McKinsey
Global Institute

Executive summary

Climate risk and response

Physical hazards and socioeconomic impacts

January 2020

McKinsey Global Institute

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MGI research combines the disciplines of economics and management, employing the analytical tools of economics with the insights of business leaders. Our "micro-to-macro" methodology examines microeconomic industry trends to better understand the broad macroeconomic forces affecting business strategy and public policy. MGI's in-depth reports have covered more than 20 countries and 30 industries. Current research focuses on six themes: productivity and growth, natural resources, labor markets, the evolution of global financial markets, the economic impact of technology and innovation, and urbanization. Recent reports have assessed the digital economy, the impact of AI and automation on employment, income inequality, the productivity puzzle, the economic benefits of tackling gender inequality, a new era of global competition, Chinese innovation, and digital and financial globalization.

MGI is led by three McKinsey & Company senior partners: James Manyika, Sven Smit, and Jonathan Woetzel. James and Sven also serve as co-chairs of MGI. Michael Chui, Susan Lund, Anu Madgavkar, Jan Mischke, Sree Ramaswamy, Jaana Remes, Jeongmin Seong, and Tilman Tacke are MGI partners, and Mekala Krishnan is an MGI senior fellow.

Project teams are led by the MGI partners and a group of senior fellows and include consultants from McKinsey offices around the world. These teams draw on McKinsey's global network of partners and industry and management experts. The MGI Council is made up of leaders from McKinsey offices around the world and the firm's sector practices and includes Michael Birshan, Andrés Cadena, Sandrine Devillard, André Dua, Kweilin Ellingrud, Tarek Elmasry, Katy George, Rajat Gupta, Eric Hazan, Acha Leke, Gary Pinkus, Oliver Tonby, and Eckart Windhagen. The Council members help shape the research agenda, lead high-impact research and share the findings with decision makers around the world. In addition, leading economists, including Nobel laureates, advise MGI research.

The partners of McKinsey fund MGI's research; it is not commissioned by any business, government, or other institution. For further information about MGI and to download reports for free, please visit www.mckinsey.com/mgi.

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Preface

McKinsey has long focused on issues of environmental sustainability, dating to client studies in the early 1970s. We developed our global greenhouse gas abatement cost curve in 2007, updated it in 2009, and have since conducted national abatement studies in countries including Brazil, China, Germany, India, Russia, Sweden, the United Kingdom, and the United States. Recent publications include *Shaping climate-resilient development: A framework for decision-making* (jointly released with the Economics of Climate Adaptation Working Group in 2009), *Towards the Circular Economy* (joint publication with Ellen MacArthur Foundation in 2013), *An integrated perspective on the future of mobility* (2016), and *Decarbonization of industrial sectors: The next frontier* (2018). The McKinsey Global Institute has likewise published reports on sustainability topics including *Resource revolution: Meeting the world's energy, materials, food, and water needs* (2011) and *Beyond the supercycle: How technology is reshaping resources* (2017).

In this report, we look at the physical effects of our changing climate. We explore risks today and over the next three decades and examine cases to understand the mechanisms through which physical climate change leads to increased socioeconomic risk. We also estimate the probabilities and magnitude of potential impacts. Our aim is to help inform decision makers around the world so that they can better assess, adapt to, and mitigate the physical risks of climate change.

This report is the product of a yearlong, cross-disciplinary research effort at McKinsey & Company, led by MGI together with McKinsey's Sustainability Practice and McKinsey's Risk Practice. The research was led by Jonathan Woetzel, an MGI director based in Shanghai, and Mekala Krishnan, an MGI senior fellow in Boston, together with McKinsey senior partners Dickon Pinner in San Francisco and Hamid Samandari in New York, partner Hauke Engel in Frankfurt, and associate partner Brodie Boland in Washington, DC. The project team was led by Tilman Melzer, Andrey Mironenko, and Claudia Kampel and consisted of Vassily Carantino, Peter Cooper, Peter De Ford, Jessica Dharmasiri, Jakob Graabak, Ulrike Grassinger, Sebastian Kahlert, Dhiraj Kumar, Hannah Murdoch, Karin Östgren, Jemima Peppel, Pauline Pfuderer, Carter Powis, Byron Ruby, Sarah Sargent, Erik Schilling, Anna Stanley, Marlies Vasmel, and Johanna von der Leyen. Brian Cooperman, Eduardo Doryan, Jose Maria Quiros, Vivien Singer, and Sulay Solis provided modeling, analytics, and data support. Michael Birshan, Jacques Bughin, David Fine, Lutz Goedde, Cindy Levy, James Manyika, Scott Nyquist, Vivek Pandit, Daniel Pacthod, Matt Rogers, and Thomas Vahlenkamp provided critical input and considerable expertise.

While McKinsey employs many scientists, including climate scientists, we are not a climate research institution. Woods Hole Research Center (WHRC) produced the scientific analyses of physical climate hazards in this report. WHRC has been focused on climate science research since 1985; its scientists are widely published in major scientific journals, testify to lawmakers around the world, and are regularly sourced in major media outlets. Methodological design and results were independently reviewed by senior scientists at the University of Oxford's Environmental Change Institute to ensure impartiality and test the scientific foundation for the new analyses in this report. Final design choices and interpretation of climate hazard results were made by WHRC. In addition, WHRC scientists produced maps and data visualization for the report.

We would like to thank our academic advisers, who challenged our thinking and added new insights: Dr. Richard N. Cooper, Maurits C. Boas Professor of International Economics at Harvard University; Dr. Cameron Hepburn, director of the Economics of Sustainability

Programme and professor of environmental economics at the Smith School of Enterprise and the Environment at Oxford University; and Hans-Helmut Kotz, Program Director, SAFE Policy Center, Goethe University Frankfurt, and Resident Fellow, Center for European Studies at Harvard University.

We would like to thank our advisory council for sharing their profound knowledge and helping to shape this report: Fu Chengyu, former chairman of Sinopec; John Haley, CEO of Willis Towers Watson; Xue Lan, former dean of the School of Public Policy at Tsinghua University; Xu Lin, US China Green Energy Fund; and Tracy Wolstencroft, president and chief executive officer of the National Geographic Society. We would also like to thank the Bank of England for discussions and in particular, Sarah Breeden, executive sponsor of the Bank of England's climate risk work, for taking the time to provide feedback on this report as well as Laurence Fink, chief executive officer of BlackRock, and Brian Deese, global head of sustainable investing at BlackRock, for their valuable feedback.

Our climate risk working group helped develop and guide our research over the year and we would like to especially thank: Murray Birt, senior ESG strategist at DWS; Dr. Andrea Castanho, Woods Hole Research Center; Dr. Michael T. Coe, director of the Tropics Program at Woods Hole Research Center; Rowan Douglas, head of the capital science and policy practice at Willis Towers Watson; Dr. Philip B. Duffy, president and executive director of Woods Hole Research Center; Jonathon Gascoigne, director, risk analytics at Willis Towers Watson; Dr. Spencer Glendon, senior fellow at Woods Hole Research Center; Prasad Gunturi, executive vice president at Willis Re; Jeremy Oppenheim, senior managing partner at SYSTEMIQ; Carlos Sanchez, director, climate resilient finance at Willis Towers Watson; Dr. Christopher R. Schwalm, associate scientist and risk program director at Woods Hole Research Center; Rich Sorkin, CEO at Jupiter Intelligence; and Dr. Zachary Zobel, project scientist at Woods Hole Research Center.

A number of organizations and individuals generously contributed their time, data, and expertise. Organizations include AECOM, Arup, Asian Development Bank, Bristol City Council, CIMMYT (International Maize and Wheat Improvement Center), First Street Foundation, International Food Policy Research Institute, Jupiter Intelligence, KatRisk, SYSTEMIQ, Vietnam National University Ho Chi Minh City, Vrije Universiteit Amsterdam, Willis Towers Watson, and World Resources Institute. Individuals who guided us include Dr. Marco Albani of the World Economic Forum; Charles Andrews, senior climate expert at the Asian Development Bank; Dr. Channing Arndt, director of the environment and production technology division at IFPRI; James Bainbridge, head of facility engineering and management at BBraun; Haydn Belfield, academic project manager at the Centre for the Study of Existential Risk at Cambridge University; Carter Brandon, senior fellow, Global Commission on Adaptation at the World Resources Institute; Dr. Daniel Burillo, utilities engineer at California Energy Commission; Dr. Jeremy Carew-Reid, director general at ICEM; Dr. Amy Clement, University of Miami; Joyce Coffee, founder and president of Climate Resilience Consulting; Chris Corr, chair of the Florida Council of 100; Ann Cousins, head of the Bristol office's Climate Change Advisory Team at Arup; Kristina Dahl, senior climate scientist at the Union of Concerned Scientists; Dr. James Daniell, disaster risk consultant at CATDAT and Karlsruhe Institute of Technology; Matthew Eby, founder and executive director at First Street Foundation; Jessica Elengical, ESG Strategy Lead at DWS; Greg Fiske, senior geospatial analyst at Woods Hole Research Center; Susan Gray, global head of sustainable finance, business, and innovation, S&P Global; Jesse Keenan, Harvard University Center for the Environment; Dr. Kindie Tesfaye Fantaye, CIMMYT (International Maize and Wheat Improvement Center); Dr. Xiang Gao, principal research scientist at Massachusetts Institute of Technology; Beth Gibbons, executive director of the American Society of Adaptation Professionals; Sir Charles Godfray, professor at Oxford University; Patrick Goodey, head of flood management in the Bristol City Council; Dr. Luke J. Harrington, Environmental Change Institute at University of Oxford; Dr. George Havenith, professor of environmental physiology and ergonomics at Loughborough University; Brian Holtemeyer, research analyst at IFPRI; David Hodson, senior scientist at CIMMYT; Alex Jennings-Howe, flood risk modeller in the Bristol City Council; Dr.

Matthew Kahn, director of the 21st Century Cities Initiative at Johns Hopkins University; Dr. Benjamin Kirtman, director of the Cooperative Institute for Marine and Atmospheric Studies and director of the Center for Computational Science Climate and Environmental Hazards Program at the University of Miami; Nisha Krishnan, climate finance associate at the World Resources Institute, Dr. Michael Lacour-Little, director of economics at Fannie Mae; Dr. Judith Ledlee, project engineer at Black & Veatch; Dag Lohmann, chief executive officer at KatRisk; Ryan Lewis, professor at the Center for Research on Consumer Financial Decision Making, University of Colorado Boulder; Dr. Fred Lubnow, director of aquatic programs at Princeton Hydro; Steven McAlpine, head of Data Science at First Street Foundation; Manuel D. Medina, founder and managing partner of Medina Capital; Dr. Ilona Otto, Potsdam Institute for Climate Impact Research; Kenneth Pearson, head of engineering at BBraun; Dr. Jeremy Porter, Academic Research Partner at First Street Foundation; Dr. Maria Pregnolato, expert on transport system response to flooding at University of Bristol; Jay Roop, deputy head of Vietnam of the Asian Development Bank; Dr. Rich Ruby, director of technology at Broadcom; Dr. Adam Schlosser, deputy director for science research, Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology; Dr. Paolo Scussolini, Institute for Environmental Studies at the Vrije Universiteit Amsterdam; Dr. Kathleen Sealey, associate professor at the University of Miami; Timothy Searchinger, research scholar at Princeton University; Dr. Kai Sonder, head of the geographic information system unit at CIMMYT (International Maize and Wheat Improvement Center); Joel Sonkin, director of resiliency at AECOM; John Stevens, flood risk officer in the Bristol City Council; Dr. Thi Van Thu Tran, Viet Nam National University Ho Chi Minh City; Dr. James Thurlow, senior research fellow at IFPRI; Dr. Keith Wiebe, senior research fellow at IFPRI; David Wilkes, global head of flooding and former director of Thames Barrier at Arup; Dr. Brian Wright, professor at the University of California, Berkeley; and Wael Youssef, associate vice president, engineering director at AECOM.

Multiple groups within McKinsey contributed their analysis and expertise, including ACRE, McKinsey's center of excellence for advanced analytics in agriculture; McKinsey Center for Agricultural Transformation; McKinsey Corporate Performance Analytics; Quantum Black; and MGI Economics Research. Current and former McKinsey and MGI colleagues provided valuable input including: Knut Alicke, Adriana Aragon, Gassan Al-Kibsi, Gabriel Morgan Asaftei, Andrew Badger, Edward Barriball, Eric Bartels, Jalil Bensouda, Tiago Berni, Urs Binggeli, Sara Boettiger, Duarte Brage, Marco Breu, Katharina Brinck, Sarah Brody, Stefan Burghardt, Luís Cunha, Eoin Daly, Kaushik Das, Bobby Demissie, Nicolas Denis, Anton Derkach, Valerio Dilda, Jonathan Dimson, Thomas Dormann, Andre Dua, Omar El Hamamsy, Travis Fagan, Ignacio Felix, Fernando Ferrari-Haines, David Fiocco, Matthieu Francois, Marcus Frank, Steffen Fuchs, Ian Gleeson, Jose Luis Gonzalez, Stephan Gorner, Rajat Gupta, Ziad Haider, Homayoun Hatamai, Hans Helbekkmo, Kimberly Henderson, Liz Hilton Segel, Martin Hirt, Blake Houghton, Kia Javanmardian, Steve John, Connie Jordan, Sean Kane, Vikram Kapur, Joshua Katz, Greg Kelly, Adam Kendall, Can Kendi, Somesh Khanna, Kelly Kolker, Tim Koller, Gautam Kumra, Xavier Lamblin, Hugues Lavandier, Chris Leech, Sebastien Leger, Martin Lehnich, Nick Leung, Alastair Levy, Jason Lu, Jukka Maksimainen, John McCarthy, Ryan McCullough, Erwann Michel-Kerjan, Jean-Christophe Mieszala, Jan Mischke, Hasan Muzaffar, Mihir Mysore, Kerry Naidoo, Subbu Narayanaswamy, Fritz Nauck, Joe Ngai, Jan Tijs Nijssen, Arjun Padmanabhan, Gillian Pais, Guofeng Pan, Jeremy Redenius, Occo Roelofsen, Alejandro Rojas, Ron Ritter, Adam Rubin, Sam Samdani, Sunil Sanghvi, Ali Sankur, Grant Schlereth, Michael Schmeink, Joao Segorbe, Ketan Shah, Stuart Shilson, Marcus Sieberer, Halldor Sigurdsson, Pal Erik Sjatil, Sven Smit, Kevin Sneader, Dan Stephens, Kurt Strovink, Gernot Strube, Ben Sumers, Humayun Tai, Ozgur Tanrikulu, Marcos Tarnowski, Chris Thomas, Oliver Tonby, Chris Toomey, Christer Tryggestad, Andreas Tschiesner, Selin Tunguc, Magnus Tyreman, Roberto Uchoa de Paula, Robert Uhlaner, Soyoko Umeno, Gregory Vainberg, Cornelius Walter, John Warner, Olivia White, Bill Wiseman, and Carter Wood.

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As with all MGI research, this work is independent, reflects our own views, and has not been commissioned by any business, government, or other institution. We welcome your comments on the research at MGI@mckinsey.com.

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In brief

Climate risk and response: Physical hazards and socioeconomic impacts

After more than 10,000 years of relative stability—the full span of human civilization—the Earth's climate is changing. As average temperatures rise, acute hazards such as heat waves and floods grow in frequency and severity, and chronic hazards, such as drought and rising sea levels, intensify. Here we focus on understanding the nature and extent of physical risk from a changing climate over the next three decades, exploring physical risk as it is the basis of both transition and liability risks. We estimate inherent physical risk, absent adaptation and mitigation, to dimension the magnitude of the challenge and highlight the case for action. Climate science makes extensive use of scenarios ranging from lower (Representative Concentration Pathway 2.6) to higher (RCP 8.5) CO_2 concentrations. We have chosen to focus on RCP 8.5, because the higher-emission scenario it portrays enables us to assess physical risk in the absence of further decarbonization. We link climate models with economic projections to examine nine cases that illustrate exposure to climate change extremes and proximity to physical thresholds. A separate geospatial assessment examines six indicators to assess potential socioeconomic impact in 105 countries. The research also provides decision makers with a new framework and methodology to estimate risks in their own specific context. Key findings:

Climate change is already having substantial physical impacts at a local level in regions across the world; the affected regions will continue to grow in number and size. Since the 1880s, the average global temperature has risen by about 1.1 degrees Celsius with significant regional variations. This brings higher probabilities of extreme temperatures and an intensification of hazards. A changing climate in the next decade, and probably beyond, means the number and size of regions affected by substantial physical impacts will continue to grow. This will have direct effects on five socioeconomic systems: livability and workability, food systems, physical assets, infrastructure services, and natural capital.

The socioeconomic impacts of climate change will likely be nonlinear as system thresholds are breached and have knock-on effects. Most of the past increase in direct impact from hazards has come from greater exposure to hazards versus increases in their mean and tail intensity. In the future, hazard intensification will likely assume a greater role. Societies and systems most at risk are close to physical and biological thresholds. For example, as heat and humidity increase in India, by 2030 under an RCP 8.5 scenario, between 160 million and 200 million people could live in regions with an average 5 percent annual probability of experiencing a heat wave that exceeds the survivability threshold for a healthy human being, absent an adaptation response. Ocean warming could reduce fish catches, affecting the livelihoods of 650 million to 800 million people who rely on fishing revenue. In Ho Chi Minh City, direct infrastructure damage from a 100-year flood could rise from about $200 million to $300 million today to $500 million to $1 billion by 2050, while knock-on costs could rise from $100 million to $400 million to between $1.5 billion and $8.5 billion.

The global socioeconomic impacts of climate change could be substantial as a changing climate affects human beings, as well as physical and natural capital. By 2030, all 105 countries examined could experience an increase in at least one of the six indicators of socioeconomic impact we identify. By 2050, under an RCP 8.5 scenario, the number of people living in areas with a non-zero chance of lethal heat waves would rise from zero today to between 700 million and 1.2 billion (not factoring in air conditioner penetration). The average share of annual outdoor working hours lost due to extreme heat and humidity in exposed regions globally would increase from 10 percent today to 15 to 20 percent by 2050. The land area experiencing a shift in climate classification compared with 1901–25 would increase from about 25 percent today to roughly 45 percent.

Financial markets could bring forward risk recognition in affected regions, with consequences for capital allocation and insurance. Greater understanding of climate risk could make long-duration borrowing unavailable, impact insurance cost and availability, and reduce terminal values. This could trigger capital reallocation and asset repricing. In Florida, for example, estimates based on past trends suggest that losses from flooding could devalue exposed homes by $30 billion to $80 billion, or about 15 to 35 percent, by 2050, all else being equal.

Countries and regions with lower per capita GDP levels are generally more at risk. Poorer regions often have climates that are closer to physical thresholds. They rely more on outdoor work and natural capital and have less financial means to adapt quickly. Climate change could also benefit some countries; for example, crop yields could improve in Canada.

Addressing physical climate risk will require more systematic risk management, accelerating adaptation, and decarbonization. Decision makers will need to translate climate science insights into potential physical and financial damages, through systematic risk management and robust modeling recognizing the limitations of past data. Adaptation can help manage risks, even though this could prove costly for affected regions and entail hard choices. Preparations for adaptation—whether seawalls, cooling shelters, or drought-resistant crops—will need collective attention, particularly about where to invest versus retreat. While adaptation is now urgent and there are many adaptation opportunities, climate science tells us that further warming and risk increase can only be stopped by achieving zero net greenhouse gas emissions.

How a changing climate could impact socioeconomic systems

Five systems directly affected by physical climate change

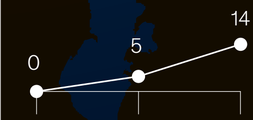
- Livability and workability
- Food systems
- Physical assets
- Infrastructure services
- Natural capital

Examples of direct impact of physical climate risk across geographies and sectors, **today, 2030, and 2050**

This assessment of the hazards and impacts of physical climate risk is based on an "inherent risk" scenario absent any adaptation and mitigation response. Analysis based on modeling of an RCP 8.5 scenario of greenhouse gas concentrations.

India

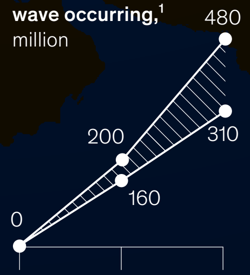
Annual likelihood of experiencing a lethal heat wave[1] in climate-exposed regions, %



~10%

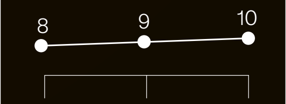
of Indian households owned an air conditioning unit in 2018

People living in areas having some probability of a lethal heat wave occurring,[1] million



Global breadbaskets

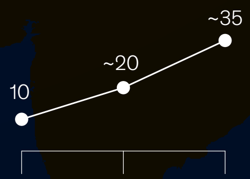
Land-weighted global average share of decade spent in drought, %



~60%

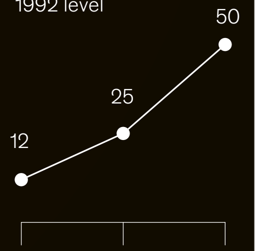
of global food production occurs in only 5 regions

Global annual harvest >15% below average at least once per decade, % likelihood



Florida

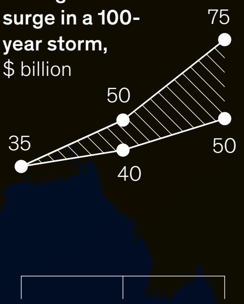
Sea level rise, cm over 1992 level



$200B

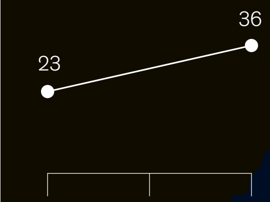
of residential real estate is < 1.8 meters above high tide

Residential real estate damage from storm surge in a 100-year storm, $ billion



Ho Chi Minh City

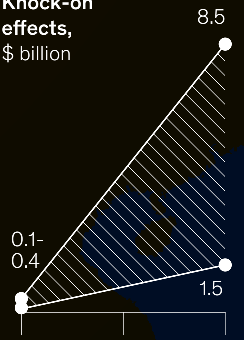
Flooded area of city in a 100-year flood, %



~10M–13M

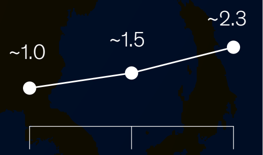
people living in Ho Chi Minh city by 2050

Knock-on effects, $ billion



Glaciers

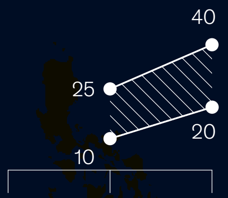
Median temperature anomaly, °C relative to 1850–1900



>16%

of people rely on glacial water for drinking and irrigation

Glacial mass melt in some Hindu Kush Himalayan subregions, %



A global geospatial assessment of climate risk **by 2050**

0.7B–1.2B

people living in areas with a 14 percent average annual likelihood of lethal heat waves.

Increase

in volatility of yields globally, some countries could benefit while others could see increased risk.

2×–4×

the amount of capital stock that could be damaged from riverine flooding by 2030 and 2050.

~45%

of the earth's land area projected to experience biome shifts, impacting ecosystem services, local livelihoods, and species' habitat.

What can be done to adapt to increased physical climate risk?

- **Protect people and assets**
- **Build resilience**
- **Reduce exposure**
- **Insure**
- **Finance**

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[1] Lethal heat waves are defined as three-day events during which average daily maximum wet-bulb temperature could exceed the survivability threshold for a healthy human being resting in the shade. The numbers here do not factor in air conditioner penetration. These projections are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cooling island effects.

For the dates, the climate state today is defined as the average conditions between 1998 and 2017, 2030 refers to the average of the years 2021–40, while 2050 refers to the average of the years 2041–60.

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Coping with rising temperatures in Singapore.
© Getty Images

Executive summary

McKinsey has a long history of research on topics related to the economics of climate change. Over the past decade, we have published a variety of research including a cost curve illustrating feasible approaches to abatement and reports on understanding the economics of adaptation and identifying the potential to improve resource productivity.[1] This research builds on that work and focuses on understanding the nature and implications of physical climate risk in the next three decades.

We draw on climate model forecasts to showcase how the climate has changed and could continue to change, how a changing climate creates new risks and uncertainties, and what steps can be taken to best manage them. Climate impact research makes extensive use of scenarios. Four "Representative Concentration Pathways" (RCPs) act as standardized inputs to climate models. They outline different atmospheric greenhouse gas concentration trajectories between 2005 and 2100. During their inception, RCPs were designed to collectively sample the range of then-probable future emission pathways, ranging from lower (RCP2.6) to higher (RCP 8.5) CO_2 concentrations. Each RCP was created by an independent modeling team and there is no consistent design of the socio-economic parameter assumptions used in the derivation of the RCPs. By 2100, the four RCPs lead to very different levels of warming, but the divergence is moderate out to 2050 and small to 2030. Since the research in this report is most concerned with understanding inherent physical risks, we have chosen to focus on the higher-emission scenario, i.e. RCP 8.5, because of the higher-emissions, lower-mitigation scenario it portrays, in order to assess physical risk in absence of further decarbonization (Exhibit E1).

We focus on physical risk—that is, the risks arising from the physical effects of climate change, including the potential effects on people, communities, natural and physical capital, and economic activity, and the implications for companies, governments, financial institutions, and individuals. Physical risk is the fundamental driver of other climate risk types—transition risk and liability risk.[2] We do not focus on transition risks, that is, impacts from decarbonization, or liability risks associated with climate change. While an understanding of decarbonization and the risk and opportunities it creates is a critical topic, this report contributes by exploring the nature and costs of ongoing climate change in the next one to three decades in the absence of decarbonization.

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[1] See, for example, *Shaping climate-resilient development: A framework for decision-making*, Economics of Climate Adaptation, 2009; "Mapping the benefits of the circular economy," *McKinsey Quarterly*, June 2017; *Resource revolution: Meeting the world's energy, materials, food, and water needs*, McKinsey Global Institute, November 2011; and *Beyond the supercycle: How technology is reshaping resources*, McKinsey Global Institute, February 2017. For details of the abatement cost curves, see *Greenhouse gas abatement cost curves*, McKinsey.com.

[2] Transition risk can be defined as risks arising from transition to a low-carbon economy; liability risk as risks arising from those affected by climate change seeking compensation for losses. See *Climate change: What are the risks to financial stability?* Bank of England, KnowledgeBank.

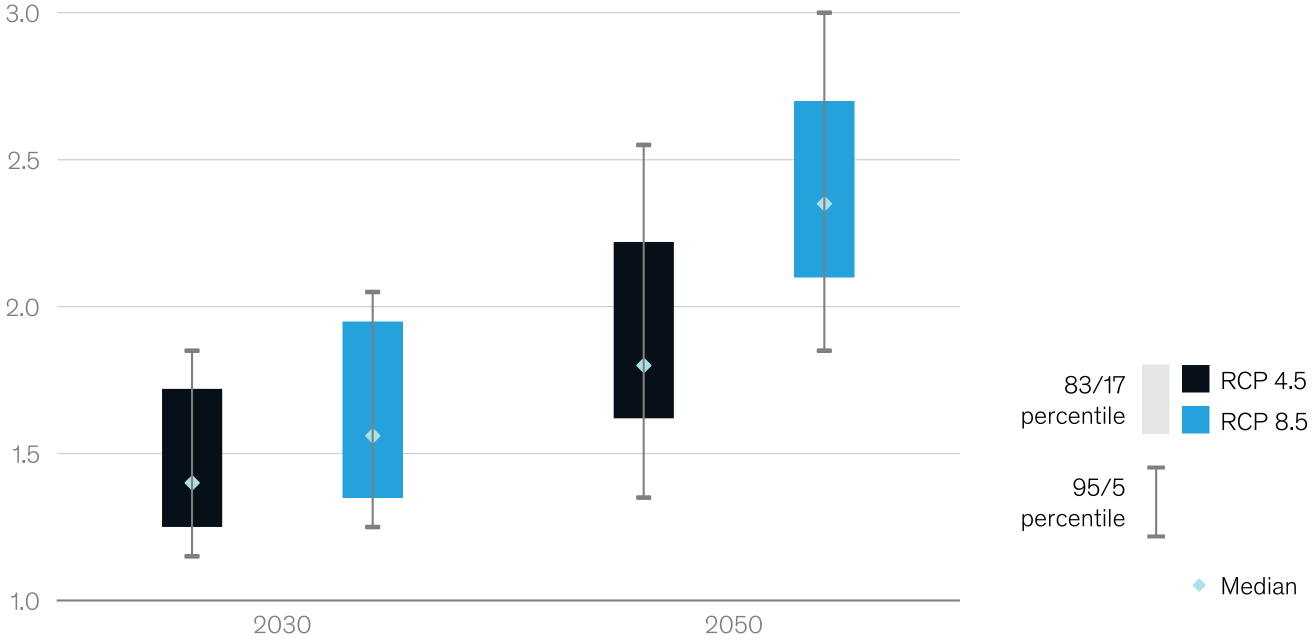
Our work offers both a call to action and a set of tools and methodologies to help assess the socioeconomic risks posed by climate change. We assess the socioeconomic risk from "acute" hazards, which are one-off events like floods or hurricanes, as well as from "chronic" hazards, which are long-term shifts in climate parameters like temperature.[3] We look at two periods: between now and 2030 and from 2030 to 2050. In doing so, we have relied on climate hazard data from climate scientists and focused on establishing socioeconomic impact, given potential changes in climate hazards (see Box E1, "Our research methodology"). We develop a methodology to measure the risk from the changing climate and the uncertainties associated with these estimates (see Box E2, "How our methodology addresses uncertainties"). At the end of this executive summary, we highlight questions for stakeholders seeking to respond to the challenge of heightened physical climate risk (see Box E3, "Questions for individual stakeholders to consider").

Exhibit E1

We make use of RCP 8.5, because the higher-emission scenario it portrays enables us to assess physical risk in the absence of further decarbonization.

Global average land and sea surface temperature anomaly relative to 1850–1900 average

°C



Note: For clarity of graph, outliers beyond 95th to 5th percentile are not shown. This chart shows two RCPs that are most commonly used in climate models, to provide a sense of the spread in scenarios.

Source: Intergovernmental Panel on Climate Change, The Physical Science Basis, 2013

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[3] By hazards, we mean climate-induced physical phenomena that have the potential to impact natural and socioeconomic systems.

Box E1

Our research methodology

In this report, we measure the impact of climate change by the extent to which it could affect human beings, human-made physical assets, and the natural world. While many scientists, including climate scientists, are employed at McKinsey & Company, we are not a climate modeling institution. Our focus in this report has been on translating the climate science data into an assessment of physical risk and its implications for stakeholders. Most of the climatological analysis performed for this report was done by Woods Hole Research Center (WHRC), and in other instances, we relied on publicly available climate science data, for example from institutions like the World Resources Institute. WHRC's work draws on the most widely used and thoroughly peer-reviewed ensemble of climate models to estimate the probabilities of relevant climate events occurring. Here, we highlight key methodological choices:

Case studies

In order to link physical climate risk to socioeconomic impact, we investigate nine specific cases that illustrate exposure to climate change extremes and proximity to physical thresholds. These cover a range of sectors and geographies and provide the basis of a "micro-to-macro" approach that is a characteristic of MGI research. To inform our selection of cases, we considered over 30 potential combinations of climate hazards, sectors, and geographies based on a review of the literature and expert interviews on the potential direct impacts of physical climate hazards. We find these hazards affect five different key socioeconomic systems: livability and workability, food systems, physical assets, infrastructure services, and natural capital.

We ultimately chose nine cases to reflect these systems and based on their exposure to the extremes of climate change and their proximity today to key physiological, human-made, and ecological thresholds. As such, these cases represent leading-edge examples of climate change risk. They show that the direct risk from climate hazards is determined by the severity of the hazard and its likelihood, the exposure of various "stocks" of capital (people, physical capital, and natural capital) to these hazards, and the resilience of these stocks to the hazards (for example, the ability of physical assets to withstand flooding). Through our case studies, we also assess the knock-on effects that could occur, for example to downstream sectors or consumers. We primarily rely on past examples and empirical estimates for this assessment of knock-on effects, which is likely not exhaustive given the complexities associated with socioeconomic systems. Through this "micro" approach, we offer decision makers a methodology by which to assess direct physical climate risk, its characteristics, and its potential knock-on impacts.

Global geospatial analysis

In a separate analysis, we use geospatial data to provide a perspective on climate change across 105 countries over the next 30 years. This geospatial analysis relies on the same five-systems framework of direct impacts that we used for the case studies. For each of these systems, we identify a measure, or measures, of the impact of climate change, using indicators where possible as identified in our cases.

Similar to the approach discussed above for our cases, our analyses are conducted at a grid-cell level, overlaying data on a hazard (for example, floods of different depths, with their associated likelihoods), with exposure to that hazard (for example, capital stock exposed to flooding), and a damage function that assesses resilience (for example, what share of capital stock is damaged when exposed to floods of different depth). We then combine these grid-cell values to country and global numbers. While the goal of this analysis is to measure direct impact, due to data availability issues, we have used five measures of socioeconomic impact and one measure of climate hazards themselves—drought. Our set of 105 countries represents 90 percent of the world's population and 90 percent of global GDP. While we seek to include a wide range of risks and as many countries as possible, there are some we could not cover due to data limitations (for example, the impact of forest fires and storm surges).

What this report does not do

Since the purpose of this report is to understand the physical risks and disruptive impacts of climate change, there are many areas which we do not address.

- We do not assess the efficacy of climate models but instead draw on best practice approaches from climate science literature and highlight key uncertainties.

- We do not examine in detail areas and sectors that are likely to benefit from climate change such as the potential for improved agricultural yields in parts of Canada, although we quantify some of these benefits through our geospatial analysis.

- As the consequences of physical risk are realized, there will likely be acts of adaptation, with a feedback effect on the physical risk. For each of our cases, we identify adaptation responses. We have not conducted a detailed bottom-up cost-benefit analysis of adaptation but have built on existing literature and expert interviews to understand the most important measures and their indicative cost, effectiveness, and implementation challenges, and to estimate the expected global adaptation spending required.

- We note the critical importance of decarbonization in a climate risk management approach but a detailed discussion of decarbonization is beyond the scope of this report.

- While we attempt to draw out qualitatively (and, to the extent possible, quantitatively) the knock-on effects from direct physical impacts of climate change, we recognize the limitations of this exercise given the complexity of socioeconomic systems. There are likely knock-on effects that could occur which our analysis has not taken into account. For this reason, we do not attempt to size the global GDP at risk from climate change (see Box 4 in Chapter 4 for a detailed discussion).

- We do not provide projections or deterministic forecasts, but rather assess risk. The climate is the statistical summary of weather patterns over time and is therefore probabilistic in nature. Following standard practice, our findings are therefore framed as "statistically expected values"—the statistically expected average impact across a range of probabilities of higher or lower climate outcomes.[1]

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[1] We also report the value of "tail risks"—that is, low-probability, high-impact events like a 1-in-100-year storm—on both an annual and cumulative basis. Consider, for example, a flooding event that has a 1 percent annual likelihood of occurrence every year (often described as a "100-year flood"). In the course of the lifetime of home ownership—for example, over a 30-year period—the cumulative likelihood that the home will experience at least one 100-year flood is 26 percent.

Box E2

How our methodology addresses uncertainties

One of the main challenges in understanding the physical risk arising from climate change is the range of uncertainties involved. Risks arise as a result of an involved causal chain. Emissions influence both global climate and regional climate variations, which in turn influence the risk of specific climate hazards (such as droughts and sea-level rise), which then influence the risk of physical damage (such as crop shortages and infrastructure damages), which finally influence the risk of financial harm. Our analysis, like any such effort, relies on assumptions made along the causal chain: about emission paths and adaptation schemes; global and regional climate models; physical damage functions; and knock-on effects. The further one goes along the chain, the greater the intrinsic model uncertainty.

Taking a risk-management lens, we have developed a methodology to provide decision makers with an outlook over the next three decades on the inherent risk of climate change—that is, risk absent any adaptation and mitigation response. Separately, we outline how this risk could be reduced via an adaptation response in our case studies. Where feasible, we have attempted to size the costs of the potential adaptation responses. We believe this approach is appropriate to help stakeholders understand the potential magnitude of the impacts from climate change and the commensurate response required.

The key uncertainties include the emissions pathway and pace of warming, climate model accuracy and natural variability, the magnitude of direct and indirect socioeconomic impacts, and the socioeconomic response. Assessing these uncertainties, we find that our approach likely results in conservative estimates of inherent risk because of the skew in uncertainties of many hazard projections toward "worse" outcomes as well as challenges with modeling the many potential knock-on effects associated with direct physical risk.[1]

Emissions pathway and pace of warming

As noted above, we have chosen to focus on the RCP 8.5 scenario because the higher-emission scenario it portrays enables us to assess physical risk in the absence of further decarbonization. Under this scenario, science tells us that global average temperatures will reach just over 2 degrees Celsius above preindustrial levels by 2050. However, action to reduce emissions could mean that the projected outcomes—both hazards and impacts—based on this trajectory are delayed post 2050. For example, RCP 8.5 predicts global average warming of 2.3 degrees Celsius by 2050, compared with 1.8 degrees Celsius for RCP 4.5. Under RCP 4.5, 2.3 degrees Celsius warming would be reached in the year 2080.

Climate model accuracy and natural variability

We have drawn on climate science that provides sufficiently robust results, especially over a 30-year period. To minimize the uncertainty associated with any particular climate model, the mean or median projection (depending on the specific variable being modeled) from an ensemble of climate models has been used, as is standard practice in the climate literature. We also note that climate model uncertainty on global temperature increases tends to skew toward worse outcomes; that is, differences across climate models tend to predict outcomes that are skewed toward warmer rather than cooler global temperatures. In addition, the climate models used here omit potentially important biotic feedbacks including greenhouse gas emissions from thawing permafrost, which will tend to increase warming.

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[1] See Naomi Oreskes and Nicholas Stern, "Climate change will cost us even more than we think," *New York Times*, October 23, 2019.

To apply global climate models to regional analysis, we used techniques established in climate literature.[2] The remaining uncertainty related to physical change is variability resulting from mechanisms of natural rather than human origin. This natural climate variability, which arises primarily from multiyear patterns in ocean and/or atmosphere circulation (for example, the El Niño/La Niña oscillation), can temporarily affect global or regional temperature, precipitation, and other climatic variables. Natural variability introduces uncertainty surrounding how hazards could evolve because it can temporarily accelerate or delay the manifestation of statistical climate shifts.[3] This uncertainty will be particularly important over the next decade, during which overall climatic shifts relative to today may be smaller in magnitude than an acceleration or delay in warming due to natural variability.

Direct and indirect socioeconomic impacts

Our findings related to socioeconomic impact of a given physical climate effect involve uncertainty, and we have provided conservative estimates. For direct impacts, we have relied on publicly available vulnerability assessments, but they may not accurately represent the vulnerability of a specific asset or location. For indirect impacts, given the complexity of socioeconomic systems, we know that our results do not capture the full impact of climate change knock-on effects. In many cases, we have either discussed knock-on effects in a qualitative manner alone or relied on empirical estimations. This may underestimate the direct impacts of climate change's inherent risk in our cases, for example the knock-on effects of flooding in Ho Chi Minh City or the potential for financial devaluation in Florida real estate. This is not an issue in our 105-country geospatial analysis, as the impacts we are looking at there are direct and as such we have relied on publicly available vulnerability assessments as available at a regional or country level.

Socioeconomic response

The amount of risk that manifests also depends on the response to the risk. Adaptation measures such as hardening physical infrastructure, relocating people and assets, and ensuring backup capacity, among others, can help manage the impact of climate hazards and reduce risk. We follow an approach that first assesses the inherent risk and then considers a potential adaptation response. The inherent or ex ante level of risk is the risk without taking any steps to reduce its likelihood or severity. We have not conducted a detailed bottom-up cost-benefit analysis of adaptation measures but have built on existing literature and expert interviews to understand the most important measures and their indicative cost, effectiveness, and implementation challenges in each of our cases, and to estimate the expected global adaptation spending required. While we note the critical importance of decarbonization in an appropriate climate risk management approach, a detailed discussion of decarbonization is beyond the scope of this report.

How decision makers incorporate these uncertainties into their management choices will depend on their risk appetite and overall risk-management approach. Some may want to work with the outcome considered most likely (which is what we generally considered), while others may want to consider a worse- or even worst-case scenario. Given the complexities we have outlined above, we recognize that more research is needed in this critical field. However, we believe that despite the many uncertainties associated with estimates of impact from a changing climate, it is possible for the science and socioeconomic analysis to provide actionable insights for decision makers. For an in-depth discussion of the main uncertainties and how we have sought to resolve them, see Chapter 1.

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[2] See technical appendix for details.

[3] Kyle L. Swanson, George Sugihara, and Anastasios A. Tsonis, "Long-term natural variability and 20th century climate change," *Proceedings of the National Academy of Sciences*, September 2009, Volume 106, Number 38.

We find that risk from climate change is already present and growing. The insights from our cases help highlight the nature of this risk, and therefore how stakeholders should think about assessing and managing it. Seven characteristics stand out. Physical climate risk is:

- **Increasing.** In each of our nine cases, the level of physical climate risk increases by 2030 and further by 2050. Across our cases, we find increases in socioeconomic impact of between roughly two and 20 times by 2050 versus today's levels. We also find physical climate risks are generally increasing across our global country analysis even as some countries find some benefits (such as increased agricultural yields in Canada, Russia, and parts of northern Europe).

- **Spatial.** Climate hazards manifest locally. The direct impacts of physical climate risk thus need to be understood in the context of a geographically defined area. There are variations between countries and also within countries.

- **Non-stationary.** As the Earth continues to warm, physical climate risk is ever-changing or non-stationary. Climate models and basic physics predict that further warming is "locked in" over the next decade due to inertia in the geophysical system, and that the temperature will likely continue to increase for decades to come due to socio-technological inertia in reducing emissions.[4] Climate science tells us that further warming and risk increase can only be stopped by achieving zero net greenhouse gas emissions. Furthermore, given the thermal inertia of the earth system, some amount of warming will also likely occur after net-zero emissions are reached.[5] Managing that risk will thus require not moving to a "new normal" but preparing for a world of constant change. Financial markets, companies, governments, or individuals have mostly not had to address being in an environment of constant change before, and decision making based on experience may no longer be reliable. For example, engineering parameters for infrastructure design in certain locations will need to be re-thought, and home owners may need to adjust assumptions about taking on long-term mortgages in certain geographies.

- **Nonlinear.** Socioeconomic impacts are likely to propagate in a nonlinear way as hazards reach thresholds beyond which the affected physiological, human-made, or ecological systems work less well or break down and stop working altogether. This is because such systems have evolved or been optimized over time for historical climates. Consider, for example, buildings designed to withstand floods of a certain depth, or crops grown in regions with a specific climate. While adaptation in theory can be carried out at a fairly rapid rate for some systems (for example, improving the floodproofing of a factory), the current rate of warming—which is at least an order of magnitude faster than any found in the past 65 million years of paleoclimate records—means that natural systems such as crops are unable to evolve fast enough to keep pace.[6] Impacts could be significant if system thresholds are breached even by small amounts. The occurrence of multiple risk factors (for example, exposure to multiple hazards, other vulnerabilities like the ability to finance adaptation investments, or high reliance on a sector that is exposed to climate hazard) in a single geography, something we see in several of our cases, is a further source of potential nonlinearity.

- **Systemic.** While the direct impact from climate change is local, it can have knock-on effects across regions and sectors, through interconnected socioeconomic and financial systems. For example, flooding in Florida could not only damage housing but also raise insurance costs, affect property values of exposed homes, and in turn reduce property tax revenues

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[4] H. Damon Matthews et al., "Focus on cumulative emissions, global carbon budgets, and the implications for climate mitigation targets," *Environmental Research Letters,* January 2018, Volume 13, Number 1.

[5] H. Damon Matthews et al., "Focus on cumulative emissions, global carbon budgets, and the implications for climate mitigation targets," *Environmental Research Letters,* January 2018, Volume 13, Number 1; H. Damon Matthews & Ken Caldeira, "Stabilizing climate requires near zero emissions". *Geophysical Research Letters* February 2008, Volume 35; Myles Allen et al, *"Warming caused by cumulative carbon emissions towards the trillionth ton."* Nature, April 2009, Volume 485.

[6] Noah S. Diffenbaugh and Christopher B. Field, "Changes in ecologically critical terrestrial climate conditions," *Science,* August 2013, Volume 341, Number 6145; Seth D. Burgess, Samuel Bowring, and Shu-zhong Shen, "High-precision timeline for Earth's most severe extinction," Proceedings of the National Academy of Sciences, March 2014, Volume 111, Number 9.

for communities. Like physical systems, many economic and financial systems have been designed in a manner that could make them vulnerable to a changing climate. For example, global production systems like supply chains or food production systems have optimized efficiency over resiliency, which makes them vulnerable to failure if critical production hubs are impacted by intensifying hazards. Insurance systems are designed so that property insurance is re-priced annually; however, home owners often have longer-term time horizons of 30 years or more on their real estate investments. As a result of this duration mismatch, home owners could be exposed to the risk of higher costs, in the form of rising premiums (which could be appropriate to reflect rising risks), or impacts on the availability of insurance. Similarly, debt levels in many places are also at thresholds, so knock-on effects on relatively illiquid financial instruments like municipal bonds should also be considered.

— **Regressive.** The poorest communities and populations within each of our cases typically are the most vulnerable. Across all 105 countries in our analysis, we find an increase in at least one of six indicators of socioeconomic impact by 2030. Emerging economies face the biggest increase in potential impact on workability and livability. Poorer countries also rely more on outdoor work and natural capital and have less financial means to adapt quickly. Climate change can bring benefits as well as costs to specific areas, for example shifting tourism from southern to northern Europe.

— **Under-prepared.** While companies and communities have been adapting to reduce climate risk, the pace and scale of adaptation are likely to need to significantly increase to manage rising levels of physical climate risk. Adaptation is likely to entail rising costs and tough choices that may include whether to invest in hardening or relocate people and assets. It thus requires coordinated action across multiple stakeholders.

Climate change is already having substantial physical impacts at a local level; these impacts are likely to grow, intensify, and multiply

Earth's climate is changing, and further change is unavoidable in the next decade and in all likelihood beyond. The planet's temperature has risen by about 1.1 degrees Celsius on average since the 1880s.[7] This has been confirmed by both satellite measurements and by the analysis of hundreds of thousands of independent weather station observations from across the globe. The rapid decline in the planet's surface ice cover provides further evidence. This rate of warming is at least an order of magnitude faster than any found in the past 65 million years of paleoclimate records.[8]

The average conceals more dramatic changes at the extremes. In statistical terms, distributions of temperature are shifting to the right (towards warmer) and broadening. That means the average day in many locations is now hotter ("shifting means"), and extremely hot days are becoming more likely ("fattening tails"). For example, the evolution of the distribution of observed average summer temperatures for each 100-by-100-kilometer square in the Northern Hemisphere shows that the mean summer temperature has increased over time (Exhibit E2). The percentage of the Northern Hemisphere (in square kilometers) that experiences a substantially hotter summer—a two-standard-deviation warmer average temperature in a given year—has increased more than 15 times, from less than 1 percent to 15 percent. The share of the Northern Hemisphere (in square kilometers) that experiences an extremely hot summer—three-standard-deviation hotter average temperature in a given summer—has increased from zero to half a percent.

Averages also conceal wide spatial disparities. Over the same period that the Earth globally has warmed by 1.1 degrees, in southern parts of Africa and in the Arctic, average temperatures

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[7] NASA GISTEMP (2019) and Nathan J. L. Lenssen et al., "Improvements in the GISTEMP uncertainty model," *Journal of Geophysical Resources: Atmospheres*, June 2019, Volume 124, Number 12.

[8] Noah S. Diffenbaugh and Christopher B. Field, "Changes in ecologically critical terrestrial climate conditions," *Science*, August 2013, Volume 341, Number 6145; Seth D. Burgess, Samuel Bowring, and Shu-zhong Shen, "High-precision timeline for Earth's most severe extinction," *Proceedings of the National Academy of Sciences*, March 2014, Volume 111, Number 9.

have risen by 0.2 and 0.5 degrees Celsius and by 4 to 4.3 degrees Celsius, respectively.[9] In general, the land surface has warmed faster than the 1.1-degree global average, and the oceans, which have a higher heat capacity, have warmed less.

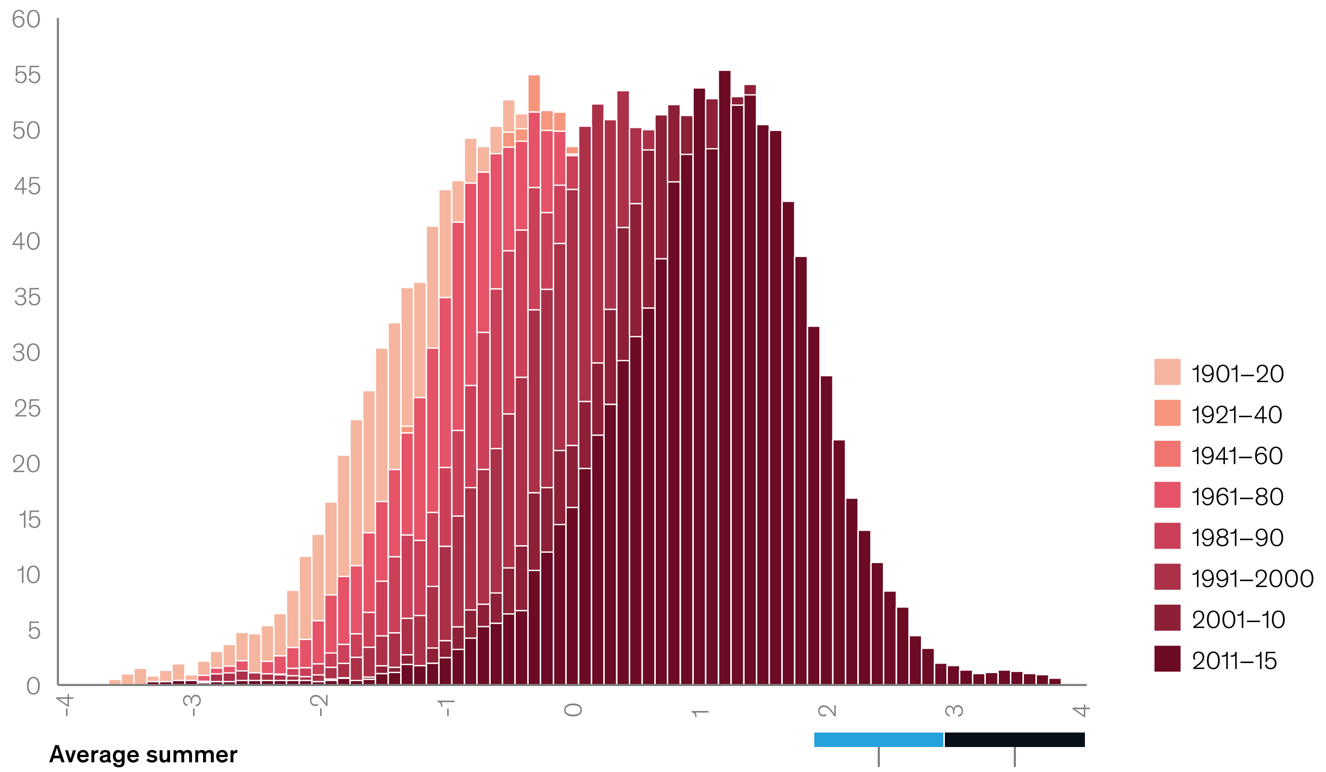
Looking forward, further change is unavoidable over the next decade at least, and in all likelihood beyond. The primary driver of the observed rate of temperature increase over the past two centuries is the human-caused rise in atmospheric levels of carbon dioxide (CO_2) and other greenhouse gases, including methane and nitrous oxide.[10] Since the beginning of the Industrial Revolution in the mid-18th century, humans have released nearly 2.5 trillion tonnes of CO_2 into the atmosphere, raising atmospheric CO_2 concentrations from about 280 parts per million by volume (ppmv) to 415 ppmv, increasing at more than 2 ppmv per year .

Exhibit E2

A small shift in the average can hide dramatic changes at the extremes.

Frequency of local temperature anomalies in the Northern Hemisphere

Number of observations, thousands



Unusually hot summers (>2 standard deviations) in 2015 occur at 15% of land surface, compared with 0.2% prior to 1980

Extremely hot summers (>3 standard deviations) in 2015 occur at 0.5% of land surface, compared with 0% prior to 1980

Note: Because the signal from anthropogenic greenhouse gas emissions did not emerge strongly prior to 1980, some of the early time period distributions in the above figure overlap and are difficult to see. Northern Hemisphere land surface divided into 100km x 100km grid cells. Standard deviations based on measuring across the full sample of data across all grid-cells and years.

Source: Sippel et al., 2015; McKinsey Global Institute analysis with advice from University of Oxford Environmental Change Institute

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[9] Goddard Institute for Space Studies (GISS), GISTEMP Reanalysis dataset (2019).

[10] Between 98 and 100 percent of observed warming since 1850 is attributable to the rise in atmospheric greenhouse gas concentrations, and approximately 75 percent is attributable to CO_2 directly. The remaining warming is caused by short-lived greenhouse gases like methane and black carbon, which, because they decay in the atmosphere, warm the planet as a function of rate (or flow) of emissions, not cumulative stock of emissions. Karsten Haustein et al., “A real-time Global Warming Index,” *Nature Scientific Reports*, November 13, 2017; Richard J. Millar and Pierre Friedlingstein, “The utility of the historical record for assessing the transient climate response to cumulative emissions,” *Philosophical Transactions of the Royal Society*, May 2018, Volume 376, Number 2119.

Carbon dioxide persists in the atmosphere for hundreds of years.[11] As a result, in the absence of large-scale human action to remove CO_2 from the atmosphere, nearly all of the warming that occurs will be permanent on societally relevant timescales.[12] Additionally, because of the strong thermal inertia of the ocean, more warming is likely already locked in over the next decade, regardless of emissions pathway. Beyond 2030, climate science tells us that further warming and risk increase can only be stopped by achieving zero net greenhouse gas emissions.[13]

With increases in global average temperatures, climate models indicate a rise in climate hazards globally. According to climate science, further warming will continue to increase the frequency and/or severity of acute climate hazards across the world, such as lethal heat waves, extreme precipitation, and hurricanes, and will further intensify chronic hazards such as drought, heat stress, and rising sea levels.[14] Here, we describe the prediction of climate models analyzed by WHRC, and also publicly available data for a selection of hazards for an RCP 8.5 scenario (Exhibits E3 and E4):

— **Increase in average temperatures.**[15] Global average temperatures are expected to increase over the next three decades, resulting in a 2.3-degree Celsius (+0.5/-0.3) average increase relative to the preindustrial period by 2050, under an RCP 8.5 scenario. Depending on the exact location, this can translate to an average local temperature increase of between 1.5 and 5.0 degrees Celsius relative to today. The Arctic in particular is expected to warm more rapidly than elsewhere.

— **Extreme precipitation.**[16] In parts of the world, extreme precipitation events, defined here as one that was a once in a 50-year event (that is, with a 2 percent annual likelihood) in the 1950–81 period, are expected to become more common. The likelihood of extreme precipitation events is expected to grow more than fourfold in some regions, including parts of China, Central Africa, and the east coast of North America compared with the period 1950–81.

— **Hurricanes.**[17] While climate change is seen as unlikely to alter the frequency of tropical hurricanes, climate models and basic physical theory predict an increase in the average severity of those storms (and thus an increase in the frequency of severe hurricanes). The likelihood of severe hurricane precipitation—that is, an event with a 1 percent likelihood annually in the 1981–2000 period—is expected to double in some parts of the southeastern United States and triple in some parts of Southeast Asia by 2040. Both are densely populated areas with large and globally connected economic activity.

— **Drought.**[18] As the Earth warms, the spatial extent and share of time spent in drought is projected to increase. The share of a decade spent in drought conditions is projected to be up to 80 percent in some parts of the world by 2050, notably in parts of the Mediterranean, southern Africa, and Central and South America.

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[11] David Archer. *"Fate of Fossil Fuel CO_2 in geological time."* Journal of Geophysical Research, March 2005, Volume 110.

[12] H. Damon Matthews et al., "Focus on cumulative emissions, global carbon budgets, and the implications for climate mitigation targets," *Environmental Research Letters,* January 2018, Volume 13, Number 1. David Archer. *"Fate of Fossil Fuel CO_2 in geological time."* Journal of Geophysical Research, March 2005, Volume 110; H. Damon Matthews & Susan Solomon. *"Irreversible does not mean unavoidable."* Science. April 2013, Volume 340, Issue 6131.

[13] H. Damon Matthews et al., "Focus on cumulative emissions, global carbon budgets, and the implications for climate mitigation targets," *Environmental Research Letters,* January 2018, Volume 13, Number 1; H. Damon Matthews & Ken Caldeira, "Stabilizing climate requires near zero emissions". *Geophysical Research Letters* February 2008, Volume 35; Myles Allen et al, *"Warming caused by cumulative carbon emissions towards the trillionth ton."* Nature, April 2009, Volume 485.

[14] This list of climate hazards is a subset, and the full list can be found in the full report. The list is illustrative rather than exhaustive. Due to data and modeling constraints, we did not include the following hazards: increased frequency and severity of forest fires, increased biological and ecological impacts from pests and diseases, increased severity of hurricane wind speed and storm surge, and more frequent and severe coastal flooding due to sea-level rise.

[15] Taken from KNMI Climate Explorer (2019), using the mean of the full CMIP5 ensemble of models.

[16] Modeled by WHRC using the median projection from 20 CMIP5 Global Climate Models (GCMs). To accurately estimate the probability of extreme precipitation events, a process known as statistical bootstrapping was used. Because these projections are not estimating absolute values, but rather changes over time, bias correction was not used.

[17] Modeled by WHRC using the Coupled Hurricane Intensity Prediction System (CHIPS) model from Kerry Emanuel, MIT, 2019. Time periods available for the hurricane modeling were 1981–2000 baseline, and 2031–50 future period. These are the results for two main hurricane regions of the world; other including the Indian sub-continent were not modeled.

[18] Modeled by WHRC using the median projection of 20 CMIP5 GCMs, using the self-correcting Palmer Drought Severity Index (PDSI). Projections were corrected to account for increasing atmospheric CO_2 concentrations.

Exhibit E3

Climate hazards are projected to intensify in many parts of the world.

Based on RCP 8.5

Today | **2030** | **2050**

Increase in average annual temperature

Shift compared to preindustrial climate

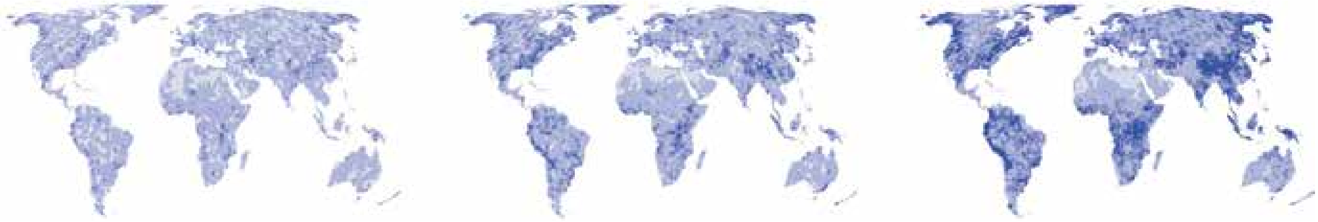
°C

■ 0–0.5
■ 0.6–1.0
■ 1.1–1.5
■ 1.6–2.0
■ 2.1–2.5
■ 2.6–3.0
■ 3.1–3.5
■ 3.6–4.0
■ 4.1–4.5
■ 4.6–5.0
■ 5.1–5.5
■ 5.6–6.0
■ 6.1–6.5
■ 6.6–7.0
■ >7.0

Extreme precipitation

Change of likelihood compared to 1950–81 of an 1950–81 50-year precipitation event

■ ≤1x ■ 1–2x ■ 2–3x ■ 3–4x ■ >4x



Hurricane (precipitation)

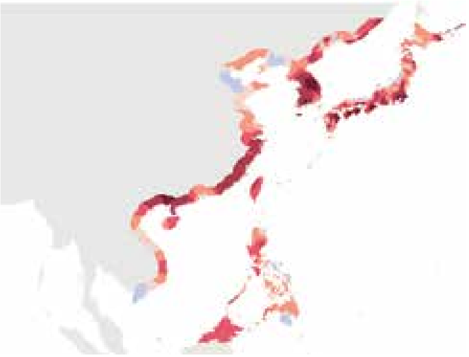
Change of likelihood in 2040 compared with 1981–2000 of a 1981–2000 100-year hurricane

Southeast United States

■ ≤1.0x
■ 1.1–1.5x
■ 1.6–2.0x
■ >2.0x

Southeast Asia

■ ≤1.00x
■ 1.01–1.25x
■ 1.26–1.75x
■ 1.76–2.25x
■ 2.26–3.00x
■ >3.00x



Note: See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we typically define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: Woods Hole Research Center; World Resources Institute Water Risk Atlas (2018); World Resources Institute Flood Risk A nalyzer; McKinsey Global Institute analysis

Exhibit E4

Climate hazards are projected to intensify in many parts of the world (continued).

Based on RCP 8.5

Today **2030** **2050**

Drought frequency[1]

% of decade in drought

■ 0 ■ 1–10 ■ 11–20 ■ 21–40 ■ 41–60 ■ 61–80 ■ >80

Lethal heat wave probability[2]

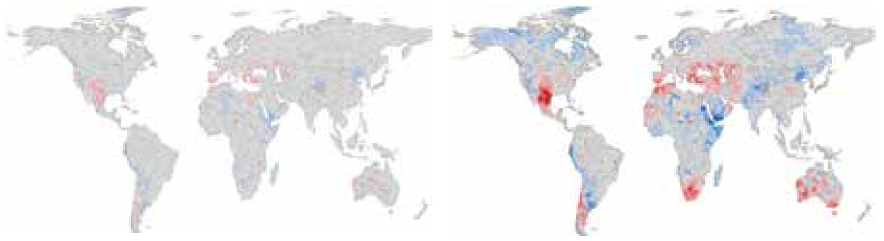
% p.a.

■ ≤2 ■ 3–5 ■ 6–10 ■ 11–15 ■ 16–30 ■ 31–45 ■ 46–60 ■ >60

Water supply

Change in surface water compared with 2018 (%)
Boundaries on the map represent water basins

■ >70% decrease
■ 41–70% decrease
■ 20–40% decrease
■ Near normal
■ 20–40% increase
■ 41–70% increase
■ >70% increase



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1. Measured using a three-month rolling average. Drought is defined as a rolling three month period with Average Palmer Drought Severity Index (PDSI) <-2. PDSI is a temperature and precipitation-based drought index calculated based on deviation from historical mean. Values generally range from +4 (extremely wet) to -4 (extremely dry).
2. A lethal heat wave is defined as a three-day period with maximum daily wet-bulb temperatures exceeding 34°C wet-bulb, where wet-bulb temperature is defined as the lowest temperature to which a parcel of air can be cooled by evaporation at constant pressure. This threshold was chosen because the commonly defined heat threshold for human survivability is 35°C wet-bulb, and large cities with significant urban heat island effects could push 34°C wet-bulb heat waves over the 35°C threshold. Under these conditions, a healthy, well-hydrated human being resting in the shade would see core body temperatures rise to lethal levels after roughly 4–5 hours of exposure. These projections are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cooling island effects.

Note: See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we typically define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: Woods Hole Research Center; World Resources Institute Water Risk Atlas (2018); World Resources Institute Flood Risk Analyzer; McKinsey Global Institute analysis

- **Lethal heat waves.**[19] Lethal heat waves are defined as three-day events during which average daily maximum wet-bulb temperature could exceed the survivability threshold for a healthy human being resting in the shade.[20] Under an RCP 8.5 scenario, urban areas in parts of India and Pakistan could be the first places in the world to experience heat waves that exceed the survivability threshold for a healthy human being, with small regions projected to experience a more than 60 percent annual chance of such a heat wave by 2050.

- **Water supply.**[21] As rainfall patterns, evaporation, snowmelt timing, and other factors change, renewable freshwater supply will be affected. Some parts of the world like South Africa and Australia are expected to see a decrease in water supply, while other areas, including Ethiopia and parts of South America, are projected to experience an increase. Certain regions, for example, parts of the Mediterranean region and parts of the United States and Mexico, are projected to see a decrease in mean annual surface water supply of more than 70 percent by 2050. Such a large decline in water supply could cause or exacerbate chronic water stress and increase competition for resources across sectors.

The socioeconomic impacts of climate change will likely be nonlinear as system thresholds are breached and have knock-on effects

Climate change affects human life as well as the factors of production on which our economic activity is based and, by extension, the preservation and growth of wealth. We measure the impact of climate change by the extent to which it could disrupt or destroy stocks of capital—human, physical, and natural—and the resultant socioeconomic impact of that disruption or destruction. The effect on economic activity as measured by GDP is a consequence of the direct impacts on these stocks of capital.

Climate change is already having a measurable socioeconomic impact. Across the world, we find examples of these impacts and their linkage to climate change. We group these impacts in a five-systems framework (Exhibit E5). As noted in Box E1, this impact framework is our best effort to capture the range of socioeconomic impacts from physical climate hazards.

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[19] Modeled by WHRC using the mean projection of daily maximum surface temperature and daily mean relative humidity taken from 20 CMIP5 GCMs. Models were independently bias corrected using the ERA-Interim dataset.

[20] We define a lethal heat wave as a three-day period with maximum daily wet-bulb temperatures exceeding 34 degrees Celsius wet-bulb, where wet-bulb temperature is defined as the lowest temperature to which a parcel of air can be cooled by evaporation at constant pressure. This threshold was chosen because the commonly defined heat threshold for human survivability is 35 degrees Celsius wet-bulb, and large cities with significant urban heat island effects could push 34C wet-bulb heat waves over the 35C threshold. At this temperature, a healthy human being, resting in the shade, can survive outdoors for four to five hours. These projections are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cooling island effects. If a non-zero probability of lethal heat waves in certain regions occurred in the models for today, this was set to zero to account for the poor representation of the high levels of observed atmospheric aerosols in those regions in the CMIP5 models. High levels of atmospheric aerosols provide a cooling effect that masks the risk. See the India case and our technical appendix for more details. Analysis based on an RCP 8.5 scenario.

[21] Taken from the World Resources Institute Water Risk Atlas (2018), which relies on 6 underlying CMIP5 models. Time periods of this raw dataset are the 20-year periods centered on 2020, 2030, and 2040. The 1998–2017 and 2041–60 data were linearly extrapolated from the 60-year trend provided in the base dataset.

Exhibit E5

Socioeconomic impact of climate change is already manifesting and affects all geographies.

Impacted economic system	Area of direct risk		Socioeconomic impact	How climate change exacerbated hazard
Livability and workability	1	2003 European heat wave	$15 billion in losses	2x more likely
	2	2010 Russian heat wave	~55,000 deaths attributable	3x more likely
	3	2013–14 Australian heat wave	~$6 billion in productivity loss	Up to 3x more likely
	4	2017 East African drought	~800,000 people displaced in Somalia	2x more likely
	5	2019 European heat wave	~1,500 deaths in France	~10x more likely in France
Food systems	6	2015 Southern Africa drought	Agriculture outputs declined by 15%	3x more likely
	7	Ocean warming	Up to 35% decline in North Atlantic fish yields	Ocean surface temperatures have risen by 0.7°C globally
Physical assets	8	2012 Hurricane Sandy	$62 billion in damage	3x more likely
	9	2016 Fort McMurray Fire, Canada	$10 billion in damage, 1.5 million acres of forest burned	1.5 to 6x more likely
	10	2017 Hurricane Harvey	$125 billion in damage	8–20% more intense
Infrastructure services	11	2017 flooding in China	$3.55 billion of direct economic loss, including severe infrastructure damage	2x more likely
Natural capital	12	30-year record low Arctic sea ice in 2012	Reduced albedo effect, amplifying warming	70% to 95% attributable to human-induced climate change
	13	Decline of Himalayan glaciers	Potential reduction in water supply for more than 240 million people	~70% of global glacier mass lost in past 20 years is due to human-induced climate change

Source: R. Garcia-Herrera et al., 2010; K. Zander et al., 2015; Yin Sun et al., 2019; Parkinson, Claire L. et al., 2013; Kirchmeier-Young, Megan C. et al., 2017; Philip, Sjoukje et al., 2018; Funk, Chris et al., 2019; ametsoc.net; Bellprat et al., 2015; cbc.ca; coast.noaa.gov; dosomething.org; eea.europa.eu; Free et al., 2019; Genner et al., 2017; iopscience.iop.org; jstage.jst.go.jp; Lin et al., 2016; livescience.com; Marzeion et al., 2014; Perkins et al., 2014; preventionweb.net; reliefweb.int; reuters.com; Peterson et al., 2004; theatlantic.com; theguardian.com; van Oldenburgh, 2017; water.ox.ac.uk; Wester et al., 2019; Western and Dutch Central Bureau of Statistics; worldweatherattribution.org; McKinsey Global Institute analysis

Individual climate hazards could impact multiple systems. For example, extreme heat may affect communities through lethal heat waves and daylight hours rendered unworkable, even as it shifts food systems, disrupts infrastructure services, and endangers natural capital such as glaciers. Extreme precipitation and flooding can destroy physical assets and infrastructure while endangering coastal and river communities. Hurricanes can impact global supply chains, and biome shifts can affect ecosystem services. The five systems in our impact framework are:

- **Livability and workability.** Hazards like heat stress could affect the ability of human beings to work outdoors or, in extreme cases, could put human lives at risk. Heat reduces labor capacity because workers must take breaks to avoid heatstroke and because the body naturally limits its efforts to prevent overexertion. Increased temperatures could also shift disease vectors and thus affect human health.

- **Food systems.** Food production could be disrupted as drought conditions, extreme temperatures, or floods affect land and crops. A changing climate could both improve and degrade food system performance while introducing more or less volatility. In some cases, crop yields may increase; in other cases, thresholds could be exceeded beyond which some crops fail entirely.

- **Physical assets.** Physical assets like buildings could be damaged or destroyed by extreme precipitation, tidal flooding, forest fires, and other hazards. Hazards could even materially affect an entire network of assets such as a city’s central business district.

- **Infrastructure services.** Infrastructure assets are a particular type of physical asset that could be destroyed or disrupted in their functioning, leading to a decline in the services they provide or a rise in the cost of these services. For example, power systems could become less productive under very hot conditions. A range of hazards including heat, wind, and flooding can disrupt infrastructure services. This in turn can have knock-on effects on other sectors that rely on these infrastructure assets.

- **Natural capital.** Climate change is shifting ecosystems and destroying forms of natural capital such as glaciers, forests, and ocean ecosystems, which provide important services to human communities. This in turn imperils the human habitat and economic activity. These impacts are hard to model but could be nonlinear and in some cases irreversible, such as glacier melting, as the temperature rises. In some cases, human mismanagement may play a role—for example, with forest fires and water scarcity—but its extent and impact are multiplied by climate change.

The nine distinct cases of physical climate risk in various geographies and sectors that we examine, including direct impact and knock-on effects, as well as adaptation costs and strategies, help illustrate the specific socioeconomic impact of the different physical climate hazards on the examined human, physical, or natural system. Our cases cover each of the five systems across geographies and include multiple climate hazards, sometimes occurring at the same location. Overall, our cases highlight a wide range of vulnerabilities to the changing climate.

Specifically, we looked at the impact of climate change on livability and workability in India and the Mediterranean; disruption of food systems through looking at global breadbaskets and African agriculture; physical asset destruction in residential real estate in Florida and in supply chains for semiconductors and heavy rare earth metals; disruption of five types of infrastructure services and, in particular, the threat of flooding to urban areas; and destruction of natural capital through impacts on glaciers, oceans, and forests.

Our case studies highlight that physical climate risk is growing, often in nonlinear ways. Physical climate impacts are spreading across regions, even as the hazards grow more intense within regions.

To assess the magnitude of direct physical climate risk in each case, we examine the severity of the hazard and its likelihood; the exposure of people, assets, or economic activity to the hazard; and the extent to which systems are vulnerable to the hazard. Researchers have examined insurance data on losses from natural disasters and found that most of the increase in direct impact to date has come more from greater exposure than from increases in the climate hazards themselves.[22] Changes in climate itself in the future are likely to play a bigger role. As the Earth warms, hazards will become more intense and or more frequent. Since physiological, human-made, and ecological systems have evolved or been optimized over time for historical climates, even small changes in hazard intensity can have large consequences if physical thresholds for resilience are breached.

Indeed, thresholds exist for all systems we have examined. For example: the human body functions at a stable core temperature of about 37 degrees Celsius, above which physical and mental functioning could be fatally impaired; corn yields can decline significantly above 20 degrees Celsius; cell phone towers have typically been built to withstand certain wind speeds above which they may fail (Exhibit E6).

The impacts, once such thresholds are crossed, could be significant. For example, by 2030 in an RCP 8.5 scenario, absent an effective adaptation response, we estimate that 160 million to 200 million people in India could live in regions with a 5 percent annual probability of experiencing a heat wave that exceeds the survivability threshold for a healthy human being (without factoring in air conditioner penetration).[23]

Outdoor labor productivity is also expected to fall, thus reducing the effective number of hours that can be worked outdoors (Exhibit E7). As of 2017, in India, heat-exposed work produces about 50 percent of GDP, drives about 30 percent of GDP growth, and employs about 75 percent of the labor force, some 380 million people.[24] By 2030, the average number of lost daylight working hours in India could increase to the point where between 2.5 and 4.5 percent of GDP could be at risk annually, according to our estimates.

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[22] Various researchers have attempted to identify the role played by each of these factors in driving economic losses to date. Insurance records of losses from acute natural disasters like floods, hurricanes, and forest fires show a clear upward trend in losses in real terms over time, and analyses show that the majority of this is driven by an increase in exposure. This is based on normalizing the real losses for increases in GDP, wealth, and exposure to strip out the effects of a rise in exposure. See for example, Roger Pielke, "Tracking progress on the economic costs of disasters under the indicators of the sustainable development goals," *Environmental Hazards*, 2019, Volume 18, Number 1. The work by Pielke finds no upward trend in economic impact after normalizing the damage data, and indeed a decrease in weather /climate losses as a proportion of GDP since 1990. Other researchers find a small upward trend after accounting for effects of GDP, wealth, and population, suggesting some potential role of climate change in losses to date. See for example, Fabian Barthel and Eric Neumayer, "A trend analysis of normalized insured damage from natural disasters," *Climatic Change*, 2012, Volume 113, Number 2; Robert Muir-Wood et al., "The search for trends in a global catalogue of normalized weather-related catastrophe losses," Climate Change and Disaster Losses Workshop, May 2006; and Robert Ward and Nicola Ranger, *Trends in economic and insured losses from weather-related events: A new analysis*, Centre for Climate Change Economics and Policy and Munich Re, November 2010. For example, Muir-Wood et al. conduct analysis of insurance industry data between 1970 to 2005 and find that weather-related catastrophe losses have increased by 2 percent each year since the 1970s, after accounting for changes in wealth, population growth and movement, and inflation (notably, though, in some regions including Australia, India, and the Philippines, such losses have declined). Analysis by Munich Re finds a statistically significant increase in insured losses from weather-related events in the United States and in Germany over the past approximately 30 to 40 years.

[23] A lethal heat wave is defined as a three-day period with maximum daily wet-bulb temperatures exceeding 34 degrees Celsius wet-bulb. This threshold was chosen because the commonly defined heat threshold for human survivability is 35 degrees Celsius wet-bulb, and large cities with significant urban heat island effects could push 34C wet-bulb heat waves over the 35C threshold. These projections are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cooling island effects. If a non-zero probability of lethal heat waves in certain regions occurred in the models for today, this was set to zero to account for the poor representation of the high levels of observed atmospheric aerosols in those regions in the CMIP5 models. High levels of atmospheric aerosols provide a cooling effect that masks the risk. See India case for further details. This analysis excludes grid-cells where the likelihood of lethal heat waves is <1 percent, to eliminate areas of low statistical significance.

[24] Exposed sectors include exclusively outdoor sectors such as agriculture, mining, and quarrying, as well as indoor sectors with poor air-conditioning penetration, including manufacturing, hospitality, and transport. Reserve Bank of India, Database on Indian Economy, dbie.rbi.org.in/DBIE/dbie.rbi?site=home.

Exhibit E6

Direct impacts of climate change can become nonlinear when thresholds are crossed.

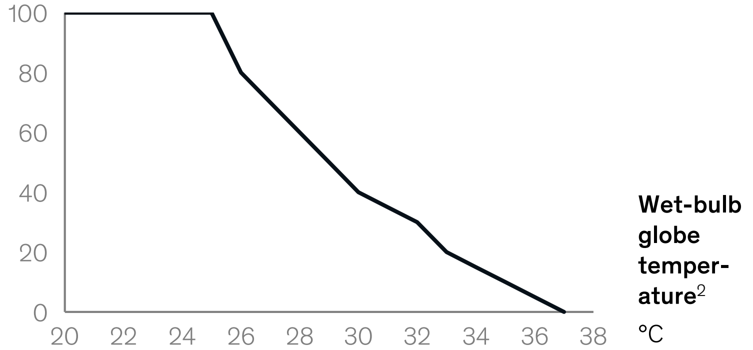
System | **Example** | **Nonlinear behavior**

Human

Impact of heat and humidity on outdoor labor

Share of labor capacity in a given hour[1]

%

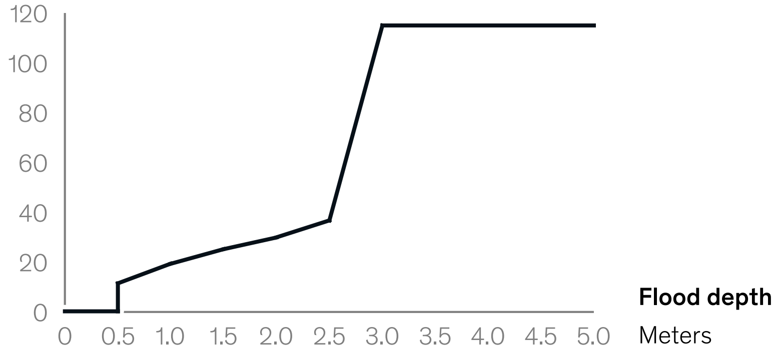


Physical

Floodwater impacts on an exemplary UK train station

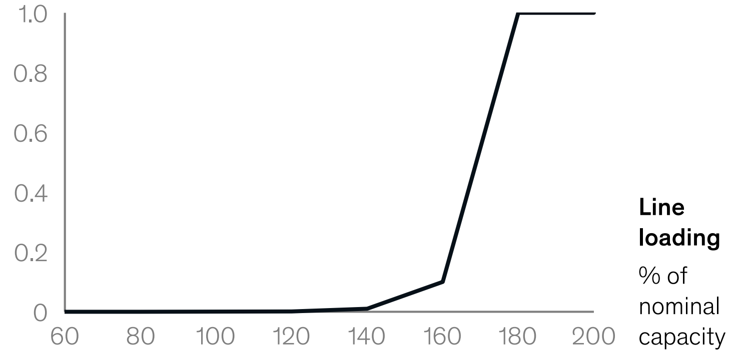
Asset impact[3]

$ million



Effects of line overloading (eg, sagging due to heat) in an electrical grid[4]

Probability of line tripping

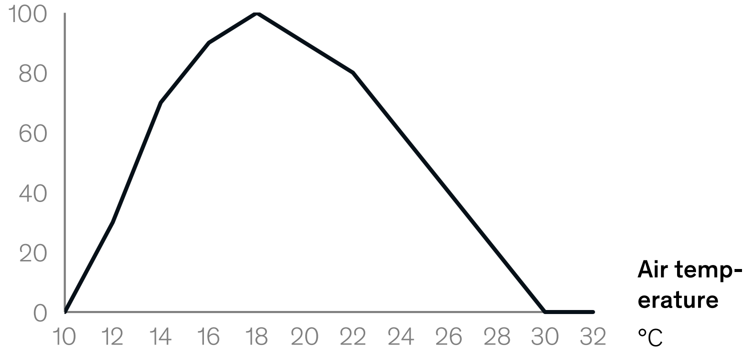


Natural

Temperature impact on crop yield

Corn reproductive growth rate

%



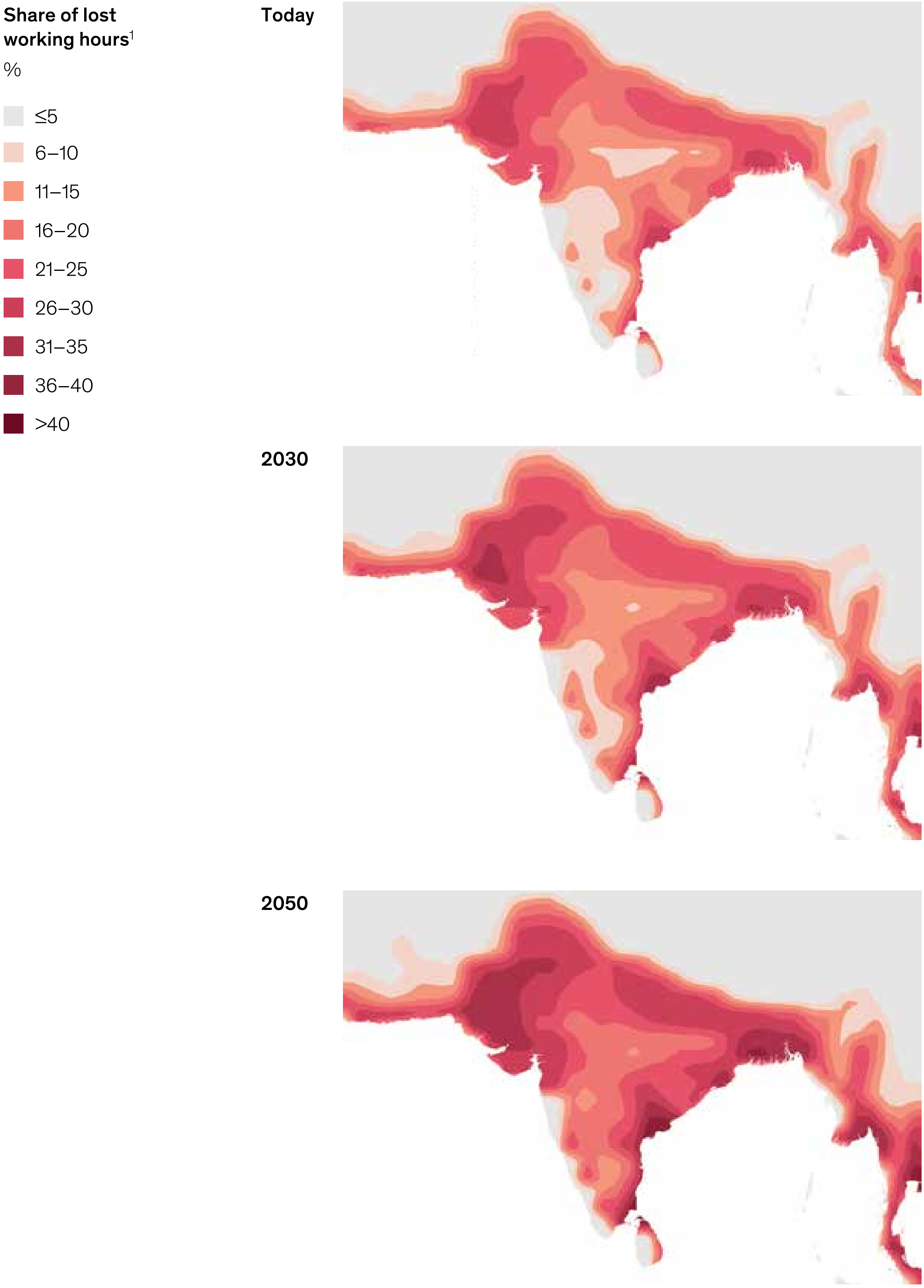
1. Immediate effect; longer exposure will cause rapidly worsening health impacts. Humans can survive exposure to 35C wet-bulb temperatures for between four to five hours. During this period, it is possible for a small amount of work to be performed, which is why the working hours curve does not approach zero at 35C WBGT (which, in the shade, is approximately equivalent to 35C wet-bulb).
2. Based on in-shade wet-bulb globe temperature (WBGT). WBGT is defined as a type of apparent temperature which usually takes into account the effect of temperature, humidity, wind speed, and visible and infrared radiation on humans.
3. Average cost of a new build train station globally used for asset impact/cost on UK train station; salvageable value is assumed zero once asset passes destruction threshold.
4. Both acute events (eg, flooding, fires, storms) and chronic changes in climatic conditions (eg, heat) can affect the grid and may lead to outages.

Source: Dunne et al., 2013, adjusted according to Foster et al., 2018; Henneaux, 2015; Korres et al., 2016; CATDAT global database on historic flooding events; McKinsey infrastructure benchmark costs; EU Commission Joint Research Centre damage functions database; historical insurance data and expert engineer interviews on failure thresholds; McKinsey Global Institute analysis

Exhibit E7

The affected area and intensity of extreme heat and humidity is projected to increase, leading to a higher expected share of lost working hours.

Based on RCP 8.5



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1. Lost working hours include loss in worker productivity as well as breaks, based on an average year that is an ensemble average of climate models.

Note: See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: Woods Hole Research Center

Economic and financial systems have similarly been designed and optimized for a certain level of risk and increasing hazards may mean that such systems are vulnerable. We have already noted that supply chains are often designed for efficiency over resiliency, by concentrating production in certain locations and maintaining low inventory levels. Food production is also heavily concentrated; just five regional “breadbasket” areas account for about 60 percent of global grain production. Rising climate hazards might therefore cause such systems to fail, for example if key production hubs are affected. Finance and insurance have vulnerabilities, too; while they were designed to manage for some level of risk, intensifying climate hazards could stretch their limits. For example, consider the residential real estate market in Florida (Exhibit E8). Home owners rely on insurance to build financial resilience against risks like floods, but premiums could rise in the face of increasing risk and insurance does not cover devaluations of home prices. Lenders may bear some risk if home owners default. Among other possible repercussions, federal governments have been acting as backstops but may need to be prepared to finance more.

Other cases we examined highlight large knock-on impacts when thresholds are breached. These come about in particular when the people and assets affected are central to local economies and those local economies are tied into other economic and financial systems.

Ho Chi Minh City, a city prone to monsoonal and storm surge flooding, is one example. We estimate that direct infrastructure asset damage from a 100-year flood today would be on the order of $200 million to $300 million. This could rise to $500 million to $1 billion in 2050, assuming no additional adaptation investment and not including real estate–related impacts. Beyond this direct damage, we estimate that the knock-on costs could be substantial. They would rise from $100 million to $400 million today to between $1.5 billion and as much as $8.5 billion in 2050. We estimate that at least $20 billion of new infrastructure assets are currently planned for construction by 2050, more than doubling the number of major assets in Ho Chi Minh City (Exhibit E9). Many of these new infrastructure assets, particularly the local metro system, have been designed to tolerate an increase in flooding. However, in a worst-case scenario such as a sea-level rise of 180 centimeters, these thresholds could be breached in many locations.[25]

A further example from our case studies, that of coastal real estate in Florida, shows how climate hazards could have unpredictable financial impacts. The geography of Florida, with its expansive coastline, low elevation, and porous limestone foundation, makes it vulnerable to flooding. Absent any adaptation response, direct physical damages to real estate could grow with the changing climate. Average annual losses for residential real estate due to storm surge from hurricanes amount to $2 billion today. This is projected to increase to about $3 billion to $4.5 billion by 2050, depending on whether exposure is constant or increasing.[26] For a tail 100-year hurricane event, storm surge damages could rise from $35 billion today to between $50 billion and $75 billion by 2050.

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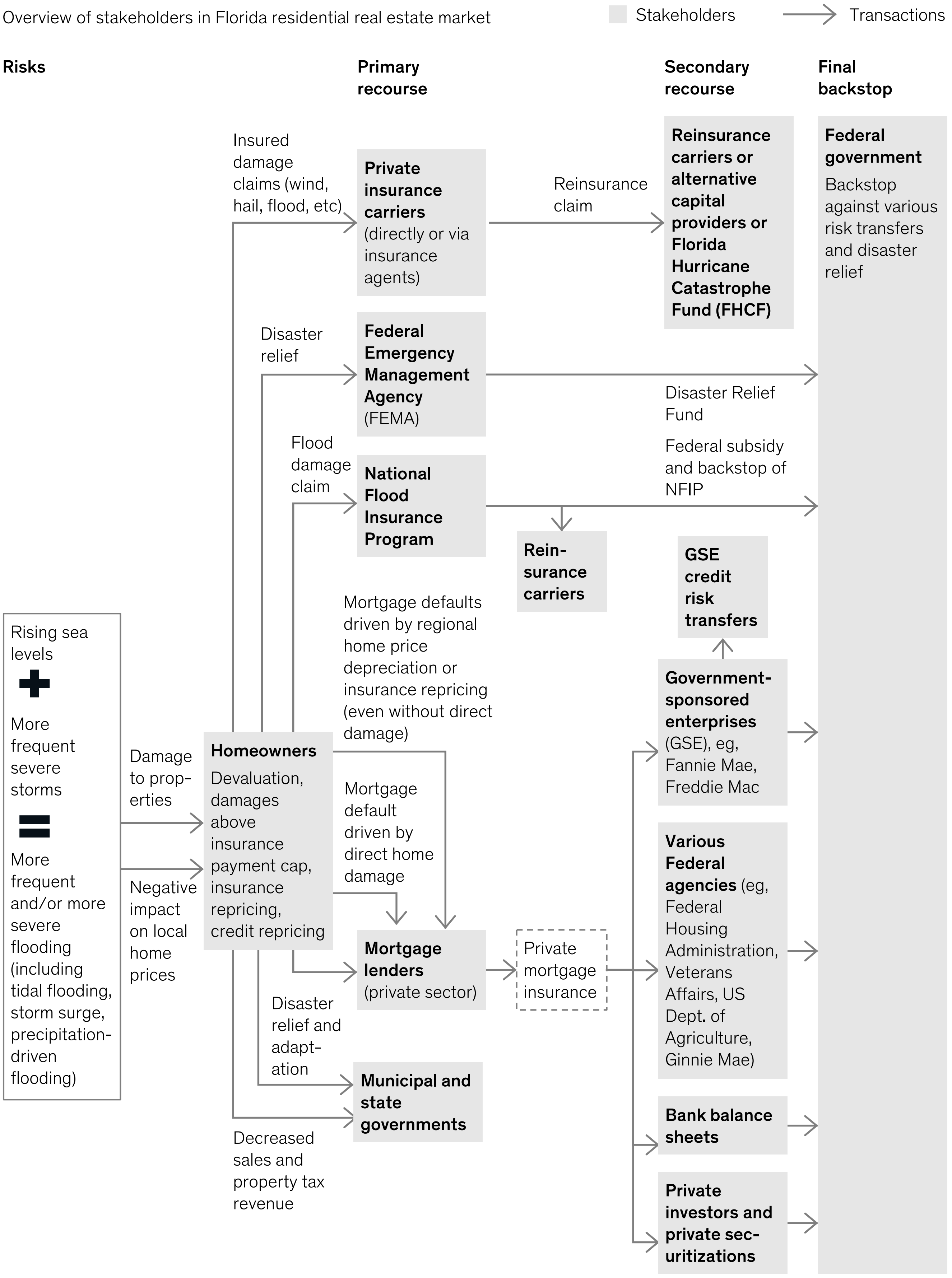
[25] This scenario is extreme, and the probability of it occurring by 2050 is negligible. Nonetheless, it illustrates that infrastructure planned for completion in or shortly before 2050 could experience another step change in risk at some point in 2060 or beyond if significant mitigation does not take place.

[26] KatRisk, 2019; direct average annual losses to all residential real estate (insured and uninsured properties). This is the long-term average loss expected in any one year, calculated by modeling the probability of a climate hazard occurring multiplied by the damage should that hazard occur, and summing over events of all probabilities. Analyses based on sea level rise in line with the US Army Corps of Engineers high curve, one of the recommended curves from the Southeast Florida Regional Climate Change Compact. Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, *Unified sea level rise projection: Southeast Florida,* October 2015. More broadly, considering the hurricane hazard, while total hurricane frequency is expected to remain unchanged or to decrease slightly as the climate changes, cumulative hurricane rainfall rates, average intensity, and proportion of storms that reach Category 4–5 intensity are projected to increase, even for a 2°C or less increase in global average temperatures. Thomas Knutson et al., *Tropical cyclones and climate change assessment: Part II. Projected response to anthropogenic warming*, American Meteorological Society, 2019. Range based on assessing how exposure varies; from constant exposure to exposure based on historical rates of growth of real estate.

Exhibit E8

Who holds the risk?

Overview of stakeholders in Florida residential real estate market



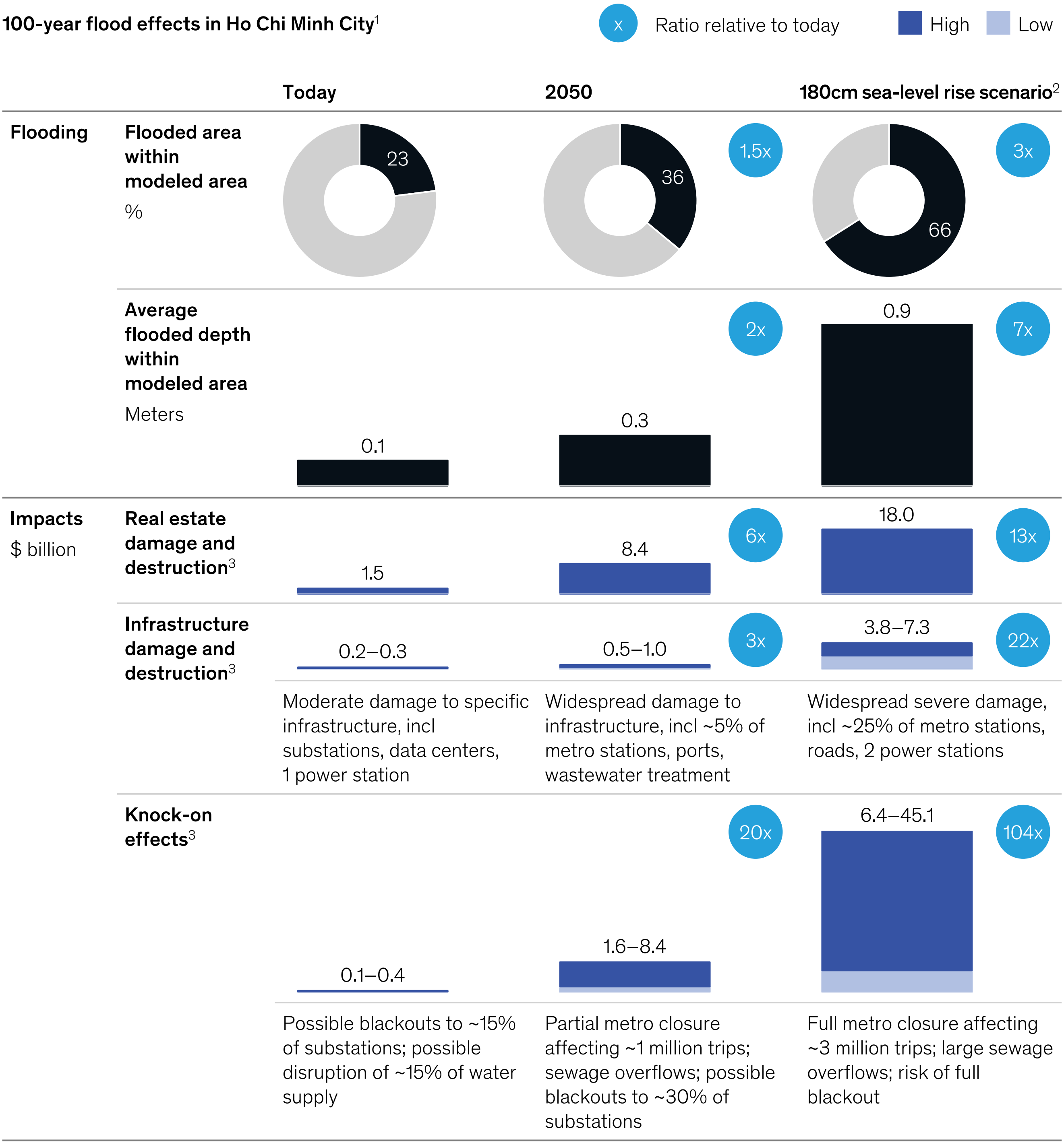
Source: McKinsey Global Institute analysis

Exhibit E9

Ho Chi Minh City could experience 5 to 10 times the economic impact from an extreme flood in 2050 vs today.

Based on RCP 8.5

100-year flood effects in Ho Chi Minh City[1]



Infrastructure damage and destruction:

- Today: Moderate damage to specific infrastructure, incl substations, data centers, 1 power station
- 2050: Widespread damage to infrastructure, incl ~5% of metro stations, ports, wastewater treatment
- 180cm sea-level rise scenario: Widespread severe damage, incl ~25% of metro stations, roads, 2 power stations

Knock-on effects:

- Today: Possible blackouts to ~15% of substations; possible disruption of ~15% of water supply
- 2050: Partial metro closure affecting ~1 million trips; sewage overflows; possible blackouts to ~30% of substations
- 180cm sea-level rise scenario: Full metro closure affecting ~3 million trips; large sewage overflows; risk of full blackout

1. Repair and replacement costs. Qualitative descriptions of damage and knock-on effects are additional to previous scenarios.
2. Assets in planning today with long expected design lives (such as the metro) could exist long enough to experience a 1% probability flood in a 180-centimeter sea-level-rise worst-case scenario by the end of the century if significant action is not taken to mitigate climate change.
3. Value of wider societal consequences of flooding, with a focus on those attributable to infrastructure failure, includes loss of freight movement, lost data revenues, and lost working hours due to a lack of access to electricity, clean water, and metro services. Adjusted for economic and population growth to 2050 for both 2050 and 180cm sea-level rise scenarios.

Note: See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Following standard practice, we define future states (current, 2030, 2050) as the average climatic behavior over multidecade periods. The climate state today is defined as the average conditions between 1998–2017, in 2030 as the average between 2021–40, and in 2050 between 2041–60. Assumes no further adaptation action is taken. Figures may not sum to 100% because of rounding.

Source: Asian Development Bank; BTE; CAPRA; CATDAT disaster database; Daniell et al., 2017; Dutch Ministry of Infrastructure and Environment; ECLAC; EU Commission; HAZUS; Oxford Economics; People's Committee of Ho Chi Minh City; Scussolini et al., 2017; UN; Viet Nam National University, Ho Chi Minh City; World Bank; historical insurance data; review of critical points of failure in infrastructure assets by chartered engineering consultants; McKinsey Global Institute analysis

These numbers do not include the potential devaluation of flooding affected real estate. Exposed homes could see a devaluation of $30 billion to $80 billion, or about 15 to 35 percent, by 2050, all else being equal.[27] Lower real estate prices could in turn have knock-on effects, including forgone property tax revenue (a major source of state income), reduced wealth and spending by home owners, reduced, halted, or reversed resident inflow, and forced changes in government spending. For example, rough estimates suggest that the price effects discussed above could impact property tax revenue in some of the most affected counties by about 15 to 30 percent (though impacts across the state could be less, at about 2 to 5 percent). Business activity could be negatively affected, as could the availability and/or price of insurance and mortgage financing in high-risk counties. Financial markets could bring these risks forward, and the recognition of large future changes could lead to price adjustments. Awareness of climate risk could make long-duration borrowing more expensive or unavailable and reduce valuations, for example. This recognition could happen quickly, with the possibility of cascading consequences.

Climate change could create inequality—simultaneously benefiting some regions while hurting others. For example, rising temperatures may boost tourism in areas of northern Europe while reducing the economic vitality of southern European resorts. The volume of water in basins in northern Africa, Greece, and Spain could decline by more than 15 percent by 2050 even as volume in basins in Germany and the Netherlands increases by between 1 and 5 percent.[28] The mild Mediterranean climate is expected to grow hotter—by 2050, the climate in the French port city of Marseille could more closely resemble that of Algiers today—which could disrupt key sectors such as tourism and agriculture.[29]

Within regions, the poorest communities and populations within each of our cases typically are the most vulnerable to climate events. They often lack financial means. For example, acute climate events could trigger harvest failure in multiple breadbasket locations—that is, significantly lower-than-average yields in two or more key production regions for rice, wheat, corn, and soy. We estimate that the chance of a greater than 15 percent yield shock once in the next ten years could rise from 10 percent today to 18 percent in 2030, while the chance of a greater than 10 percent yield shock occurring in the next decade could rise from 46 to 69 percent.[30] Given current high grain stocks, totaling about 30 percent of consumption, the world would not run out of grain. However, historical precedent suggests that prices could spike by 100 percent or more in the short term, in the event of a greater than 15 percent decline in global supply that reduces stocks. This would particularly hurt the poorest communities, including the 750 million people living below the international poverty line.

The global socioeconomic impacts of climate change could be substantial as a changing climate directly affects human, physical, and natural capital

While our case studies illustrate the localized impacts of a changing climate, rising temperatures are a global trend. To understand how physical climate hazards could evolve around the world, we developed a global geospatial assessment of climate impacts over the next 30 years covering 105 countries.[31] We again rely on our framework of the direct impacts of climate change on five human, physical, and natural systems. For each system we have identified one or more measures

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[27] Analysis supported by First Street Foundation, 2019. Ranges based on whether homes that frequently flood (>50x per year), see more significant devaluations or not. Note that other factors could also affect the prices of homes and that has not been factored in. Much of the literature finds that, at least historically, prices of exposed properties have risen slower than prices of unexposed properties, rather than declined in absolute terms. For further details, see the Florida case study.

[28] World Resources Institute Water Risk Atlas, 2018.

[29] Jean-Francois Bastin et al., Understanding climate change from a global analysis of city analogues. PLoS ONE 14(7): e0217592, 2019.

[30] To estimate the likelihood, we employ crop models from the AgMIP model library that translate outputs from climate models into crop yields for each modeled grid cell. Using all available climate models over a period of 20 years, we construct a probability distribution of yields for each crop in each grid cell. Note that we are taking into account potentially positive effects on plant growth from higher CO_2 levels ("CO_2 fertilization"). Analysis is based on an assumption of no improvements in agricultural productivity (consistent with our "inherent risk" framing). See breadbasket case for further details.

[31] To conduct this analysis, we have relied on geospatial climate hazard data, including from Woods Hole Research Center analysis of CMIP5 Global Climate Model output, the World Resources Institute, the European Center for Medium-Range Weather Forecasts and data from Rubel et al. (obtained from the National Oceanic and Atmospheric Administration). We used geospatial data on population, capital stock, and GDP from the European Commission Global Human Settlement (GHS) and the UN *Global Assessment Report on Disaster Risk Reduction*, as well as data from other sources as described in Chapter 4. Notably, we have focused our analysis on a subset of possible climate hazards: lethal heat waves, heat and humidity and its impact on workability, water stress, riverine flooding, drought, and the impact of increased temperature and changes in precipitation on biome shifts. Analysis based on an RCP 8.5 scenario.

to define the impact of climate change, often building on the risk measures used in our case studies, and choosing the best possible measures based on broad country coverage and data availability.[32] For example, for livability and workability, we use the measures of the share of population living in areas projected to experience a non-zero annual probability of lethal heat waves as well as the annual share of effective outdoor working hours affected by extreme heat and humidity in climate-exposed regions. This is similar to the approach followed in our India case study.

We find that all 105 countries are expected to experience an increase in at least one major type of impact on their stock of human, physical, and natural capital by 2030. Intensifying climate hazards could put millions of lives at risk, as well as trillions of dollars of economic activity and physical capital, and the world's stock of natural capital. The intensification of climate hazards across regions will bring areas hitherto unexposed to impacts into new risk territory.

— **Livability and workability.** By 2030, under an RCP 8.5 scenario, our research suggests that between 250 million and 360 million people could live in regions where there is a non-zero probability of a heat wave exceeding the threshold for survivability for a healthy human being in the shade (a measure of livability, without factoring in air conditioner penetration).[33] The average probability of a person living in an at-risk region experiencing such a lethal heat wave at least once over the decade centered on 2030 is estimated to be approximately 60 percent.[34] Some exposed regions will have a lower probability, and some regions higher. By 2050, the number of people living in regions exposed to such heat waves could rise further, to between 700 million and 1.2 billion, again without factoring in an adaptation response via air conditioner penetration. This reflects the fact that some of the most heavily populated areas of the world are usually also the hottest and most humid, and, as described below, these areas are becoming even hotter and more humid. Today, air conditioner penetration is roughly 10 percent across India, and roughly 60 percent across China.[35] The global average number of working hours that could be lost due to increasing heat and humidity in exposed regions (a measure of workability impacts) could almost double by 2050, from 10 percent to 15 to 20 percent. This is because more regions of the world are exposed, and the ones that are exposed would see higher intensity of heat and humidity effects. We used these projections to estimate the resulting GDP at risk from lost working hours. This could amount to $4 trillion to $6 trillion globally at risk by 2050 in an average year (Exhibit E10). This the equivalent of 2 to 3.5 percent of 2050 GDP, up from about 1.5 percent today.[36]

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[32] The indicators used in our geospatial analysis include: share of population that lives in areas experiencing a non-zero annual probability of lethal heat waves, annual share of effective outdoor working hours affected by extreme heat and humidity in climate exposed-regions, water stress as measured by the annual demand of water as a share of annual supply of water (these three are measures of livability and workability, and are considered in our India case and Mediterranean cases), annual share of capital stock at risk of flood damage in climate-exposed regions (asset destruction and infrastructure services; similar measures of capital stock damage are used in our Florida and Inundation cases), share of time spent in drought over a decade (measure of food systems; we also consider the impact of drought in our Mediterranean case), share of land surface changing climate classification annually (measure of natural capital; this was used for our geospatial analysis to allow us to develop a global measure of natural capital risk). Notably, drought is the one measure of hazard rather than risk used in this framework. This was done because of data limitations with obtaining data on impacts on agricultural yield by country, since the AgMIP climate models used to project agricultural yields tend only to be used for relatively large breadbasket regions, rather than at a country level. We are able to use the AgMIP results to provide global trends on breadbaskets and results pertaining to large breadbasket regions; however, such results were not included in the country-by-country analysis. We also excluded risk due to hazards like hurricanes, storm surge, and forest fires due to challenges obtaining sufficiently granular and robust data across countries. See Chapter 4 for details.

[33] Here, as before, lethal heat wave refers to a three-day period with average daily maximum wet-bulb temperatures exceeding 34 degrees Celsius. This temperature was chosen because urban areas with a high urban heat island effect could amplify 34°C ambient temperatures over the 35°C wet-bulb survivability threshold. These numbers are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cool island effects. If a non-zero probability of lethal heat waves in certain regions occurred in the models for today, this was set to zero to account for the poor representation of the high levels of observed atmospheric aerosols in those regions in the CMIP5 models. High levels of atmospheric aerosols provide a cooling effect that masks the risk. See India case for further details. This analysis excludes grid-cells where the the likelihood of lethal heat waves is <1 percent, to eliminate areas of low statistical significance. Additionally, these numbers assume no air-conditioning protection, and as such should be considered an upper bound. See Chapter 2 for details. Analysis based on an RCP 8.5 scenario.

[34] This calculation is a rough approximation. It assumes that the annual probability of roughly 9 percent applies to every year in the decade centered around 2030. We first calculate the cumulative probability of a heat wave not occurring in that decade, which is 91 percent raised to the power of 10. The cumulative probability of a heat wave occurring at least once in the decade is then 1 minus that number.

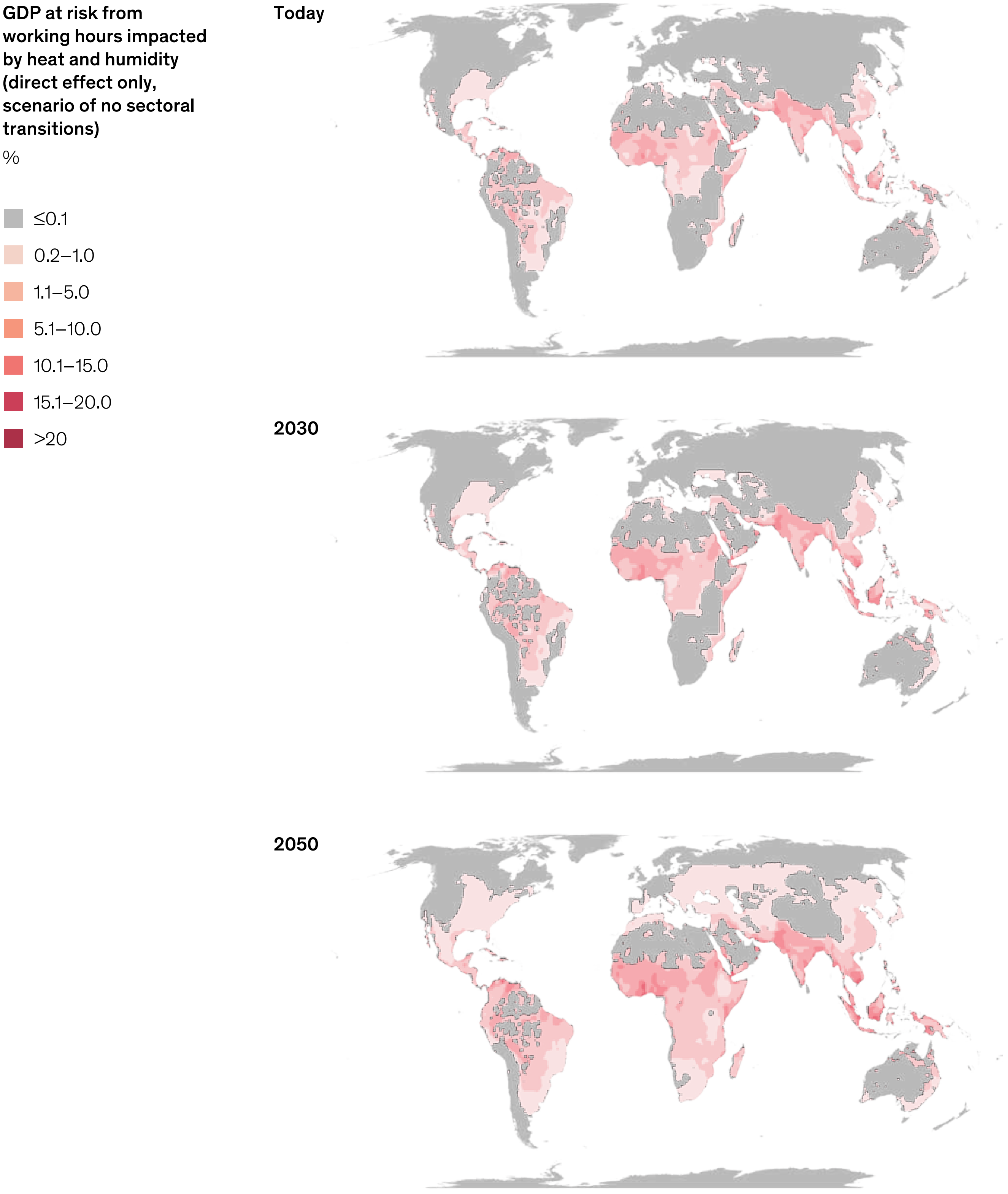
[35] India Cooling Action Plan Draft, Ministry of Environment, Forest & Climate Change, Government of India, September 2018; The Future of Cooling in China, IEA, Paris, 2019.

[36] The range here is based on the pace of sectoral transition across countries. GDP at risk will be higher if a greater portion of the economy is occupied in outdoor work. The lower end of the range assumes that today's sectoral composition persists, while the higher end is based on projections from IHS Markit Economics and Country Risk on sectoral transitions.

Exhibit E10

GDP at risk from the effect of extreme heat and humidity on effective working hours is expected to increase over time.

Based on RCP 8.5



Note: See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. These maps do not consider sectoral shifts when projecting impact on labor productivity into the future—the percentage and spatial distribution of outdoor labor are held constant. For this analysis, outdoor labor is considered to include agriculture, construction, and mining and quarrying only, and knock-on impacts on other sectors are not considered. Following standard practice, we define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: IHS Markit Economics and Country Risk; Woods Hole Research Center; McKinsey Global Institute analysis

— **Food systems.** Our research suggests an increase in global agricultural yield volatility that skews toward worse outcomes. For example, by 2050, the annual probability of a greater than 10 percent reduction in yields for wheat, corn, soy, and rice in a given year is projected to increase from 6 to 18 percent.[37] The annual probability of a greater than 10 percent increase in yield in a given year is expected to rise from 1 percent to 6 percent. These trends are not uniform across countries and, importantly, some could see improved agricultural yields, while others could suffer negative impacts. For example, the average breadbasket region of Europe and Russia is expected to experience a 4 percent increase in average yields by 2050. While the annual probability of a greater than 10 percent yield failure there will increase, from 8 percent to 11 percent annually by 2050, the annual probability of a bumper year with a greater than 10 percent higher-than-average yield in the same period will increase by more, from 8 percent to 18 percent.

— **Physical assets and infrastructure services.** Assets can be destroyed or services from infrastructure assets disrupted from a variety of hazards, including flooding, forest fires, hurricanes, and heat. Statistically expected damage to capital stock from riverine flooding could double by 2030 from today's levels and quadruple by 2050. Data availability has made it challenging to develop similar estimates for the much larger range of impacts from tidal flooding, fires, and storms.[38]

— **Natural capital.** With temperature increases and precipitation changes, the biome in parts of the world is expected to shift. The biome refers to the naturally occurring community of flora and fauna inhabiting a particular region. For this report, we have used changes in the Köppen Climate Classification System as an indicative proxy for shifts in biome.[39] For example, tropical rainforests exist in a particular climatic envelope that is defined by temperature and precipitation characteristics. In many parts of the world, this envelope could begin to be displaced by a much drier "tropical Savannah" climate regime that threatens tropical rainforests. Today, about 25 percent of the Earth's land area has already experienced a shift in climate classification compared with the 1901–25 period. By 2050, that number is projected to increase to about 45 percent. Almost every country will see some risk of biome shift by 2050, affecting ecosystem services, local livelihoods, and species' habitat.

Countries with the lowest per capita GDP levels are generally more exposed

While all countries are affected by climate change, our research suggests that the poorest countries are generally more exposed, as they often have climates closer to dangerous physical thresholds. The patterns of this risk increase look different across countries. Broadly speaking, countries can be divided into six groups based on their patterns of increasing risk (Exhibits E11, E12, and E13).[40]

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[37] Global yields based on an analysis of six global breadbaskets that make up 70 percent of global production of four crops; wheat, soy, maize, and rice. Cumulative likelihood calculated for the decade centered on 2030 and 2050 by using annual probabilities for the climate state in the 2030 period, and the 2050 period respectively. Annual probabilities are independent and can therefore be aggregated to arrive at a cumulative decadal probability. Yield anomalies here are measured relative to the 1998-2017 average yield.

[38] See Chapter 4 for details.

[39] The Köppen climate system divides climates into five main climate groups with each group further subdivided based on seasonal precipitation and temperature patterns. This is not a perfect system for assessing the location and composition of biomes; however, these two characteristics do correlate very closely with climate classification, and therefore this was assessed as a reasonable proxy for risk of disruptive biome changes.

[40] These patterns were primarily based on looking at indicators relating to livability and workability, food systems, and natural capital. The annual share of capital stock at risk of riverine flood damage in climate-exposed regions indicator was considered but was not found to be the defining feature of any country grouping aside from a lower-risk group of countries.

Exhibit E11

We identify six types of countries based on their patterns of expected change in climate impacts.

Based on RCP 8.5

⬜ Risk decrease ░ No or slight risk increase ▒ Moderate risk increase █ High risk increase

Change in… (2018–50, pp)

Country	Livability and workability: Share of population that lives in areas experiencing a non-zero annual probability of lethal heat waves[1]	Livability and workability: Annual share of effective outdoor working hours affected by extreme heat and humidity in climate exposed-regions	Livability and workability: Water stress[2]	Food systems: Share of time spent in drought over a decade	Physical assets/ infrastructure services: Annual share of capital stock at risk of riverine flood damage in climate-exposed regions[3]	Natural capital: Share of land surface changing climate classification
Significantly hotter and more humid countries						
Bangladesh	█	█	⬜	⬜	░	▒
India	█	█	⬜	⬜	▒	█
Nigeria	█	█	⬜	░	░	░
Pakistan	█	▒	⬜	░	░	▒
Other countries in group: Benin, Burkina Faso, Cambodia, Cote d'Ivoire, Eritrea, Ghana, Myanmar, Niger, Senegal, Thailand, Vietnam, Yemen						
Average (all countries in group)	█	█	⬜	⬜	▒	▒
Hotter and more humid countries						
Ethiopia	░	▒	⬜	⬜	▒	█
Indonesia	░	█	⬜	░	█	░
Japan	░	▒	⬜	░	█	█
Philippines	░	█	⬜	⬜	░	▒
Other countries in group: Angola, Cameroon, Chad, Ecuador, Guinea, Guyana, Jordan, Laos, Liberia, Madagascar, Papua New Guinea, Saudi Arabia, Somalia, Suriname, Tanzania, Uganda, Uruguay, Zambia						
Average (all countries in group)	░	█	⬜	▒	▒	▒
Hotter countries						
Colombia	░	▒	░	░	█	▒
Dem. Rep. Congo	░	█	░	▒	▒	▒

1. We define a lethal heat wave as a 3-day period with maximum daily wet-bulb temperatures exceeding 34°C wet-bulb. This threshold was chosen because the commonly defined heat threshold for human survivability is 35°C wet-bulb, and large cities with significant urban heat island effects could push 34°C wet-bulb heat waves over the 35°C threshold. These projections are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cooling island effects.
2. Water stress is measured as annual demand of water as a share of annual supply of water. For this analysis, we assume that the demand for water stays constant over time, to allow us to measure the impact of climate change alone. Water stress projections for arid, low-precipitation regions were excluded due to concerns about projection robustness.
3. Risk values are calculated based on “expected values”, ie, probability-weighted value at risk.

Note: See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: Woods Hole Research Center; World Resources Institute Water Risk Atlas, 2018; World Resources Institute Aqueduct Glob al Flood Analyzer; Rubel and Kottek, 2010; McKinsey Global Institute analysis

Exhibit E12

We identify six types of countries based on their patterns of expected change in climate impacts (continued).

Based on RCP 8.5

⬜ Risk decrease ░ No or slight risk increase ▒ Moderate risk increase █ High risk increase

Country	**Livability and workability**			**Food systems**	**Physical assets/ infrastructure services**	**Natural capital**
Change in… (2018–50, pp)	Share of population that lives in areas experiencing a non-zero annual probability of lethal heat waves[1]	Annual share of effective outdoor working hours affected by extreme heat and humidity in climate exposed-regions	Water stress[2]	Share of time spent in drought over a decade	Annual share of capital stock at risk of riverine flood damage in climate-exposed regions[3]	Share of land surface changing climate classification
Hotter countries (continued)						
Malaysia	░	█	░	⬜	▒	░
South Korea	░	▒	▒	░	▒	█
Other countries in group: Botswana, Central African Rep., Cuba, Gabon, Guatemala, Honduras, Hungary, Libya, Malawi, Mali, Mauritania, Mozambique, Namibia, Nicaragua, Oman, Paraguay, Rep. Congo, Romania, Serbia, Venezuela, Zimbabwe						
Average (all countries in group)	░	█	░	█	▒	█
Increased water stress countries						
Egypt	░	█	█	█	░	░
Iran	░	▒	█	▒	█	█
Mexico	░	▒	█	░	█	█
Turkey	░	▒	█	█	▒	█
Other countries in group: Algeria, Australia, Azerbaijan, Bulgaria, Greece, Italy, Kazakhstan, Kyrgyzstan, Morocco, Portugal, South Africa, Spain, Syria, Tajikistan, Tunisia, Turkmenistan, Ukraine, Uzbekistan						
Average (all countries in group)	░	▒	█	█	▒	█
Lower-risk countries						
France	░	▒	░	░	█	█
Germany	░	▒	░	░	▒	█

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1. We define a lethal heat wave as a 3-day period with maximum daily wet-bulb temperatures exceeding 34°C wet-bulb. This threshold was chosen because the commonly defined heat threshold for human survivability is 35°C wet-bulb, and large cities with significant urban heat island effects could push 34°C wet-bulb heat waves over the 35°C threshold. These projections are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cooling island effects.
2. Water stress is measured as annual demand of water as a share of annual supply of water. For this analysis, we assume that the demand for water stays constant over time, to allow us to measure the impact of climate change alone. Water stress projections for arid, low-precipitation regions were excluded due to concerns about projection robustness.
3. Risk values are calculated based on "expected values", ie, probability-weighted value at risk.

Note: See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

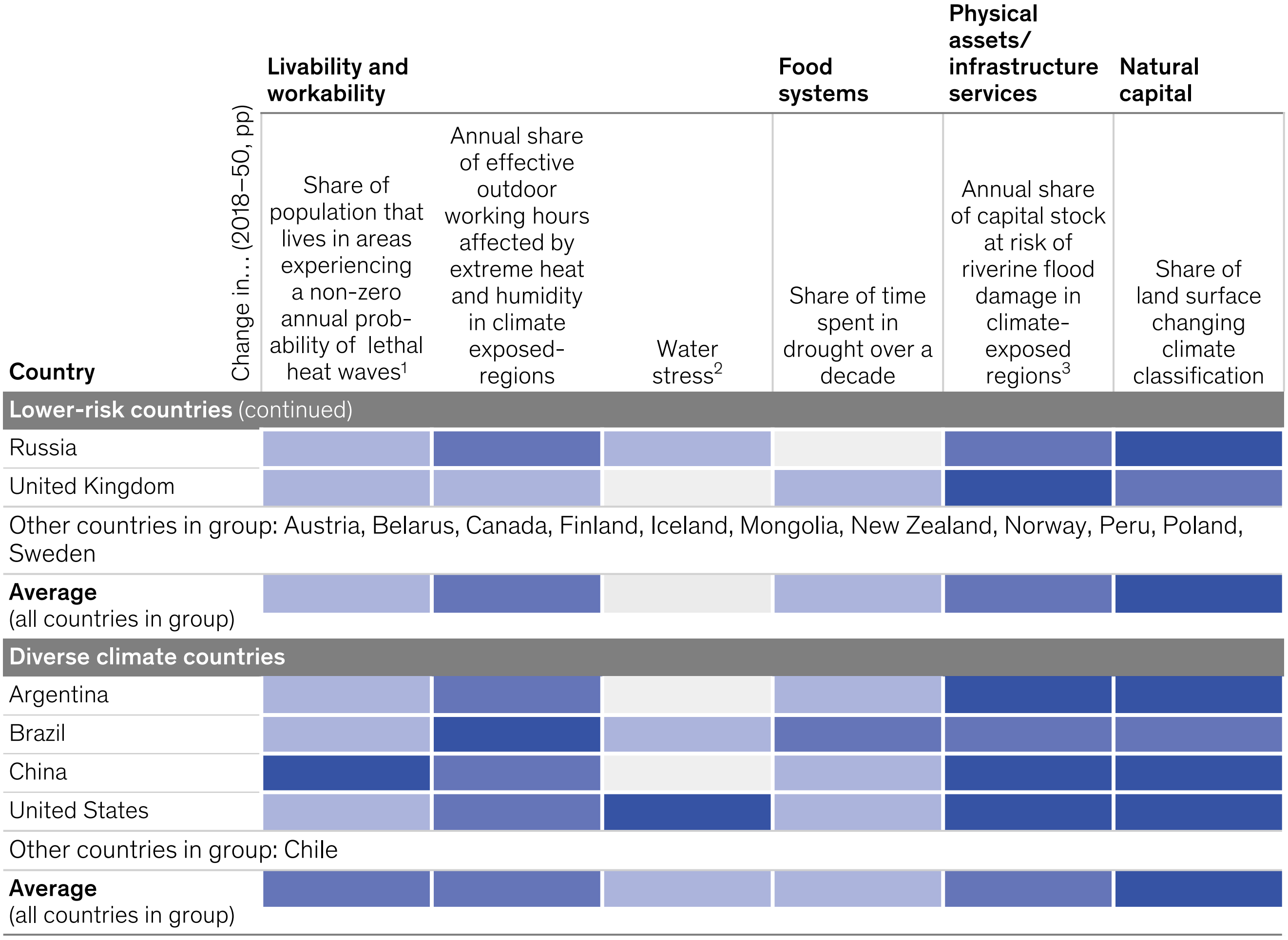
Source: Woods Hole Research Center; World Resources Institute Water Risk Atlas, 2018; World Resources Institute Aqueduct Glob al Flood Analyzer; Rubel and Kottek, 2010; McKinsey Global Institute analysis

Exhibit E13

We identify six types of countries based on their patterns of expected change in climate impacts (continued).

Based on RCP 8.5

⬜ Risk decrease ░ No or slight risk increase ▒ Moderate risk increase ▓ High risk increase



Country	Livability and workability: Share of population that lives in areas experiencing a non-zero annual probability of lethal heat waves[1]	Livability and workability: Annual share of effective outdoor working hours affected by extreme heat and humidity in climate exposed-regions	Livability and workability: Water stress[2]	Food systems: Share of time spent in drought over a decade	Physical assets/ infrastructure services: Annual share of capital stock at risk of riverine flood damage in climate-exposed regions[3]	Natural capital: Share of land surface changing climate classification
Change in… (2018–50, pp)						
Lower-risk countries (continued)						
Russia	░	▒	░	⬜	▒	▓
United Kingdom	░	░	⬜	░	▓	▒
Other countries in group: Austria, Belarus, Canada, Finland, Iceland, Mongolia, New Zealand, Norway, Peru, Poland, Sweden						
Average (all countries in group)	░	▒	⬜	░	▒	▓
Diverse climate countries						
Argentina	░	▒	⬜	░	▓	▓
Brazil	░	▓	░	▒	▒	▒
China	▓	▒	⬜	░	▓	▓
United States	░	▒	▓	░	▓	▓
Other countries in group: Chile						
Average (all countries in group)	▒	▒	░	░	▒	▓

Change in potential impact, 2018–50[4] (percentage points)

Risk decrease	n/a	n/a	<0	<0	<0	n/a
Slight risk increase	0.0–0.5	0.0–0.5	0–3	0–3	0–0.05	0–5
Moderate risk increase	0.5–5.0	0.5–5.0	3–7	3–7	0.05–0.10	5–10
High risk increase	>5.0	>5.0	>7	>7	>0.10	>10

1. We define a lethal heat wave as a 3-day period with maximum daily wet-bulb temperatures exceeding 34°C wet-bulb. This threshold was chosen because the commonly defined heat threshold for human survivability is 35°C wet-bulb, and large cities with significant urban heat island effects could push 34°C wet-bulb heat waves over the 35°C threshold. These projections are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cooling island effects.
2. Water stress is measured as annual demand of water as a share of annual supply of water. For this analysis, we assume that the demand for water stays constant over time, to allow us to measure the impact of climate change alone. Water stress projections for arid, low-precipitation regions were excluded due to concerns about projection robustness.
3. Risk values are calculated based on “expected values”, ie, probability-weighted value at risk.
4. Calculated assuming constant exposure. Constant exposure means that we do not factor in any increases in population or assets, or shifts in the spatial mix of population and assets. This was done to allow us to isolate the impact of climate change alone. Color coding for each column based on the spread observed across countries within the indicator.

Note: See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: Woods Hole Research Center; World Resources Institute Water Risk Atlas, 2018; World Resources Institute Aqueduct Glob al Flood Analyzer; Rubel and Kottek, 2010; McKinsey Global Institute analysis

- **Significantly hotter and more humid countries.** Hot and humid countries such as India and Pakistan are expected to become significantly hotter and more humid by 2050. Countries in this group are near the equator in Africa, Asia, and the Persian Gulf. They are characterized by extreme increases in heat and humidity impacts on workability, as well as a decrease in water stress. The potential livability impact that countries in this group face is projected to increase, because of the combination of heat and humidity.

- **Hotter and more humid countries.** This group includes the Philippines, Ethiopia, and Indonesia. These countries are typically between the equator and the 30-degree north and 30-degree south lines of latitude. They face a large potential increase in heat and humidity impacts on workability but may not become so hot or humid that they exceed livability thresholds. Water stress is also expected to decrease for these countries.

- **Hotter countries.** This group includes Colombia, the Democratic Republic of Congo, and Malaysia. Many countries in this group are near the equator. They are characterized by a large increase in heat and humidity impact on workability but are not expected to become so hot or humid that they pass livability thresholds. This group of countries is not expected to become wetter, and some of these countries could even become substantially drier and see increased water stress.

- **Increased water stress countries.** This group includes Egypt, Iran, and Mexico, which intersect the 30-degree north or south line of latitude. They are characterized by a large increase in water stress and drought frequency, and among the largest increases in biome change. In these locations, Hadley cells (the phenomenon responsible for the atmospheric transport of moisture from the tropics, and therefore location of the world's deserts) are expanding, and these countries face a projected reduction in rainfall.

- **Lower-risk increase countries.** This group includes Germany, Russia, and the United Kingdom. Many countries in this group lie outside the 30-degree north and south lines of latitude and are generally cold countries. Some are expected to see a decrease in overall impact on many indicators. These countries are characterized by very low levels of heat and humidity impacts and many countries are expected to see decreases in water stress and time spent in drought. As these countries grow warmer, they will likely see the largest increase in biome change as the polar and boreal climates retreat poleward and disappear. The share of capital stock at risk of riverine flood damage in climate-exposed regions could also potentially increase in some of these countries.

- **Diverse climate countries.** The final group consists of countries that span a large range of latitudes and therefore are climatically heterogeneous. Examples include Argentina, Brazil, Chile, China, and the United States.[41] While average numbers may indicate small risk increases, these numbers mask wide regional variations. The United States, for example, has a hot and humid tropical climate in the Southeast, which will see dramatic increases in heat risk to outdoor work but is not projected to struggle with water scarcity. The West Coast region, however, will not see a big increase in heat risk to outdoor work, but will struggle with water scarcity and drought. In Alaska, the primary risk will be the shifting boreal biome and the attendant ecosystem disruptions.

The risk associated with the impact on workability from rising heat and humidity is one example of how poorer countries could be more vulnerable to climate hazards (Exhibit E14).

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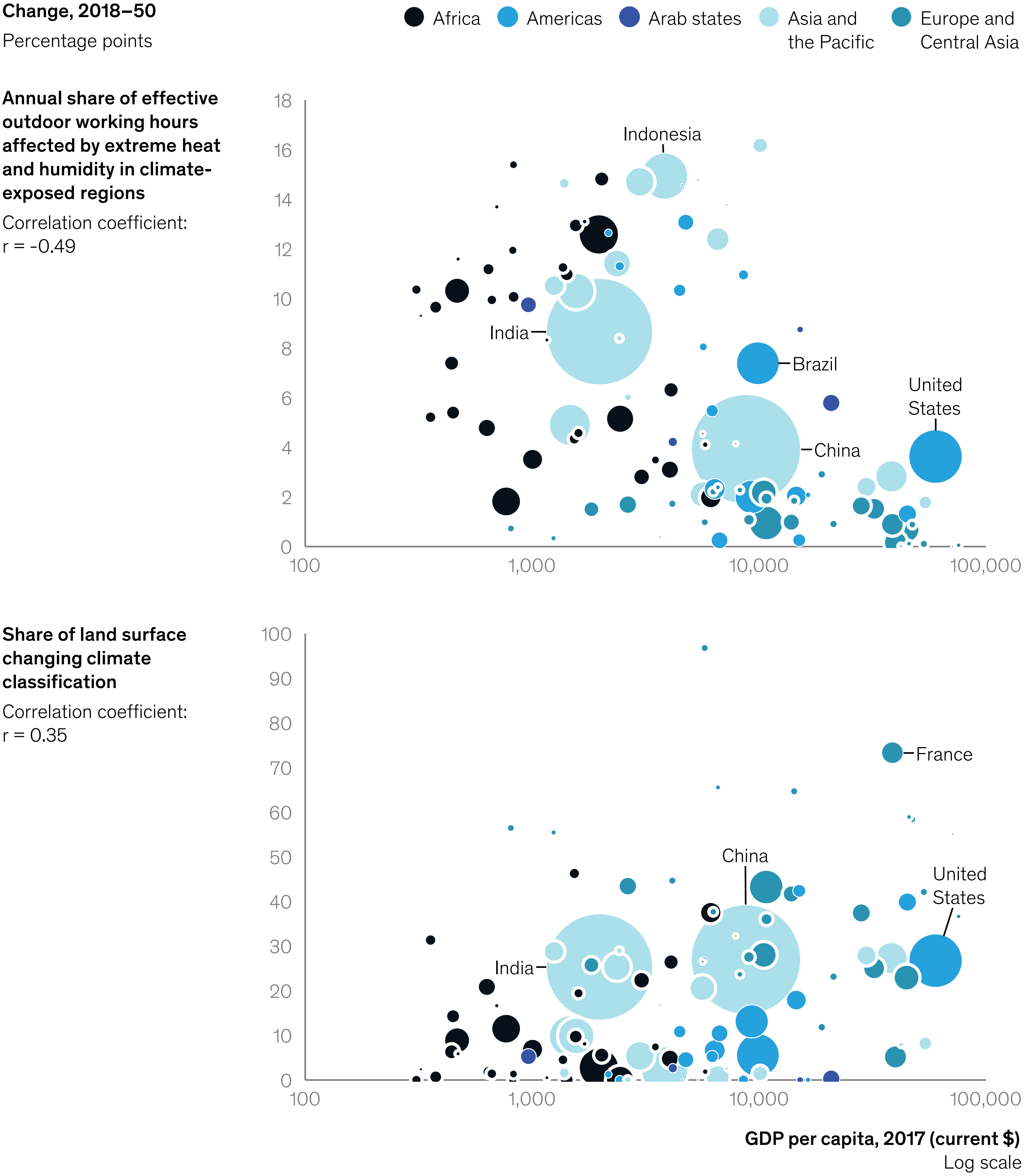
[41] To some extent, many countries could experience diversity of risk within their boundaries. Here we have focused on highlighting countries with large climatic variations, and longitudinal expanse, which drives different outcomes in different parts of the country.

Exhibit E14

Countries with the lowest per capita GDP levels face the biggest increase in risk for some indicators.

Based on RCP 8.5



Change, 2018–50
Percentage points

Annual share of effective outdoor working hours affected by extreme heat and humidity in climate-exposed regions
Correlation coefficient:
r = -0.49

Share of land surface changing climate classification
Correlation coefficient:
r = 0.35

GDP per capita, 2017 (current $)
Log scale

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1. We define a lethal heat wave as a 3-day period with maximum daily wet-bulb temperatures exceeding 34°C wet-bulb. This threshold was chosen because the commonly defined heat threshold for human survivability is 35°C wet-bulb, and large cities with significant urban heat island effects could push 34°C wet-bulb heat waves over the 35°C threshold. These projections are subject to uncertainty related to the future behavior of atmospheric aerosols and urban heat island or cooling island effects.

Note: Not to scale. See the Technical Appendix for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: Woods Hole Research Center; Rubel and Kottek, 2010; IMF; Harvard World Map; McKinsey Global Institute analysis

When looking at the workability indicator (that is, the share of outdoor working hours lost to extreme heat and humidity), the top quartile of countries (based on GDP per capita) have an average increase in risk by 2050 of approximately one to three percentage points, whereas the bottom quartile faces an average increase in risk of about five to ten percentage points. Lethal heat waves show less of a correlation with per capita GDP, but it is important to note that several of the most affected countries—Bangladesh, India, and Pakistan, to name a few—have relatively low per capita GDP levels.

Conversely, biome shift is expected to affect northern and southern latitude countries. Since many of these countries have higher per capita GDP levels, this indicator shows a positive correlation with development levels.

Leaders will need to better understand the impacts of physical climate risk, while accelerating adaptation and mitigation

In the face of these challenges, policy makers and business leaders will need to put in place the right tools, analytics, processes, and governance to properly assess climate risk, adapt to risk that is locked in, and decarbonize to reduce the further buildup of risk. In Box E3 that concludes this summary, we present a range of questions that stakeholders could consider as they look to manage risk.

Integrating climate risk into decision making

Much as thinking about information systems and cyber-risks has become integrated into corporate and public-sector decision making, climate change will also need to feature as a major factor in decisions. For companies, this will mean taking climate considerations into account when looking at capital allocation, development of products or services, and supply chain management, among others. For cities, a climate focus will become essential for urban planning decisions. Financial institutions could consider the risk in their portfolios.[42] Moreover, while this report has focused on physical risk, a comprehensive risk management strategy will also need to include an assessment of transition and liability risk, and the interplay between these forms of risk.

Developing a robust quantitative understanding is complex, for the many reasons outlined in this report. It requires the use of new tools, metrics, and analytics. Companies and communities are beginning to assess their exposure to climate risk, but much more needs to be done. Lack of understanding significantly increases risks and potential impacts across financial markets and socioeconomic systems, for example, by driving capital flows to risky assets in risky geographies or increasing the likelihood of stakeholders being caught unprepared.

At the same time, opportunities from a changing climate will emerge and require consideration. These could arise from a change in the physical environment, such as new places for agricultural production, or for sectors like tourism, as well as through the use of new technologies and approaches to manage risk in a changing climate.

One of the biggest challenges could stem from using the wrong models to quantify risk. These range from financial models used to make capital allocation decisions to engineering models used to design structures. As we have discussed, there is uncertainty associated with global and regional climate models, underlying assumptions on emissions paths, and, most importantly, in translating climate hazards to potential physical and financial damages. While these uncertainties are non-negligible, continued reliance on current models based on stable historical climate and economic data presents an even higher "model risk."

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[42] See, for example, *Getting physical: Scenario analysis for assessing climate-related risks*, Blackrock Investment Institute, April 2019.

Three examples of how models could be inappropriate for the changing climate are as follows:

- **Geography.** Current models may not sufficiently take into account geospatial dimensions. As this report highlights, direct impacts of climate change are local in nature, requiring understanding exposure to risk via geospatial analysis. For example, companies will need to understand how their global asset footprint is exposed to different forms of climate hazard in each of their main locations and indeed in each of the main locations of their critical suppliers.

- **Non-stationarity.** Given the constantly changing or non-stationary climate, assumptions based on historical precedent and experience will need to be rethought. That could include, for example, how resilient to make new factories, what tolerance levels to employ in new infrastructure, and how to design urban areas. Decisions will need to take into consideration that the climate will continue to change over the next several decades.

- **Sample bias.** Decision makers often rely on their own experiences as a frame for decisions; in a changing climate, that can result in nonlinear effects and thus lead to incorrect assessments of future risk.

Accelerating the pace and scale of adaptation

Societies have been adapting to the changing climate, but the pace and scale of adaptation will likely need to increase significantly. Key adaptation measures include protecting people and assets, building resilience, reducing exposure, and ensuring that appropriate financing and insurance are in place.

- **Protecting people and assets.** Measures to protect people and assets to the extent possible can help limit risk. Steps can range from prioritizing emergency response and preparedness to erecting cooling shelters and adjusting working hours for outdoor workers exposed to heat. Hardening existing infrastructure and assets is a key response. According to the UN Environment Programme, the cost of adaptation for developing countries may range from $140 billion to $300 billion a year by 2030. This could rise to $280 billion to $500 billion by 2050.[43] Hardening of infrastructure could include both "gray" infrastructure—for example, raising elevation levels of buildings in flood-prone areas—and natural capital or "green" infrastructure. One example of this is the Dutch Room for the River program, which gives rivers more room to manage higher water levels.[44] Another example is mangrove plantations, which can provide storm protection.

  Factoring decisions about protection into new buildings will likely be more cost-effective than retrofitting.[45] For example, infrastructure systems or factories may be designed to withstand what used to be a 1-in-200-year event. With a changing climate, what constitutes such an event may look different, and design parameters will need to be reassessed. Estimates suggest that $30 trillion to $50 trillion will be spent on infrastructure in the next ten years, much of it in developing countries.[46] Designing such infrastructure with climate risk in mind may help reduce downstream repair and rebuilding costs. Moreover, infrastructure that specifically helps protect assets and people will be needed, for example cooling technologies including green air-conditioning (high energy efficiency HVAC powered by low carbon power, for example), emergency shelters, and passive urban design.

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[43] Anne Olhoff et al., *The adaptation finance gap report*, UNEP DTU Partnership, 2016.

[44] See Room for the River, ruimtevoorderivier.nl/english/.

[45] Michael Della Rocca, Tim McManus, and Chris Toomey, *Climate resilience: Asset owners need to get involved now*, McKinsey.com, January 2009.

[46] *Bridging global infrastructure gaps*, McKinsey Global Institute, June 2016; *Bridging infrastructure gaps: Has the world made progress?* McKinsey Global Institute, October 2017.

— **Building resilience.** Asset hardening will need to go hand-in-hand with measures that make systems more resilient and robust in a world of rising climate hazard. Building global inventory to mitigate risks of food and raw material shortages is an example of resilience planning, leveraging times of surplus and low prices. To make the food system more resilient, private and public research could be expanded, for example on technology that aims to make crops more resistant to abiotic and biotic stresses. As noted, climate change challenges key assumptions that have been used to optimize supply chain operations in the past. Those assumptions may thus need to be rethought, for example by building backup inventory levels in supply chains to protect against interrupted production, as well as establishing the means to source from alternate locations and/or suppliers.

— **Reducing exposure.** In some instances, it may also be necessary to reduce exposure by relocating assets and communities in regions that may be too difficult to protect, that is, to retreat from certain areas or assets. Given the long lifetimes of many physical assets, the full life cycle will need to be considered and reflected in any adaptation strategy. For example, it may make sense to invest in asset hardening for the next decade but also to shorten asset life cycles. In subsequent decades, as climate hazards intensify and the cost-benefit equation of physical resilience measures is no longer attractive, it may become necessary to relocate and redesign asset footprints altogether.

— **Insurance and finance.** While insurance cannot eliminate the risk from a changing climate, it is a crucial shock absorber to help manage risk.[47] Insurance can help provide system resilience to recover more quickly from disasters and reduce knock-on effects. It can also encourage behavioral changes among stakeholders by sending appropriate risk signals—for example, to homeowners buying real estate, lenders providing loans, and real estate investors financing real estate build-out.

Instruments such as parametrized insurance and catastrophe bonds can provide protection against climate events, minimizing financial damage and allowing speedy recovery after disasters. These products may help protect vulnerable populations that could otherwise find it challenging to afford to rebuild after disasters. Insurance can also be a tool to reduce exposure by transferring risk (for example, crop insurance allows transferring the risk of yield failure due to drought) and drive resilience (such as by enabling investments in irrigation and crop-management systems for rural populations who would otherwise be unable to afford this).

However, as the climate changes, insurance might need to be further adapted to continue providing resilience and, in some cases, avoid potentially adding vulnerability to the system. For example, current levels of insurance premiums and levels of capitalization among insurers may well prove insufficient over time for the rising levels of risk; and the entire risk transfer process (from insured to insurer to reinsurer to governments as insurers of last resort) and each constituents' ability to fulfil their role may need examination. Without changes in risk reduction, risk transfer, and premium financing or subsidies, some risk classes in certain areas may become harder to insure, widening the insurance gap that already exists in some parts of the world without government intervention.

Innovative approaches will also likely be required to help bridge the underinsurance gap. Premiums are already sometimes subsidized—one example is flood insurance, which is often nationally provided and subsidized. Such support programs however might need to be carefully rethought to balance support to vulnerable stakeholders with allowing appropriate risk signals in the context of growing exposure and multiple knock-on effects. One answer might be providing voucher programs to help ensure affordability for vulnerable populations, while maintaining premiums at a level that reflects the appropriate

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[47] Goetz von Peter, Sebastian von Dahlen, and Sweta Saxena, *Unmitigated disasters? New evidence on the macroeconomic cost of natural catastrophes*, BIS Working Papers, Number 394, December 2012.

risk. Trade-offs between private and public insurance, and for individuals, between when to self-insure or buy insurance, will need to be carefully evaluated. In addition, underwriting may need to shift to drive greater risk reduction in particularly vulnerable areas (for example, new building codes or rules around hours of working outside). This is analogous to fire codes that emerged in cities in order to make buildings insurable. Insurance may also need overcome a duration mismatch; for example, homeowners may expect long-term stability for their insurance premiums, whereas insurers may look to reprice annually in the event of growing hazards and damages. This could also apply to physical supply chains that are currently in place or are planned for the future, as the ability to insure them affordably may become a criterion of growing significance.

Mobilizing finance to fund adaptation measures, particularly in developing countries, is also crucial. This may require public-private partnerships or participation by multilateral institutions, to prevent capital flight from risky areas once climate risk is appropriately recognized. Innovative products and ventures have been developed recently to broaden the reach and effectiveness of these measures. They include "wrapping" a municipal bond into a catastrophe bond, to allow investors to hold municipal debt without worrying about hard-to-assess climate risk. Governments of developing nations are increasingly looking to insurance/reinsurance carriers and other capital markets to improve their resiliency to natural disasters as well as give assurances to institutions that are considering investments in a particular region.

— **Addressing tough adaptation choices.** Implementing adaptation measures could be challenging for many reasons. The economics of adaptation could worsen in some geographies over time, for example, those exposed to rising sea levels. Adaptation may face technical or other limits. In other instances, there could be hard trade-offs that need to be assessed, including who and what to protect and who and what to relocate. For example, the impact on individual home owners and communities needs to be weighed against the rising burden of repair costs and post-disaster aid, which affects all taxpayers.

Individual action will likely not be sufficient in many interventions; rather, coordinated action bringing together multiple stakeholders could be needed to promote and enable adaptation. This may include establishing building codes and zoning regulations, mandating insurance or disclosures, mobilizing capital through risk-sharing mechanisms, sharing best practices within and across industry groups, and driving innovation. Integrating diverse perspectives including those of different generations into decision making will help build consensus.

Decarbonizing at scale

An assessment and roadmap for decarbonization is beyond the scope of this report. However, climate science and research by others tell us that the next decade will be decisive not only to adapt to higher temperatures already locked in but also to prevent further buildup of risk through decarbonization at scale.[48] Stabilizing warming (and thus further buildup of risk) will require reaching net-zero emissions, meaning taking carbon out of future economic activity to the extent possible, as well as removing existing CO_2 from the atmosphere to offset any residual hard-to-abate emissions (that is, achieving negative emissions).[49] An important consideration in this context is that climate science also tells us a number of feedback loops are present in the climate system, such as the melting of Arctic permafrost, which would release significant amounts of greenhouse gases. If activated, such feedback loops could cause significant further warming, possibly pushing the Earth into a "hot house" state.[50] Scientists estimate that restricting warming to below 2 degrees Celsius would reduce the risk of initiating many of the serious feedback loops, while further restricting warming to 1.5 degrees Celsius would reduce the risk of initiating most of them.[51] Because warming is a function of cumulative emissions, there is a specific amount of CO_2 that can be emitted before we are expected to reach the 1.5- or 2-degree Celsius thresholds (a "carbon budget").[52] Scientists estimate that the remaining 2-degree carbon budget of about 1,000 $GtCO_2$ will be exceeded in approximately 25 years given current annual emissions of about 40 $GtCO_2$.[53] Similarly, the remaining 1.5-degree carbon budget is about 480 $GtCO_2$, equivalent to about 12 years of current annual emissions. Hence, prudent risk management would suggest aggressively limiting future cumulative emissions to minimize the risk of activating these feedback loops. While decarbonization is not the focus of this research, decarbonization investments will need to be considered in parallel with adaptation investments, particularly in the transition to renewable energy. Stakeholders should consider assessing their decarbonization potential and opportunities from decarbonization.

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[48] Christina Figueres, H. Joachim Shellnhuber, Gail Whiteman, Johan Rockstrom, Anthony Hobley, & Stefan Rahmstorf. "Three years to safeguard our climate". Nature. June 2017.

[49] Jan C. Minx et al. (2018) "Negative emissions – Part 1: Research landscape and synthesis." *Environmental Research Letters.* May 2018, Volume 13, Number 6.

[50] Will Steffen et al., "Trajectories of the Earth system in the Anthropocene," *Proceedings of the National Academy of Sciences,* August 2018, Volume 115, Number 33; M. Previdi et al. "Climate sensitivity in the Anthropocene." *Royal Meteorological Society,* 2013. Volume 139; Makiko Sato et al. "Climate sensitivity, sea level, and atmospheric carbon dioxide." *Philosophical Transactions of the Royal Society,* 2013. Volume 371.

[51] Will Steffen et al., "Trajectories of the Earth system in the Anthropocene," *Proceedings of the National Academy of Sciences*, August 2018, Volume 115, Number 33; Hans Joachim Schellnhuber, "Why the right goal was agreed in Paris," *Nature Climate Change*, 2016, Volume 6; Timothy M. Lenton et al., "Tipping elements in the Earth's climate system," *Proceedings of the National Academy of Sciences*, March 2008, Volume 105, Number 6; Timothy M. Lenton, "Arctic climate tipping points," *Ambio*, February 2012, Volume 41, Number 1; Sarah Chadburn et al., "An observation-based constraint on permafrost loss as a function of global warming," *Nature Climate Change*, April 2017, Volume 7, Number 5; and Robert M. DeConto and David Pollard, "Contribution of Antarctica to past and future sea-level rise," *Nature*, March 2016, Volume 531, Number 7596.

[52] This budget can increase or decrease based on emission rates of short-lived climate pollutants like methane. However, because of the relative size of carbon dioxide emissions, reducing short-lived climate pollutants increases the size of the carbon budget by only a small amount, and only if emission rates do not subsequently increase; H. Damon Matthews et al., "Focus on cumulative emissions, global carbon budgets, and the implications for climate mitigation targets," *Environmental Research Letters*, January 2018, Volume 13, Number 1.

[53] Richard J. Millar et al., "Emission budgets and pathways consistent with limiting warming to 1.5°C," *Nature Geoscience*, 2017, Volume 10; Joeri Rogelj et al., "Estimating and tracking the remaining carbon budget for stringent climate targets," *Nature*, July 2019, Volume 571, Number 7765.

Box E3

Questions for individual stakeholders to consider

All stakeholders can respond to the challenge of heightened physical climate risk by integrating it into decision making. Below we outline a broad range of questions that stakeholders may consider as they prepare themselves and their communities for physical climate risk, based on their risk exposure and risk appetite. Stakeholders may fall into one or more categories (for example, a nonfinancial corporation may also conduct investment activities).This list is not exhaustive and the implications of the changing climate will prompt others.

Insurers

- Should we continue to invest in forward-looking climate-related modeling capabilities in order to better price climate risk in insurance products and quantify value at risk from climate change in today's portfolio and future investments?

- Could we further drive innovations in insurance products, for example by developing new parametric insurance products that can help reduce transaction costs in writing and administering insurance policies, and by considering coverage caps and public-private partnerships?

- Could we offer risk advisory services to complement standard insurance products including educating target communities on the present and future risks from climate change and developing tool kits for building adaptation and resilience?

- What are possible new measures and incentives to encourage risk-reducing behavior, for example by rewarding implementation of adaptation measures such as hardening physical assets?

- Where insurance can help reduce risk without inducing buildup of further exposure, how can we work with reinsurers, national insurance programs, governments, and other stakeholders to make coverage affordable (for example, crop insurance for smallholder farmers)?

Investors and lenders

- How could we use recommendations of the Task Force on Climate-related Financial Disclosures to develop better risk management practices?[1] Should investees and borrowers be encouraged to make appropriate financial disclosures of climate risk in order to increase transparency?

- How could we integrate climate risk assessments into portfolio allocation and management decisions, including via stress tests and quantifying climate value at risk (VAR) in portfolios using probabilistic forward-looking models that reflect physical climate risk, based on the best available science?

- Is it possible to incorporate climate risk into new lending and investment activity by understanding its potential impact on different geographies and on loans and investments of differing durations, and then adjusting credit policies to reflect VAR for future investments?

- What opportunities exist for capital deployment in sectors and product classes with increasing capital need driven by higher levels of climate change, such as resilient infrastructure bonds?

- In what innovative ways could capital be deployed to fill the growing need for adaptation, especially in areas where business models currently do not provide an operating return (for example, marrying tourism revenues to coral reef protection, providing long-term finance for wastewater treatment systems tied to flood cost reduction, or developing country adaptation funds, possibly with risk-sharing agreements with public financial institutions)?

- How could we best educate debtors on current and future climate risks, including developing tool kits and data maps to help build investee information and capabilities?

Regulators, rating agencies, and central banks

- What could be appropriate measures to increase risk awareness (for example, providing guidance on stress testing, supporting capability building on forward-looking models, or supporting risk disclosures)?

- How could we encourage sharing of best practices across private-sector entities, for example through convening industry associations or publishing risk management tool kits?

- How could we help manage the risk of discontinuous movement of capital, or "capital flight," based on climate change, including considering whether and how to adjust the sovereign risk ratings of low-income, highly climate-exposed countries?

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[1] *Final report: Recommendations of the Task Force on Climate-related Financial Disclosures,* Task Force on Climate-related Financial Disclosures, June 2017.

Companies outside the financial sector

- What opportunities exist to convene the industry around physical risk, including by building knowledge that is sector- and region-specific?
- How could we incorporate a structured risk-management process that enables good decision making and integrates an assessment of physical and transition climate risk into core business decisions (for example, sourcing, capital planning, and allocation decisions)?
- How might climate change affect core production (risk of disruption or interruption of production, increased cost of production factors); sourcing and distribution (risk of disruption of the upstream supply chain or the downstream distribution, delaying or preventing inflow of inputs and distribution of goods, increasing costs or reducing product prices); financing and risk management (risk of reduced availability or increased cost of financing, insurance, and hedging); and franchise value (risk of declining value of investments and goodwill, disruption of right to operate or legal liabilities)? What business model shifts will be needed?
- How big and urgent are the most relevant climate change risks and what countermeasures should be taken to adapt to and manage them, based on risk appetite (for instance, if risks to sourcing of inputs have been recognized, identifying alternate suppliers or raising inventory levels to create backup stock; or if climate exposure is expected to drive market shifts or impact terminal value of assets, reallocating growth investment portfolio)?

Governments

- How could we integrate an understanding of physical climate risk into policy and strategic agendas especially around infrastructure and economic development planning, including by investing in probabilistic future-based modeling of physical climate impact?
- How could we best address areas of market failure and information asymmetry in the community (for example, making hazard maps readily available, providing adaptation finance directly to affected communities) and agency failures (for instance, in flood insurance)?
- Based on assessments of risk and cost-benefit analysis, how could we plan and execute appropriate adaptation measures, especially physical hardening of critical assets such as public infrastructure? How to think about measures that involve difficult choices—for example, when to relocate versus when to spend on hardening?
- How could we integrate diverse voices into decision making (for example, using public forums or convening local communities) to support more effective adaptation planning, and help identify and reduce distributional effects (for example, unexpected costs of adaptation measures on neighboring communities)?
- How could we best ensure financial resilience to enable adaptation spending and support disaster relief efforts, including drawing on global commitments and multilateral institutions, and collaborating with investors and lenders?
- Do we need to play a role in the provision of insurance, including potential opportunities for risk pooling across regions, and if so, where?

Individuals

- Am I increasing my personal and peer education and awareness of climate change through dialogue and study?
- Do I incorporate climate risk in my actions as a consumer (for example, where to buy real estate), as an employee (for instance, to inform corporate action), and as a citizen?

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