqueen Smith, MA
Vice President

Dr. Wanda Martin, PhD
Past President

Public Health Association of British Columbia
#210 – 1027 Pandora Avenue
Victoria, BC V8V 3P6
Phone: (250) 595-8422 / Fax: (250) 595-8622
staff@phabc.org
www.phabc.org

PHABC

December 14, 2018

This is Exhibit "L" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

....
A Commissioner for taking Affidavits within British Columbia

Via Email

Generation Squeeze
Attn: Dr. Paul Kershaw
17280 Ford Road
Pitt Meadows, BC

Dear Dr. Kershaw:

Re: Court of Appeal for Ontario, File No. C65807, a reference respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018*, No. 1, SC 2018, c. 12 (the "Reference Case")

I write on behalf of the Public Health Association of British Columbia ("PHABC") to confirm our membership in the coalition of organizations joining Generation Squeeze in applying for leave to intervene in the Reference Case. We share your commitment to intergenerational justice in climate policy and we believe this application is an important opportunity to protect the interests of young Canadians and future generations in a healthy and sustainable climate.

PHABC is a non-profit, non-governmental organization founded in 1953. Our vision is a fair and healthy British Columbia for all, and our mission is to promote health, well-being and equity for all British Columbians through leadership in public health.

We are a volunteer organization with close to 500 members. The association is made up of public health professionals ranging from students, researchers, policy makers, practitioners and academics in the field. Our Board of Directors is composed of public health leaders from various locales including Health Authorities, the BC Ministry of Health, post-secondary institutions, and the non-profit sector.

As a member-driven organization, we fulfill our mission through advocacy, collaboration and engagement activities, education, and research throughout the spectrum of public health practice and systems including prevention, promotion, protection and policy. PHABC pursues cross-sectoral partnerships with allies in NGOs, civil society and government to help advance evidence-based policies that promote the health and wellbeing of the people of British Columbia.

Our strategic priorities include:

- Reducing health/socioeconomic inequities; and
- Addressing climate change and healthy environments.

PHABC

Climate change is an urgent problem that demands attention to targets and timelines. As the second Lancet Commission on Climate Change pointed out, "The effects of climate change are being felt today, and future projections represent an unacceptably high and potentially catastrophic risk to human health."[1] We know the impacts from greenhouse gas emissions and climate change will fall most heavily on today's children and future generations. We recognize that a national price on GHG emissions is an essential part of an effective climate change plan.

Again, PHABC is proud to be a member of the intergenerational climate coalition applying for leave to intervene in the Reference Case.

Sincerely,

S Turner

Shannon Turner
Executive Director

[1] The Lancet, Health and climate change: policy responses to protect public health," Vol. 386, No. 10006, p. 1861.

Youth Climate Lab

December 14, 2018

This is Exhibit "M" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

....

A Commissioner for taking Affidavits within British Columbia

Via Email

Generation Squeeze
Attn: Dr. Paul Kershaw
17280 Ford Road
Pitt Meadows, BC

Dear Dr. Kershaw:

Re: Court of Appeal for Ontario, File No. C65807, a reference respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018*, No. 1, SC 2018, c. 12 (the "Reference Case")

I write on behalf of Youth Climate Lab to confirm our membership in the coalition of organizations joining Generation Squeeze in applying for leave to intervene in the Reference Case. We share your commitment to intergenerational justice in climate policy and we believe this application is an important opportunity to protect the interests of young Canadians and future generations in a healthy and sustainable climate.

Youth Climate Lab is a non-profit organization founded in 2017 and dedicated to supporting and creating youth-driven, innovative projects for climate action. We work with governments, businesses, civil society, and intergenerational organizations to identify, design and test new ideas for effective climate action. Our mission is to break down barriers for youth to access and influence climate finance and policy.

Youth Climate Lab has members and staff from Toronto, Ottawa, and around the world, including in Mexico and the United States of America.

We are a "youth-for-youth" organization: young people working to help and enable other young people to combat climate change. We are dedicated to promoting social and environmental justice and to advocating for inter-generational and intra-generational equity.

Youth Climate Lab recognizes that today's youth will inherit the consequences of decisions being made now, despite having limited opportunities to participate in climate negotiations. Young people can provide intergenerational viewpoints of present and future citizens, which are fundamental to sustainable development. Our goal is to build spaces and provide concrete resources for youth taking climate action. Our projects fit into two streams of work: climate policy and climate entrepreneurship. Some examples include:

- Greenpreneurs, a 10-week virtual accelerator program and business plan competition to help young people around the globe build and validate their business proposals for solutions that positively impact the future. Themes in the program included energy, water and sanitation, land-use and agriculture and green city development. The program

Youth Climate Lab

received over 350 applications and supported 10 teams of young entrepreneurs from four continents. This project is in partnership with Green Growth Global Institute (GGGI) and Student Energy.

- Delegation Support Teams, in which youth from small island developing states and climate-vulnerable Commonwealth countries work with youth from other countries to support national negotiating teams at international climate negotiations. I have enclosed a copy of the report from our Seychelles Support Team at COP23 for your information.[1]

Again, Youth Climate Lab is proud to be a member of the intergenerational climate coalition applying for leave to intervene in the Reference Case.

Sincerely,

Larissa Parker

Larissa Parker
Director of Programs (Canada)

encl.

[1] https://static1.squarespace.com/static/59ec036ef9a61ebf918040ac/t/5ae9cc688a922d1389c65ac5/1525271657272/Seychelles+Support+Team_+Report+from+COP23.pdf

This is Exhibit "N" referred to in the
Affidavit of Paul Kershaw, sworn before me at
North Vancouver this 18th day of December,
2018.

....

A Commissioner for taking Affidavits
within British Columbia

Canadian Coalition for the Rights of Children
Coalition canadienne pour les droits des enfants

December 15, 2018 Via Email

Generation Squeeze
Attn: Dr. Paul Kershaw
17280 Ford Road
Pitt Meadows, BC

Dear Dr. Kershaw:

Re: Court of Appeal for Ontario, File No. C65807, respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018*, No. 1, SC 2018, c. 12 (the "Reference Case")

I write on behalf of the Canadian Coalition for the Rights of Children ("CCRC") to confirm our support for and membership in the coalition of organizations joining Generation Squeeze in applying for leave to intervene in the Reference Case. We share your commitment to intergenerational justice in climate policy and we believe this application is an important opportunity to protect the rights of young Canadians and future generations to a healthy and sustainable climate.

The Canadian Coalition for the Rights of Children

The CCRC is a network of organizations and individuals who promote respect for the rights of children. It was formed in 1989, following Canada's adoption of the United Nations Convention on the Rights of the Child (the "Convention"), to inform the Canadian public about the Convention and provide a forum for civil society to participate in its implementation. The CCRC has status as a UN-recognized NGO independent of the government. Ontario joined Canada and other provinces in ratification of the Convention in 1991.

The CCRC is composed of national organizations that work with children, local children's charities, and individuals with expertise and interest in implementation of the Convention in Canada, including UNICEF Canada, the Justice for Children and Youth Foundation, the Child Welfare League of Canada, and Plan International – Canada. The CCRC board, elected at each Annual General Meeting, is composed of staff persons from children's rights organizations and professionals with experience and expertise in children's rights.

The CCRC has engaged and continues to engage in a wide range of activities to increase awareness and involvement in the implementation of the Convention, including:

- organizing national, multi-disciplinary conferences, such as *The Best Interests of the Child: Its Meaning and Application in Canada* (2009), *Children's Rights Impact*

Assessments: Making Children Visible in Public Policy (2013) and *Raising the Bar for Children's Rights in Canada* (2018);
- providing policy advice at the national level for specific legislation that affects children, for Canada's Action Plan entitled "A Canada Fit for Children," and for parliamentary committees studying issues related to children's rights; and
- providing an avenue for Canadian civil society organizations to participate in the regular five-year reviews of Canada's implementation of the Convention before the UN Committee on the Rights of the Child and other international children's rights events, such as the UN Special Session for Children.

Board members and other members of the CCRC have participated in the development of international guidelines for implementation of the Convention, including:

- the General Comment on the Rights of Indigenous Children, which addresses the relationship between collective rights, rights to cultural identity, and the individual rights of a child, within the framework of the Convention; and
- "General comment No. 15 (2013) on the right of the child to the enjoyment of the highest attainable standard of health (art. 24)," which concerns children's right to health under Article 24 of the Convention ("General Comment No. 15").

The CCRC also has intervened and otherwise participated in prominent reference cases concerning the rights of children, including:

- *Canada (Prime Minister) v. Khadr*, 2010 SCC 3, regarding the duty of a state to protect the rights and best interests of a Canadian child being exploited through use as a child soldier; and
- *Reference re: Section 293 of the Criminal Code of Canada*, 2011 BCSC 1588, regarding the state's obligation to protect Canadian persons under the age of 18 in relation to the practice of polygamy.

Children's Rights, the Environment, and Climate Change

The CCRC recognizes the connection between children's rights and the environment and has worked to increase awareness and engagement on this issue. In particular, climate change is a fundamental threat to children's health and development, and therefore is a serious threat to the rights protected by the Convention.

Many of the rights protected by the Convention depend on a healthy environment, including the rights:

- to life, survival and maximum development (Article 6);
- to the enjoyment of the highest attainable standard of health (Article 24);
- to a standard of living adequate for the child's physical, mental, spiritual, moral and social development (Article 27); and
- to rest and leisure, to engage in play and recreational activities appropriate to the age of the child and to participate freely in cultural life and the arts (Article 31).

In January 2018, the Special Rapporteur on human rights and the environment to the United Nations General Assembly Human Rights Council (the "Special Rapporteur") released the "Report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment."[1] That report focuses on the way that environmental harm prevents children from enjoying their human rights and the obligations of states to protect children from such harm. Among other things, the Special Rapporteur observed that:

- no group is more vulnerable to environmental harm than children, and environmental harm has especially severe effects on children under the age of five (para. 15);
- a healthy environment is necessary for children's enjoyment of the rights to life, development and health (para. 33); and
- the cumulative effects of long-term environmental harm, such as climate change and the loss of biodiversity, increase over time, so that decisions taken today will affect children much more than adults (para. 57).

The UN Committee on the Rights of the Child (the "Committee") was established under the Convention to examine the progress made by states in realizing the obligations set out in the Convention and to provide guidance to states through, among other things, General Comments and General Days of Discussion.

In December 2012, the Committee issued its "Concluding observations on the combined third and fourth periodic report of Canada," which included a recommendation that "the views of the child be a requirement for all official decision-making processes that relate to children, including custody cases, child welfare decisions, criminal justice, immigration, and the environment" (para. 37).[2]

Since receiving the Concluding Observations in 2012, the CCRC has consistently advocated for an action plan to respond to its recommendations. Among other things, the CCRC participated in the public review process on Bill C-69 (An Act to enact the Impact Assessment Act and the Canadian Energy Regulator Act, to amend the Navigation Protection Act and to make consequential amendments to other Acts) and made a submission on Bill C-69 regarding youth voice in the environmental assessment process.[3]

In 2013, the Committee issued General Comment No. 15, which elaborates the right to the enjoyment of the highest attainable standard of health and provides guidance to states on how to implement it.[4] Among other things, the Committee:

[1] http://undocs.org/A/HRC/37/58
[2] https://tbinternet.ohchr.org/_layouts/treatybodyexternal/Download.aspx?symbolno=CRC/C/CAN/CO/3-4&Lang=En
[3] http://rightsofchildren.ca/wp-content/uploads/2018/04/Rights-of-Children-to-a-Healthy-Environment-and-Bill-C-69.pdf
[4] https://www2.ohchr.org/english/bodies/crc/docs/GC/CRC-C-GC-15_en.doc

- acknowledges “There is also a growing understanding of the impact of climate change and rapid urbanization on children’s health” (para. 5); and
- “draws attention to the relevance of the environment, beyond environmental pollution, to children’s health. Environmental interventions should, inter alia, address climate change, as this is one of the biggest threats to children’s health and exacerbates health disparities. States should, therefore, put children’s health concerns at the centre of their climate change adaptation and mitigation strategies” (para. 50).

In May 2017, the Office of the United Nations High Commissioner for Human Rights released an “Analytical study on the relationship between climate change and the full and effective enjoyment of the rights of the child.”[5] That study found, among other things:

- all children are exceptionally vulnerable to the negative impacts of climate change, including the increasing frequency and intensity of natural disasters, changing precipitation patterns, food and water shortages, and the increased transmission of communicable diseases (para. 50);
- a child rights-based approach to climate change requires that children should not be treated as passive victims of events beyond their influence, but rather as agents of change whose preferences and choices are fairly reflected in policy design and implementation (para. 40); and
- the principle of intergenerational equity underlying international frameworks, such as the Paris Agreement, places a duty on current generations to act as responsible stewards of the planet and ensure the rights of future generations to meet their developmental and environmental needs (para. 35).

In Canada, federal, provincial, and territorial governments share the duties of states to implement the Convention because the responsibility for public policies that affect children’s rights crosses jurisdictional divisions of power. The CCRC has presented to Ministers and Senate Committees evidence that implementation of the Convention by all levels of government advances fulfillment of shared obligations to protect the rights and well-being of children. For this reason, the CCRC believes the international legal obligations of Canada under the Convention should also be considered when interpreting the jurisdictional provisions of the Constitution.

Conclusion

Again, the CCRC is proud to be a member of the intergenerational climate coalition applying for leave to intervene in the Reference Case.

Sincerely,

Katherine Vandergrift

Katherine Vandergrift
Chair, CCRC

[5] https://undocs.org/en/a/hrc/35/13

United Nations

CRC/C/GC/15

Convention on the Rights of the Child

Distr.: General
17 April 2013

Original: English

Committee on the Rights of the Child

General comment No. 15 (2013) on the right of the child to the enjoyment of the highest attainable standard of health (art. 24)*

This is Exhibit "O" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

....

A Commissioner for taking Affidavits within British Columbia

* Adopted by the Committee at its sixty-second session (14 January – 1 February 2013).

Contents

I. Introduction

1. The present general comment is based on the importance of approaching children's health from a child-rights perspective that all children have the right to opportunities to survive, grow and develop, within the context of physical, emotional and social well-being, to each child's full potential. Throughout this general comment, "child" refers to an individual below the age of 18 years, in accordance with article 1 of the Convention on the Rights of the Child (hereinafter "the Convention''). Despite the remarkable achievements in fulfilling children's rights to health in recent years since the adoption of the Convention, significant challenges remain. The Committee on the Rights of the Child (hereinafter "the Committee") recognizes that most mortality, morbidity and disabilities among children could be prevented if there were political commitment and sufficient allocation of resources directed towards the application of available knowledge and technologies for prevention, treatment and care. The present general comment was prepared with the aim of providing guidance and support to States parties and other duty bearers to support them in respecting, protecting and fulfilling children's right to the enjoyment of the highest attainable standard of health (hereinafter "children's right to health").

2. The Committee interprets children's right to health as defined in article 24 as an inclusive right, extending not only to timely and appropriate prevention, health promotion, curative, rehabilitative and palliative services, but also to a right to grow and develop to their full potential and live in conditions that enable them to attain the highest standard of health through the implementation of programmes that address the underlying determinants of health. A holistic approach to health places the realization of children's right to health within the broader framework of international human rights obligations.

3. The Committee addresses this general comment to a range of stakeholders working in the fields of children's rights and public health, including policymakers, programme implementers and activists, as well as parents and children themselves. It is explicitly generic in order to ensure its relevance to a wide range of children's health problems, health systems and the varied contexts that exist in different countries and regions. It focuses primarily on article 24, paragraphs 1 and 2, and also addresses article 24, paragraph 4.[1] Implementation of article 24 must take into account all human rights principles, especially the guiding principles of the Convention, and must be shaped by evidence-based public health standards and best practices.

4. In the Constitution of the World Health Organization, States have agreed to regard health as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.[2] This positive understanding of health provides the public health foundation for the present general comment. Article 24 explicitly mentions primary health care, an approach to which was defined in the Declaration of Alma-Ata[3] and reinforced by the World Health Assembly.[4] This approach emphasizes the need to eliminate exclusion and reduce social disparities in health; organize health services around people's needs and expectations; integrate health into related sectors; pursue collaborative models of

[1] Article 24, paragraph 3, is not covered because a general comment on harmful practices is currently being developed.

[2] Preamble to the Constitution of the World Health Organization (WHO) as adopted by the International Health Conference, New York, 22 July 1946.

[3] Declaration of Alma-Ata, International Conference on Primary Health Care, Alma-Ata, 6–12 September 1978.

[4] World Health Assembly, Primary health care including health systems strengthening, document A62/8.

policy dialogue; and increase stakeholder participation, including the demand for and appropriate use of services.

5. Children's health is affected by a variety of factors, many of which have changed during the past 20 years and are likely to continue to evolve in the future. This includes the attention given to new health problems and changing health priorities, such as: HIV/AIDS, pandemic influenza, non-communicable diseases, importance of mental health care, care of the new born, and neonatal and adolescent mortality; increased understanding of the factors that contribute to death, disease and disability in children, including structural determinants, such as the global economic and financial situation, poverty, unemployment, migration and population displacements, war and civil unrest, discrimination and marginalization. There is also a growing understanding of the impact of climate change and rapid urbanization on children's health; the development of new technologies, such as vaccines and pharmaceuticals; a stronger evidence base for effective biomedical, behavioural and structural interventions, as well as some cultural practices that relate to child-rearing and have proved to have a positive impact on children.

6. Advances in information and communication technologies have created new opportunities and challenges to achieve children's right to health. Despite the additional resources and technologies that have now become available to the health sector, many countries still fail to provide universal access to basic children's health promotion, prevention and treatment services. A wide range of different duty bearers need to be involved if children's right to health is to be fully realized and the central role played by parents and other caregivers needs to be better recognized. Relevant stakeholders will need to be engaged, working at national, regional, district and community levels, including governmental and non-governmental partners, private sector and funding organizations. States have an obligation to ensure that all duty bearers have sufficient awareness, knowledge and capacity to fulfil their obligations and responsibilities, and that children's capacity is sufficiently developed to enable them to claim their right to health.

II. Principles and premises for realizing children's right to health

A. The indivisibility and interdependence of children's rights

7. The Convention recognizes the interdependence and equal importance of all rights (civil, political, economic, social and cultural) that enable all children to develop their mental and physical abilities, personalities and talents to the fullest extent possible. Not only is children's right to health important in and of itself, but also the realization of the right to health is indispensable for the enjoyment of all the other rights in the Convention. Moreover, achieving children's right to health is dependent on the realization of many other rights outlined in the Convention.

B. Right to non-discrimination

8. In order to fully realize the right to health for all children, States parties have an obligation to ensure that children's health is not undermined as a result of discrimination, which is a significant factor contributing to vulnerability. A number of grounds on which discrimination is proscribed are outlined in article 2 of the Convention, including the child's, parent's or legal guardian's race, colour, sex, language, religion, political or other opinion, national, ethnic or social origin, property, disability, birth or other status. These also include sexual orientation, gender identity and health status, for example HIV status

and mental health.[5] Attention should also be given to any other forms of discrimination that might undermine children's health, and the implications of multiple forms of discrimination should also be addressed.

9. Gender-based discrimination is particularly pervasive, affecting a wide range of outcomes, from female infanticide/foeticide to discriminatory infant and young child feeding practices, gender stereotyping and access to services. Attention should be given to the differing needs of girls and boys, and the impact of gender-related social norms and values on the health and development of boys and girls. Attention also needs to be given to harmful gender-based practices and norms of behaviour that are ingrained in traditions and customs and undermine the right to health of girls and boys.

10. All policies and programmes affecting children's health should be grounded in a broad approach to gender equality that ensures young women's full political participation; social and economic empowerment; recognition of equal rights related to sexual and reproductive health; and equal access to information, education, justice and security, including the elimination of all forms of sexual and gender-based violence.

11. Children in disadvantaged situations and under-served areas should be a focus of efforts to fulfil children's right to health. States should identify factors at national and subnational levels that create vulnerabilities for children or that disadvantage certain groups of children. These factors should be addressed when developing laws, regulations, policies, programmes and services for children's health, and work towards ensuring equity.

C. The best interests of the child

12. Article 3, paragraph 1, of the Convention places an obligation on public and private social welfare institutions, courts of law, administrative authorities and legislative bodies to ensure that the best interests of the child are assessed and taken as a primary consideration in all actions affecting children. This principle must be observed in all health-related decisions concerning individual children or children as a group. Individual children's best interests should be based on their physical, emotional, social and educational needs, age, sex, relationship with parents and caregivers, and their family and social background, and after having heard their views according to article 12 of the Convention.

13. The Committee urges States to place children's best interests at the centre of all decisions affecting their health and development, including the allocation of resources, and the development and implementation of policies and interventions that affect the underlying determinants of their health. For example, the best interests of the child should:

(a) Guide treatment options, superseding economic considerations where feasible;

(b) Aid the resolution of conflict of interest between parents and health workers; and

(c) Influence the development of policies to regulate actions that impede the physical and social environments in which children live, grow and develop.

14. The Committee underscores the importance of the best interests of the child as a basis for all decision-making with regard to providing, withholding or terminating

[5] General comment No. 4 (2003) on adolescent health and development in the context of the Convention on the Rights of the Child, *Official Records of the General Assembly, Fifty-ninth Session, Supplement No. 41* (A/59/41), annex X, para. 6.

treatment for all children. States should develop procedures and criteria to provide guidance to health workers for assessing the best interests of the child in the area of health, in addition to other formal, binding processes that are in place for determining the child's best interests. The Committee in its general comment No. 3[6] has underlined that adequate measures to address HIV/AIDS can be undertaken only if the rights of children and adolescents are fully respected. The child's best interests should therefore guide the consideration of HIV/AIDS at all levels of prevention, treatment, care and support.

15. In its general comment No. 4, the Committee underlined the best interests of the child to have access to appropriate information on health issues.[7] Special attention must be given to certain categories of children, including children and adolescents with psychosocial disabilities. Where hospitalization or placement in an institution is being considered, this decision should be made in accordance with the principle of the best interests of the child, with the primary understanding that it is in the best interests of all children with disabilities to be cared for, as far as possible, in the community in a family setting and preferably within their own family with the necessary supports made available to the family and the child.

D. Right to life, survival and development and the determinants of children's health

16. Article 6 highlights the States parties' obligation to ensure the survival, growth and development of the child, including the physical, mental, moral, spiritual and social dimensions of their development. The many risks and protective factors that underlie the life, survival, growth and development of the child need to be systematically identified in order to design and implement evidence-informed interventions that address a wide range of determinants during the life course.

17. The Committee recognizes that a number of determinants need to be considered for the realization of children's right to health, including individual factors such as age, sex, educational attainment, socioeconomic status and domicile; determinants at work in the immediate environment of families, peers, teachers and service providers, notably the violence that threatens the life and survival of children as part of their immediate environment; and structural determinants, including policies, administrative structures and systems, social and cultural values and norms.[8]

18. Among the key determinants of children's health, nutrition and development are the realization of the mother's right to health[9] and the role of parents and other caregivers. A significant number of infant deaths occur during the neonatal period, related to the poor health of the mother prior to, and during, the pregnancy and the immediate post-partum

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6 General comment No. 3 (2003) on HIV/AIDS and the rights of the child, *Official Records of the General Assembly, Fifty-ninth Session, Supplement No. 41* (A/59/41), annex IX.

7 General comment No. 4 (2003) on adolescent health and development in the context of the Convention, *Official Records of the General Assembly, Fifty-ninth Session, Supplement No. 41* (A/59/41), annex X, para. 10.

8 See general comment No. 13 (2011) on the right of the child to be free from all forms of violence, *Official Records of the General Assembly, Sixty-seventh Session, Supplement No. 41* (A/67/41), annex V.

9 See Committee on the Elimination of Discrimination against Women, general recommendation No. 24 (1999) on women and health, *Official Records of the General Assembly, Fifty-fourth Session, Supplement No. 38* (A/54/38/Rev.1), chap. I, sect. A.

period, and to suboptimal breastfeeding practices. The health and health-related behaviours of parents and other significant adults have a major impact on children's health.

E. Right of the child to be heard

19. Article 12 highlights the importance of children's participation, providing for children to express their views and to have such views seriously taken into account, according to age and maturity.[10] This includes their views on all aspects of health provisions, including, for example, what services are needed, how and where they are best provided, barriers to accessing or using services, the quality of the services and the attitudes of health professionals, how to strengthen children's capacities to take increasing levels of responsibility for their own health and development, and how to involve them more effectively in the provision of services, as peer educators. States are encouraged to conduct regular participatory consultations, which are adapted to the age and maturity of the child, and research with children, and to do this separately with their parents, in order to learn about their health challenges, developmental needs and expectations as a contribution to the design of effective interventions and health programmes.

F. Evolving capacities and the life course of the child

20. Childhood is a period of continuous growth from birth to infancy, through the preschool age to adolescence. Each phase is significant as important developmental changes occur in terms of physical, psychological, emotional and social development, expectations and norms. The stages of the child's development are cumulative and each stage has an impact on subsequent phases, influencing the children's health, potential, risks and opportunities. Understanding the life course is essential in order to appreciate how health problems in childhood affect public health in general.

21. The Committee recognizes that children's evolving capacities have a bearing on their independent decision-making on their health issues. It also notes that there are often serious discrepancies regarding such autonomous decision-making, with children who are particularly vulnerable to discrimination often less able to exercise this autonomy. It is therefore essential that supportive policies are in place and that children, parents and health workers have adequate rights-based guidance on consent, assent and confidentiality.

22. To respond and understand children's evolving capacities and the different health priorities along the life cycle, data and information that are collected and analysed should be disaggregated by age, sex, disability, socioeconomic status and sociocultural aspects and geographic location, in accordance with international standards. This makes it possible to plan, develop, implement and monitor appropriate policies and interventions that take into consideration the changing capacities and needs of children over time, and that help to provide relevant health services for all children.

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[10] See general comment No. 12 (2009) on the right of the child to be heard, *Official Records of the General Assembly, Sixty-fifth Session, Supplement No. 41* (A/65/41), annex IV.

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Convention on Tobacco Control. Special measures should be taken to promote community and workplace support for mothers in relation to pregnancy and breastfeeding and feasible and affordable childcare services; and compliance with the International Labour Organization Convention No. 183 (2000) concerning the revision of the Maternity Protection Convention (Revised), 1952.

45. Adequate nutrition and growth monitoring in early childhood are particularly important. Where necessary, integrated management of severe acute malnutrition should be expanded through facility and community-based interventions, as well as treatment of moderate acute malnutrition, including therapeutic feeding interventions.

46. School feeding is desirable to ensure all pupils have access to a full meal every day, which can also enhance children's attention for learning and increase school enrolment. The Committee recommends that this be combined with nutrition and health education, including setting up school gardens and training teachers to improve children's nutrition and healthy eating habits.

47. States should also address obesity in children, as it is associated with hypertension, early markers of cardiovascular disease, insulin resistance, psychological effects, a higher likelihood of adult obesity, and premature death. Children's exposure to "fast foods" that are high in fat, sugar or salt, energy-dense and micronutrient-poor, and drinks containing high levels of caffeine or other potentially harmful substances should be limited. The marketing of these substances – especially when such marketing is focused on children – should be regulated and their availability in schools and other places controlled.

(c) The provision of clean drinking water

48. Safe and clean drinking water and sanitation are essential for the full enjoyment of life and all other human rights.[15] Government departments and local authorities responsible for water and sanitation should recognize their obligation to help realize children's right to health, and actively consider child indicators on malnutrition, diarrhoea and other water-related diseases and household size when planning and carrying out infrastructure expansion and the maintenance of water services, and when making decisions on amounts for free minimum allocation and service disconnections. States are not exempted from their obligations, even when they have privatized water and sanitation.

(d) Environmental pollution

49. States should take measures to address the dangers and risks that local environmental pollution poses to children's health in all settings. Adequate housing that includes non-dangerous cooking facilities, a smoke-free environment, appropriate ventilation, effective management of waste and the disposal of litter from living quarters and the immediate surroundings, the absence of mould and other toxic substances, and family hygiene are core requirements to a healthy upbringing and development. States should regulate and monitor the environmental impact of business activities that may compromise children's right to health, food security and access to safe drinking water and to sanitation.

50. The Committee draws attention to the relevance of the environment, beyond environmental pollution, to children's health. Environmental interventions should, inter alia, address climate change, as this is one of the biggest threats to children's health and exacerbates health disparities. States should, therefore, put children's health concerns at the centre of their climate change adaptation and mitigation strategies.

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[15] General Assembly resolution 64/292 on the human right to water and sanitation.

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Annual report of the United Nations High Commissioner for Human Rights and reports of the Office of the High Commissioner and the Secretary-General

Promotion and protection of all human rights, civil political, economic, social and cultural rights, including the right to development

This is Exhibit "P" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

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A Commissioner for taking Affidavits within British Columbia

Analytical study on the relationship between climate change and the full and effective enjoyment of the rights of the child

Report of the Office of the United Nations High Commissioner for Human Rights

Summary

The present analytical study on the relationship between climate change and the full and effective enjoyment of the rights of the child is submitted pursuant to Human Rights Council resolution 32/33. In the study, the Office of the United Nations High Commissioner for Human Rights examines the impacts of climate change on children and the related human rights obligations and responsibilities of States and other actors, including the elements of a child rights-based approach to climate change policies. The study provides examples of good practices and concludes with several recommendations.

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Contents

I. Introduction

1. The present study is submitted pursuant to Human Rights Council resolution 32/33, in which the Council requested the Office of the United Nations High Commissioner for Human Rights (OHCHR) to conduct a detailed analytical study, in consultation with relevant stakeholders, on the relationship between climate change and the full and effective enjoyment of the rights of the child.

2. On 9 September 2016, OHCHR circulated a note verbale and questionnaire to Member States requesting inputs for the study. Communications were also sent to other stakeholders, including international organizations, national human rights institutions and civil society. Their inputs were summarized in a conference room paper prepared by OHCHR in advance of the panel discussion on the adverse impact of climate change on States' efforts to realize the rights of the child and related policies, lessons learned and good practices, held on 2 March 2017.[1] The panel discussion, written inputs, consultations and independent research have informed the present study.

3. In the study, OHCHR examines the impacts of climate change on children and the related human rights obligations and responsibilities of States and other actors, including the elements of a child rights-based approach to climate change policies. It provides examples of good practices and concludes with concrete recommendations for fulfilling human rights obligations, particularly those related to children's rights, in the context of climate change.

II. Key impacts of climate change on children

4. Children are disproportionately affected by changes in their environment, due to their unique metabolism, physiology and developmental needs.[2] Changes in temperature, air and water quality and nutrition are likely to have more severe and long-term impacts on children's health, development and well-being. Young children, because of their less developed physiology and immune systems, will experience most intensely the effects of climate change-related stresses.[3] During childhood, alterations to the social and physical environment can have far-reaching implications for children's long-term physical and mental health and overall quality of life.

5. According to United Nations Children's Fund (UNICEF), there may be no greater threat facing the world's children, and future generations, than climate change.[4] In 2014, there were 2.2 billion children in the world, with approximately 30 per cent of the world's population being under 18 years old.[5] Existing and future demographic trends reveal that many of the countries that have been identified as highly vulnerable to climate change also have higher proportions of children in their overall population. These include parts of South Asia, the Pacific islands and other small island developing States, equatorial Africa and the Pacific coast of South America.

6. As discussed below, some of the most substantial impacts of climate change on children are caused by extreme weather and natural disasters, water scarcity and food insecurity, air pollution and vector-borne diseases and resulting psychological trauma. Children in vulnerable situations are disproportionately affected by climate change.

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1 For the summary of the panel discussion, see A/HRC/35/14. The original inputs received and the informal summary of those inputs are available at www.ohchr.org/EN/Issues/HRAndClimateChange/Pages/RightsChild.aspx.

2 See generally World Health Organization (WHO), *Inheriting a Sustainable World? Atlas on Children's Health and the Environment* (2017), available at www.who.int/ceh/publications/inheriting-a-sustainable-world/en/.

3 P.J. Landrigan and A. Garg, "Children are not little adults", in *Children's Health and the Environment: A Global Perspective*, J. Pronczuk-Garbino, ed. (Geneva, WHO, 2005).

4 UNICEF, *Unless We Act Now: The Impact of Climate Change on Children* (New York, 2015), p. 6.

5 UNICEF, *The State of the World's Children 2014: Every Child Counts* (New York, 2014).

A. Extreme weather and natural disasters

7. Climate change contributes to the increasing frequency and intensity of extreme weather events. Globally, nearly 160 million children have been identified as living in areas of high or extremely high drought severity.[6] More than half a billion children live in zones of extremely high flood occurrence, and approximately 115 million children live in zones of high or extremely high tropical cyclone risk.[7] Even under a medium-low emission scenario, the Intergovernmental Panel on Climate Change predicts a global sea-level rise of 0.53 metres by 2100, with coastal and low-lying areas at risk of submergence, flood damage, erosion and impeded drainage.[8] Floods and other natural disasters caused by extreme weather are likely to elevate mortality and morbidity among children.

8. Young children are more susceptible to injury and death during natural disasters. In the aftermath of the 2010 floods in Pakistan, rates of under-5 mortality in flood-affected areas were notably higher than the national average.[9] Natural disasters can also result in the separation of children from their family unit, increasing their vulnerability to subsequent harm.

9. Climate change is also expected to increase the duration and intensity of heat waves. This will affect children disproportionately, as their bodies adapt at a slower rate to changes in heat and they may suffer from heat rash, heat-related cramps, exhaustion, renal disease, respiratory illness, stroke and death.[10]

10. Extreme weather events can disrupt access to essential educational, health and housing services. For example, children's access to education can be interrupted by damage to educational facilities and critical infrastructure and by the use of schools as emergency shelters.[11] Similarly, damage to health infrastructure and essential drug supplies can make post-emergency interventions less effective. Floods and landslides, sea-level rise and powerful storms can degrade and destroy housing units and water and sanitation infrastructure, worsening living conditions, particularly for children, in unplanned and underserviced settlements.[12]

11. Climate change-related disasters can also disrupt child protection systems and exacerbate pre-existing tensions and conflicts, leaving children susceptible to abuse, child labour, trafficking and other forms of exploitation.[13]

B. Water scarcity and food insecurity

12. Climate change is already affecting water and food supplies, with severe consequences for children in poor communities. Changing patterns of precipitation, sea-level rise and increased evaporation as a result of climate change will reduce surface and

6 UNICEF, *Unless We Act Now*.
7 Ibid.
8 Christopher B. Field and others, eds., *Climate Change 2014: Impacts, Adaptation and Vulnerability*, Working Group II contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (New York, Cambridge University Press, 2014), pp. 368-369.
9 UNICEF, *Unless We Act Now*, p. 30; see also WHO, "Pakistan floods 2010: early recovery plan for the health sector" (2011), p. 52.
10 See, for example, Johns Hopkins Medicine, "Heat-related illnesses (heat cramps, heat exhaustion, heat stroke)", available from www.hopkinsmedicine.org/healthlibrary/conditions/pediatrics/heat-related_illnesses_heat_cramps_heat_exhaustion_heat_stroke_90,P01611/.
11 Katie Harris and Kelly Hawrylyshyn, "Climate extremes and child rights in South Asia: a neglected priority" (Overseas Development Institute, 2012).
12 See generally A/64/255 on climate change and the right to adequate housing, para. 21 on the disproportionate impacts on children.
13 Sheridan Bartlett, "Climate change and urban children: impacts and implications for adaptation in low- and middle-income countries", *Environment and Urbanization*, vol. 20, No. 2 (October 2008), pp. 509-510; Global Protection Cluster, "Strengthening protection in natural disaster response: children", available at www.globalprotectioncluster.org/en/tools-and-guidance/essential-protection-guidance-and-tools/protection-in-natural-disasters-essential-guidance-and-tools.html.

groundwater resources in most dry subtropical regions.[14] Droughts are expected to intensify, reducing access to water for personal consumption, agriculture and economic activities. Acidification and increasing water temperatures further threaten the fisheries upon which many coastal communities rely for subsistence.

13. Shortages of safe drinking water and food staples will have disproportionate impacts on children, particularly the poor. Children's consumption needs per body weight are higher than those of adults and food and water scarcity undermines their physical and cognitive growth.[15] Globally, undernutrition is responsible for nearly half of all under-5 deaths and is a major factor exacerbating the frequency and severity of other diseases and infections.[16] Inadequate responses to malnourishment during the first two years of life result in irreversible stunting with lifelong consequences for children's cognitive capacity, school performance and economic productivity.[17] It is estimated that, by 2030, climate change will result in an additional 7.5 million children under the age of 5 who are moderately or severely stunted.[18]

14. Food and water crises pose additional risks, such as increased incidences of school dropout, child labour and domestic violence. Crop and income loss has been linked to significant increases in the level of child labour used for household chores such as fetching water and searching for firewood.[19] When extreme weather affects the security of household incomes and families increase their reliance on child labour, children have less time and energy to dedicate to school activities.

C. Air pollution

15. In 2012, indoor and outdoor air pollution combined were linked to approximately 700,000 deaths among children under 5 years of age.[20] Although air pollution is not caused by climate change, some forms of air pollution cause climate change. Further, climate change can exacerbate some forms of air pollution, for example, by intensifying the toxicity of pollutants, such as ozone, a trigger of childhood asthma.[21] The heightened risk of wildfires associated with heat waves and drought affects air quality and children's respiratory systems, and warmer temperatures are also linked with the release of airborne allergens that can exacerbate asthma and allergic respiratory diseases.[22] Thus, air pollution and climate change contribute to a vicious cycle that disproportionately affects children, who, due to their higher breathing rate, are more susceptible to respiratory problems and infections related to air pollution.[23]

D. Vector-borne and infectious diseases

16. Children are more susceptible than adults to many vector-borne and infectious diseases. Waterborne diseases typically spread in the aftermath of climate change-related floods and storms, especially when water and sanitation infrastructure is damaged. Poor hygiene and consumption of contaminated water can contribute to increased incidence of diarrhoea and cholera, among other illnesses. Diarrhoea is the second leading cause of

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[14] Field and others, *Climate Change 2014*, p. 232.
[15] Landrigan and Garg, "Children", pp. 3-4.
[16] UNICEF, "Undernutrition contributes to nearly half of all deaths in children under 5 and is widespread in Asia and Africa", available at https://data.unicef.org/topic/nutrition/malnutrition/.
[17] Cesar G. Victora, and others, "Maternal and child undernutrition: consequences for adult health and human capital", *Lancet*, vol. 371, No. 9609 (2008).
[18] WHO, *Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s* (Geneva, 2014), p. 80.
[19] Kathleen Beegle, Rajeev H. Dehejia and Roberta Gatti, "Child labor and agricultural shocks", *Journal of Development Economics*, vol. 81, No. 1 (October 2006).
[20] WHO, *Inheriting a Sustainable World?*, p. 16.
[21] UNICEF, *Unless We Act Now*, p. 44.
[22] Field and others, *Climate Change 2014*, p. 729.
[23] Landrigan and Garg, "Children".

mortality in children under 5.[24] By 2030, it is projected that climate change impacts will result in 48,000 additional deaths from diarrhoeal disease in children under 15.[25]

17. Climate change is also likely to expand the seasonal and geographic range of vector-borne diseases, including insect-borne diseases with hosts sensitive to variations in temperature, humidity and precipitation. Malaria is expected to expand into tropical highland regions where the medical and immunological responses of populations may be ill-equipped to cope.[26] Infants and young and poor children living in areas with substandard health facilities are at particular risk. In 2015, roughly 300,000 children under the age of 5 died from malaria;[27] the majority lived on the African continent. Outbreaks of other diseases that affect children, such as dengue, Zika, leptospirosis, viral infections, meningitis, varicella, viral hepatitis, leishmaniasis and pertussis, have been linked to climate change.[28]

E. Impacts on mental health

18. Climate change and the impacts of traumatic stress connected to climate change, such as war/insecurity, sexual and physical violence and witnessing deaths and injury related to extreme weather disasters, negatively affect children's mental health. Children who lose a family member or experience life-threatening situations as a result of the impacts of climate change have a higher chance of experiencing post-traumatic stress, anxiety disorders, suicidal ideation and depression. Disasters can also affect children's cognitive capacity with corresponding impacts on their emotional well-being. For example, children affected by El Niño during early childhood posted lower scores in language development, memory and spatial reasoning than other children of a similar age.[29] Lower cognitive functioning in early life has been shown to increase the risk of future mental health problems.[30]

19. Children may also experience anxiety related to fear of separation from their families and heightened household tensions resulting from the loss of family livelihoods.[31] Children whose families are affected by climate change may be exposed to higher risks of violence, physical abuse, child labour, trafficking and exploitation. Their needs for rest and play may be subordinated to basic survival interests. In cases of displacement, separation from traditional lands and territories, from communities and from family members can have impacts on children's education, cultural identity and access to social support systems. All of these climate impacts have potentially severe mental health repercussions.

F. Disproportionate impacts on children in vulnerable situations

20. According to the Intergovernmental Panel on Climate Change, "people who are socially, economically, culturally, politically, institutionally or otherwise marginalized are especially vulnerable to climate change and also to some adaptation and mitigation responses".[32] The negative impacts of climate change will disproportionately affect poor children, indigenous children, minorities, migrants and other children on the move, children

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24 WHO, "Diarrhoeal disease", Fact sheet No. 330 (2013), available from www.who.int/mediacentre/factsheets/fs330/en/.

25 WHO, *Quantitative Risk*, p. 44.

26 UNICEF, *Unless We Act Now*, p. 48.

27 WHO, "Malaria in children under 5" (2016), available at www.who.int/malaria/areas/high_risk_groups/children/en/.

28 A/HRC/32/23.

29 Arturo Aguilar and Marta Vicarelli, "El Niño and Mexican children: medium-term effects of early-life weather shocks on cognitive and health outcomes" (2011).

30 Chuan Yu Chen and others, "Mild cognitive impairment in early life and mental health problems in adulthood", *American Journal of Public Health*, vol. 96, No. 10 (October 2006).

31 Agnes A. Babugara, "Vulnerability of children and youth in drought disasters: a case study of Botswana", *Children, Youth and Environments*, vol. 18, No. 1 (2008).

32 Field and others, *Climate Change 2014*, p. 50.

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recommendation on gender-related dimensions of disaster risk reduction in a changing climate,[75] while the Committee on the Rights of the Child has issued, on several occasions, concluding observations including observations and recommendations on climate change.[76] In 2015, the Commonwealth Forum of National Human Rights Institutions issued the St. Julian's Declaration on Climate Justice, in which the institutions committed to, inter alia, "promote the principle of equality and non-discrimination in climate action, including the rights of children". The Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment, whose forthcoming report will focus on children, and other special procedure mandate holders have focused on the impacts of climate change on human rights in their reporting.[77] Finally, specific recommendations related to climate change and its impacts on the rights of the child have been issued on several occasions in the context of the universal periodic review of the Human Rights Council.[78]

V. Conclusions and recommendations

49. **The conclusions and recommendations below are derived from the various elements that have informed the present study.**

A. Conclusions

50. **The negative impacts of climate change, including the increasing frequency and intensity of natural disasters, changing precipitation patterns, food and water shortages, and the increased transmission of communicable diseases, threaten the enjoyment by children of their rights to health, life, food, water and sanitation, education, housing, culture and development, among others. Climate change heightens existing social and economic inequalities, intensifies poverty and reverses progress towards improvement in children's well-being. All children are exceptionally vulnerable to the negative impacts of climate change, with the youngest children being most at risk.**

51. **Climate change has a disproportionate impact on some children, including children with disabilities, children on the move, poor children, children separated from their families and indigenous children. Girls also face heightened risks due to climate change. In climate-vulnerable States and climate-sensitive areas, climate change poses a contemporaneous threat to inhabitants' rights to life, survival and development, among others. The rights and opportunities of children living in such areas can be severely affected. Beyond threatening children's physical well-being, climate change poses a threat to their cultural identity, to their connections with the natural environment and to their education.**

52. **The human rights obligations and responsibilities contained in the Convention on the Rights of the Child, the Paris Agreement and other international human rights instruments require States and other duty bearers, including businesses, to take action to protect the rights and best interests of children from the adverse effects of climate change. Many States already have in place laws, policies and commitments related to the protection of children's rights, the preservation of a healthy environment and climate change mitigation and adaptation. However, further action is needed to promote accountability for all actors, ensure children's access to justice and protect children from the negative impacts of climate change. Children have a right to meaningful participation in climate policymaking aimed at accomplishing these**

[75] See www.ohchr.org/EN/HRBodies/CEDAW/Pages/DraftGRDisasterRisk.aspx.
[76] See, for example, CRC/C/GBR/CO/5.
[77] See, for example, A/HRC/31/52 and www.thecvf.org/wp-content/uploads/2015/05/humanrightsSRHRE.pdf.
[78] See, for example, A/HRC/33/6 (Samoa, 2016), A/HRC/30/13 and Corr.1 (Marshall Islands, 2015), A/HRC/26/9 (Vanuatu, 2014), A/HRC/24/8 (Tuvalu, 2013) and A/HRC/16/7 (Maldives, 2011).

objectives and should play an active role in inspiring and shaping more effective climate policies.

53. **Human rights, climate change, development and disaster risk reduction, including relevant international instruments and processes, are inextricably linked. A child rights-based approach to climate change mitigation and adaptation is called for by the intersections of these various frameworks with human rights obligations. It requires States to take affirmative measures to respect, protect, promote and fulfil the human rights of all children and to integrate their rights in all climate mitigation and adaptation policies and actions.**

54. **Fundamentally, a child rights-based approach requires:**

(a) **Ambitious mitigation measures to minimize the future negative impacts of climate change on children to the greatest extent possible by limiting warming to no more than 1.5°C above pre-industrial levels, as called for in the Paris Agreement;**

(b) **Adaptation measures that focus on protecting those children most vulnerable to the impacts of climate change;**

(c) **Mitigation and adaptation actions that are the product of participatory, evidence-based decision-making processes that take into account the ideas and best interests of children as expressed by children themselves.**

55. **Within these efforts, particular attention should be paid to girls, children with disabilities, indigenous children and other children who may be disproportionately affected by climate change. All children should be treated as active participants in climate action.**

56. **Truly sustainable, rights-based development requires climate actions that are informed by and take into consideration children's rights, intergenerational equity and the needs of future generations. These actions should be evidence based and supported by a free, transparent exchange of good practices, resources and technical assistance adequate to address the threat of climate change in line with international human rights laws, norms and standards.**

B. Recommendations

57. **A child-rights based approach to climate change requires all relevant actors to take steps to ensure children's rights policy coherence, empower children to participate in climate policymaking, guarantee children access to remedies for climate harm, better understand the impacts of climate change on children and mobilize adequate resources for child rights-based climate action. When pursuing these objectives, the particular needs of those children most vulnerable to climate change and its impacts must be taken into account.**

1. Ensure children's rights policy coherence

58. **States should ensure that children's rights considerations are integrated in their climate, disaster risk reduction and development activities. Efforts should be taken to link actions, positions and processes related to the United Nations Framework Convention on Climate Change, the Human Rights Council, the 2030 Agenda for Sustainable Development and the Sendai Framework for Disaster Risk Reduction 2015-2030 in order to establish a coherent approach to sustainable development that benefits all persons, particularly children. This should include:**

(a) **Implementing the Sustainable Development Goals relating to child poverty and malnutrition, access to education, child mortality and health, and water and sanitation, among others, in such a way as to enhance children's resilience to climate change and reduce inequalities;**

(b) **Integrating children's rights considerations in the implementation of the United Nations Framework Convention on Climate Change, including in the**

transparency framework, in intended nationally determined contributions and other communications and in the work of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts and its taskforce on displacement, in order to promote accountability and more effective climate policies;

(c) **Ensuring that climate adaptation policies improve disaster risk preparedness and enhance the adaptation capacities of all children, taking into account the needs and vulnerabilities of those most at risk. Gender considerations, for example, should be accounted for in climate change and disaster risk management policies, projects and planning processes.**

59. **Human rights mechanisms, including the Committee on the Rights of the Child, should consider ways to hold States accountable for their climate commitments, to better document the impacts of climate change and to promote rights-based climate action. As recommended during the day of general discussion on children's rights and the environment held by the Committee on the Rights of the Child, the issue of the environment could be routinely integrated in concluding observations. Civil society inputs to the Committee review process should address climate change and its impacts on children's rights and draw attention to the adequacy of States' individual contributions to efforts to limit climate change to 1.5°C above pre-industrial levels, as well as the impacts of climate actions. Similarly, States should use the universal periodic review mechanism of the Human Rights Council to promote accountability for climate and human rights commitments.**

2. Empower children to participate in climate policymaking

60. **All children, without discrimination, should be prepared for and included in climate decision-making in order to ensure that their best interests are protected. Children's involvement in the design and implementation of climate policies and climate vulnerability assessments should be facilitated according to their age and maturity.**[79] **Consultative mechanisms, improved dissemination of information and other strategies to engage children are needed for their meaningful participation. States should facilitate the participation of children in ongoing processes related to the United Nations Framework Convention on Climate Change that are likely to affect their development and survival.**

61. **Climate change education can empower educators, parents and children as agents of change. Educational curricula should transfer knowledge and develop skills that will equip children to confront climate-related challenges taking into account each child's particular local context and, as appropriate, traditional knowledge. Climate education should, inter alia:**

(a) **Raise awareness about appropriate lifestyle choices for sustainable development, such as low-carbon transportation, energy and consumption behaviours;**[80]

(b) **Emphasize solidarity, promote cooperation with children from other countries and create opportunities for children's participation in environmental decision-making;**[81]

(c) **Include access to up-to-date, meaningful and age-appropriate information about the causes of climate change, its impacts and adaptive responses, including disaster risk reduction and emergency preparedness.**

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[79] For example, the inclusion of girls as participants in the design, planning and implementation of climate strategies will lead to more effective policy formation. See, for example, United Nations Entity for Gender Equality and the Empowerment of Women (UN-Women) and Mary Robinson Foundation — Climate Justice, *The Full View: Ensuring a Comprehensive Approach to Achieve the Goal of Gender Balance in the UNFCCC Process*, 2nd ed. (2016), available at www.mrfcj.org/wp-content/uploads/2016/11/MRFCJ-Full-View-Second-Edition.pdf.

[80] See, for example, target 4.7 of the Sustainable Development Goals.

[81] See, for example, Committee on the Rights of the Child, general comment No. 1, paras. 9 and 13.

3. Guarantee children access to remedies

62. **States and other responsible actors should take measures to ensure that children have access to effective remedies when they suffer harm from climate action and inaction. Such measures could include:**

(a) **Integrating the right to a healthy environment and the rights of future generations in national constitutions and legislation in order to promote the justiciability of those rights and strengthen accountability systems;**

(b) **Ratifying the Optional Protocol to the Convention on the Rights of the Child on a communications procedure, which established a complaints procedure for violations of children's rights;**

(c) **Employing extraterritorial jurisdiction and taking other measures, as appropriate, to ensure responsible conduct by businesses not only in emissions reductions but also in remedying past harm;**

(d) **Developing a loss and damage system that ensures effective remedies for climate-related human rights harm, particularly that experienced by children;**

(e) **Ensuring that climate mitigation and adaptation projects provide access to effective redress mechanisms for human rights harm.**

4. Better understand the impacts of climate change on children

63. **In order to better protect children from the impacts of climate change, all actors should support improved understanding of the relationship between climate change and children's rights. This could be promoted through measures such as:**

(a) **Disaggregated data collection;**

(b) **Impact assessments with respect to children's rights and future generations;**

(c) **Enhanced intersectoral cooperation, as called for in the Geneva Pledge for Human Rights in Climate Action;**

(d) **Establishment of standing consultative committees that include children's perspectives;**

(e) **Improved reporting on children's rights and climate change to relevant United Nations Framework Convention on Climate Change and human rights mechanisms.**

64. **In this regard, civil society actors and participants at the 2010 Social Forum have called for the appointment of a United Nations special rapporteur on human rights and climate change.**[82]

5. Mobilize adequate resources for child rights-based climate action

65. **States, keeping in mind their human rights obligations and their common but differentiated responsibilities and respective capabilities, should take measures to mobilize adequate resources for effective climate action that does not harm but rather benefits children. States should ensure transparent, participatory and informed decision-making in the allocation of resources, including by conducting impact assessments with respect to children's rights and future generations. Further, measures should be taken to improve international cooperation and build capacity for climate action in developing countries through the transfer of technology and the sharing of technical expertise. Mitigation must be a top priority, as it is the key to minimizing the negative impacts of climate change. In these efforts, businesses also have human rights responsibilities, which must not be neglected.**

66. **With regard to climate adaptation, resources should be directed towards efforts to promote non-discriminatory access to basic necessities and services for children in**

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[82] A/HRC/16/62.

the light of the adverse effects of climate change. Investments in education and related infrastructure are a rights-based, cost-effective and sustainable method of empowering children. Health, water and sanitation, housing infrastructure and related services are also critical to children's adaptation and resilience. Disaster risk reduction, including training for teachers, parents and children, and climate-resilient schools and infrastructure, is another key area for investment. In the aftermath of climate-related disasters, resources should be devoted to ensure children's access to health services, to reunite children with their families and to not only protect them with physical support, such as food and clean water, but also to provide psychosocial care to prevent or address fear and traumas.[83] Support should take into account children's distinct needs for play and safety.

[83] See Committee on the Rights of the Child, general comment No. 15, para. 40.

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Report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment

Note by the Secretariat

The Secretariat has the honour to transmit to the Human Rights Council the report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment, John H. Knox, on the relationship between children's rights and environmental protection.

This is Exhibit "Q" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

....
A Commissioner for taking Affidavits within British Columbia

Report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment

Contents

I. Introduction

1. After reviewing the activities of the Special Rapporteur in 2017, the present report focuses on the rights of children in relation to the environment, addressing the ways that environmental harm prevents children from enjoying their human rights and the obligations that States have to protect children from such harm.

2. The Special Rapporteur held an expert meeting and a public consultation on 17–18 October on "framework principles" on human rights and the environment, which are the subject of a separate report to the thirty-seventh session of the Council (A/HRC/37/59). He carried out two country visits, to Uruguay in April and to Mongolia in September, which are also the subject of separate reports (A/HRC/37/58/Add.1 and Add.2). He sent or joined in 27 communications to States regarding alleged violations of human rights obligations relating to the environment. He worked with the United Nations Environment Programme and other partners, including the Global Judicial Institute for the Environment, to conduct a regional workshop for judges on rights-based approaches to environmental issues, which was held in Brasília on 22–23 May. A regional workshop for Asian judges is expected to take place in Pakistan in February 2018.

3. In accordance with the encouragement of the Council in its resolution 28/11 to continue to contribute to and participate in, where appropriate, intergovernmental conferences and meetings relevant to the mandate, the Special Rapporteur spoke on 31 July to the negotiators of a regional agreement on implementation of principle 10 of the Rio Declaration on Environment and Development, on rights of information, participation and remedy. He presented a statement to the sixth meeting of the parties to the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (the Aarhus Convention) on 14 September, and on 4–5 December, he participated in the third session of the United Nations Environment Assembly, in Nairobi. He also spoke at the World Bank on 4 May, and at the Swedish International Development Cooperation Agency on 19 October.

4. The Special Rapporteur continues to draw attention to threats facing environmental defenders around the world. He participated in conferences on environmental defenders at the University of Oxford, in the United Kingdom of Great Britain and Northern Ireland, on 20–21 June and in Mexico City on 6 November. Together with the Universal Rights Group, he organized a meeting of environmental defenders in Bogotá on 8–9 November, at which the Spanish-language version of a web portal for environmental defenders, environment-rights.org, was launched. He also supported a new environmental rights initiative at the United Nations Environment Programme, which will, among other things, try to address threats facing individuals and groups working to protect the environment.

5. In preparation for the present report, the Special Rapporteur participated in the day of general discussion of the Committee on the Rights of the Child on children's rights and the environment, on 23 September 2016. He held an expert meeting and a public consultation on 22–23 June 2017, and sent a questionnaire to States and other interested stakeholders, which elicited over 40 responses. He also examined statements and reports of human rights mechanisms and international organizations, as well as other sources.

6. Section II of the present report reviews the increasing attention being paid to the relationship of the rights of children to environmental harm. Section III describes the severe effects of environmental harm on the rights of children. Section IV outlines the human rights obligations relating to children's rights in the environmental context. Section V addresses the relationship of future generations and children's rights. Section VI concludes with recommendations aimed at protecting the rights of children from environmental harm.

II. International attention to the relationship between children's rights and the environment

7. The international community has long recognized that environmental harm interferes with the full enjoyment of the rights of children. The Convention on the Rights of the Child, adopted in 1989, requires its parties to pursue full implementation of children's right to

health by taking measures, among others, to combat disease and malnutrition through "the provision of adequate nutritious foods and clean drinking-water, taking into consideration the dangers and risks of environmental pollution" (art. 24 (2) (c)).

8. In the World Declaration on the Survival, Protection and Development of Children, adopted at the World Summit for Children in 1990, States recognized that millions of children suffer from environmental degradation, and committed to work for common measures for the protection of the environment, at all levels, so that all children can enjoy a safer and healthier future (see A/45/625, annex, paras. 5 and 20 (9)). The World Programme of Action for Youth to the Year 2000 and Beyond, adopted in 1995, includes specific environmental initiatives and states that implementation of the Programme of Action requires the full enjoyment by young people of all human rights and fundamental freedoms (see General Assembly resolution 50/81, annex, para. 20). States reiterated the importance of environmental protection in the document entitled "A world fit for children", adopted in 2002, one of whose ten principles and objectives is to "protect the Earth for children" (see General Assembly resolution S-27/2, annex, para. 7).

9. At the national level, many States reported to the Special Rapporteur that they have taken innovative steps to recognize and protect children's rights to live in a healthy environment. For example, the Plurinational State of Bolivia, El Salvador, Mexico and Paraguay have introduced national legislation that recognizes the right of children to a healthy, ecological and sustainable environment. Denmark, Saudi Arabia and Slovenia have adopted measures to protect children's health from environmental degradation and chemicals. Serbia is using the media to raise children's awareness about environmental issues, and Germany is promoting their participation in environmental initiatives. Many States, including Australia, Azerbaijan, El Salvador, France, Georgia, the State of Palestine, the Philippines and Switzerland, report that they have introduced measures to improve children's environmental education. Oman and Qatar have each designated a "national day of the environment" through which they raise awareness about the environment among children and promote children's participation in environmental activities.[1]

10. The Human Rights Council has often drawn attention to the effects of climate change on the rights of children. In its resolution 32/33, it recognized that children are among the most vulnerable to climate change, which may have a serious impact on their enjoyment of the highest attainable standard of physical and mental health, access to education, adequate food, adequate housing, safe drinking water and sanitation. In its resolution 35/20, it emphasized that climate change affects some children more than others, including children with disabilities, children on the move, children living in poverty, children separated from their families and indigenous children. In resolution 32/33, the Council called on States to continue and enhance international cooperation and assistance for adaptation measures to help developing countries, especially those that are particularly vulnerable to the adverse effects of climate change and persons in vulnerable situations, including children most at risk.

11. In recent years, human rights experts have begun to examine more closely the effect of environmental harm on the enjoyment of children's rights. In 2015, the United Nations Children's Fund (UNICEF) published a report on the effects of climate change on children.[2] In August 2016, the Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes, Baskut Tuncak, issued a report describing the "silent pandemic" of disability and disease associated with childhood exposure to toxics and pollution, and explaining the obligations of States and the responsibilities of business enterprises to protect against such exposure (A/HRC/33/41). At the request of the Human Rights Council, the Office of the United Nations High Commissioner for Human Rights (OHCHR) issued a report in May 2017 on the relationship between climate change and the rights of the child (A/HRC/35/13).

[1] All of the submissions are available at www.ohchr.org/EN/Issues/Environment/SREnvironment/Pages/RepliesEnvironmentAndRightsChild.aspx.

[2] UNICEF, *Unless we act now: The impact of climate change on children* (November 2015).

12. The Committee on the Rights of the Child has also given increasing attention to the relationship of environmental protection and children's rights. The Committee often addresses environmental concerns in its review of country reports under the Convention.[3] At its day of general discussion on 23 September 2016, the Committee brought together over 250 participants, including children, representatives of Governments, civil society organizations, United Nations agencies and academics, to examine the effects of environmental harm on the rights of children, both directly and through aggravating underlying causes of serious violations through conflict over limited resources, increasing inequalities, forced migration and even early marriage.[4]

13. The Committee on the Rights of the Child, UNICEF, other special procedures, States and civil society organizations, among others, continue to study and clarify the relationship of children's rights and the environment. The Special Rapporteur hopes that the present report will contribute to that ongoing discussion by providing an overview of the principal effects of environmental harm on the rights of children and outlining the corresponding obligations of States.

III. The effects of environmental harm on the rights of children

14. This section describes first the effects of environmental harm on children's well-being, and then how those effects interfere with the enjoyment of their human rights, including their rights to life, health and development, to an adequate standard of living and to play and recreation.

A. The effects of environmental harm on children

15. Taken as a whole, no group is more vulnerable to environmental harm than children (persons under the age of 18), who make up 30 per cent of the world's population. Environmental harm has especially severe effects on children under the age of 5. Of the 5.9 million deaths of children under the age of 5 in 2015, the World Health Organization (WHO) estimates that more than one quarter — more than 1.5 million deaths — could have been prevented through the reduction of environmental risks.[5] In addition, one quarter of the total disease burden in children under the age of 5 is attributed to environmental exposures.[6] Childhood exposure to pollutants and other toxic substances also contributes to disabilities, diseases and premature mortality in adulthood.

1. Air pollution

16. Air pollution causes approximately 600,000 deaths of children under the age of 5 every year.[7] Countless more children suffer disease and disability, often with lifelong effects. Children are more susceptible to air pollution than adults for many reasons, including that their smaller respiratory airways are more easily blocked by infections, and that they breathe more quickly and take in more air per unit of body weight.[8] Because their

[3] The Special Rapporteur compiled statements of the Committee on the Rights of the Child on environmental issues in "Mapping human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment: individual report on the United Nations Convention on the Rights of the Child" (December 2013). Available at http://srenvironment.org/mapping-report-2014-2/.

[4] Committee on the Rights of the Child, "Report of the 2016 day of general discussion: children's rights and the environment", p. 5. Available from www.ohchr.org/EN/HRBodies/CRC/Pages/Discussion2016.aspx.

[5] WHO, "Don't pollute my future! The impact of the environment on children's health" (Geneva, 2017), p. 1.

[6] Ibid., p. 22.

[7] Ibid., p. 3. Roughly 500,000 of these deaths are attributed to household air pollution and 100,000 to ambient air pollution. See UNICEF, *Clear the air for children: The impact of air pollution on children* (2016), p. 24.

[8] UNICEF, *Clear the air for children*, pp. 8 and 40.

immune systems are still developing, they are at higher risk of respiratory infections and have less ability to combat them.[9]

17. Ambient air pollution mainly results from factories and vehicles, and household air pollution comes primarily from the use of wood, coal and other solid fuels for cooking and heating. The vast majority of children — about 2 billion — live in areas that exceed the WHO ambient standard for particulate matter, and 300 million children live in areas whose ambient air pollution exceeds international standards by six times or more.[10] Over 1 billion children around the world live in homes that use solid fuels for cooking and heating.[11] WHO has estimated that together, ambient and household air pollution cause more than one half of all lower respiratory infections, such as pneumonia and bronchitis, in children under 5 in low- and middle-income countries, and that lower respiratory infections accounted for 15.5 per cent of deaths of all children under the age of 5 in 2015.[12]

18. Children who survive early exposure to air pollution can still suffer from it throughout their lives: it can disrupt their physical and cognitive development and make them more prone to lung cancer, asthma, other respiratory diseases and cardiovascular diseases.[13] The harm from air pollution begins before birth. As the Special Rapporteur on hazardous substances and wastes has said, children are often born "pre-polluted" because of their mothers' exposure to pollutants during pregnancy, which is associated with preterm delivery, lower birthweight and early fetal loss (see A/HRC/33/41, paras. 5 and 16).[14]

2. Water pollution

19. Water pollution resulting primarily from unsafe sanitation practices contributes to diarrhoeal diseases that cause more than 350,000 deaths a year of children under 5 years old, and another 80,000 deaths of children aged 5 to 14.[15] Water pollution also contributes to intestinal and parasitic infections such as schistosomiasis, which gravely affect the physical and cognitive development of children.[16] These infections, as well as diarrhoea, impair the proper functioning of the digestive system and prevent the absorption of nutrients essential for growth and development.[17] Lack of access to safe water also increases the incidence of other diseases, including trachoma, the main preventable cause of blindness.[18] More generally, unsafe water contributes to food insecurity, malnutrition and stunting of children.[19] UNICEF stated in 2013 that approximately 165 million children under 5 suffer from stunting as a result of inadequate nutrition and unhealthy water and sanitation.[20] Stunted children are not only shorter than they should be for their age; they suffer harm throughout their lives, including weaker immune systems and reduced brain development.

20. Children are particularly at risk from water pollution, like air pollution, because their bodies are still developing. In addition, they drink more water than adults in relation to their body weight, and they absorb a greater proportion of some waterborne chemicals.[21]

[9] Ibid., pp. 9 and 40.
[10] Ibid., pp. 8 and 60.
[11] Ibid., p. 9.
[12] WHO, "Don't pollute my future!", pp. 2–3.
[13] UNICEF, *Clear the air for children*, pp. 29–32; WHO, "Don't pollute my future!", p. 8.
[14] See also UNICEF, *Clear the air for children,* pp. 8 and 43–44; WHO, *Inheriting a sustainable world? Atlas on children's health and the environment* (Geneva, 2017), p. 49.
[15] WHO, "Don't pollute my future!", pp. 3 and 13.
[16] Ibid., p. 5.
[17] WHO, *Inheriting a sustainable world?*, p. 25.
[18] WHO, *Preventing disease through healthy environments: A global assessment of the burden of disease from environmental risks* (Geneva, 2016), p. 22; WHO, *Inheriting a sustainable world?*, p. 26.
[19] WHO, "Don't pollute my future!", p. 6; WHO, *Inheriting a sustainable world?*, pp. 10–11.
[20] UNICEF, "Sustainable development starts and ends with safe, healthy and well-educated children" (May 2013), p. 8.
[21] WHO, *Inheriting a sustainable world?*, p. 25.

Children spend more time than adults playing in water bodies that are unclean, and they may be less able than adults to recognize or act upon environmental risks.[22]

21. Between 1990 and 2015, as the number of people without access to an improved source of water fell from over 2 billion to approximately 660 million, the number of diarrhoeal deaths of children under 5 years more than halved.[23] Some waterborne diseases, such as guinea worm, have been nearly eradicated. But much more remains to be done. At least one in every four people around the world still drinks water that is faecally contaminated.[24] Proper management of water sources is also critical to reducing vector-borne diseases such as malaria. Although the number of malarial deaths of children under 5 decreased by more than one half between 2000 and 2015, malaria still caused approximately 300,000 deaths in 2015, accounting for one in every ten child deaths in sub-Saharan Africa.[25]

3. Climate change

22. The Executive Director of UNICEF has stated that "there may be no greater, growing threat facing the world's children — and their children — than climate change".[26] As explained in the 2017 OHCHR report (A/HRC/35/13), climate change contributes to extreme weather events, water scarcity and food insecurity, air pollution and vector-borne and infectious diseases, all of which already have severe effects on children.

23. For example, climate change increases the frequency and severity of droughts, and approximately 160 million children already live in areas of high or extremely high drought severity.[27] Because children need to consume more food and water per unit of body weight than adults, they are more vulnerable to the deprivation of food and water, which can lead to irreversible stunting.[28] Water scarcity leads to the use of unsafe water, which in turn contributes to communicable diseases.[29]

24. Climate change also contributes to severe storms and flooding. More than 500 million children live in areas, mostly in Asia, that have extremely high likelihoods of flooding, and approximately 115 million live in zones of high or extremely high risk of tropical cyclones.[30] Beyond the immediate dangers of death and injury, severe storms and floods cause a cascade of additional harms, including compromising safe water supplies, damaging sanitation facilities and destroying housing. Like droughts, floods can cause massive displacement. Children are particularly vulnerable during displacements, when the loss of connections to families, communities and protective services can increase their vulnerability to abuses including child labour and trafficking.[31]

25. Climate change has many other harmful effects on human health, including increasing the frequency and severity of heatwaves, compounding the toxicity of fossil-fuel pollutants such as ozone and contributing to wildfires.[32] Children are, again, more vulnerable to all of these effects. For example, UNICEF has indicated that "infants and small children are more likely to die or suffer from heatstroke because they are unable or lack agency to regulate their body temperature and control their surrounding environment".[33] Over the longer term, rising temperatures and changing rainfall patterns are likely to exacerbate the spread of vector-borne diseases such as malaria, dengue and cholera,[34] and contribute to food scarcity and undernutrition. WHO estimates that by 2030,

22 Ibid., pp. 25–26.
23 Ibid., p. 24.
24 Ibid.
25 Ibid., p. 38.
26 UNICEF, *Unless we act now*, p. 6.
27 Ibid., p. 22
28 Ibid.
29 Ibid.
30 Ibid., pp. 30 and 34.
31 Ibid.
32 Ibid., pp. 40 and 44
33 Ibid., p. 40.
34 Ibid., pp. 48–52.

the effects of climate change on nutrition will result in an additional 7.5 million children who are moderately or severely stunted, and approximately 100,000 additional deaths.[35]

26. The ramifications of climate change for children go far beyond its effects on their health, as disastrous as those may be. As OHCHR has stated, "climate change heightens existing social and economic inequalities, intensifies poverty and reverses progress towards improvement in children's well-being" (see A/HRC/35/13, para. 50). To give just one example, climate change-induced food insecurity is already increasing the number of marriages of girl children, who are pressured to marry to reduce burdens on their families of origin.[36]

4. Chemicals, toxic substances and waste

27. The 2016 report of the Special Rapporteur on hazardous substances and wastes describes the harms to children from exposure to chemicals, toxic substances and waste. He states that the number of deaths from air and water pollution is only one part of a silent pandemic of disability and disease, much of which may not manifest for years or decades (see A/HRC/33/41, para. 4). The rapid growth of hazardous chemicals in the environment has occurred together with increasing incidence of cancer, diabetes and asthma, among other diseases. More than 800 chemicals have been identified as known or suspected disruptors of the normal functioning of human and/or animal endocrine systems, and humans are most sensitive to endocrine disruption during periods of development, including early childhood and puberty.[37] Children begin their exposure to toxic substances before birth; hundreds of hazardous chemicals have been found in children as a result of their mother's exposure, resulting in the children being born "pre-polluted" (see A/HRC/33/41, para. 5). He emphasizes that children in low-income, minority, indigenous and marginalized communities are at more risk, as exposure levels in such communities are often higher and are exacerbated by malnutrition, with the adverse effects inadequately monitored (ibid., para. 6).

28. Although the connection between exposure to a particular toxic substance and the harm to an individual is not always traceable, in large part because information about exposure to and effects of these substances is typically not required or provided, some effects are clear. For example, lead poisoning causes irreversible intellectual disabilities in 600,000 children annually (ibid., para. 9). Artisanal and small-scale mining, in which approximately 1 million children participate, commonly employs mercury, which causes lifelong harm to the developing nervous systems of children, as well as contributing to cardiovascular and other diseases.[38] Discarded mobile telephones and other electronic products are often shipped from high-income to lower-income countries. Children are often employed to extract valuable elements from these products, without protective equipment, exposing themselves to toxic substances such as lead, mercury, cadmium, chromium and arsenic.[39]

29. Another increasing source of harm is the use of pesticides, the subject of a recent joint report by the Special Rapporteur on hazardous substances and wastes and the Special Rapporteur on the right to food. They state that exposure to even low levels of pesticides, for example through wind drift or residues on food, may be very damaging to children's health, disrupting their mental and physiological growth and possibly leading to a lifetime of diseases and disorders (see A/HRC/34/48, para. 24). The effects of pesticides and of chemicals ingested other ways, including through food, may include asthma, cancer and neurological damage.[40]

[35] WHO, *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s* (Geneva, 2014), pp. 80 and 89.

[36] Gethin Chamberlain, "Why climate change is creating a new generation of child brides", *Guardian*, 26 November 2017; Human Rights Watch, "Marry before your house is swept away: child marriage in Bangladesh", 9 June 2015.

[37] WHO, "Don't pollute my future!", p. 6.

[38] WHO, *Inheriting a sustainable world?*, pp. 81–82.

[39] Ibid., p. 88.

[40] Ibid., pp. 67 and 72.

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Child does not have an explicit provision on remedies, the requirement of effective remedies to redress violations is implicit in the Convention. To provide for effective remedies, States should ensure that individuals have access to judicial and administrative procedures that meet basic requirements, including that the procedures are impartial, independent, affordable, transparent and fair (see A/HRC/37/59, annex, framework principle 10). Decisions should be made public and promptly and effectively enforced. States should provide guidance about how to seek access to justice, and should help to overcome obstacles to access such as language, illiteracy, expense and distance.

52. Because children's dependent status creates obstacles to their pursuit of remedies, the Committee on the Rights of the Child has made clear that States need to give particular attention to ensuring that there are effective, child-sensitive procedures available to children and their representatives. These should include the provision of child-friendly information, advice, advocacy, including support for self-advocacy, and access to independent complaints procedures and to the courts with necessary legal and other assistance. Where rights are found to have been breached, there should be appropriate reparation, including compensation, and, where needed, measures to promote physical and psychological recovery, rehabilitation and reintegration, as required by article 39.[69]

53. In the context of environmental harm, children may face additional barriers to access to justice. For example, they and their representatives may lack information about the effects of particular harms or the harms may manifest only years after exposure, which may make it difficult or impossible for those affected to have standing to bring a case, meet applicable limitations periods or carry their burdens of proof and persuasion.[70] States should take steps to overcome these obstacles, including by allowing collective suits (or "class actions") on behalf of children. Moreover, when determining the level or form of reparation, mechanisms should take into account that children can be more vulnerable to the effects of abuse of their rights than adults and that the effects can be irreversible and result in lifelong damage. They should also take into account the evolving nature of children's development and capacities and reparation should be timely to limit ongoing and future damage to the child or children affected; for example, if children are identified as victims of environmental pollution, immediate steps should be taken by all relevant parties to prevent further damage to the health and development of children and repair any damage done.[71]

54. Because environmental harm can cause irreversible effects, such as early mortality or lifelong disability, for which no remedies are truly adequate, States must do what they can to prevent the harm from occurring in the first place. In some cases, that may be possible through injunctive relief ordered by judicial tribunals or administrative bodies. In addition, States must adopt and enforce effective regulatory measures, as described in the following section.

B. Substantive obligations to protect children from environmental harm

55. Ideally, States would set substantive environmental standards at levels that would prevent all harmful environmental interference with the full enjoyment of human rights. While States have obligations to take deliberate, concrete and targeted measures towards that goal, they have some discretion in deciding which means are appropriate in light of available resources.[72] However, this discretion is not unlimited. For example, environmental standards must comply with obligations of non-discrimination, and they should take into account relevant international health and safety standards (see A/HRC/37/59, annex, framework principle 11). Once States have adopted substantive environmental standards, they should ensure their effective implementation by private as well as public actors (ibid., framework principle 12).

[69] See Committee on the Rights of the Child, general comment No. 5, para. 24.
[70] Committee on the Rights of the Child, "Report of the 2016 day of general discussion", pp. 21–22.
[71] See Committee on the Rights of the Child, general comment No. 16, para. 31.
[72] See, for example, Committee on the Rights of the Child, general comment No. 15, para. 72.

56. The discretion of States with respect to the protection of children's rights is further restricted by their obligations under the Convention on the Rights of the Child and other agreements to adopt and implement special measures of protection, assistance and care for children, and to ensure that the best interests of children are a primary consideration in all actions concerning children.[73] These obligations require States not just to protect children from harm, but also to ensure their well-being and development, including by taking into account the possibility of future risk and harm.[74]

57. The discretion accorded States in deciding appropriate levels of environmental protection rests on the assumption that societies will make informed decisions as to how to balance the costs of environmental harm against the benefits of spending resources for other goals, such as faster short-term economic growth. But the cost-benefit calculus is very different for children, especially younger children. The consequences of environmental harm are usually far more severe, and may include death or irreversible, lifelong effects. The cumulative effects of long-term environmental harm, such as climate change and the loss of biodiversity, increase over time, so that decisions taken today will affect children much more than adults. The lack of full information about many types of environmental harm means that their long-term effects are often poorly understood and underestimated. And, finally, the voices of children are only rarely heard in environmental decision-making.

58. Therefore, to satisfy their obligations of special protection and care, and to ensure that the best interests of the child are taken into account, States have heightened obligations to take effective measures to protect children from environmental harm. They should make certain that they are protecting children's rights before they make decisions that may cause environmental harm, including by: collecting and disseminating disaggregated information on the effects of pollution, chemicals and other potentially toxic substances on the health and well-being of children; ensuring that the views of children are taken into account in environmental decision-making; and carrying out children's rights impact assessments. States should adopt and implement environmental standards that are consistent with the best available science and relevant international health and safety standards, and they should never take retrogressive measures.[75] The lack of full scientific certainty should never be used to justify postponing effective and proportionate measures to prevent environmental harm to children, especially when there are threats of serious or irreversible damage. On the contrary, States should take precautionary measures to protect against such harm.[76] Once standards protective of children's rights are adopted, States must ensure that they are effectively implemented and enforced. To that end, they must provide regulatory agencies with sufficient resources to monitor and enforce compliance with domestic laws, including by investigating complaints and bringing appropriate remedial actions.[77]

59. As part of their obligations to protect children from environmental harm, States must adequately regulate private actors, including business enterprises. Businesses can cause environmental harm to children's rights in many ways, including by producing hazardous products, polluting the air and water, creating hazardous waste, contributing to climate change and destroying forests and other natural ecosystems.[78] They can also commit human rights abuses such as violating child labour protections or colluding with governmental or private security forces to use violence against peaceful protestors.

60. As the Committee on the Rights of the Child has stated, States must take all necessary, appropriate and reasonable measures to prevent business enterprises from causing or contributing to abuses of children's rights.[79] This includes ensuring that businesses comply with all applicable environmental standards. States should require businesses, including State-owned businesses, to carry out "child-rights due diligence" to

[73] See Convention on the Rights of the Child, art. 3; International Covenant on Economic, Social and Cultural Rights, art. 10 (3).

[74] See Committee on the Rights of the Child, general comment No. 14, paras. 24 and 71.

[75] See Committee on the Rights of the Child, general comment No. 15, para. 72.

[76] See Rio Declaration on Environment and Development, principle 15.

[77] See Committee on the Rights of the Child, general comment No. 16, para. 61.

[78] Ibid., para. 19.

[79] Ibid., para. 28.

ensure that they identify, prevent and mitigate their impact on children's rights.[80] This due diligence should include careful consideration of the effects of their actual and proposed actions on the rights of children through environmental harm. States must also ensure that information held by businesses relevant to the health and well-being of children is made publicly available.

61. States should cooperate with one another to address the effects of global and transboundary harm on the rights of children.[81] For example, in the negotiation and implementation of multilateral environmental agreements, they should address children's rights, for example by providing that national action plans should include strategies to protect children as well as other vulnerable segments of the population.[82] States should work together to ensure that businesses operating in more than one country comply with their obligations under all applicable domestic laws. The Committee on the Rights of the Child has set out a framework for such cooperation: host States have the primary responsibility to regulate business enterprises operating within their territory, but home States can also have regulatory obligations when there is a reasonable link between the State and the conduct in question. For example, home States in such situations should assist host States with investigation and enforcement; enable access to effective remedies for children and their families who have suffered human rights abuses; and provide that their international assistance agencies identify and protect against harmful effects of any projects that they support.[83]

62. Businesses have direct responsibilities to respect children's rights. To meet these responsibilities, it is necessary, but not sufficient, that businesses comply with domestic laws. Certainly businesses should never seek to evade applicable laws through corruption or other practices, or abuse those laws by, for example, bringing criminal defamation suits against those who oppose their activities. But that is a low bar. To respect the rights of children to be free from environmental harm, businesses should comply with the Guiding Principles on Business and Human Rights; the Children's Rights and Business Principles;[84] and the recommendations of the Committee on the Rights of the Child in its general comment No. 16 (2013) on State obligations regarding the impact of the business sector on children's rights. Among other things, they should undertake environmental and human rights impact assessments that examine the effects of proposed actions on children; develop and make public information about the effects of their actions and products on the health and well-being of children; facilitate children's participation, as appropriate, in consultations; seek to strengthen environmental, health and safety standards, rather than lobby against them; and, in general, avoid causing or contributing to environmental harm to children and remediate any such harm when it does occur.

C. Obligations of non-discrimination

63. The Convention on the Rights of the Child requires its States parties to respect and ensure the rights in the Convention to each child within their jurisdiction without discrimination of any kind, irrespective of the child's or his or her parent's or legal guardian's race, colour, sex, language, religion, political or other opinion, national, ethnic or social origin, property, disability, birth or other status (art. 2). Children are also encompassed by the non-discrimination obligations of States under many other human rights agreements, including the International Covenant on Civil and Political Rights (arts. 2 (1) and 26)) and the International Covenant on Economic, Social and Cultural Rights (art. 2 (2)).

64. The obligations of States to prohibit discrimination and to ensure equal and effective protection against discrimination undoubtedly apply to the equal enjoyment of human rights relating to a safe, clean, healthy and sustainable environment (see A/HRC/37/59, annex, framework principle 3). These obligations apply not only to direct discrimination, but also

[80] Ibid., para. 62.
[81] Ibid., para. 41.
[82] See, for example, Minamata Convention on Mercury, annex C, art. 1 (i).
[83] See Committee on the Rights of the Child, general comment No. 16, paras. 42–45.
[84] The Children's Rights and Business Principles were developed by UNICEF, the United Nations Global Compact and Save the Children, and released in 2012.

to indirect discrimination, when facially neutral laws, policies or practices have a disproportionate impact on the exercise of human rights as distinguished by prohibited grounds of discrimination.[85] The Committee on the Rights of the Child has emphasized that the right to non-discrimination does not just prohibit all forms of discrimination in the enjoyment of rights under the Convention, but also requires appropriate proactive measures taken by the State to ensure effective equal opportunities for all children to enjoy the rights under the Convention. This may require positive measures aimed at redressing a situation of real inequality.[86]

65. While all children are vulnerable to environmental harm, some are particularly at risk. To highlight just a few examples: girl children are more likely to suffer from the lack of clean and safe sources of water; indigenous children from the destruction of natural ecosystems on which they rely for food, water, housing and culture; children with disabilities from the failure to anticipate and respond safely and effectively to natural disasters; and children from low-income families from a vast range of environmental problems, including household air pollution, lack of clean water, exposure to toxic substances and a lack of access to safe and clean opportunities for play and recreation.

66. States should take effective measures to ensure that children in these and other particularly vulnerable situations are able to exercise their human rights on an equal basis, and that environmental harm does not affect them disproportionately. For example, States and business enterprises should require that their children's rights impact assessment procedures take fully into account the impacts of proposed policies, programmes and projects on the most vulnerable. Environmental educational programmes should reflect the cultural and environmental situation of the children involved. States should collect disaggregated data to identify disparate impacts of environmental harm on different groups of children.[87] Environmental information should be made available to children and their parents or other caretakers in their own language. States should ensure that girls, children with disabilities and children from marginalized communities are able to voice their views and that their views are given due weight.[88] States should take steps to enable children with disabilities, as well as others, to play and engage in recreational activities in safe and healthy environments.[89] Children at particular risk and their caretakers should be provided with assistance in accessing effective remedies.

V. Future generations

67. International environmental agreements and declarations on sustainable development often express concerns about the effects of environmental harm on future generations.[90] Indeed, the definition of sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".[91] However, human rights law does not attempt to define the rights of future generations or of obligations of States to them. It is understandable that international environmental and development policy and human rights law take different approaches to

[85] See Committee on Economic, Social and Cultural Rights, general comment No. 20 (2009) on non-discrimination in economic, social and cultural rights, para. 7.

[86] See Committee on the Rights of the Child, general comment No. 14, para. 41.

[87] See, for example, Committee on the Rights of the Child, general comment No. 5, para. 12; general comment No. 9 (2006) on the rights of children with disabilities, para. 19; general comment No. 11 (2009) on indigenous children and their rights under the Convention, para. 26.

[88] See, for example, Committee on the Rights of the Child, general comment No. 12, paras. 77–78; general comment No. 9, para. 32; general comment No. 11, para. 39.

[89] See Convention on the Rights of Persons with Disabilities, art. 30; Committee on the Rights of the Child, general comment No. 17, para. 50.

[90] The many examples include the Rio Declaration on Environment and Development, principle 3; the United Nations Framework Convention on Climate Change, art. 3 (1); the Convention on Biological Diversity, preamble; Transforming our world: the 2030 Agenda for Sustainable Development.

[91] See the report of the World Commission on Environment and Development entitled "Our Common Future" (A/42/427, annex), ch. 2, para. 1 (p. 54). See also the report of the Secretary-General on intergenerational solidarity and the needs of future generations (A/68/322).

issues concerning future generations. While the former is concerned with the long-term as well as short-term consequences of present decisions, the latter is based primarily on the rights of individual human beings. It is difficult, if not impossible, to define the rights of individuals who are not yet alive.

68. Nevertheless, the division between present and future generations is less sharp than it sometimes appears to be. Concerns about future generations and sustainable development often focus on the state of the environment in particular years in the future, such as the year 2030 or 2100. Many people that will be living in 2100 are not yet born, and in that sense truly belong to future generations. But many people who will be living then are already alive today. To take a personal example, the Special Rapporteur has twin nieces who were born in 2016. The next century will begin before they celebrate their eighty-fourth birthday. Moreover, the line between future generations and today's children shifts every time another baby arrives and inherits their full entitlement of human rights. It is critical, therefore, that discussions of future generations take into account the rights of the children who are constantly arriving, or have already arrived, on this planet. We do not need to look far to see the people whose future lives will be affected by our actions today. They are already here.

VI. Conclusions and recommendations

69. **No group is more vulnerable to environmental harm than children. Air pollution, water pollution and exposure to toxic substances, together with other types of environmental harm, cause 1.5 million deaths of children under the age of 5 every year, and contribute to disease, disability and early mortality throughout their life. In addition, climate change and the loss of biodiversity threaten to cause long-term effects that will blight children's lives for years to come. Making matters worse, children are often not able to exercise their rights, including their rights to information, participation and access to effective remedies.**

70. **States must do more to respect, protect and fulfil the rights of children in relation to environmental harm. To that end, the present report includes a number of specific recommendations, which build on the work of other special rapporteurs, the Committee on the Rights of the Child, OHCHR, UNICEF, WHO and the many others who submitted oral and written communications during the preparation of the report.**

71. **With respect to children's educational and procedural rights, States should, among other things:**

(a) **Ensure that educational programmes increase children's understanding of environmental issues and strengthen their capacity to respond to environmental challenges;**

(b) **Ensure that the effects of proposed measures on children's rights are assessed before the measures are taken or approved;**

(c) **Collect information about sources of environmental harm to children and make the information publicly available and accessible;**

(d) **Facilitate the participation of children in environmental decision-making processes, and protect them from reprisals for their participation or otherwise expressing their views on environmental matters;**

(e) **Remove barriers that children face to access to justice for environmental harm to the full enjoyment of their human rights.**

72. **States also have heightened obligations to take effective substantive measures to protect children from environmental harm, including by ensuring that their best interests are a primary consideration with respect to all decision-making that may cause them environmental harm. In particular, States should adopt and implement environmental standards that are consistent with the best available science and relevant international health and safety standards, never take retrogressive measures,**

and pursue precautionary measures to protect against environmental harm, especially when there are threats of serious or irreversible damage.

73. **In this light, States should consider and, wherever possible, implement recommendations from expert agencies on specific measures to protect children's health and well-being from environmental harm.**[92] **WHO and UNICEF, in particular, have published detailed recommendations, including many examples of good practices.**[93] **Some simple changes could have enormous effects. For example, WHO states that widespread handwashing with soap after defecation and before preparing food would greatly reduce the incidence of diarrhoea, trachoma and respiratory infections that kill or harm so many children under the age of 5.**[94]

74. **States should cooperate to address the effects of environmental harm on the rights of children, including by sharing information on the toxicity and other characteristics of chemicals and other products and ensuring that international trade in chemicals and waste is in full compliance with the relevant environmental treaties.**

75. **With respect to the activities of business enterprises operating in more than one State, the States concerned should cooperate to ensure that the businesses comply with all applicable environmental laws, including by providing that victims of environmental harm allegedly caused by businesses have access to effective remedies in the courts of the States where the businesses are based as well as the States where the victims experienced the harm.**

76. **States should ensure that children in particularly vulnerable situations are able to exercise their human rights on an equal basis and that environmental harm does not affect them disproportionately, including by ensuring that impact assessment procedures take fully into account the effects of proposed policies, programmes and projects on the children most at risk.**

77. **States that have not yet done so should become parties to the Optional Protocol to the Convention on the Rights of the Child, and the State that has not yet ratified the Convention on the Rights of the Child should do so without further delay.**

78. **International financial mechanisms should ensure that the projects that they support do not cause environmental harm that adversely affects the rights of children, by including appropriate protections in their social and environmental safeguards.**

79. **Business enterprises should protect children's rights from environmental harm from their activities, including by carrying out environmental and human rights impact assessments that examine the effects of proposed actions on children, and by fully complying with the Guiding Principles on Business and Human Rights, the Children's Rights and Business Principles, and the recommendations of the Committee on the Rights of the Child in its general comment No. 16.**

80. **The Committee on the Rights of the Child should consider adopting a new general comment on children's rights and the environment.**

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[92] States should also implement the recommendations of the Special Rapporteur on hazardous substances and wastes with respect to the threats to children from toxic chemicals (see A/HRC/33/41, paras. 110–114), and those of OHCHR contained in its report on climate change and human rights (see A/HRC/35/13, paras. 57–66).

[93] See, for example, WHO, *Inheriting a sustainable world?*; WHO, "Don't pollute my future!", UNICEF, *Clear the air for children*; UNICEF, *Unless we act now.*

[94] WHO, *Inheriting a sustainable world?*, p. 32, indicates that it is estimated that handwashing with soap could reduce diarrhoeal disease by 23 per cent and prevent 297,000 deaths per year from diarrhoea alone.

This is Exhibit "R" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

....

A Commissioner for taking Affidavits within British Columbia

December 14, 2018 Via Email

Generation Squeeze
Attn: Dr. Paul Kershaw
17280 Ford Road
Pitt Meadows, BC

Dear Dr. Kershaw:

Re: Court of Appeal for Ontario, File No. C65807, a reference respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018*, No. 1, SC 2018, c. 12 (the "Reference Case")

I write on behalf of the Canadian Association of Physicians for the Environment ("CAPE") to confirm our support for and membership in the coalition of organizations joining Generation Squeeze in applying for leave to intervene in the Reference Case. We share your commitment to intergenerational justice in climate policy and we believe this application is an important opportunity to protect the interests of young Canadians and future generations in a healthy and sustainable climate.

The Canadian Association of Physicians for the Environment

CAPE is a volunteer, non-profit organization founded by three doctors in 1993 with the mission to improve human health by protecting the planet. The majority of our board members are physicians, with spots held for medical learners, an Indigenous physician, and several available for members from other disciplines.

CAPE acts as a resource to physicians, other healthcare workers, public health professionals, the public and policy makers to better understand how environmental issues can impact public health and how policies and programs can protect the public and improve public health. Among other things, CAPE produces informational material for public health professionals and doctors regarding the relationship between environmental factors and public health.

CAPE also conducts and publishes research and publicly advocates for meaningful, evidence-based policies that reflect the important interaction between public health and the environment. Our areas of focus include the relationship between climate health and policy, the development of healthy and sustainable energy, and the development of healthy and sustainable communities.

Climate-Related Impacts to Public Health are Serious and Increasing

In 2015, the *Lancet* Commission on Health and Climate Change concluded that changes to the climate from human activity threatened to undermine the gains made in public health worldwide over the last 50 years. The Commission also concluded that a comprehensive response to climate change could be the greatest global health opportunity of the 21st century.

Following the 2015 Commission report, a multi-disciplinary collaboration between 24 academic institutions and intergovernmental organizations was organized to track progress on health and climate change and publish its findings annually in the *Lancet,* the world's leading medical journal, until 2030. This annual report, the *Lancet* Countdown: Tracking Progress on Health and Climate Change, provides an independent assessment of the health effects of climate change. The *Lancet* Countdown will track a number of indicators of progress and report annually on the state of the climate, the implementation of the Paris Agreement, and efforts to mitigate and adapt to climate change.

The *Lancet* Countdown's 2017 report[1] set out a number of key messages based on the analysis of 40 indicators including:

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

- Global wheat production has been demonstrated to be reduced by 6% for every 1 degree Celsius increase in temperature;

- To meet the mitigation levels set out in the Paris Agreement, energy systems will need to largely complete the transition to near zero-carbon emissions by around 2050 and emissions will then need to be negative in the second half of the century;

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

- Although progress has been historically slow, the past five 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.

As part of the *Lancet* Countdown process, briefing reports were written for a number of individual countries that provide information on indicators contextualized to that country. I was the lead author of both the *Lancet Countdown 2017 Report: Briefing for Canadian*

[1] https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(17)32464-9/fulltext

Policymakers[2] and the *Lancet Countdown 2018 Report: Briefing for Canadian Policymakers* [3].

The 2017 *Lancet* Canada Brief builds on the central conclusion of the *Lancet* Countdown, stating that "[t]he human symptoms of climate change are unequivocal and potentially irreversible – affecting the health of populations around the world, today. Whilst these effects will disproportionately impact the most vulnerable in society, every community will be affected."

Global inaction to prevent or mitigate climate change to date has created a high-end emissions trajectory with between 2.6 degrees Celsius and 4.8 degrees Celsius of global surface temperature warming by the end of the century. This level could be disastrous to health even if we maximize our efforts to adapt.

A wide range of adverse health effects from climate change are, and will be, experienced by Canadians across all regions, including:

- Increased heat-related illness, such as heat stroke and death;
- Higher pollen levels (with the potential to trigger more severe asthma);
- Increased air pollution from wildfire smoke;
- Increased ground-level ozone resulting in increased heart and respiratory disease;
- Increased food insecurity in the Canadian Artic from reduced access to traditional foods;
- Region-specific impacts on agriculture that range from potentially helpful milder winters to crop-damaging severe weather and drought;
- Increased stress and displacement for individual Canadians from disasters like wildfires and floods;
- An increase in the range of vector-borne diseases, such as Lyme Disease;
- Increased risk of water-borne diseases from changed precipitation patterns; and
- Greater exposure to higher levels of ultraviolet radiation.

The 2017 *Lancet* Canada Brief also noted the impact of recent weather-related disasters on public health in Canada, including the following wildfire activity:

[2] https://www.cpha.ca/sites/default/files/uploads/advocacy/2017_lancet_canada_brief.pdf
[3] https://cape.ca/wp-content/uploads/2018/11/2018-Lancet-Countdown-Policy-Brief-Canada.pdf

- The evacuation of 13,000 people from La Ronge, Saskatchewan in 2015, the largest evacuation in Saskatchewan history;

- 2014 wildfires in Northwest Territories that left Yellowknife covered in smoke for much of the summer;

- Fires in and around Fort McMurray, Alberta that resulted in a mandatory evacuation order, the loss of approximately 2400 buildings, and impacts felt by approximately 88,000 people; and

- 2017 wildfires in and around Williams Lake, British Columbia forcing the evacuation of 24,000 people.

From a public health perspective these wildfire events cause, in addition to the local damage and evacuation orders, massive smoke plumes that can travel large distances and can increase exposure to air pollution for populations located far from the originating fire. Wildfire smoke is linked to a number of adverse health consequences, including increased asthma exacerbations; pneumonia; conjunctivitis; headache; feelings of sadness, isolation, and worry about climate change; and possible reduced birth weight in infants exposed *in utero*.

The 2018 *Lancet* Canada Brief, which was released on November 29, 2018, made a number of statements regarding the health impacts in Canada from climate change and Canada's role in causing climate change, including:

- "Present day changes in labour capacity, vector-borne disease, and food security provide early warning of compounded and overwhelming impacts expected if temperature continues to rise. Trends in climate change impacts, exposures, and vulnerabilities demonstrate an unacceptably high level of risk for the current and future health of populations across the world."

- Especially vulnerable populations include children and pregnant women; and

- Canada is not doing its fair share to reduce greenhouse gas emissions, as Canadian emissions increased more than 100 megatonnes between 1990 and 2016.

Conclusion

Again, CAPE is proud to be a member of the intergenerational climate coalition applying for leave to intervene in the Reference Case.

Sincerely,

Dr. Courtney Howard
President, CAPE

This is Exhibit "S" referred to in the
Affidavit of Paul Kershaw, sworn before
me at North Vancouver this 18th day of
December, 2018.
....
A Commissioner for taking Affidavits
within British Columbia

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

Nick Watts, Markus Amann, Sonja Ayeb-Karlsson, Kristine Belesova, Timothy Bouley, Maxwell Boykoff, Peter Byass, Wenjia Cai, Diarmid Campbell-Lendrum, Jonathan Chambers, Peter M Cox, Meaghan Daly, Niheer Dasandi, Michael Davies, Michael Depledge, Anneliese Depoux, Paula Dominguez-Salas, Paul Drummond, Paul Ekins, Antoine Flahault, Howard Frumkin, Lucien Georgeson, Mostafa Ghanei, Delia Grace, Hilary Graham, Rébecca Grojsman, Andy Haines, Ian Hamilton, Stella Hartinger, Anne Johnson, Ilan Kelman, Gregor Kiesewetter, Dominic Kniveton, Lu Liang, Melissa Lott, Robert Lowe, Georgina Mace, Maquins Odhiambo Sewe, Mark Maslin, Slava Mikhaylov, James Milner, Ali Mohammad Latifi, Maziar Moradi-Lakeh, Karyn Morrissey, Kris Murray, Tara Neville, Maria Nilsson, Tadj Oreszczyn, Fereidoon Owfi, David Pencheon, Steve Pye, Mahnaz Rabbaniha, Elizabeth Robinson, Joacim Rocklöv, Stefanie Schütte, Joy Shumake-Guillemot, Rebecca Steinbach, Meisam Tabatabaei, Nicola Wheeler, Paul Wilkinson, Peng Gong, Hugh Montgomery*, Anthony Costello**

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See Online for infographic

This online publication has been corrected. The corrected version first appeared at thelancet.com on November 23, 2017

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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 ($PM_{2\cdot5}$) exposure has increased by 11·2% since 1990, and about 71% of the 2971 cities in the WHO air pollution database exceed guideline annual $PM_{2\cdot5}$ 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.

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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, *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.

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

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,

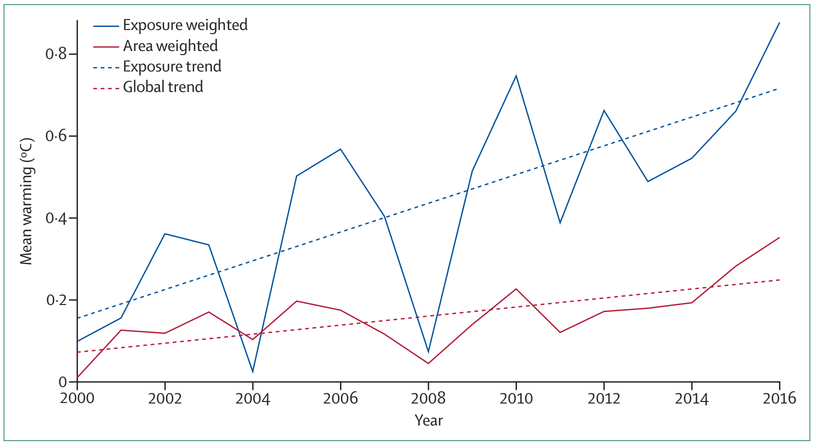

Figure 1: **Mean summer warming relative to the 1986–2008 average**
The time series are global mean temperatures calculated from the gridded data, weighted by area (to avoid bias from measurements near the poles) and by exposure (to show the number of people exposed).

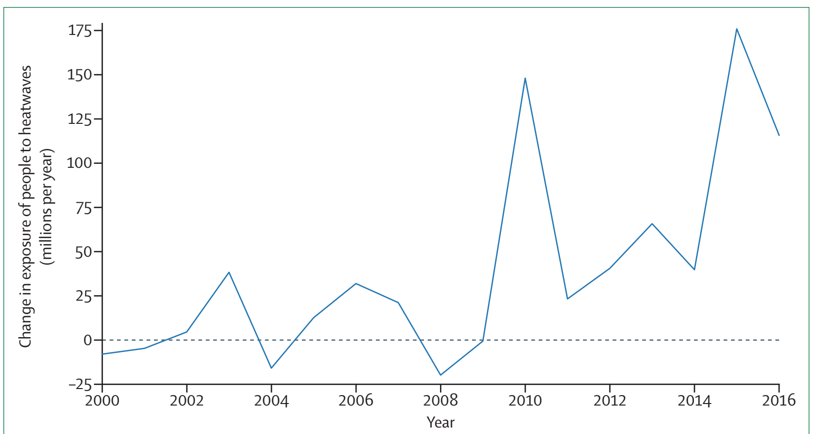

Figure 2: **The change in heatwave exposure (in people older than 65 years), relative to the 1986–2008 average**

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.

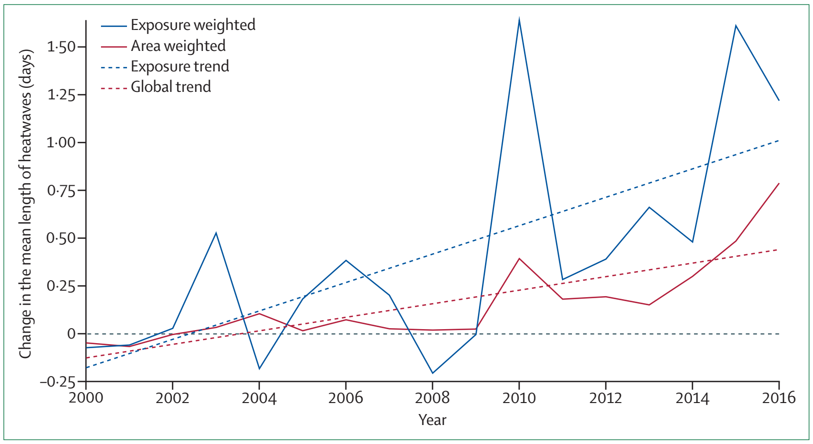

Figure 3: Change in mean heatwave lengths worldwide, relative to the 1986–2008 average

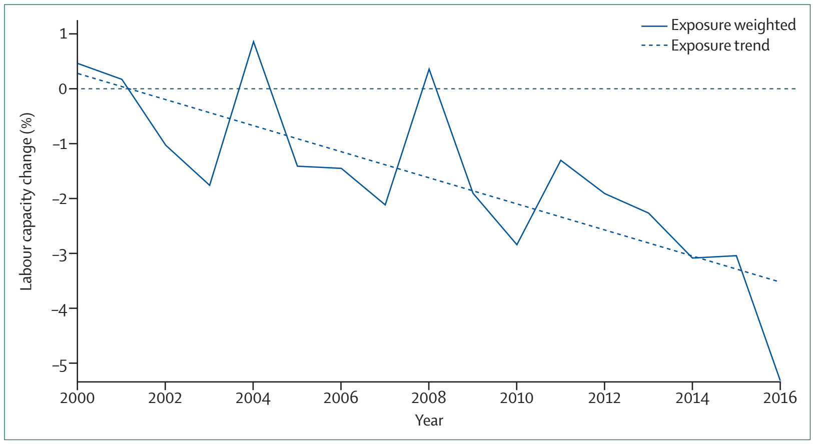

Figure 4: Labour capacity change worldwide, relative to the 1986–2008 average

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

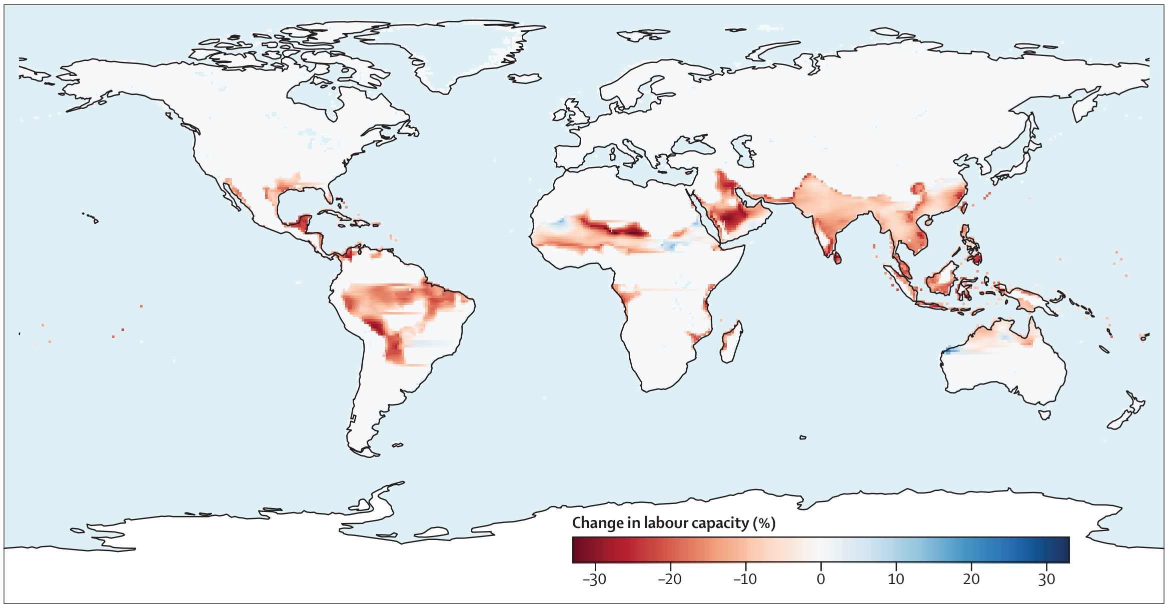

Figure 5: Change in labour capacity loss, relative to the 1986–2008 average

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.

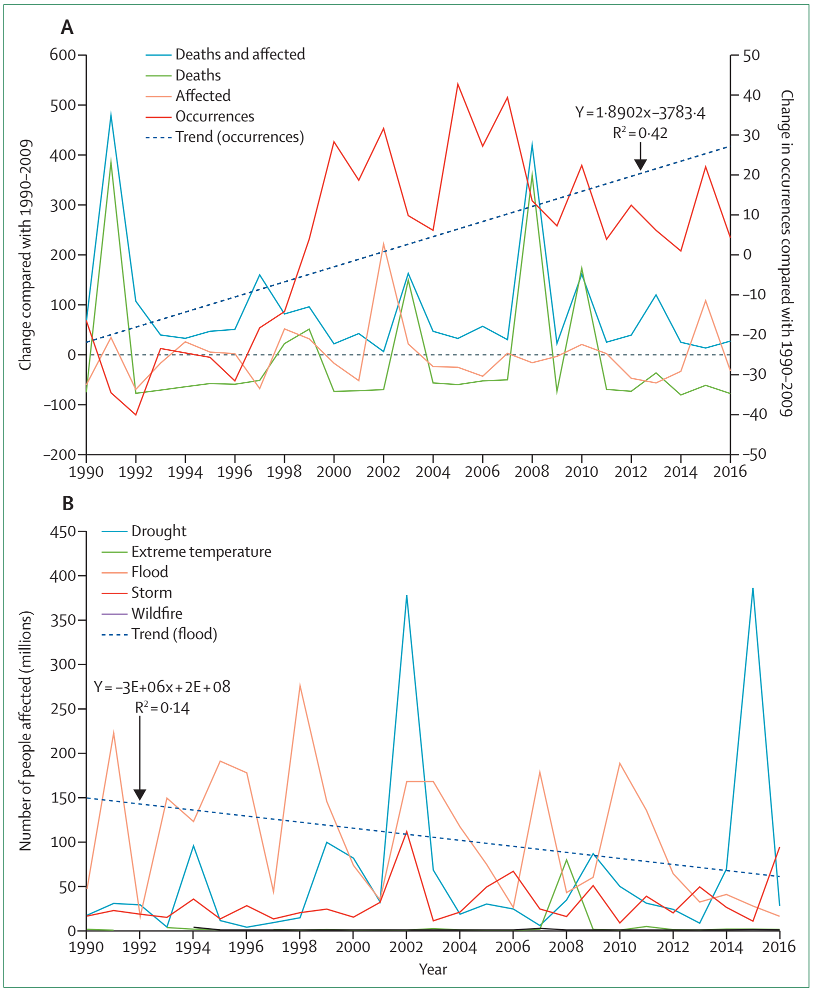

Figure 6: **Number of deaths and people affected by weather-related disasters**
(A) Number of deaths, number of affected people, and the ratio of these (measured against the 1990–2009 average), worldwide. (B) Number of people affected by different weather-related disasters worldwide.

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

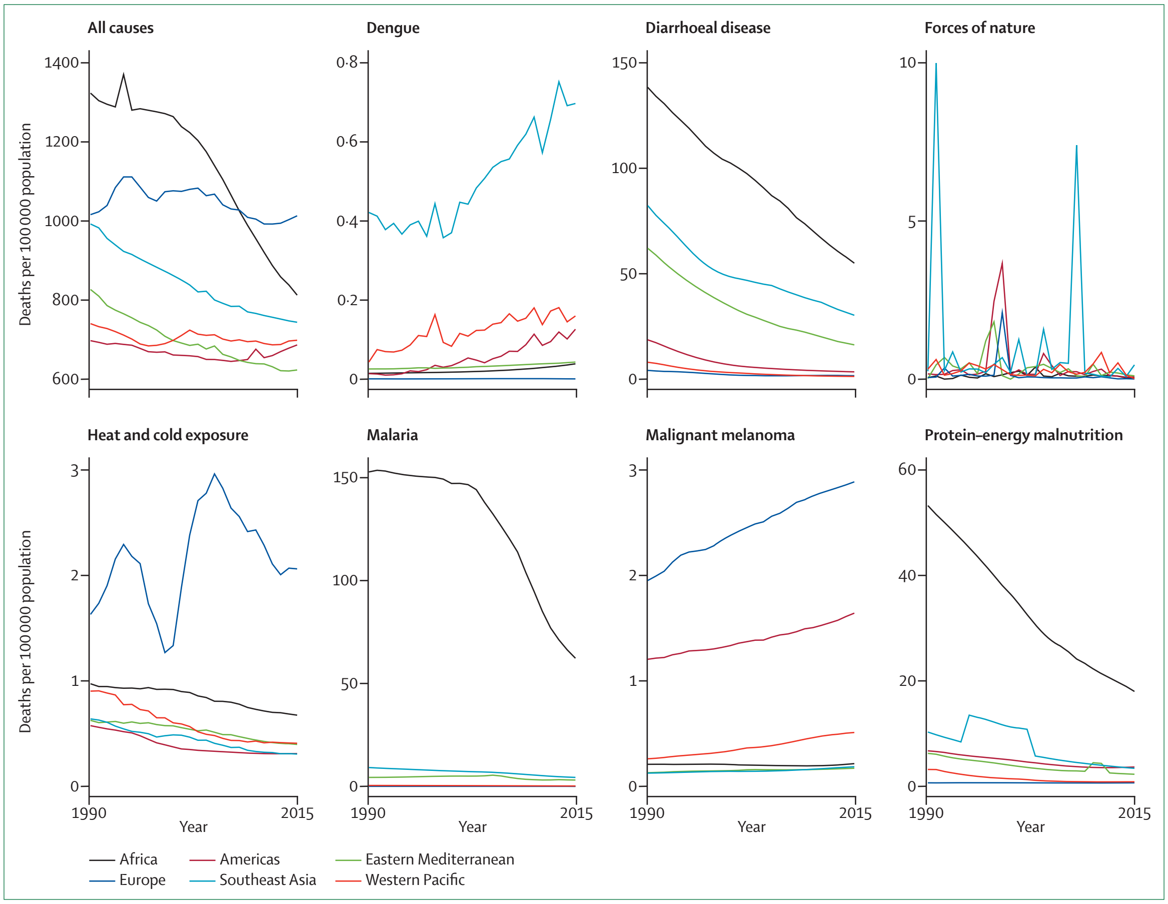

Figure 7: **Trends in mortality from selected causes of death, as estimated by the Global Burden of Disease Study 2015, by WHO region**

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 aegypti* 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]

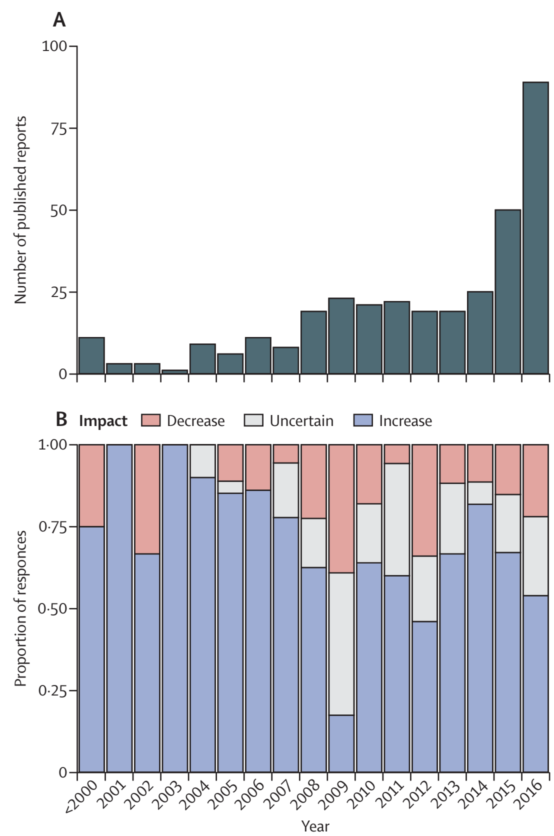

***Figure 8:* Systematic review of scientific literature about climate-sensitive infectious diseases**
(A) Number of academic reports about climate-sensitive infectious diseases, by year. (B) Proportion of responses reported in publications, by year and direction of impact.

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

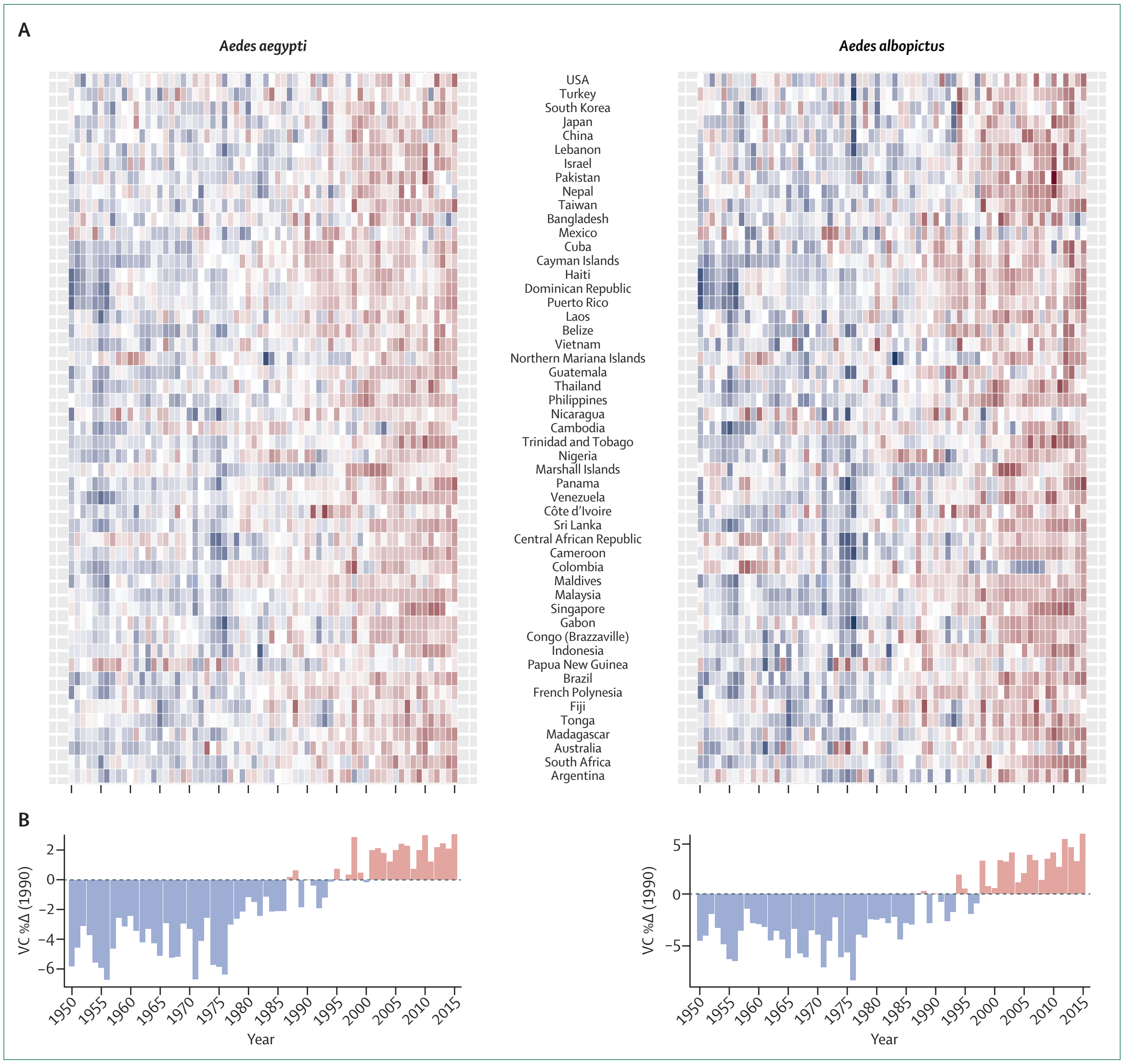

Figure 9: **Average annual vectorial capacity (VC) for dengue in *Aedes aegypti* and *Aedes albopictus* for selected *Aedes*-positive countries**
(A) Matrix coloured relative to country mean in 1950–2015; red indicates relatively higher VC, and blue indicates relatively lower VC. Countries are ordered 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,

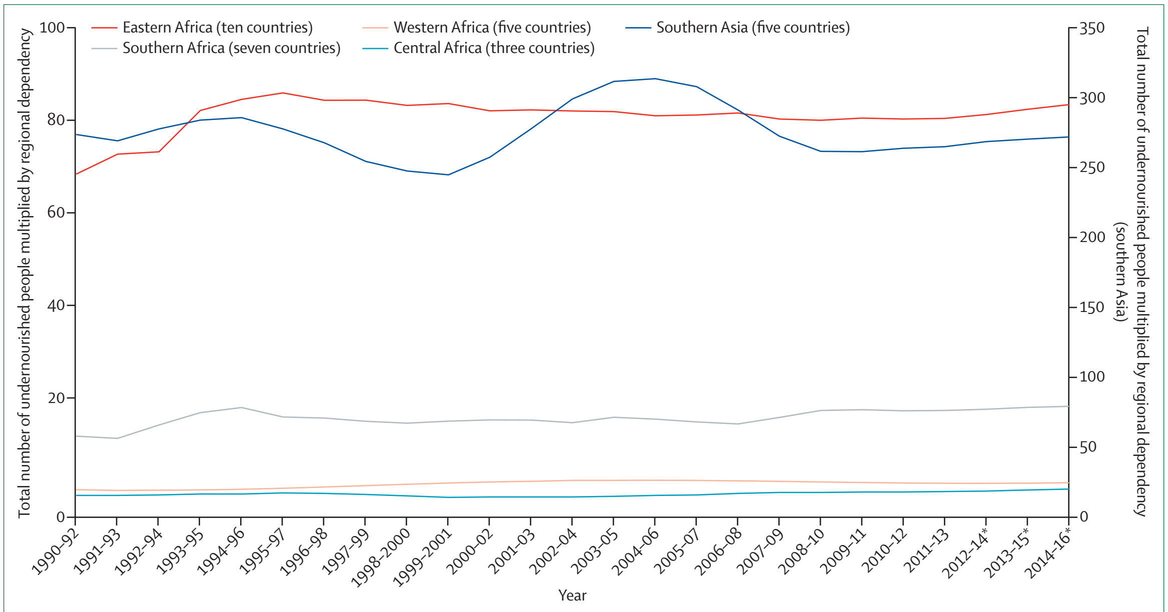

***Figure 10*:** **Total number of undernourished people multiplied by regional dependency on grain production for countries**

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

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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.

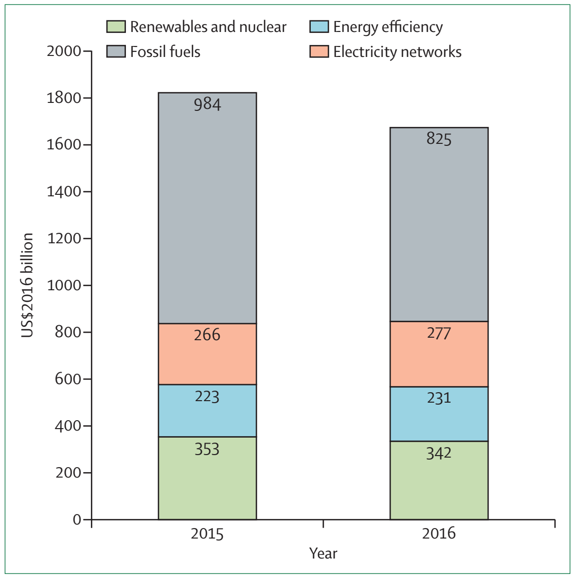

Figure 31: **Annual investment in the global energy system**

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

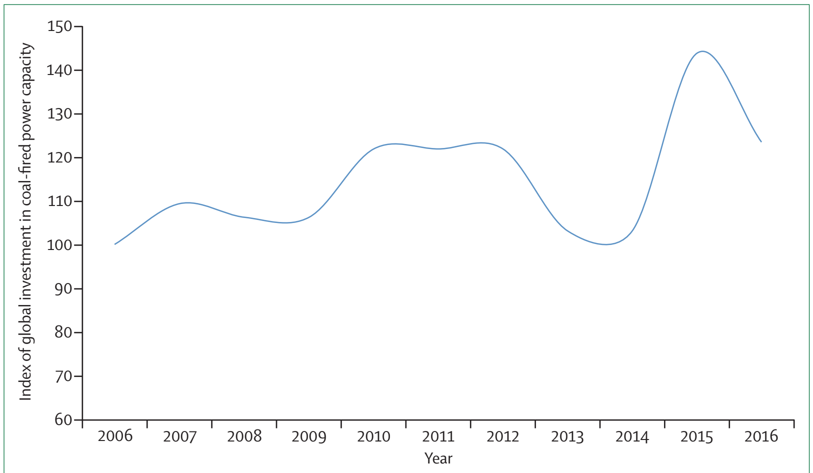

Figure 32: **Annual investment in coal-fired power capacity from 2006 to 2016**
An index score of 100 corresponds to 2006 levels. Source: International Energy Agency.

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

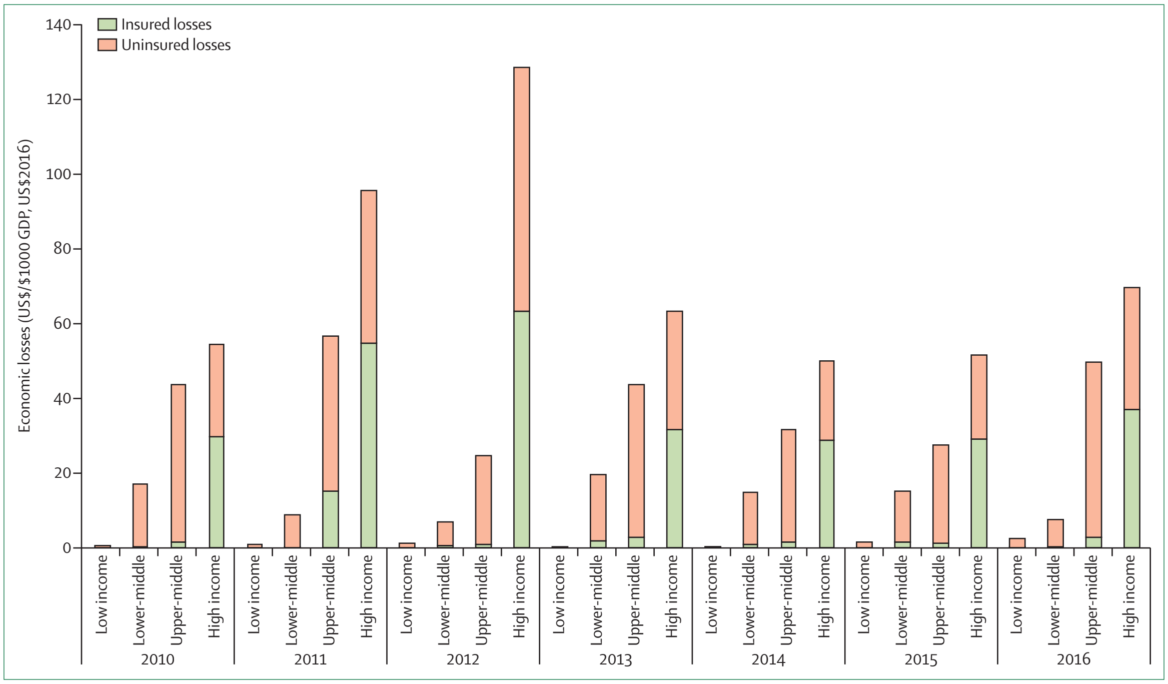

Figure 33: **Economic losses from climate-related events—absolute**
Insured and uninsured economic losses resulting from all large meteorological, climatological, and hydrological events across the world, by country income group. GDP=gross domestic product.

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

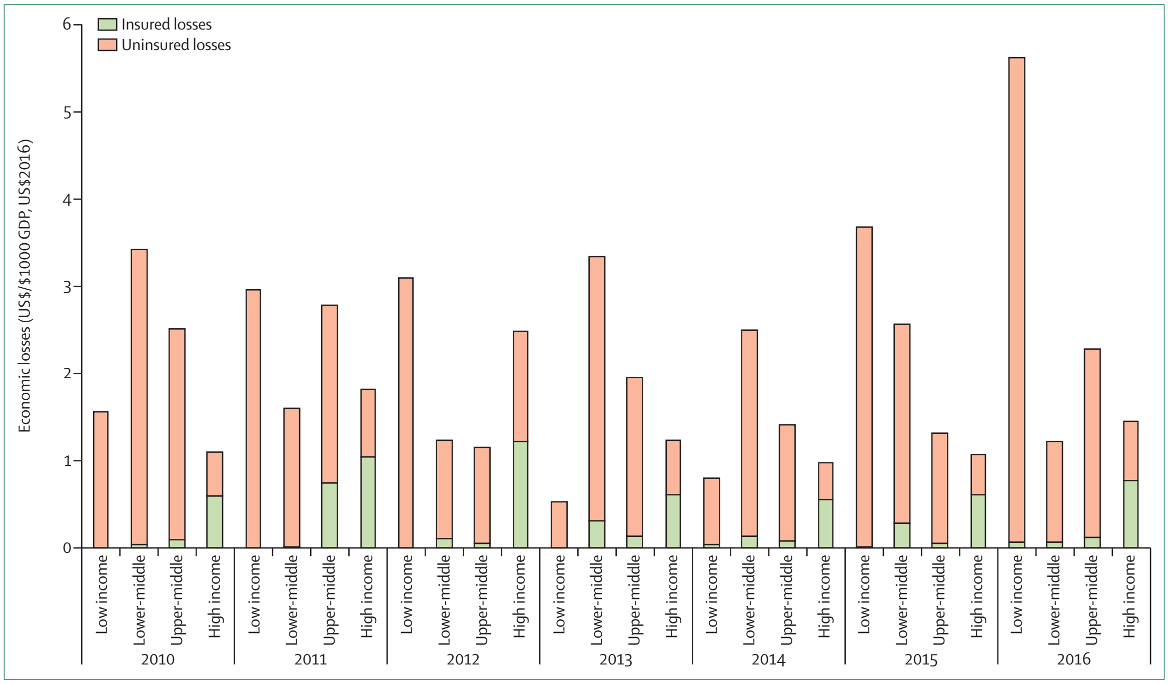

Figure 34: **Economic losses from climate-related events—intensity**
GDP=gross domestic product.

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

LANCET COUNTDOWN: TRACKING PROGRESS ON HEALTH AND CLIMATE CHANGE

ASSOCIATION MÉDICALE CANADIENNE · CANADIAN MEDICAL ASSOCIATION

CANADIAN PUBLIC HEALTH ASSOCIATION · ASSOCIATION CANADIENNE DE SANTÉ PUBLIQUE
The Voice of Public Health
La voix de la santé publique

Lancet Countdown 2018 Report:
Briefing for Canadian Policymakers

November 2018

This is Exhibit "T" referred to in the Affidavit of Paul Kershaw, sworn before me at North Vancouver this 18th day of December, 2018.

....

A Commissioner for taking Affidavits within British Columbia

Introduction

Climate change is the biggest global health threat of the 21st century,[1] and tackling it could be our greatest health opportunity.[2] In this era of strained ecological systems, is clear that our ability to optimize Planetary Health, defined as "the health of human civilization and the natural systems upon which it depends,"[3] will define wellness globally for generations to come.

This briefing, launched in parallel with the 2018 International *Lancet Countdown on Health and Climate Change*, focuses on the links between climate change and health, and their implications for Canadian policymakers. It has been developed in conjunction with the Canadian Medical Association and the Canadian Public Health Association, and draws on data provided by the *Lancet Countdown* to make evidence-informed recommendations.

Acknowledgements

The concept of this brief was developed by the *Lancet Countdown on Health and Climate Change*. This brief was written by Courtney Howard, MD; Caren Rose, PhD; and Nicholas Rivers, PhD. Scientific review was provided by Peter Berry, PhD and colleagues from Health Canada. Edits and review were provided by (alphabetical): Owen Adams, PhD; Sandra Allison, MD, MPH; Michael Brauer, ScD; Ian Culbert, Ashlee Cunsolo, PhD; Ian Hamilton, PhD; Trevor Hancock MB, BS, MHSc, HonFFPH; Katie Hayes, MA; Margot Parkes, MD, MBChB, MAS, PhD; Kim Perrotta, MSc; Andre Picard; Bora Plumptre, MSc; Robert Rattle, BSc; and Joe Vipond, MD. Contributions and review on behalf of the *Lancet Countdown* were provided by Dr Nick Watts.

Strategic Partners

THE LANCET

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About the Lancet Countdown

The *"Lancet Countdown: Tracking Progress on Health and Climate Change"* is a global, interdisciplinary research collaboration between 27 academic institutions and inter-governmental organizations. It monitors progress on the relationships between health and climate, and their implications for national governments, reporting annually. The 2018 report presents data on 41 indicators selected following a consultation process in 2017. These span 5 domains, from health impacts and adaptation, to mitigation and the economic and political drivers of response.[2]

About the Canadian Medical Association

The Canadian Medical Association (CMA) unites physicians on national health and medical matters. Formed in Quebec City in 1867, the CMA's rich history of advocacy led to some of Canada's most important health policy changes. As we look to the future, the CMA will focus on advocating for a healthy population and a vibrant profession.

About the Canadian Public Health Association

The Canadian Public Health Association (CPHA) is a national, independent, non-governmental organization that advances public health education, research, policy and practice in Canada and around the world through the *Canadian Journal of Public Health*, position statements, discussion documents and other resources.

Recommendations for 2018

Recommendation 1

Coordinate federal governmental departments, local governments and national institutions to standardize surveillance and reporting of heat-related illness and deaths; develop knowledge translation strategies to inform the public about the threat of heatwaves to health; and generate a clinical and public health response plan that minimizes the health impacts of heat now, and anticipates worsening impacts to come as climate change progresses.

Recommendation 2

Rapidly integrate climate change and health into the curriculum of all medical and health sciences faculties.

Recommendation 3

Increase ambition in reducing greenhouse gas emissions and air pollution in Canada and twin this with an emphasis on Just Transition Policies to support an equitable transition for people who work in the fossil fuel industry as the energy economy transforms.

Recommendation 4

Phase out coal-powered electricity in Canada by 2030 or sooner, with a minimum of two thirds of the power replaced by non-emitting sources, and any gap made up by lowest-emitting natural gas technology in a system designed to minimize fugitive methane emissions.

Recommendation 5

Apply carbon pricing instruments as soon and as broadly as possible, enhancing ambition gradually in a predictable manner, and integrate study of resulting air pollution-related health and healthcare impacts into ongoing policy decisions.

Recommendation 6

Ensure consistent, pro-active external communications by health-related organizations pointing out the links between climate change and health impacts in real time as events that have been shown to be increasing due to climate change (e.g. heat waves, spread of tick-borne disease, wildfires, extreme weather) occur.

Recommendation 7

Fund increased study into the mental health impacts of climate change and psychosocial adaptation opportunities.

Key Messages from the 2018 International Lancet Countdown Report

- Present day changes in labour capacity, vector-borne disease, and food security provide early warning of compounded and overwhelming impacts expected if temperature continues to rise. Trends in climate change impacts, exposures, and vulnerabilities demonstrate an unacceptably high level of risk for the current and future health of populations across the world.

- A lack of progress in reducing emissions and building adaptive capacity threatens both human lives and the viability of the national health systems they depend on, with the potential to disrupt core public health infrastructure and overwhelm health services.

- Despite these delays, trends in a number of sectors are breathing life in to the beginning of a low-carbon transition, and it is clear that the nature and scale of the response to climate change will be the determining factor in shaping the health of nations for centuries to come.

- Ensuring a widespread understanding of climate change as a central public health issue will be vital in delivering an accelerated response, with the health profession beginning to rise to this challenge.[2]

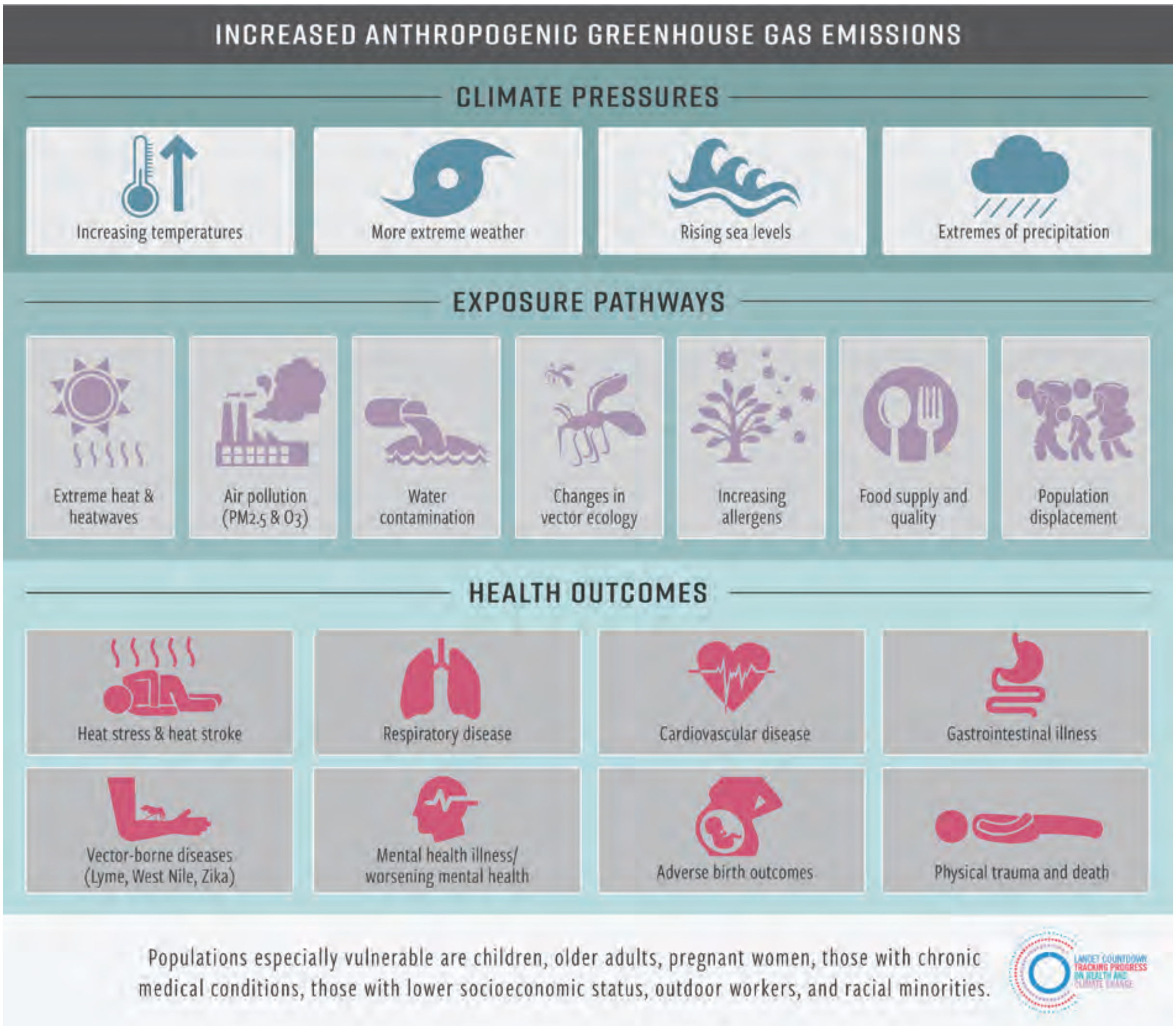

Figure 1: Health Impacts of Climate Change. Credit: M.Lee for the US *Lancet Countdown* Brief

Overview of the Health Impacts of Climate Change in Canada

Though Canada's well-developed healthcare and public health system provides advantages in terms of initial adaptation to climate change, as a circumpolar country it contains some of the most rapidly-warming areas in the world: observed temperatures in Inuvik, Northwest Territories have increased by 3°C in the past 50 years.[4]

Rapid change in the Arctic is already increasing health risks from food insecurity due to decreased access to traditional foods,[5, 6] decreased safety of ice-based travel, and mental health impacts from changed landscapes.[7,8]

Health concerns in the rest of Canada vary by region, but include increased heat stroke and death;[6,9] more intense and prolonged pollen seasons with the potential to cause additional hay fever and asthma exacerbations;[6] trauma, post-traumatic stress disorder and displacement from wildfire and floods;[10-12] spread of Lyme disease;[13,14] cardiorespiratory impacts from worsening air pollution due to wildfires,[15] and increased ground-level ozone.[6]

Milder winters and increased precipitation in parts of the country could potentially improve agricultural yields, and thus reduce food insecurity, but this is balanced by the possibility of crop-damaging severe weather and drought in other areas.[16] There is an increased risk of water-borne disease following changed precipitation patterns, and of greater exposure to higher levels of ultraviolet radiation.[6] The potential for 'tipping cascades' makes the risk of rapid and dramatic climate change impacts more difficult to predict and more likely.[17]

Heat-Related Health Impacts

Indicator 1.2 Health Effects of Temperature Change

The health impacts of warmer summers were vividly demonstrated in 2018, with more than 90 people suspected to have died as a direct result of a heat wave in Quebec in July.[18] Health-related impacts of heat include including heat rash, heat edema,[19] heat stress, heat stroke, cardiovascular disease and renal disease.[2] Preliminary evidence has also linked heat with increased suicide risk.[20] Impacts are most common in vulnerable populations such as adults over 65 years, the homeless,[21] urban dwellers and people with pre-existing disease.[2]

Humans around the globe are having to cope with hotter temperatures. The international *Lancet Countdown* report found that in 2017 the mean global summer temperature increase relative to the 1986-2008 reference period was 0.3°C, with the change experienced by humans (i.e., population-exposure-weighted) more than double that, at 0.8°C. This discrepancy results largely from the fact that populations are migrating in to the areas worst affected by climate change.

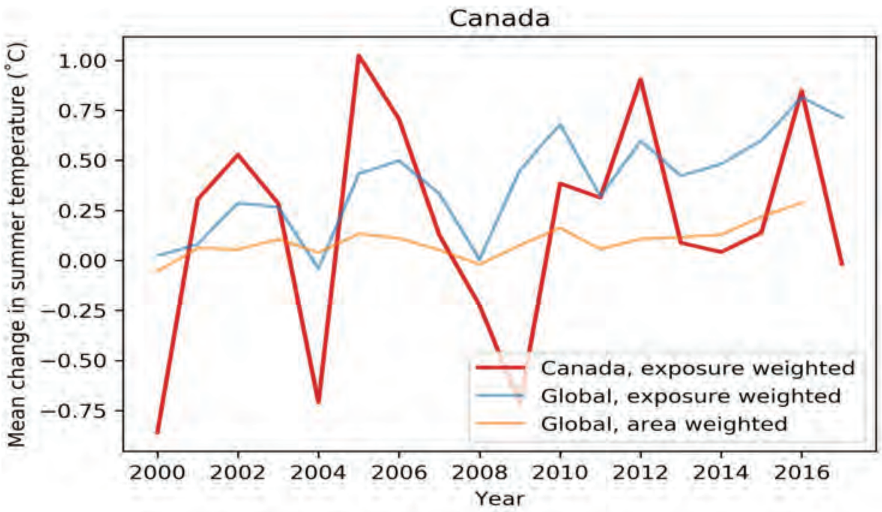

Figure 2: Mean area and population-exposure-weighted summer temperature change in Canada and globally from 2000 to 2017.

As a northern country that must also manage mortality due to cold temperatures,[22,23] health authorities in Canada are now increasing their response to the health risks of extreme heat.[24] Lives can be saved by having integrated surveillance and monitoring systems to gather data on heat-related illness and death, and integrating this into a pro-active public health response.[25] Elements of this include forecasting heat events and ensuring cooperation between public health, emergency management officials and community-members to issue alerts and ensure that vulnerable people such as the elderly have adequate access to water and cool-air shelters.[26] Longer term strategies include creating urban areas rich in green space that minimize the urban heat island effect, and buildings designed with natural ventilation in mind in order to reduce the need for air conditioning,[26] which can lead to increased energy use, and health-harming air pollution.[27]

A well-trained workforce is required to respond to these challenges. The Canadian Public Health Association's Ecological Determinants Group on Education has been working to integrate an eco-social approach into public health education,[28] including facilitating the participation of the Canadian Federation of Medical Students in an International Federation of Medical Students' Associations initiative which seeks to see climate change and health gain a foothold in curricula by 2020 with fuller integration by 2025.[29]

Recommendation 1

Coordinate federal governmental departments, local governments and national institutions to standardize surveillance and reporting of heat-related illness and deaths; develop knowledge translation strategies to inform the public about the threats of heatwaves to health; and generate a clinical and public health response plan that minimizes the health impacts of heat now and anticipates worsening impacts to come as climate change progresses.

Recommendation 2

Rapidly integrate climate change and health into the curriculum of all medical and health sciences faculties.

Health Costs of Energy and Air Pollution

Towards a healthier, low-carbon world.

Canada is not doing its fair share to reduce greenhouse gas (GHG) emissions. In 2016, Canadian emissions were 704 MT CO_2eq, an actual *increase* of over one hundred megatonnes since 1990.[30] In contrast, the United Kingdom reduced its greenhouse gas emissions 41% between 1990 and 2016,[31] and China is hitting its greenhouse gas targets ahead of schedule.[32] The 2017 Canadian Federal Auditor General's report estimated that emissions in 2020 are projected to be 111 MT CO_2eq above Canada's 2020 target of 620 MT CO_2eq.[33] In 2016, the Canadian transportation sector accounted for 25% of total national emissions, while the oil and gas sector accounted for 26% of total national emissions, having gone up 70% from 107 Mt CO_2eq in 1990 to 183 Mt CO_2eq in 2016, an increase that is mostly attributable to higher levels of production of crude oil and the expansion of the oil sands industry.[30]

Business-as-usual emissions trajectories currently have the world on course to 2.6-4.8°C of warming by 2100.[34] As the 2018 *Lancet Countdown* states, "present day changes in labour capacity, vector-borne disease, and food security provide early warning of compounded and overwhelming impacts expected if temperature continues to rise. Trends in climate change impacts, exposures, and vulnerabilities demonstrate an unacceptably high level of risk for the current and future health of populations across the world."[2]

In an effort to alter course, in December 2015, 195 countries, including Canada, signed the Paris Agreement, which pledges to keep the global mean temperature rise to well below 2°C. A recent report by the Intergovernmental Panel on Climate Change underlines the health benefits of keeping warming to 1.5°C,[13] but makes clear the magnitude of that challenge, stating, "global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate."[35] It finds that in order to stay below 1.5°C, "global net human-caused emissions of carbon dioxide (CO_2) would need to fall by about 45 percent from 2010 levels by 2030, reaching 'net zero' around 2050."[35]

There are signs of progress: the 2018 *Lancet Countdown* reports that in 2017 there were 157 Gigawatts (GW) of new installed renewable energy, as compared to 70 GW of fossil fuel capacity; a 50% increase in the uptake of electric vehicles across the global rolling stock; and a cumulative total of $33.6 billion USD now divested of fossil fuels by health institutions.[2]

Many policies that reduce greenhouse gas emissions also decrease air pollution, resulting in immediate benefits to health and healthcare cost savings, as described in the next section.

Indicator 3.5.2 Premature Mortality from Air Pollution by Sector

Headline Finding: Data for Canada provided by the *Lancet Countdown* shows a total of 7142 deaths from chronic exposure to anthropogenic $PM_{2.5}$ air pollution in 2015, (Figure 3) resulting in a loss in economic welfare for Canadians valued at approximately $53.5 billion.[36]

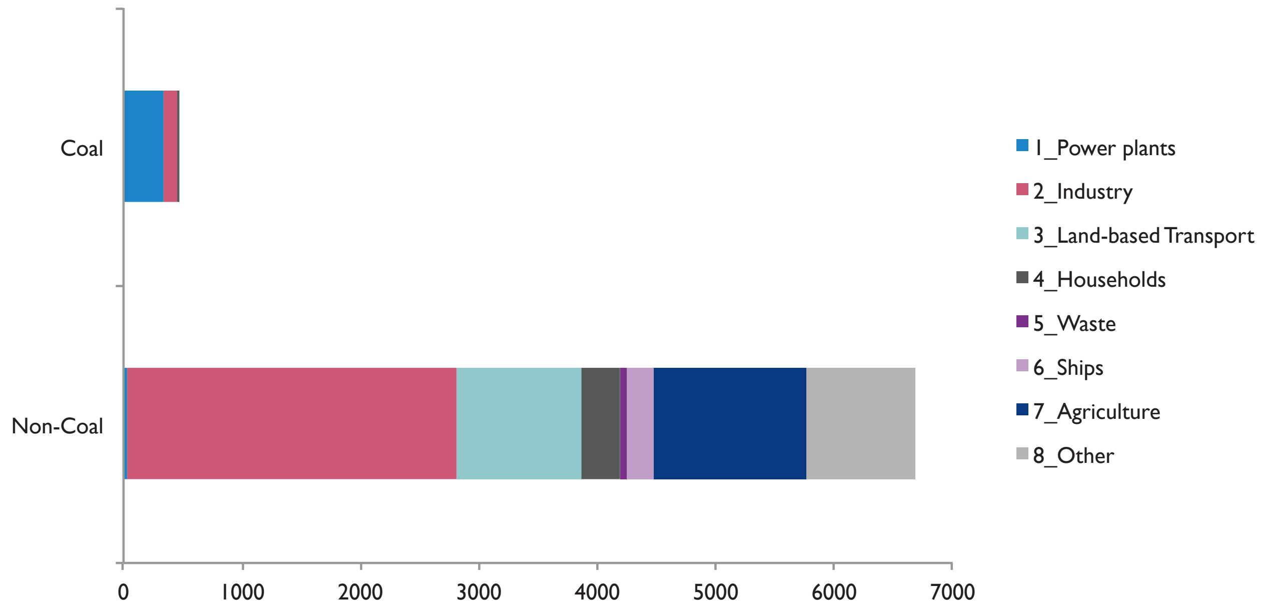

Figure 3: Annual Premature Deaths from Ambient $PM_{2.5}$ in Canada

The 2018 International *Lancet Countdown* report found that fine particulate ambient air pollution ($PM_{2.5}$) resulted in more than 2.9 million deaths globally in 2015, with coal responsible for about 16% of this.[2] These numbers are based on chronic exposure and include deaths from ischemic heart disease, stroke, lung cancer, acute lower respiratory infections and COPD.

Health Canada estimated in 2017 that 9,500 deaths per year in Canada are attributable to above-background concentrations of $PM_{2.5}$.[37] A 2016 report by the World Bank showed 9,466 deaths in Canada in 2013 due to $PM_{2.5}$ with direct welfare costs of US$40.4 billion (2011 prices).[38] This analysis by the *Lancet Countdown* showed 7142 deaths including 345 deaths from coal-fired power plants; another 105 from coal-related industries; 2,762 deaths from non-coal industry; 1063 from Land-based Transport; and 1282 from Agriculture.[2] Using official Health Canada methodologies, this translates into a loss in economic welfare for Canadians valued at approximately $53.5 billion.[36]

In addition to its air-pollution-mediated mortality impacts, in 2016 the Canadian transportation sector accounted for 25% of national GHG emissions.[30] The 2017 *Lancet Countdown* Briefing for Canadian Policymakers showed that Canada has quite a low proportion of trips taken via means of sustainable transport including by transit, bike or on foot,[39] and recommended the development of a National Active Transport Strategy.[39] Multiple health benefits would stem from this: exercise reduces anxiety[40] and depression;[41] commuting on foot or by bike has been shown to decrease cardiovascular mortality, and cycling decreases all-cause mortality and mortality from cancer.[42]

To reduce coal-related morbidity, mortality, and greenhouse gas emissions, the Government of Canada has committed to an accelerated phase out of unabated coal-fired power by 2030.[43]
As per the Regulatory Impact Analysis Statement of the proposed amendment to existing legislation on GHGs from coal-fired generation, the expected resulting reduction in cumulative GHG emissions is approximately 100Mt,[44] with $3.6 billion in avoided climate change damage benefits, and $1.3 billion in health and environmental benefits from air quality improvement.[44] The Pembina Institute previously

estimated health benefits of $5 billion in a scenario where coal-fired plants are shut down after 40 years of operation or by 2030, and which assumes the replacement of coal power by two thirds renewables and one third best-in-class gas-power.[45]

A transition which proceeds as much as possible directly from coal-fired to renewably-generated electricity is required. Methane, the primary component of natural gas, has 84 times the GHG potential of CO_2 over a twenty year period,[46] and the upstream extraction and transport system is leaky,[47-49] leading to near-term warming risks. Additionally, an increasing proportion of natural gas in Canada is being produced via hydraulic fracturing,[50] for which evidence is accumulating of negative impacts: a quantitative assessment of the peer-reviewed scientific evidence from 2009-2015 indicated that 84% of studies on public health, 69% of studies on water and 87% of studies on air quality showed concerning findings.[51]

Encouragingly, Canada's coal phase-out commitments enabled the Canadian Government to join forces with the United Kingdom at COP23 to launch the Powering Past Coal Alliance, which now has at least 60 national, provincial, state, city, business and organizational members.[52] In Canada, a Just Transition Task Force has been created to support coal workers as they move towards new employment.[53] This important initiative would do well to expand to support the social determinants of health of fossil-fuel-industry workers across Canada as the nation transforms its energy economy.

Recommendation 3

Increase ambition in reducing greenhouse gas emissions and air pollution in Canada and twin this with an emphasis on Just Transition Policies to support an equitable transition for people who work in the fossil fuel industry as the energy economy transforms.

Recommendation 4

Phase out coal-powered electricity in Canada by 2030 or sooner, with a minimum of two thirds of the power replaced by non-emitting sources, and any gap made up by lowest-emitting natural gas technology in a system designed to minimize fugitive methane emissions.

Financial and Economic Drivers of a Low-Carbon Transition

Indicator 4.7 Coverage and Strength of Carbon Pricing

This section co-authored by Nicholas Rivers, Canada Research Chair in Climate and Energy Policy.

Headline Finding: When the Chinese National Emissions Trading Scheme comes online this year, approximately 20% of global anthropogenic GHG emissions will be subject to a carbon price.[2]

The 2015 Lancet Commission on Climate Change and Health stated, "The single most powerful strategic instrument to inoculate human health against the risks of climate change would be for governments to introduce strong and sustained carbon pricing, in ways pledged to strengthen over time until the problem is brought under control. Like tobacco taxation, it would send powerful signals throughout the system, to producers and users, that the time has come to wean our economies off fossil fuels, starting with the most carbon intensive and damaging like coal."[54] On the basis of this argument, the Canadian Medical Association passed a motion at its General Council in 2015 to "promote the health benefits of a strong, predictable price on carbon emissions."[55]

News of increasing carbon pricing coverage internationally comes at a critical juncture for Canada. Carbon prices currently apply to 75% of greenhouse gas emissions in British Columbia, 72% in Alberta, 84% in Ontario, and 81% in Quebec, such that in total 61% of emissions in Canada are subject to a carbon price (42% after Ontario's proposed cap-and-trade elimination).[56]

The federal carbon pricing backstop is due to come into effect in 2019. It will start at a minimum of $10 per tonne in 2018, and rise by $10 per year to $50 per tonne in 2022.[57] Successful application of the federal carbon pricing backstop in 2019 will result in coverage of 79% of total Canadian emissions by a carbon price.[56] The current plan will be revenue-neutral at the federal level, with all proceeds staying in the province in which they were collected.[58] About 70% of Canadians will receive as much or more back in rebates as what they paid.[58]

A review of studies of BC's carbon tax showed that it has reduced emissions in the province by 5-15% compared to what they would have been without the tax, and that the tax has had negligible effects on aggregate economic performance.[59] Similar reductions in emissions in response to carbon prices have been found in other jurisdictions.[60,61]

A neglected part of the public conversation is the impact carbon pricing could have on human health, via decreases in the air-pollution-related deaths detailed in section 3.5.2. A study in the US found that "monetized human health benefits associated with air quality improvements can offset 26-1050% of the cost of US carbon policies."[62] Similarly, a recent study from China which simulated the impact of a price on CO_2 emissions consistent with China's pledge to reach a peak in CO_2 emissions by 2030, found that "national health co-benefits from improved air quality would partially or fully offset policy costs depending on chosen health valuation."[63] There is a critical need to carry out similar studies in the Canadian context.

Recommendation 5

Apply carbon pricing instruments as soon and as broadly as possible, enhancing ambition gradually in a predictable manner, and integrate study of resulting air pollution-related health and healthcare impacts into ongoing policy decisions.

Indicator 5.1 Media Coverage of Health and Climate Change

Headline Finding: Against a backdrop of a 42% global increase in media coverage between 2007 and 2017, the average aggregate number of articles per year referencing both climate change and health in 3 Canadian Newspapers (The Globe and Mail, The Toronto Star, and The National Post) dropped 24% from 98 in 2009 to 75 in 2017. (Data courtesy of the *Lancet Countdown*)

Media coverage is critical for helping populations become aware of the risks of climate change, and in influencing public support for national policy change.[64] Research shows that presenting climate change in a health frame, as opposed to as an environmental or security issue, is the best way to elicit emotional reactions consistent with support for climate change mitigation and adaptation,[65] and that more strongly positive reactions are associated with information about the health benefits of mitigation policy (e.g. the number of asthma exacerbations that will be saved as a result of the phase-out of a coal-fired power plant) than with information about health risks.[66]

A 2017 poll commissioned by Health Canada demonstrates quite a high level of public concern related to climate change: 79% of Canadians are convinced that climate change is happening, and of these, 53% accept that it is a current health risk, and 40% believe it will be a health risk in the future.[67]

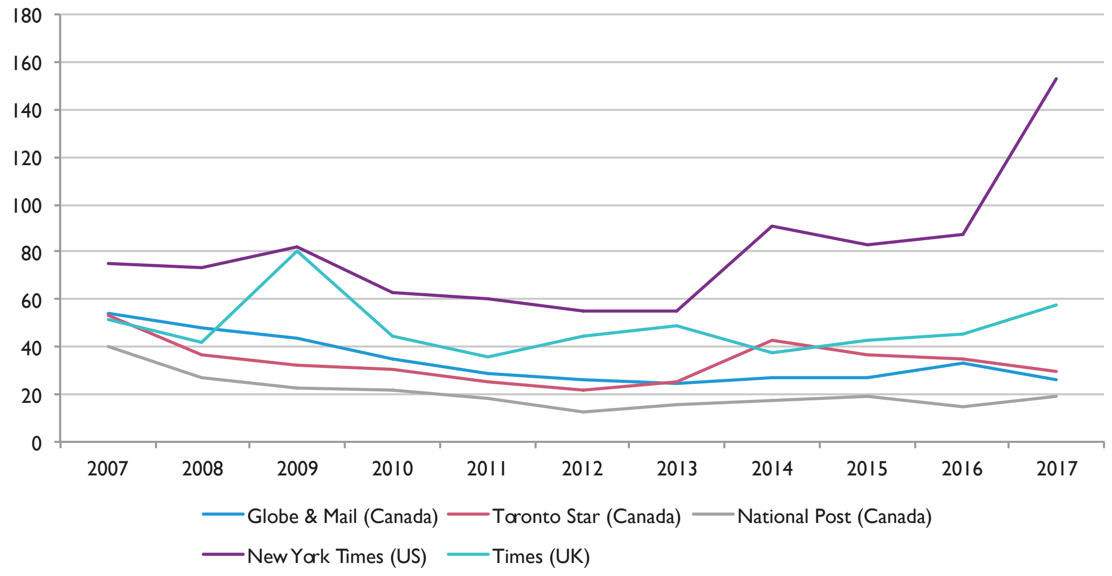

Figure 4: Number of articles in specific newspapers covering Climate Change and Health. Data provided by the *Lancet Countdown*.[2]

The three Canadian newspapers in the dataset, *The Globe and Mail, The Toronto Star,* and *The National Post*, each saw a drop in climate change and health coverage, with the average number of articles per year in Canada decreasing 24% from 98 in 2009 to 75 in 2017. In contrast, over the same period, the New York Times saw an increase of 86%. (Figure 4)

Recommendation 6

Ensure consistent, pro-active external communications by health-related organizations pointing out the links between climate change and health impacts in real time as events which have been shown to be increasing due to climate change (e.g. heat waves, spread of tick-borne disease, wildfires, extreme weather) occur.

Case Study: Canadian Contributions to Understanding of Climate Change, Mental Health and Ecological Grief

Climate-related weather events and environmental change have been linked to elevated rates of depression, anxiety, and pre-and-post-traumatic stress; increased drug and alcohol usage; and increased suicidal ideation, suicide attempts and death by suicide.[68] As a result, mental health considerations are likely to be increasingly included in climate vulnerability and impact assessments.[69] Research in Canada has particularly contributed to the evolution of concepts such as "solastalgia," explained as 'feeling homesick when you're still at home,' ecological grief and eco-anxiety.[68]

Canada's Arctic is one of the most rapidly-warming areas on earth, and has been inhabited for millennia by Indigenous communities whose close connection to and knowledge of the land make them sensitive observers of ecological change. A multi-year, community-driven enquiry into the mental health impacts of environmental change in the community of Rigolet, Nunatsiavut, demonstrated that climate change is "negatively affecting feelings of place attachment by disrupting hunting, fishing, foraging, trapping, and traveling, and changing local landscapes--changes which subsequently impact physical, mental, and emotional health and well-being." These results called for an understanding of place-based attachment as a vital indicator of health and well-being.[7]

Southwest of Rigolet, in the high subarctic area surrounding the Northwest Territories' capital of Yellowknife, the "SOS-Summer of Smoke" project investigated the health and wellness impacts of a prolonged smoke and fire exposure in 2014.[11] It found double the normal rates of emergency department visits for asthma, and interview analysis revealed strong themes of isolation, fear, loss of connection to the land and to traditional summertime activities; lack of physical activity; and a feeling of ecological grief or eco-anxiety, as participants placed the summer in the overall context of the changing climate and wondered if such summers would become the "new normal."[11]

A recent paper in Nature Climate Change defined ecological grief as, "the grief felt in relation to experienced or anticipated ecological losses.[68] It points out that, "grief is a natural and legitimate response to ecological loss, and one that may become more common as climate impacts worsen."[68]

Both the SOS study and the paper on ecological grief were published in spring 2018, just prior to one of western Canada's most severe wildfire seasons on record. As millions of Canadians sat blanketed in smoke, media interest in the concepts of solastalgia and ecological grief was unprecedented,[12,70] opening up new discussions that, at the very least, decrease people's feelings of loneliness in their grief. Grief and mourning has "we-creating" capacities, allowing for opportunities to reach across differences to connect with others.[68] Though difficult, these conversations may well create new possibilities in the pursuit of a healthy approach to climate change.

Recommendation 7

Fund increased study into the mental health impacts of climate change and psychosocial adaptation opportunities.

IN THE MATTER OF A REFERENCE to the Court of Appeal pursuant to section 8 of the *Courts of Justice Act*, RSO 1990, c. C.34, by Order-in-Council 1014/2018 respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018, No. 1,* SC 2018, c. 12

Court of Appeal File No.: C65807

COURT OF APPEAL FOR ONTARIO
Proceedings commenced at Toronto

RECORD OF THE INTERVENOR, INTERGENERATIONAL CLIMATE COALITION (GENERATION SQUEEZE ET AL)

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