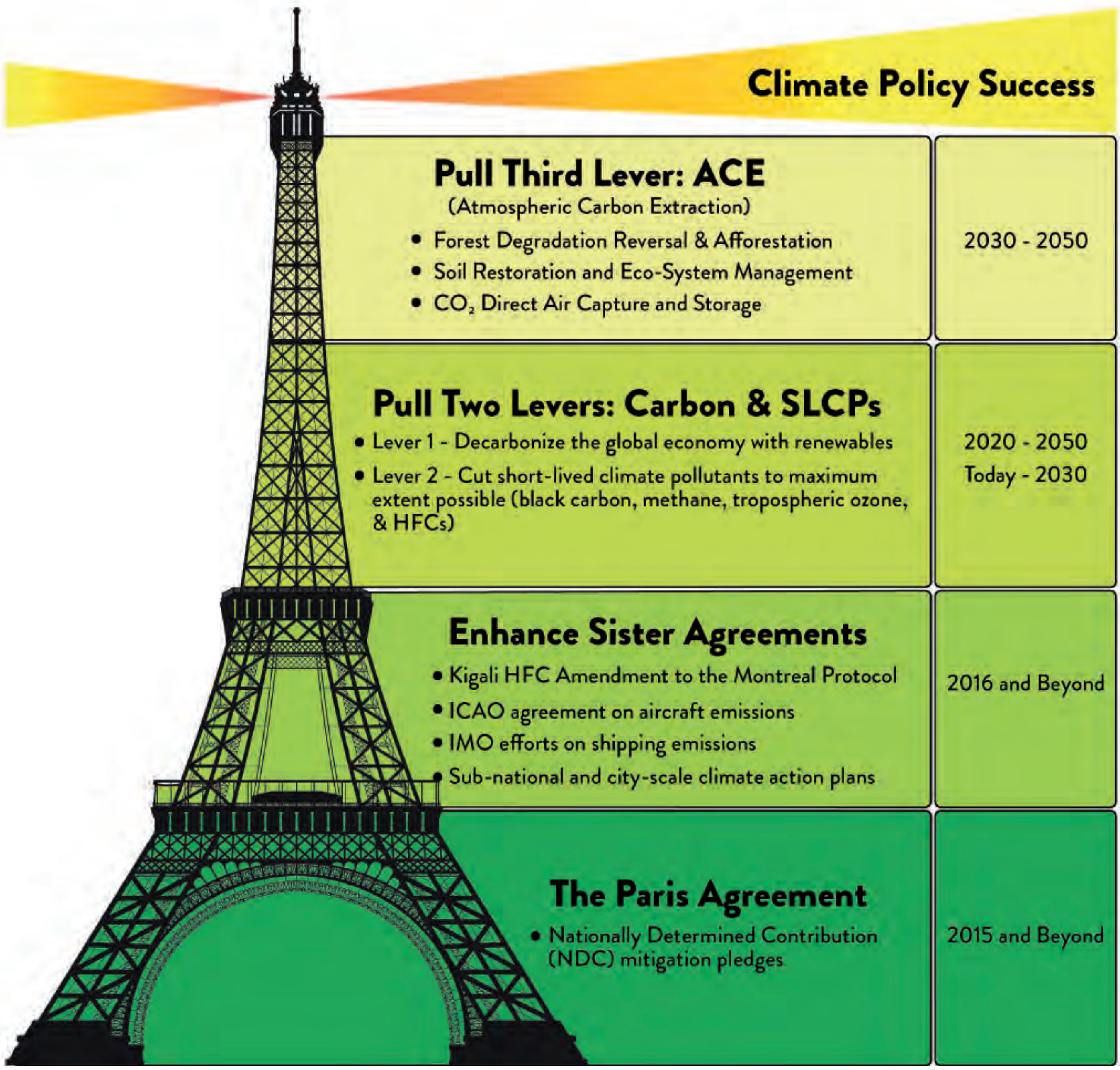
Under 2 Degrees Celsius:

Fast Action Policies to Protect People and the Planet from Extreme Climate Changes

First Report of the Committee to Prevent Extreme Climate Change

Chairs: V. Ramanathan, M. J. Molina and D. Zaelke

Released at COP22 Summit at Marrakech, 14 November 2016



This report should be referred as: Ramanathan, V., Molina, M.J., Zaelke, D., Borgford-Parnell, N., Alex, K., Auffhammer, M., Bledsoe, P., Collins, W., Croes, B., Forman, F., Gustafsson, Ö., Haines, A., Harnish, R., Jacobson, M., Kang, S., Lawrence, M., Leloup, D., Lenton, T., Morehouse, T., Munk, W., Picolotti, R., Prather, K., Raga, G., Rignot, E., Shindell, D., Singh, AK, Steiner, A., Thiemens, M., Titley, D.W., Tucker, M.E., Tripathi, S., Victor, D., & Xu, Y., Under 2 Degrees Celsius: Fast Action Policies to Protect People and the Planet from Extreme Climate Changes, 2016.

The Committee to Prevent Extreme Climate Change (CPECC)

Co-Chairs:

V. Ramanathan, M.J. Molina, D. ZaelkeTask Force Members:

Task Force Members:

1. Ken Alex, California Governor's Office
2. Max Auffhammer, UC Berkeley
3. Paul Bledsoe, Bledsoe & Associates
4. Nathan Borgford-Parnell, IGSD
5. William Collins, UC Berkeley
6. Bart Croes, California Air Resources Board
7. Fonna Forman, UC San Diego
8. Örjan Gustafsson, Stockholm University
9. Andy Haines, London School of Hygiene & Tropical Medicine
10. Reno Harnish, UC San Diego
11. Mark Jacobson, Stanford University
12. Shichang Kang, Chinese Academy of Sciences
13. Mark Lawrence, IASS Potsdam
14. Damien Leloup, Scripps
15. Tim Lenton, University of Exeter
16. Tom Morehouse, National Renewable Energy Laboratory
17. Walter Munk, Scripps Institution of Oceanography
18. Romina Picolotti, CEDHA
19. Kim Prather, UC San Diego
20. Graciela Raga, National Autonomous University of Mexico
21. Eric Rignot, UC Irvine
22. Drew Shindell, Duke University
23. AK Singh, Retired Air Marshal & Former Commander in Chief of Indian Air Force
24. Achim Steiner, Oxford University
25. Mark Thiemens, UC San Diego
26. David W. Titley, Retired Rear Admiral United States Navy
27. Mary Evelyn Tucker, Yale University
28. Sachi Tripathi, IIT Kanpur
29. David Victor, UC San Diego
30. Yangyang Xu, Texas A&M

High Level Summary

The Paris Agreement is an historic achievement. For the first time, effectively all nations have committed to limit their greenhouse gas emissions and take other actions to limit and adapt to climate change to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and pursu[e] efforts to limit the temperature increase to 1.5°C above pre-industrial levels." But the Agreement and supporting climate policies must be strengthened substantially within the next five years to prevent catastrophic warming. Until now, no specific plan or policy roadmap has been proposed to provide a realistic and reasonable chance of limiting global temperatures to safe levels and preventing unmanageable climate change. This report provides such a plan—an outline of specific solutions that serve as the building blocks for a three-lever strategy to limit warming to under 2°C and thus avoid extreme and unmanageable climate changes.

The first building block would be fully implementing the nationally determined mitigation pledges under the Paris Agreement of the UNFCCC. The next building blocks would be strengthening sister agreements and numerous sub-national and city scale climate action plans which can provide targeted and efficient mitigation. Sister agreements include the HFCs Kigali Amendment to the Montreal Protocol, the European F-gas rule, other HFC measures at national levels, and the HFC commitments under the Paris Agreement. These HFCs measures can avoid as much as 0.5°C of warming by 2100 through the global phasedown of HFCs within few decades. Other promising examples include California's Under 2 MOU signed by over 136 jurisdictions representing 32 countries and six continents and climate action plans by over 52 cities and 65 businesses around the world aiming to become carbon neutral. There are concerns that the carbon neutral goal will hinder economic progress; however, real world examples from California and Sweden since 2005 prove that economic growth can be decoupled from carbon emissions.

The third building blocks consist of pulling on two levers as hard as we can: one for drastically reducing emissions of short-lived climate pollutants (SLCPs) beginning now and completing by 2030, and the other for decarbonizing the global economy by 2050. Pulling both levers simultaneously can keep global temperature rise below 2°C through the end of the century. If we bend the CO_2 emissions curve such that global emissions peak in 2020 and begin to decrease thereafter, there is less than a 20% probability of exceeding 2°C. This call for bending the CO_2 curve beginning in 2020 is one major new proposal of this report. Many cities and jurisdictions are already on this pathway thus demonstrating its scalability.

For the final building block, we are adding a third lever, ACE (Atmospheric Carbon Extraction). This lever is added as an insurance against surprises (due to policy lapses, mitigation delays or non-linear climate changes) and requires development of scalable measures for removing the CO_2 already in the atmosphere. The amount of CO_2 that has to be removed will range from negligible, if the emissions of CO_2 and SLCPs start to decrease by 2020 and carbon neutrality is achieved by 2050, to a staggering one trillion tons, if CO_2 emissions continue to increase until 2030, and the carbon lever is pulled after 2030. This issue is raised because the NDCs (Nationally Determined Contributions) accompanying the Paris Agreement would allow CO_2 emissions to increase until 2030. We call on economists to assess the cost-effectiveness of reducing carbon and SLCPs emissions beginning in 2020 compared with delaying it by ten years and then being forced to pull the third lever to extract one trillion tons of CO_2.

The fast mitigation plan of requiring emissions reductions to begin by 2020 is urgently needed to limit the warming to under 2°C. Climate change is not a linear problem. Instead, we are facing non-linear climate tipping points that can lead to self-reinforcing and cascading climate change impacts. Tipping points are more likely with increased temperatures, and many of the potential abrupt climate shifts could happen as warming goes from 1.5°C to 2°C, with the potential to push us well beyond the Paris goals.

Where Do We Go from Here? We have almost run out of time to address these concerns. We must act now, and we must act fast. This report sets out a specific plan for reducing climate change in both the near- and long-term. With aggressive, urgent actions that begin by 2020, we can protect ourselves. Acting quickly to prevent catastrophic climate change by decarbonization will save millions of lives, trillions of dollars in economic costs, and massive suffering and dislocation to people around the world. This is a global security imperative, as it can avoid the migration and destabilization of entire societies and countries and reduce the likelihood of environmentally driven civil wars and other conflicts.

Staying at under 2°C will require a concerted global effort. We must address everything from our energy systems to our personal choices to reduce emissions to the greatest extent possible. The health of people for generations to come and the health of ecosystems crucially depend on an energy revolution beginning now that will take us away from fossil fuels and toward the renewable energy sources of the future beginning now. This is our future, and we must transition to that clean energy future quickly. Towards this vision we are articulating:

10 Scalable Solutions for Implementing Climate Stability Building Blocks

Achieving success will require the global mobilization of human, financial, and technical resources. For the global economy and society to achieve such rapid reductions in SLCPs by 2030 and carbon neutrality and climate stability by 2050, we will need multi-dimensional and multi-sectoral changes and modifications, which are grouped under Ten Scalable Solutions in the table below. We have adapted the solutions from the report: Bending the Curve* written by fifty researchers from the University of California system. These solutions, which often overlap, were in turn distilled from numerous publications and reports.

Science Solutions

1. Show that we can bend the warming curve immediately by reducing SLCPs, and long-term by replacing current fossil fuel energy systems with carbon neutral technologies.

Societal Transformation Solutions

2. Foster a global culture of climate action through coordinated public communication and education at local to global scales.

3. Build an alliance between science, religion, health care, and policy to change behavior and garner public support for drastic mitigation actions.

Governance Solutions

4. Build upon and strengthen the Paris Agreement. Strengthen sister agreements like the Montreal Protocol's Kigali Amendment to reduce HFCs.

5. Scale up subnational models of governance and collaboration around the world to embolden and energize national and international action. California's Under 2 MOU and climate action plans by over 50 cities are prime examples.

Market- and Regulations-Based Solutions

6. Adopt market-based instruments to create efficient incentives for businesses and individuals to reduce CO_2 emissions.

7. Target direct regulatory measures—such as rebates and efficiency and renewable energy portfolio standards—for high emissions sectors not covered by market-based policies.

Technology-Based Solutions

8. Promote immediate widespread use of mature technologies such as photovoltaics, wind turbines, biogas, geothermal, batteries, hydrogen fuel cells, electric light-duty vehicles, and more efficient end-use devices, especially in lighting, air conditioning and other appliances, and industrial processes. Aggressively support and promote innovations to accelerate the complete electrification of energy and transportation systems and improve building efficiency.

9. Immediately make maximum use of available technologies combined with regulations to reduce methane emissions by 50%, reduce black carbon emissions by 90%, and eliminate high-GWP HFCs ahead of the schedule in the Kigali Amendment.

Atmospheric Carbon Extraction Solutions

10. Regenerate damaged natural ecosystems and restore soil organic carbon.; Expand with urgency research and development of approaches and measures for direct extraction of CO_2.

* Adapted from Ramanathan et al (2015) and modified by authors of this report.

Table of Contents

1. The Building Blocks Approach

The Paris Agreement, which went into effect November 2016, is a remarkable, historic achievement. For the first time, effectively all nations have committed to limit their greenhouse gas emissions and take other actions to limit and adapt to climate change to hold "the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursu[e] efforts to limit the temperature increase to 1.5°C above pre-industrial levels" and "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (UNFCCC 2015). Nevertheless, the initial Paris Agreement has to be strengthened substantially within five years if we are to prevent catastrophic warming.

Until now, no specific plan or policy roadmap exists that could provide a realistic and reasonable chance of limiting global temperatures to safe levels and preventing unmanageable climate change. This report is our attempt to provide such a plan—an outline of specific solutions that serve as the building blocks for a comprehensive strategy for limiting the warming to under 2°C and avoiding extreme climate change (Figure 1).

The first building block is the full implementation of the nationally determined mitigation pledges under the Paris Agreement of the UN Framework Convention on Climate Change (Figure 1). The next building blocks are: 1) the global sister agreements, such as the HFC Kigali Amendment to the Montreal Protocol, which can provide additional targeted, fast action mitigation; 2) sub-national agreements such as California's Under 2 MOU signed by 136 jurisdictions from 30 countries in six continents; and 3) climate action plans for carbon neutrality being implemented by 52 cities and 65 businesses around the world. The third building block is targeted measures to reduce emissions of short-lived climate pollutants (SLCPs) beginning now and fully implemented by 2030, along with major measures to fully decarbonize the global economy beginning in 2020 and completed by 2050. Such a deep de-carbonization would require an energy revolution similar to the Industrial Revolution based on fossil fuels. The final building blocks are scalable and reversible carbon dioxide (CO_2) removal measures, which can begin removing CO_2 already emitted into the atmosphere.

Such a plan is urgently needed. Climate change is not a linear problem. Instead, climate tipping points that can lead to self-reinforcing, cascading climate change impacts exist. Tipping points are more likely with increased temperatures, and many of the potential abrupt climate shifts could happen as warming goes from 1.5°C to 2°C, with the potential to push us well beyond the Paris goals.

We are running out of time to address these concerns. We must act now, and we must act fast. Reduction of SLCPs will result in fast, near-term reductions in warming, while present-day reductions of CO_2 will result in long-term climate benefits. This two-lever approach will allow for realization of avoided warming in the coming decades when it is most crucial to avoid impacts from climate change as well as maintain a safe climate many decades from now. To achieve the near-term goals, we have outlined solutions to be implemented immediately. These solutions to bend the emissions curve and thus bend the warming trajectory curve follow a 2015 assessment by the University of California under its Carbon Neutrality Initiative. They are clustered into categories of social transformation, governance improvement, market- and regulation-based solutions, technological innovation and transformation, and natural and ecosystem management.

Additionally, we will need to intensely investigate and pursue a third lever—ACE (Atmospheric Carbon Extraction). While many potential technologies exist, we do not know the extent to which they can be scaled up to remove the requisite amount of carbon from the atmosphere in order to achieve the Paris Agreement goals, and any delay in mitigation will demand increasing reliance on these unproven technologies.

Yet, there is still hope. Humanity can come together, as we have done in the past, to collaborate towards a common goal. We have no choice but to tackle to the challenge of climate change. We only have the choice of when and how: either now, through the ambitious plan outlined here, or later, through radical adaptation and societal transformations in response to an ever-deteriorating climate system that will unleash devastating impacts—some of which may be beyond our capacity to fully adapt to or reverse for thousands of years.

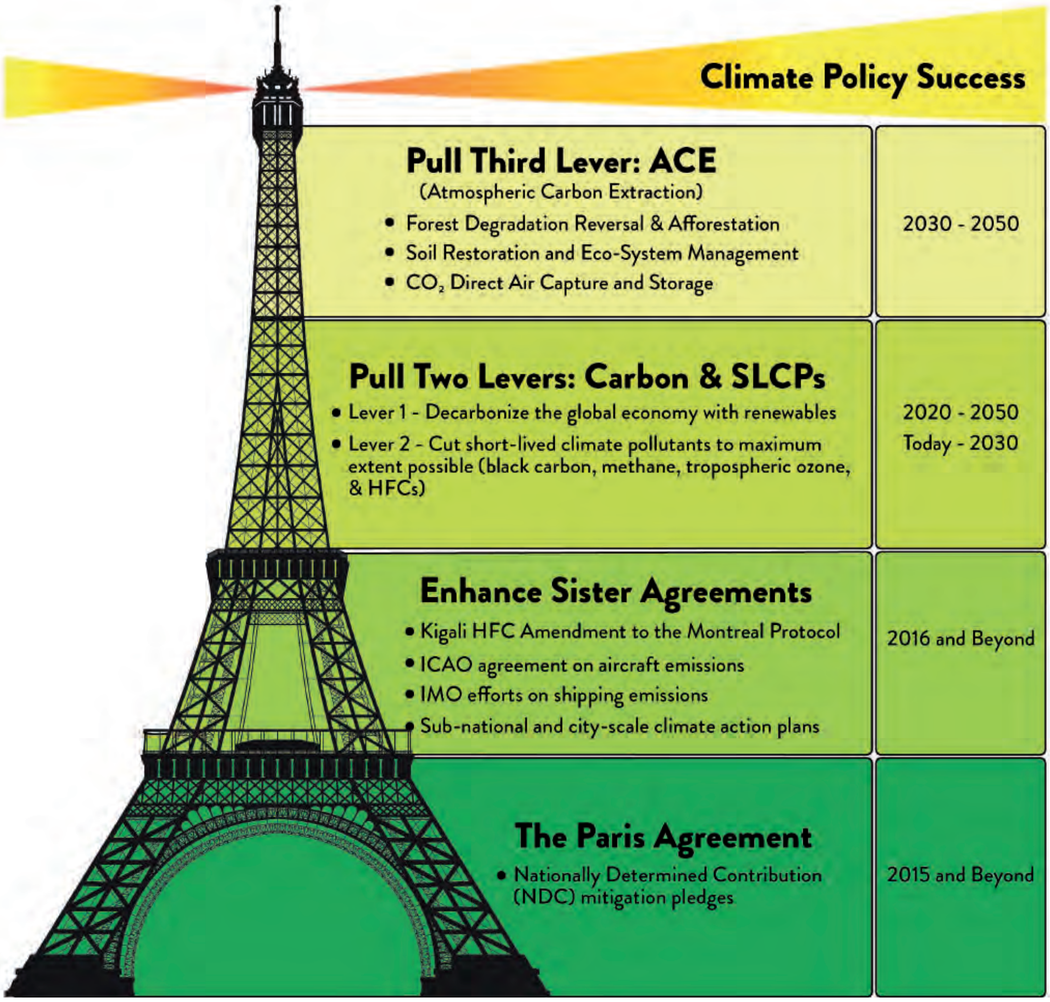


Figure 1: Four building blocks to achieve climate policy success. Timeline on the right indicates the years during which the solutions will need to be put in place and carried out.

2. Major Climate Disruptions: How Soon and How Fast?

"Without adequate mitigation and adaptation, climate change poses unacceptable risks to global public health."
WHO, 2016

The planet has already witnessed nearly 1°C warming and another 0.6°C of additional warming is currently stored in the ocean to be released over the next two to four decades. The impacts of this warming on extreme weather, droughts, and floods are being felt by society worldwide to the extent that many think of this no longer as climate change but as climate disruption. Consider the business as usual scenario:

15 years from now: In 15 years, planetary warming will reach 1.5°C above pre-industrial global mean temperature. The last time the planet was this warm was about 115,000-130,000 years ago. The impacts of this warming will affect us all yet will disproportionately affect the earth's poorest three billion people, who are primarily subsistence farmers that still rely on 18th century technologies and have the least capacity to adapt. They thus may be forced to resort to mass migration into city slums and push across international borders. The existential fate of low-lying small islands and coastal communities will also need to be addressed, as they are primarily vulnerable to sea-level rise, diminishing freshwater resources, and more intense storms. In addition, many depend on fisheries for protein, and these are likely to be affected by ocean acidification and climate change. Climate injustice could start causing visible international conflicts. The risk of passing tipping points increases.

30 years from now: In 30 years, warming is expected to exceed 2°C, which would be unprecedented with respect to historical records of at least the last one million years. Such a warming through this century could result in sea-level rise of as much as 2 meters by 2100, with greater sea-level rise to follow. The melting of most mountain glaciers, including those in the Tibetan-Himalayas, combined with mega-droughts, heat waves, storms, and floods, would adversely affect most everyone on the planet.

80 years from now: In 80 years, warming is expected to exceed 4°C, increasing the likelihood of irreversible and catastrophic change. The 2°C and 4°C values quoted above and in other reports, however, are merely the central values with a 50% probability of occurrence. There is a 20% probability the warming could be as high as 6°C due to uncertainties in the magnitude of amplifying feedbacks (see Section 4) This in turn could lead to major disruptions to natural and social systems, threatening food security, water security, and national security and fundamentally affecting all the projected 10 billion inhabitants of the planet in 2100.

3. What Are the Wild Cards for Climate Disruption?

Generally, increasing the concentrations of greenhouse gases in the atmosphere increases its radiative forcing (the difference between the amount of energy entering the atmosphere and leaving) and thus increase the global temperature. However, climate wild cards exist that can both alter the linear connection with warming and anthropogenic emissions by triggering abrupt changes in the climate. Some of these wild cards have not been thoroughly captured by the models on which policymakers rely the most. These abrupt shifts are irreversible on a human time scale and will create a notable disruption to the climate system, condemning the world to warming beyond that which we have previously projected. These climate disruptions could effectively alter our ability for future mitigation and upset mitigation strategies that we have already put in place.

1. Unmasking of Aerosol Cooling: The first such wild card is the unmasking of an estimated 0.7°C (with an uncertainty range of 0.3°C to 1.2°C) of committed warming by reducing cooling aerosols. Aerosol air pollution is a major health hazard with massive costs to public health and society, including contributing to about 7 million deaths (from household and ambient exposure) each year. While some aerosols, such as black carbon and brown carbon, strongly absorb sunlight and act as powerful climate pollutants, many reflect sunlight back into space, which cools the climate. The net impact of all manmade aerosols is negative, meaning that about 30% of the warming from greenhouse gases is being masked by co-emitted air pollution particles. As we reduce greenhouse gas emissions and implement policies to eliminate air pollution, we are also reducing the concentration of aerosols in the air. Aerosols last in the atmosphere for about a week, so if we eliminate air pollution without reducing emissions of the greenhouse gases, the unmasking alone would lead to an estimated 0.7°C of warming within a matter of decades. We must eliminate aerosol emissions due to their health effects, but we must simultaneously mitigate

emissions of CO_2, other greenhouse gases and black carbon to avoid an abrupt large jump in the near-term warming beyond 2°C.

Tipping Points: It is likely that as we cross the 1.5°C to 2°C thresholds we will trigger so called "tipping points" for abrupt and nonlinear changes in the climate system with catastrophic consequences for humanity and the environment. Once the tipping points are passed, the resulting impacts will range in timescales from: disruption of monsoon systems (very fast), loss of sea-ice (fast), dieback of major forests (medium), reorganization of ocean circulation (medium-slow), to loss of ice sheets and subsequent sea-level rise (slow). Regardless of timescale, once underway many of these changes would be irreversible.

Recent modeling work shows a "cluster" of these tipping points could be triggered between 1.5 and 2°C warming (Figure 2) including melting of land and sea-ice and changes in high-latitude ocean circulation (deep convection). This is consistent with existing observations and understanding that the polar regions are particularly sensitive to global warming and have several potentially imminent tipping points. The Arctic is warming nearly twice as quickly as the global average, which makes the abrupt changes in the Arctic more likely at a lower level of global warming. Similarly, the Himalayas are warming at roughly the same rate as the Arctic and are thus also more susceptible to incremental changes in temperature. If borne out by further research, this gives further justification for limiting warming to no more than 1.5°C.

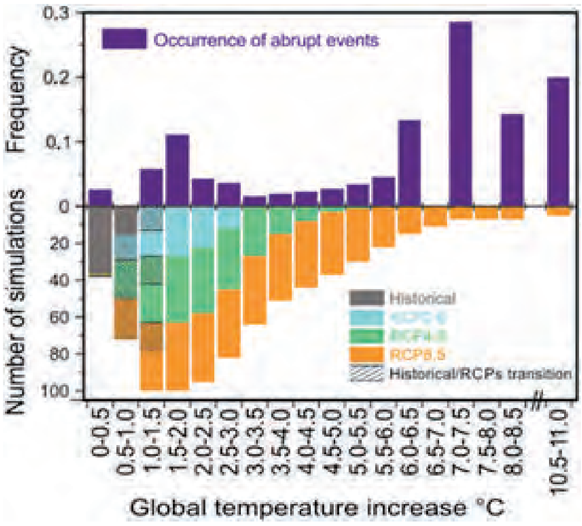


Figure 2: The occurrences of abrupt events (purple bars) show a cluster between 1.5°C and 2°C global temperature increase and again above 6°C. Source: Drijfhout et al., 2015.

2. Unstable Melting of Marine-Based Sectors of Ice Sheets: During the Eemian period (115,000 to 130,000 years ago), the earth was approximately 1.5°C warmer than present temperatures. This caused significant portions of the Greenland ice sheet and most of the marine-based portions of the west Antarctic ice sheet to melt, resulting in 6 to 9 meters of sea-level rise. The time scale of this staggering rise in sea-levels is unknown, but this paleo-record along with the recent discovery of unstable melting of the Amundsen sector of west Antarctic and the melting of Greenland glaciers has raised concern about the probability of a 2-meter sea-level rise by the end of this century.

3. Himalayan and Tibetan Glaciers and the Asian Monsoon: More than 80% of the glaciers in this region are retreating. A primary source of water for these glaciers is precipitation from the South Asian monsoon, which has decreased by about 7% during the last fifty years. Many studies have attributed the weakening monsoon to the reduction of solar radiation, known as "global dimming", due to aerosol pollution. Further, the deposition of black carbon (from diesel combustion and biomass cooking among other sources) on glaciers and snowpack is decreasing the snow's albedo, contributing to surface warming and melting. The combination of warming by greenhouse gases, weakening monsoons due to aerosol dimming, and surface melting driven by black carbon deposition is creating an unstable situation for this so-called "Water Tower of Asia," which provides headwaters for most of the major river systems in Asia.

While all climate tipping points have the potential to rapidly destabilize climate, social, and economic systems, some are also self-amplifying feedbacks that once set in motion increase warming in such a way that they perpetuate yet even more warming. Declining Arctic sea-ice, thawing permafrost, and the poleward migration of cloud systems are all examples of self-amplifying feedback mechanisms.

4. Loss of Arctic Summer Sea-Ice: Arctic summer sea-ice, which has already retreated by 40%, could disappear abruptly when the 1.5°C threshold is crossed in 15 years. As the Arctic warms, the sea-ice melts and exposes the darker ocean water beneath, which allows for greater absorption of solar radiation, increasing the ocean's temperature and acting as a force multiplier. Furthermore, the persistently warmer water hinders significant ice growth in winter, which can also impact the amount of sea-ice that melts during the summer. The increased climate forcing from the loss of Arctic summer sea-ice between 1979 and 2011, if averaged globally, is equivalent to 25% of the forcing from CO_2 over the same period.

5. Collapse of Arctic Permafrost: Permafrost is soil that stays below freezing temperatures for at least two consecutive years. Arctic permafrost contains three times as much carbon as there is in the atmosphere, and the thawing of the permafrost over land and subsea has the potential to release large quantities of this trapped carbon as both CO_2 and methane. The release of permafrost will not necessarily result in an abrupt shift in the climate, but even a release of 1% of the carbon stored in permafrost could double the rate of warming. By the end of the century carbon release from permafrost could add an estimated 0.1–0.3°C of warming and even greater and irreversible increases for centuries to come.

6. Poleward Retreat of Extra-Tropical Cloud Systems: Clouds act as giant air conditioners for the planet. Though clouds enhance the greenhouse effect, they also reflect an enormous amount of solar radiation and nearly double the albedo of the planet. Their albedo effect dominates over their greenhouse effect, balancing out to a net cooling effect of about -25 Wm-2 (compared with the 1.6 Wm-2 forcing from CO_2). More than two-thirds of this cooling is from the extensive extratropical cloud systems, which are found poleward of about 40° and are associated with jet streams and storm tracks. Satellite data reveal that these cloud systems are retreating polewards in both hemispheres, which has led to an increase in the solar radiation reaching the extratropics, further amplifying the warming. Thus, the Arctic warming is amplified by two large feedbacks: first is the decrease in albedo from the retreating sea-ice, which is then further amplified by the decrease in albedo from the retreating storm track clouds.

4. Dealing with Uncertainty and the Problem of the "Fat Tail"

Climate change projections are quantified on their likelihoods of occurrence. Our understanding of the climate system is more refined in some areas than in others, but this does not detract from the overall assessments and projections for future changes to the climate. Climate models will continue to improve their treatment of many physical, dynamical, and chemical processes, particularly those dealing with clouds, aerosols, ice sheet dynamics, and the carbon cycle. But the complexity and interconnectedness of climate and human systems means that humanity will never fully dispel all uncertainties about the exact rate, magnitude, or implications of the changes we are affecting on our world through climate change.

However, despite these uncertainties, the observed changes in our climate system and the ability of the climate models to simulate these changes and even predict the changes in many instances give us more than enough certainty to act. As warned by a team of retired admirals and generals from the U.S. in a report on climate change,

"Speaking as a soldier, we never have 100 percent certainty. If you wait until you have 100 percent certainty, something bad is going to happen on the battlefield."

However, there is one type of climate uncertainly that should inspire us to act with incredible urgency: the uncertainty of the "fat tail."

The feedbacks mentioned in the above section, and others not discussed here, give rise to a wide spread probability distribution of warming for a given forcing from increased CO_2 or other climate pollutants. For example, a doubling of CO_2 has a projected central value of warming of 3°C. The 90% probability distribution, however, includes warming as low as 2°C and as large as

4.5°C. On the lower side, there is a less than 1% chance that the warming seen under a doubling of CO_2 will be less than 1.5°C. However, on the upper limit, there is a 1% to 5% probability the warming could be as large as 6°C, which is referred to as the "fat tail". Such warming could pose an existential threat to most of the global population.

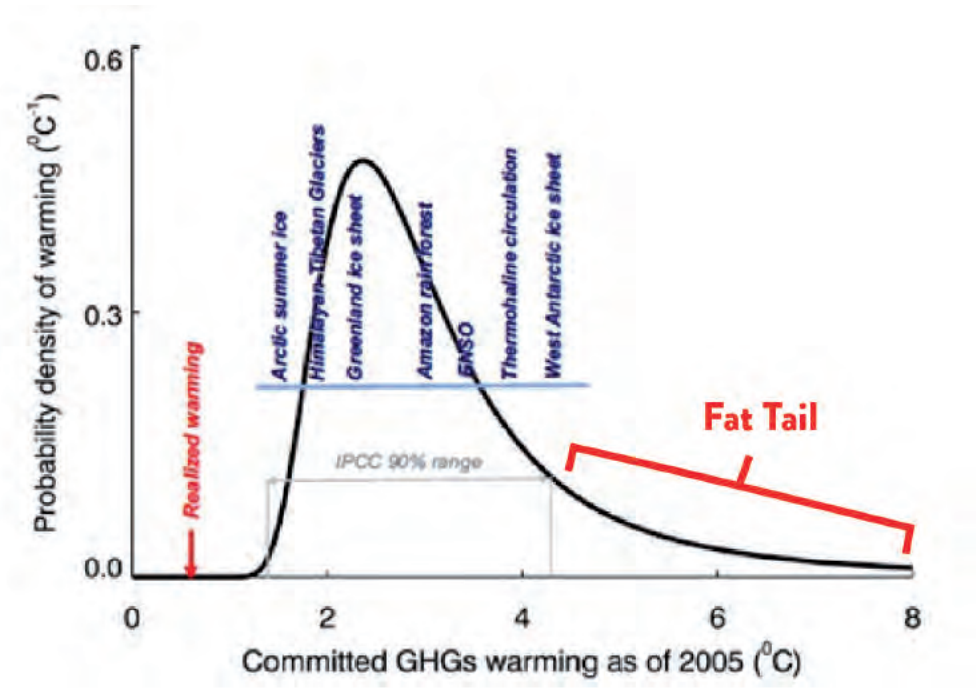


Figure 3: The figure shows a central estimate of warming of about 2°C with a 20% probability of being more than 3°C and a 5% chance of being more than 4°C. For the end of the century projection of 4°C warming, there is a 1% to 5% probability the warming could be as large as 6°C to 8°C. Source: Ramanathan & Feng, 2008.

In the context of warming and greenhouse gases, the "fat tail" indicates there exists a larger range of possible temperatures far warmer than 2°C compared to the range of possible temperature cooler than 2°C. With each incremental increase in temperature, this central value gets shifted farther towards the warmer temperature range, and with it the "fat tail" shifts in the same manner, which means that even greater temperatures exist within the realm of possibility, even if it is a small chance.

Put in perspective, how many people would choose to buckle into an airplane seat if they knew there was a 1 in 20 to 1 in 100 chance of the plane crashing? Most of us would undoubtedly stay home. The calculated odds of dying in a plane crash are closer to 1 in 11 million, which is why it is such a popular and safe form of transportation. If a 1 in 100 chance of dying in a plane crash would be enough to end air travel shouldn't it also be enough to demand fast action to address climate change?

5. What Are the Impacts on Social Systems?

Damages due to climate change have already been detected and, in the future, are expected to disproportionately affect the poorest and most vulnerable. Coastal archaeology provides use with some understanding of how past societies have responded to the impacts of rapid climate change and can serve as analogues for our present-day societal responses to anthropogenic global warming. A number of studies of coastal societies that existed more than 4,000 years ago, indicate that there are climatic thresholds to cultural tolerances, and that abrupt, unpredictable climate change can have devastating consequences on human populations by disrupting food production, forcing repeated human dispersal, and causing conflict and realignment of social and trade networks.

Limiting global average temperature rise to 1.5°C over pre-industrial temperatures will not eliminate the negative impacts of anthropogenic climate change, but it would significantly reduce the rate of temperature increase, the intensity of climate impacts and the risks to society. This is critical for both providing societies time to adapt to changes and slowing, if not avoiding, the worst predicted impacts of climate change. Actions that would bring immediate relief to the rapidly changing climate are vital for survival. With mounting evidence of past impacts, we still have a good deal to learn about how climate change will affect communities. What follows is a list of issues being discussed among social scientists, policy experts, and political leaders.

National and International Security: Climate change poses security risks "because it degrades living conditions, human security, and the ability of governments to meet the basic needs of their populations," (U.S. DOD). Climate change is a direct cause of resource conflicts in countries with weak capacities and governance challenges. The conflicts in Syria and Darfur are partially attributed to droughts that caused massive agriculture failures, which in turn have led to mass displacements and migration. Bangladesh estimates it may have to relocate 20 million people if sea-level rises by one meter.

Sustainable Development: The 17 Sustainable Development Goals (SDGs) and their 169 targets strive to eliminate poverty and hunger, improve health, expand access to clean modern energy, protect the plant, and ensure all people enjoy peace and prosperity. The current and near-term impacts of climate change will cause multiple complex impacts on human health, infrastructure, society, and the environment and thereby threaten to undermine the success of the SDGs if not put them entirely out of reach. Climate change is a multiplier of the obstacles faced in achieving the SDGs.

For example, increased extreme weather events combined with reduced crop production due to climate change can put entire food systems at risk. This threatens many of the SDGs, such as those related to food security, health (through increased malnutrition), and poverty (due to losses of traditional livelihood). Agricultural failures can also lead to massive impacts on social systems.

In 2010, extreme weather-related events were reported to have displaced nearly 31 million people. One estimate suggests that sea-level rise of one meter could displace almost 50% of Bangladeshi citizens. While the impacts of extreme, individual climate-driven disasters are relatively clear, the "cumulative impacts from small, recurrent disasters over time can equal or even exceed those from larger catastrophes" (World Bank, 2013). In addition to the direct impacts described above and the indirect impacts such as increased feed prices and food insecurity, these smaller climate-related hazards tend to exacerbate other stressors, reinforcing poverty and compounding the hardships endured by poor communities.

Public Health: Between the millions of premature deaths resulting from fossil fuel combustion—directly from air pollution and indirectly from increases in climate change-related extremes such as heat waves, droughts, floods, and forest fires—there is good evidence that "without adequate mitigation and adaptation, climate change poses unacceptable risks to global public health" (WHO, 2016). Morbidity and mortality due to heat stress alone is now common all over the world, and extreme heat events are responsible for more deaths annually than hurricanes, lighting, tornadoes, floods, and earthquakes combined.

Climate Justice:

"We have to realize that a true ecological approach always becomes a social approach; it must integrate questions of justice in debates on the environment, to hear both the cry of the earth and the cry of the poor."

Pope Francis, Laudato Si (2015)

Roughly 50% of the climate warming pollution is from the wealthiest one billion of humanity while the poorest three billion contribute 5% or less. Yet these poorest three billion will suffer the worst consequences of climate change since they are forced by poverty to rely on 18th-century technologies for meeting basic needs such as cooking. The World Bank estimates that more than 100 million people could be forced into extreme poverty within 15 years when the warming reaches 1.5°C. About 10% of the global population is at risk of forced displacement due to climate change. The impacts on mass migration, trafficking, and breakdown of social structure among the poorest three billion must be assessed urgently, and preventive measures must be put into place. The poorest three billion will be significantly more impacted by the climate change impacts occurring over the next 30 years than those in the long term, as they may not survive to see those long-term effects. In this context, speed matters to achieve climate justice.

6. How Much Time Do We Have to Protect Nature and Humanity?

At what warming level does climate change become catastrophic? Is it at 2°C, 3°C, or 4°C? A correlated question is: How do we define "catastrophic"? Even a one-meter sea-level rise (which is assured given the current atmospheric concentrations of pollutant gases) would be catastrophic for small island nations like the Federated States of Micronesia and the Maldives and low-lying coastal nations such as Bangladesh. The sort of multiyear drought that continues in California would be catastrophic for much of the poorest three billion. Heat waves and floods that have become more frequent over the last few decades are already killing thousands in many nations, including in developed nations. We are fully aware of such limitations of defining "catastrophic".

In what follows, we will build upon the Paris Agreement and discuss the time we have left to mitigate climate change to well below 2°C. We assume this to mean limiting the warming to a range between 1.5°C to 2°C. In addition, we are making a proposal of "Under 2Celsius." The climate forcing of CO_2 and all other anthropogenic greenhouse gases as of 2010, however, is 3 Wm^{-2}, which is sufficient to warm the planet by 2°C or more. So how can we keep the warming at under 2°C?

There is one way to get out of this quandary. Of the 3 Wm^{-2} greenhouse forcing, about 1.2 Wm^{-2} is from gases with atmospheric lifetimes of approximately one decade or less (methane, tropospheric ozone, and HFCs); these gases are collectively known as short-lived climate pollutants (SLCPs). In addition, black carbon, which has a lifetime of only one week, has a net positive forcing of 0.4Wm^{-2} after accounting for the cooling effects of co-emitted organic carbon particles.

The short atmospheric lifetimes of SLCPs means that reducing them will reduce their forcing within a decade. If we mitigate the emissions of these SLCPs making maximum use of available technologies, we can reduce their positive forcing by as much as 0.8 Wm^{-2} and reduce the warming by as much as 0.6°C by 2050, bringing the total warming from 2.1°C to 1.5°C by 2050.

This could cut the rate of global average warming in half by 2050 and, the rate of Arctic warming by two-thirds, as well as reduce total warming in the high-altitude Himalayan-Tibetan Plateau by at least half.

Beyond 2050, further warming can be mitigated by making the planet carbon neutral (net zero emissions of CO_2) but only if actions are taken by 2020 to aggressively reduce CO_2 emissions. The Paris Agreement, on the other hand, allows CO_2 emissions to increase until 2030 and decline afterwards. A substantial portion (20–40%) of emitted CO_2 remains in the atmosphere for centuries to millennia. This long lifetime combined with ocean thermal inertia means that cutting CO_2 emissions will not produce considerable climate benefits for several decades. As of 2010, we have emitted 2 trillion tons of CO_2. At BAU emission rates, we will have emitted the third trillionth ton by 2035. That would commit the planet to 2°C warming by 2035 from CO_2 alone, meaning that if we wait until 2035 to act, we will have already committed the planet to more than 2°C warming. If we continue with BAU until we witness 2°C warming in 2050, we will emit the fourth trillionth ton by 2055. By then the warming would be locked in at more than 3°C. These estimates of warming are only 50% probability events. The 20% probability would project warming double the 50% probability warming values. The bottom line is that we must decarbonize as fast as possible.

In short, long-lived CO_2 and SLCPs are two levers for slowing climate change that can and must both be pulled immediately to achieve our climate goals. The climate impact of each of the two levers operates on fundamentally different timescales. By mitigating the emissions of SLCPs by 2030 and by beginning the carbon neutrality pathway in 2030 and completing it by 2050, we may be able to bend down the warming curve to keep warming below 2°C throughout the rest of the century (Figure 4). However, the graph shows only a 50% probability of achieving this goal. There is still a 10-20% probability of the warming exceeding 3°C by 2100. To decrease the probability of exceeding 2°C to 20%, we have to start on the carbon neutrality pathway by 2020, i.e. emissions of CO_2 begin to decrease by 2020. A 10-year delay in beginning carbon neutrality as envisioned in the Paris Agreement would necessitate the removal of as much as one trillion tons of CO_2 from the air during the second half of this century.

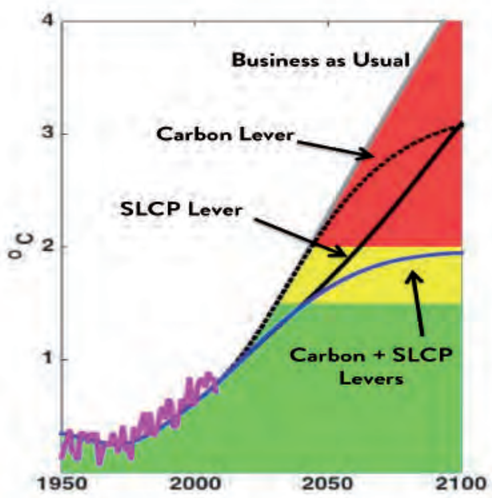


Figure 4. Possible warming trajectories under different mitigation strategies: BAU, mitigation of only CO_2 (Carbon Lever), mitigation of only SLCPs (SLCP Lever), and mitigation of both CO_2 and SLCPs (Carbon + SLCP Levers). The temperature estimates shown are anomalies relative to the 1900–1910 mean and are based on the central value of climate sensitivity. The pink line represents observations from 1900 to 2011. Source: Hu et al., 2013.

7. The Two Lever Approach: What Do We Need to Do and When?

Bending the Curve: We need to bend the curve of projected emissions of pollutants. As explained earlier, we have two levers to pull: the SLCP lever and the Carbon lever. This two-lever strategy is also justified by ethical and equity considerations. There are two time periods we must deal with: first, near-term (the next three decades) and second, long-term (beyond 2050).

The SLCP lever: The first ethical/equity issue concerns intra-generational equity. This concern focuses primarily on the fate of the poorest three billion who until now had very little to do with the climate pollution. The poorest three billion are often the most vulnerable to the impacts of climate change and the least capable of adaptation. As explained in the previous section, we need measures that can be deployed and scaled within a matter of years and provide climate relief within decades or less.

In 2011, the UNEP/WMO Assessment identified 16 technical and policy measures which, if deployed at scale by 2030, can reduce black carbon emissions by ~77% and methane emissions by ~38% (Table 2). Most of the control measures for reducing black carbon and methane can be implemented today with existing technologies and often with existing laws and institutions, including through enhancement and enforcement of existing air quality regulations. HFCs are now being phased down under the Montreal Protocol as a result of the landmark Kigali Amendment in 2016 (Box 1).

The Montreal Protocol could potentialy avoid up to 0.5°C by 2100 as the control mechanisms are strengthened next decade.

Together, these SLCP measures would avoid up to 0.6°C of projected warming by 2050 and 1.5°C by 2100. SLCP measures would also cut the rate of warming in 2050 in half, giving societies and natural systems, including glaciers, ecosystems such as coral reefs and the Amazon, managed agriculture, and rivers, urgently needed time to adapt to unavoidable changes.

Box 1: The Kigali Amendment to the Montreal Protocol – Lever 1 in action

The 2016 Kigali Amendment to the Montreal Protocol will virtually eliminate the warming caused by HFCs, one of the six main greenhouse gases, using a treaty with the experience and expertise to ensure a fast, effective, and efficient phasedown and fully implements the principle of 'common but differentiated responsibilities' by having developed countries undertake their control measures first and pay the full incremental cost of compliance for developing countries through the Multilateral Fund.

Under the Kigali Amendment, most developed countries start in 2019 with a freeze in HFC consumption, which caps future growth, and an immediate 10% reduction. The progressive group of developing countries, which includes China, freeze at 2024, with India and the Gulf States and a few other countries freezing at 2028. The early action by developed countries and the ambitious group of developing countries ensures a fast market transition, which means that the transition of those in the last group will be much faster than their formal date. Even on the original phase down schedule, the Kigali Amendment will avoid ~90% of the warming HFCs otherwise would have caused by 2100.

Moreover, the market for these chemicals has historically moved ahead of the Montreal Protocol control schedules, and recent studies calculate that countries can reduce their HFC emissions by as much as 99% by 2030 by simultaneously transitioning to already available low-GWP alternatives and super-efficient appliances. A simultaneous transition to super-efficient air conditioners sector alone could double the climate benefit of either action alone and would avoid (or free up for other uses) an amount of electricity equal to the production of between 680 and 1,587 medium-sized peak-load coal power plants by 2030 and between 1,090 and 2,540 by 2050.

In addition to climate benefits, reducing SLCPs provides strong collateral benefits for public health and food security. For example, black carbon is a component of aerosol particles, a harmful air pollutant, so the reduction of sources of particulate matter and black carbon will reduce their climate impact as well as improve air quality. Cutting emissions of SLCPs could save an estimated 2.4 million lives per year currently lost to outdoor air pollution and likely millions more from indoor air pollution. In addition, it would cut global crop losses by around 52 million tons a year, which represents an increase of up to 4% of the total annual crop production.

The Carbon Lever: CO_2 effects on climate and ecosystems last thousands of years, affecting generations yet to be born. Thus, the rationale for pulling this lever is based on intergenerational equity, which is at the core of the sustainability of nature and sustainability of humanity. Since the third trillionth ton will commit the planet to 2°C, we must limit cumulative CO_2 emissions from 2010 until the rest of the century to one trillion tons. To satisfy the maximum carbon budget of 3 trillion tons, we must decrease emissions immediately and achieve carbon neutrality by 2050.

However, making rapid changes in total CO_2 emissions will be difficult to achieve because a large portion of CO_2 emissions comes from sources with very long replacement timescales (e.g., power plants). Significantly reducing emissions from these sources is achievable in the near-term but in some cases would require early sun-setting of existing facilities and significantly increasing investments in and deployment of clean energy technologies and supporting infrastructure such as long-distance transmission.

Researchers at Stanford University have outlined pathways to deep cuts in CO_2 by employing 80% renewable energy (water, wind, and sunlight) for global energy needs across the electricity, transportation, commercial, and industrial sectors by 2030 and 100% by 2050. Theoretically, this can be achieved if all end uses of energy are converted to electricity and hydrogen fuel. Such technologies have currently been deployed at limited scales in California, Denmark, Germany, and elsewhere. In addition, 52 cities with populations ranging from 100,000 to 13 million, 63 businesses, and several universities have become living laboratories for ambitious climate mitigation programs that include carbon neutrality goals. Use of renewables and other low carbon energy sources are increasing rapidly. Catalyzed by falling prices, renewables accounted for about 50% of all new power generation in the world (primarily in China, Japan, Germany, and the United States) in 2014, representing an investment of about $270 billion. But whether they can be scaled up and done so by 2030 is uncertain.

There are concerns that the carbon neutral goal will hinder economic progress. Case studies from California and Sweden, which are already on a carbon neutral pathway, do not support such claims. These case studies reveal that between 2000 and 2014, California and Sweden grew their GDPs by nearly 30% while their CO_2 emissions declined, about 30% for Sweden, and 5% for California. The inference is that economic growth can be decoupled from carbon emissions. Other concerns have been raised about carbon neutral goals potentially harming the poor by limiting their access to energy. There are about 3 billion who still cannot afford fossil fuels for meeting basic needs such as cooking. The primary reason is they either do not have access to fossil fuels or lack the infrastructure. For these poorest three billion, decentralized power through for example, village scale micro-grids relying on solar power, wind, and biogas would be far more effective for providing access to modern forms of energy.

8. Adding a Third Lever

The two-lever strategy assumes a central value of climate sensitivity of 3°C warming for a doubling of CO_2. What does that mean? Even if we pull the two levers as hard as we can, we have at best a 50% probability of containing the warming to under 2°C. To reduce the probability of exceeding the 2°C warming from 50% to less than 20%, we must employ a third lever: capturing CO_2 from the atmosphere, known as atmospheric carbon extraction (ACE) (not to be confused with capturing CO_2 from the exhaust of power plants and cement kilns.)

The ACE measures available for us to explore are afforestation, urban forestry, bioenergy combined with carbon capture and sequestration (BECCS), soil organic carbon management, biochar, direct air capture, enhanced weathering and ocean liming, and ocean fertilization with iron. It is very likely that one or more of these techniques could eventually be used to significantly reduce the amount of anthropogenic CO_2 in the atmosphere (i.e., removing a cumulative amount of up to hundreds of GtCO2), although the development of the necessary technologies and vast infrastructures would likely take several decades. Furthermore, more analysis needs to be done to determine which BECCS technologies are carbon neutral or negative in the critical near-term period, and which are only neutral or negative in the longer term.

Given the short-timescales on which action is needed to keep global warming below 1.5°C or 2°C, it is not clear how much ACE will be able to contribute in the near term.

However, given the very real chance of a substantial overshoot of the Paris Agreement goals and the incumbent impacts, not pursuing ACE options, may result in policymakers eventually considering radical geoengineering options such as injecting particles into the stratosphere or other forms of large-scale solar radiation management, which could produce their own disastrous and potentially irreversible harms.

Given the urgency, it is critical to support ongoing research and staged deployment of CO_2 removal and albedo modification techniques such as reflective roofs over buildings.

This research needs to include technical, engineering and natural as well as social science aspects in order to be most effective in guiding policy development. It should also address aspects ranging from development of effective governance and regulation, to our societal perspective on the relationships between humans and their environments, to more concrete economic aspects, particularly considering the investments needed to scale up any of the CO_2 removal techniques and whether it would be more prudent to make the same investment directly in decarbonizing energy and production.

9. Building Blocks for the Three Lever Approach

Pulling all three levers simultaneously will require the global mobilization of human, financial, and technical resources at an unprecedented scale. For the global economy and society to achieve such rapid reductions in SLCPs by 2030 and carbon neutrality and climate stability by 2050, several steps must be taken, including societal transformation, a change in governance structure, technology innovation, the management of soil carbon, market mechanisms like cap andtrade or carbon pricing, and command-and-control instruments such as standards that set emissions limits, ensure increases in energy efficiency, or mandate a percentage of new power generation from renewables. Building upon the pioneering work of more than 50 researchers in the Bending the Curve report and earlier research, we have developed an outline of specific policies building upon the Paris Agreement and other actions that are needed to give the world a very good chance of avoiding extreme climate change. These policies are depicted below.

The scalable solutions are grouped under six clusters: 1) Science Solutions; 2) Societal Transformation Solutions; 3) Governance Solutions; 4) Market- and Regulations-Based Solutions; 5) Technology-Based Solutions; and, 6) Atmospheric Carbon Extraction Solutions.

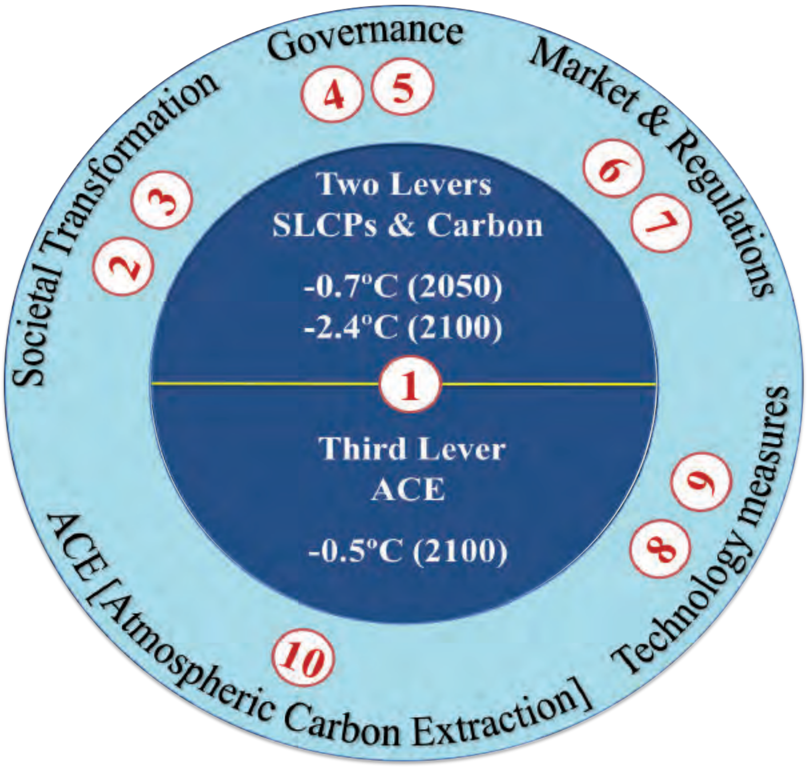


Figure 5: Scalable solutions for climate policy success highlighting the climate benefits from carbon neutrality (Carbon Lever), SLCPs (SLCP Lever), and Atmospheric Carbon Extraction (ACE Lever) mitigation. Adapted with modifications from Ramanathan et al., 2015.

Science Solutions

1. Bend the warming curve immediately by reducing short-lived climate pollutants (SLCPs) and long-term by replacing current fossil fuel energy systems with carbon neutral technologies. Solution #10 outlines SLCP reduction targets to be achieved by 2030 that would cut projected warming by approximately 50% by 2050. To limit long-term (post-2050) global warming to under 2°C, cumulative CO_2 emissions from now to 2050 must be less than 1 trillion tons of CO_2 and approach zero emissions post-2050. Solutions #8 to #10 cover technological solutions to accomplish these targets.

Societal Transformation Solutions

Top-down action will be difficult to implement without substantial support from the general public. Effective climate protection will therefore also require broad-based educational effort and a global grassroots social movement, not simply appeals to elites or controlling institutions.

2. Foster a global culture of climate action through coordinated public communication and education at local to global scales. Public support for taking drastic actions is still lacking. Major initiatives are needed to both foster that public support and change social attitudes and behavior.

- Promote coordinated information campaigns to inform choices available to strategic constituents, for example:

- The medical community can similarly influence both public and political action. There is a growing recognition in the medical community of the imminent threat climate change and air pollution pose to public health. For example, in 2015 the Lancet Commission concluded, "the effects of climate change are being felt today, and future projections represent an unacceptably high and potentially catastrophic risk to human health."

- The world's top carbon emitters, both individuals and institutions, contribute about 60% of the world's greenhouse gas emissions. This target audience is easy to reach as they have readily available access to information technologies, and we must work to engage them in these issues.

  - We need a much better communication strategy to draw in climate skeptics (nearly 40% of the U.S. population) and address false information and narratives in the public discourse.

  - We need to ensure the apportionment of accountability and responsibility for sustainable energy consumption is clear to all constituencies, for example through accurate, transparent, widely available energy calculators that reveal how much energy different constituencies are consuming.

- The military is an important constituency that can help mobilize both public and polit al action; it was instrumental in the U.S. in convincing the administration to require agencies to develop short-term mitigation and long-term mitigation plans. Further, the military needs to both build infrastructure and plan for operations to last for at least 30 years, so it has a vested interest in climate mitigation and adaptation.

- In many nations, climate change has become a political issue. We need to strive for neutral grounds for discussing climate change. Since it has become a major ethical and equity issue, religious institutions and gatherings are another domain for discussing climate change apolitically. We propose an alliance between science, policy, and religion for a transformational impact on public opinion. This already is starting, for example with the encyclical on climate change by Pope Francis in 2015.

- Provide evidence-based indicators of the cumulative impacts of climate injustices.

- Create and integrate curricula at all levels of education, from kindergarten to graduate levels, to educate a new generation about climate change impacts and solutions. Through education of college students, we must develop one million climate warriors around the world to fight climate change.

- A global citizen movement is a crucial element needed to force governments and private industry to restrict warming to 2°C. To protect our climate and prevent catastrophe, average people must become advocates of climate action.

- Educate policy makers, political leaders, corporate CEOs, civil society leaders, and citizens around the world about the dangers and policies needed to limit warming to 2°C and especially about the critical need for "fast climate action" due to the potential for cascading, runaway climate impacts if we do not act quickly.

- Consider partnering with major international membership and public-facing organizations to mobilize citizen action, educate, and utilize social media.

- Appeal directly to not just governments but also to major civil society organizations (including religious, philanthropic, medical, sports, and entertainment groups) and the private sector to take up the "2ProtectingYou" cause. www.2ProtectingYou.com is a website for reporting and a central hub for public organizing.

- Similarly, create "2ProtectingYou" chapters around the world;

- Create and disseminate a citizens' petition to be signed by millions on-line and ultimately sent to global leaders.

- Organize events and citizen actions to galvanize media and political attention.

- Pursue conventional and unconventional media relations and communications approaches.

3. Deepen the global culture of climate collaboration. Climate solutions require integrated behavioral, ethical, political, social, humanistic and scientific knowledge.

- Design venues where stakeholders, community and religious leaders, and researchers and scholars from all academic disciplines converge around concrete problems with the overall goal of initiating collaborative actions to mitigate climate disruption.

- Public universities should use their public missions and mobilize their knowledge and resources to partner with community-based agencies, local school districts, and industry partners to educate locally for climate action.

Governance Solutions

4. Build upon and strengthen the Paris Agreement through targeted multilateral sister agreements, which can drive greater ambition and provide a down payment for climate mitigation using targeted tools and expertise. The 2015 Paris Agreement was a landmark achievement, with 189 countries submitting intended National Determined Contributions (NDCs), in which each committed to greenhouse gas reductions. However, recent analysis indicates that even if all NDC pledges are achieved, global temperatures will likely reach 3.5°C by the end of the century. Sister agreements to the UNFCCC are already providing a down payment on more ambitious action (Table 1).

Table 1. Selected Sister Agreements

Kigali HFC Amendment to the Montreal Protocol	The Kigali Amendment to the Montreal Protocol, passed in October 2016, will phase down consumption and production of HFCs and will help avoid most of the °0.5C of warming that would occur if HFC production continued as currently projected.
International Civil Aviation Organization Ruling on Aircraft Emissions	In October 2016, ICAO agreed to cap net CO_2 emissions from the aviation industry by 2035 to 2020 levels, becoming the first sector to act. Any emissions growth after 2020 needs to be offset.
International Maritime Organization Ruling on Shipping Emissions	IMO is beginning to act on reducing black carbon emissions from the maritime shipping industry. In early 2015, the organization published a report assessing abatement technologies to reduce emissions. IMO also has passed mandatory measures regarding the fuel efficiency of ships, which will reduce both CO_2 and black carbon emissions.
Under 2 MOU	The Under 2 MOU (Memorandum of Understanding) brings together "136 jurisdictions representing 32 countries and six continents," who have "commit[ted] to either reducing their greenhouse gas emissions 80–%95 below 1990 levels by 2050 or achieving a per capita emissions target of less than 2 metric tons by 2050."

- The ambition of these current and pending sister agreements should be further strengthened over time to achieve even greater climate benefits.

- New targeted agreements could be developed to address specific emissions or sectors such as a multilateral treaty to address global emissions of black carbon or one addressing PFCs from the aluminum sector.

5. Scale up subnational models of governance and collaboration around the world to embolden and energize national and international action.

- National and subnational leaders must promote international action and cooperation for unilateral climate policies, such as California's climate mitigation mandate AB 32 (Global Warming Solutions Act of 2006) or the American Clean Energy and Security Act (2009).

- State- and city-level jurisdictions can set the standards and the pace for national actions by serving as living laboratories for renewable technologies, regulatory-based ("command and control") strategies and market-based solutions. California has many successful examples other state- and city-level jurisdictions can emulate. Building cross-sector collaborations among urban stakeholders is critical because creating sustainable cities is a key to global change.

- State-level climate policy should encourage innovation and commercialization of technologies and solutions that can replace fossil fuels and concurrently enable the poorer nations of the world to achieve economic growth with zero and low- carbon technologies.

- Accelerate the impact of cities on climate mitigation through:

1) Municipal and regional Climate Action Plans (CAPs)

2) Green infrastructure projects, such as:
   a) Urban forestry to improve carbon sequestration and reduce the urban heat island effect
   b) Locally decentralized microgrids using renewable energy sources

3) Smart mobility planning and design and improved mass transit systems for active living, such as mixed-use infill and transit-oriented development. This reduces greenhouse gas emissions by making cities less autocentric and more walkable and bikeable.

4) Incentivizing passive house and photovoltaic retrofits and new net-zero energy technology for buildings

5) Corresponding civic engagement and public education strategies, accompanied by concrete local opportunities for participatory climate action, to change attitudes and behaviors.

Market- and Regulations-Based Solutions

6. Adopt market-based instruments to create efficient incentives for businesses and individuals to reduce CO_2 emissions. These can include cap and trade or carbon pricing and should employ mechanisms to contain costs. High-quality emissions inventories and monitoring and enforcement mechanisms will be necessary to make these approaches work. Appropriate and progressive carbon pricing will require markets to account for externalities in the marketplace, such as the risks of triggering future tipping points that can greatly increase the present social cost of carbon.

Another artificial market distortion that must be corrected is subsidization of fossil fuels worldwide, which provides carbon-intensive fuels with an advantage over low-carbon fuels. According to the IMF fossil fuels receive approximately $5.3 trillion every year because current prices do not capture the full costs of both climate change and air pollution impacts on health. Dividing the $5.3 trillion by the approximately 38 billion tons of annual fossil fuel-related CO_2 emissions results in a social and financial cost of fossil fuels of $140 per ton of CO_2. The cost of transforming the global infrastructure to renewables is estimated to be around $1 trillion per year.

Economic theory and empirical evidence tell us that market approaches are the most cost-effective. In a few cases where market based control systems have been used at scale—such as trading of lead pollution, trading of sulfur dioxide pollution, and the European and Californian carbon markets—that theory is borne out by evidence. Yet it is already clear that market approaches are politically very difficult to implement in part for the very reasons that many analysts find them attractive: they make the real costs of action highly transparent.

- Revenues from cap and trade or carbon taxes should be used to fund aggressive pursuit of innovative new technologies that can bend the curve and protect disadvantaged communities and those adversely affected by cap and trade or other regulatory strategies.

7. Narrowly target direct regulatory measures—such as rebates and efficiency and renewable energy portfolio standards—for high emissions sectors not covered by market-based policies.

It is imperative to anticipate and design climate policies in a way that can contain compliance costs. Pure regulation leaves policies susceptible to large increases in compliance costs, particularly in the presence of capacity or production constraints that are inherent in energy markets.

- Create powerful incentives that continually reward improvements to bring down emissions while building political coalitions in favor of climate policy.

- Terminate subsidies that encourage emission-intensive activities.

- Expand subsidies that encourage innovation in low-emission technologies.

- Regulation requires extremely sophisticated institutions and enforcement (such as the California Air Resources Board) to prevent leakage and to look ahead and assess how regulatory decisions interact with business strategy and the evolution of technology.

Technology-Based Solutions

The technological measures under solution #8, if begun by 2020 and fully implemented by 2050, will reduce global warming by as much as 1.5°C by 2100 and, if combined with measures to reduce SLCPs in solution #9, will keep warming well below 2°C during the 21st century and beyond.

8A Promote immediate widespread use of mature technologies such as photovoltaics, wind turbines, biogas, geothermal, batteries, hydrogen fuel cells, electric light-duty vehicles, and more efficient end-use devices, especially in lighting, air conditioning, appliances, and industrial processes. These technologies will have even greater impact if they are the target of market-based or direct regulatory solutions such as those described in solutions #6 and #7. Together, they have the potential to achieve a 30% to 40% reduction in fossil fuel CO_2 emissions by 2030 (relative to BAU).

- Achieve a more reliable and resilient electric grid with at least 90% of all new generation capacity by 2030 from distributed and renewable technologies, such as those listed above.

- Expand electrification of highly efficient end-use devices, especially lighting, electric vehicles, machinery, and plug-load appliances.

- Examples from the University of California campuses demonstrate that deep energy efficiency investments are immediately amenable to widespread implementation.

- Accelerate the transition from fossil to zero-carbon, locally-sourced transportation fuels, such as hydrogen to power fuel cell-powered electric vehicles and low-carbon grid electricity to power battery electric vehicles, to meet the carbon reduction required from the light-duty and goods movement transportation sectors.

8B Aggressively support and promote innovations to accelerate the complete electrification of energy and transportation systems and improve building efficiency. Smart grid and microgrid technology make possible the increasing penetration of intermittent solar and wind generation resources, the emergence and integration of plug-in electric vehicles into the grid infrastructure, and a proactive response to the increasing demand for enhanced grid resiliency, thereby meeting the challenging environmental goals associated with climate change, air quality, and water consumption. The evolution of this technology represents a paradigm shift. In addition, energy storage is a vital enabling technology that holds the key to both transitioning away from fossil fuels for our vehicular needs and managing the intermittency of renewables on the electric power grid. Over the past five years, electric vehicles have been entering the market, and storage technologies are being tested now on various grid applications, mainly driven by innovations in lithium-ion batteries and hydrogen.

- Support development of lower cost energy storage for applications in transportation, resilient large-scale and distributed micro-scale grids, and residential uses.

- Support research and development of a portfolio of new energy storage technologies, including batteries, super-capacitors, compressed air, and hydrogen and thermal storage, as well as advances in heat pumps, efficient lighting, fuel cells, smart buildings and systems integration. These innovative technologies are essential for meeting the target of an 80% reduction in CO_2 emissions by 2050.

- Advanced lighting based on efficient light-emitting diode (LED) technology is now commercially available and has a pay-back time of only one to two years. The replacement of all incandescent, metal halide, and fluorescent lighting fixtures with LED lighting can reduce energy consumption from lighting by 40%. Investments are needed to capture further efficiencies, which are possible with the development of next-generation intelligent and more efficient 200 lumens per Watt LED lighting products. These will be optimized for color and brightness to improve work and school productivity and building efficiency. India established Energy Efficiency Services Limited (EESL), an energy services company run as a joint venture between the state power companies, to create a market for and support investment in energy efficiency. EESL implements the Domestic Efficient Lighting Programme, now known as UJALA (Unnat Jyoti by Affordable LEDs for All), which, as of November 2016, has successfully distributed over 175 million LEDs; this avoids just over 50,000 tons of CO_2 emissions per day.

- Upgrading air conditioning units to both use low-GWP refrigerants and be more energy efficient can provide substantial mitigation. In the room air conditioning sector alone, improving energy efficiency of equipment by 30% while simultaneously transitioning to low-GWP alternatives could save an amount of electricity equivalent to up to 2,500 medium-sized power plants globally by 2050, while providing climate mitigation of nearly 100 Gt CO_2-eq by 2050 from this sector.

- Residential natural gas consumption can be reduced by 50% or more with widespread deployment of heat pumps and systems coupled with solar thermal and solar power generation. To accelerate this goal, we recommend deploying an incentive program of rebates comparable to those for energy efficiency appliances.

- Substantially reducing the carbon footprint from light-duty vehicles and goods movement (medium-duty and heavy duty vehicles, locomotives and ships) and, at the same time, achieving urban air quality goals requires the development of zero-carbon fuels such as hydrogen and highly-efficient engines with zero criteria pollutant emissions.

- While full electrification is an achievable goal for light- duty and medium-duty transportation, some form of environmentally friendly renewable fuel solutions may be needed for heavy-duty transport, such as algal-based biofuels.

These solutions will require significant investments in both basic and applied research and development, demonstration of prototypes, and commercial deployment.

9. Immediately make maximum use of available technologies combined with regulations to reduce methane emissions by 50%, reduce black carbon emissions by 90%, and eliminate high-GWP HFCs. In addition to the climate and health benefits described under solution #1, this solution will provide access to clean cooking for the poorest 3 billion people who spend hours each day collecting solid biomass fuels and burning them indoors for cooking.

- HFCs will be phased down under the Montreal Protocol under the Kigali Amendment of October 2016. Moreover, several recent studies have shown that emissions of HFCs could be quickly phased out and their warming virtually eliminated by 2030 by using low-GWP alternatives already available on the market. With a rapid transition away from high-GWP HFCs, an additional 39–64 Gt CO2e can be avoided from future buildup of HFC banks. The climate benefits of phasing out HFCs could be more than doubled in some sectors through parallel efforts to increase energy efficiency of air conditioners and other appliances during this switch in refrigerants.

- The specific technological measures for reducing methane and black carbon are described in the table below. These measures were developed by an international panel and reported in a UNEP WMO Report, 2011.

Table 2. Selected Measures for Curbing Black Carbon and Methane Emissions

Sectors	Methane Measures
Extraction and transport of fossil fuels	Extend pre-mine degasification and recovery and oxidation of CH4 from ventilation air from coal mines
	Extend recovery and utilization, rather than venting, of associated gas and improved control of unintended fugitive emissions from production of oil and natural gas
	Reduce gas leakage from long-distance transmission pipelines
Waste management	Separate and treat biodegradable municipal waste through recycling, composting and anaerobic digestion as well as landfill gas collection with combustion/utilization
	Upgrade primary wastewater treatment to secondary/tertiary treatment with gas recovery and overflow control
Agriculture	Control CH4 emissions from livestock, mainly through farm-scale anaerobic digestion of manure from cattle and pigs, but also researching methods to reduce methane from enteric fermentation
	Promote healthy low-meat diets
	Black Carbon Measures (affecting BC and other co-emitted compounds)
Transport	Require diesel particle filters for road and off-road vehicles
	Eliminate of high-emitting vehicles in road and off-road transport
	Promote active transport
Residential	Replace coal by coal briquettes in cooking and heating stoves
	Pellet stoves and boilers, using fuel made from recycled wood waste or sawdust, to replace current wood-burning technologies in the residential sector in industrialized countries
	Introduction of clean-burning biomass stoves for cooking and heating in developing countries2,3
Industry	Replace traditional brick kilns with vertical shaft kilns and Hoffman kilns
	Replace traditional coke ovens with modern recovery ovens, including the improvement of end-of-pipe abatement measures in developing countries
Agriculture	Ban open field burning of agricultural waste

Atmospheric Carbon Extraction Solutions

10A Regenerate damaged natural ecosystems and restore soil organic carbon to improve natural sinks for carbon through afforestation, reduced deforestation, sustainable grazing strategies, efficient application of fertilizer, and restoration of soil organic carbon, including through the use of organic amendments, such as biochar or compost. Sustainable agricultural practices and maintaining natural ecosystems is an essential component of mitigating climate change, and is vital to global food security, and human health. Agriculture and residues from natural ecosystems can contribute to renewable energy production through the conversion of organic waste streams to bio-based products and fuels. Globally, food waste reduction programs that recover energy from food that is not consumed has the potential to reduce 20% of the current 50 billion tons of emissions of CO_2 and other greenhouse gases and, in addition, meet the recently approved sustainable development goals by creating wealth for the poorest 3 billion.

- The potential for carbon mitigation from afforestation, reduced deforestation, and restoration of soil organic carbon is about 8 to 12 gigatons per year.

- Agriculture accounts for 10 to 15% of global GHG emissions (60% of nitrous oxide and 50% of methane emissions). The over-use of nitrogen fertilizers is estimated to be the largest portion of direct agricultural soil management-related nitrous oxide emissions in most countries. Global agricultural nitrous oxide emissions are expected to increase by 35 to 60% by 2030 in association with increased fertilizer nitrogen use and manure production. Therefore, the efficient application of nitrogen-based fertilizers should be encouraged worldwide to mitigate GHG emissions. Appropriate fertilizer nitrogen use also increases crop biomass to help restore, maintain, and increase soil organic carbon.

- Biochar, which results from pyrolysis of waste biomass, enhances soils in addition to securely storing carbon, up to a maximum of 130 GtCO2e by 2100.

- Globally, one-third of food produced is not eaten; in the U.S. 40% is not eaten. The CO_2 and other greenhouse gases emitted in producing this wasted food contribute 3.3 gigatons annually to emissions. And when food is thrown away, methane — which is about 80 times more potent than CO_2 as a greenhouse gas — is released in landfills.

10B Other strategies to extract CO_2 from the air: The ACE measures that fall under the category of soft-geoengineering, in addition to afforestation and urban forestry, include biochar, enhanced weathering and ocean liming, ocean fertilization with iron, and direct air capture.

10. In Pursuit of the Common Good: Where Do We Go from Here?

We conclude by considering the challenges that face society and if we will rise to the challenge or give up hope before it is too late. The most fundamental question is: do we have a choice to not rise to the challenge? Given the existential threats climate change, under the business as usual emissions, poses to many ecosystems, jurisdictions, and societies, it is imperative the issue is effectively addressed this century. We are quickly running out of time to prevent hugely dangerous, expensive, and perhaps unmanageable climate change. That is a central conclusion of this report.

Yet political leaders, corporations, civil society, and the general public for the most part are acting as if we have plenty of time, not completely aware of the urgency of the climate crisis.

It IS EXTREMELY urgent.

The good news is that it is still not too late to prevent disastrous climate changes. This report sets out a specific plan for limiting climate change in both the near- and long-term. With aggressive, urgent action, we can protect ourselves. We also have many examples in our recent past proving that humanity can mobilize to achieve collective environmental objectives (Table 3).

Table 3. Examples of Environmental Successes

Montreal Protocol	In the mid-1980s, scientists realized the ozone layer above Antarctica was disappearing due to the rapid rise in the production and usage of CFCs (chlorofluorocarbons). Recognizing the threat to human health, countries signed the Montreal Protocol to phase out these chemicals in 1987. Today the Montreal Protocol has phased out nearly 100 ozone depleting substances by nearly 99% and has set the ozone layer on a path to full recovery by 2065. In the U.S., the treaty will prevent over 280 million cases of skin cancer, 1.5 million skin cancer deaths, and 45 million cataracts. Because ozone depleting substances are also powerful greenhouse gases, the Montreal Protocol also avoided the equivalent of 135 billion tons of CO_2 between 1990 and 2010, earning recognition as "one of the most successful environmental treaties in history."
Air Quality Improvements in California, New York City, and London	Recognizing the harmful effects of air pollution, particularly to human health, various cities and states have taken on air quality control measures over the last few decades. Since the 1960s, California has been highly successful in reducing air pollution, cutting emissions of ozone precursor gases, PM2.5, air toxics, and black carbon by as much as 90% despite large increases in population, number of vehicles, and diesel fuel consumption. New York City recently applied vast air quality improvements. From 2008 to 2014, annual averages of PM2.5, NO_2, and NO levels, all of which threaten public health, declined by 16–24%, and SO_2 declined by nearly 70%. In London, NO_x emissions fell by nearly 40% from 2005 to 2013.
The Convention on Long-range Transboundary Air Pollution	LTARP has resulted in drastic reductions of air pollutants in the United Nations Economic Commission for Europe region (Europe, the U.S., Canada, the Central Asian republics, and Israel). From 1990 to 2006, SO_2 and NO_x emissions, both of which contribute to acid rain, fell by 70% and 35% in the EU, respectively and 36% and approximately 25% in the U.S., respectively. PM10, which is a public health threat, levels declined by nearly 30% in the EU.

This report describes a detailed plan to restrict warming to under 2°C and provides a path toward true climate protection, with the possibility, although difficult, of limiting it to 1.5°C. Acting quickly, by 2020, to prevent catastrophic climate change will save millions of lives, trillions of dollars in economic costs, and massive suffering and dislocation to people around the world. Acting quickly to prevent runaway climate change is a global security imperative, as it can avoid the destabilization of entire societies and countries and reduce the likelihood of environmentally driven civil wars and other conflicts.

So, we must act. But how do we create the political and social momentum for the substantial changes in our energy systems that will be needed? It is likely to require, in addition to those listed under the Ten Solutions section, the following:
- A much better education and communication strategy to draw in climate change skeptics. In the U.S. almost 40% of the population falls under this category.
- We need to be willing to change some of our behaviors towards each other and towards nature and make more sustainable, environmentally conscious choices, remaining cognizant of the fact our choices will affect generations yet to be born.
- We need to garner support and cooperation from all religions, the military and the industry, including the energy industry. The solution to this problem will be lot easier with the cooperation of industry, particularly the energy industry.

As outlined above, staying under 2°C will require a concerted global effort. We must address everything from our energy systems to our personal choices in order to reduce emissions to the greatest extent possible. Decarbonization must happen immediately and rapidly for our best chance to under 2°C, and even with this drastic action, removing existing carbon from the atmosphere will almost certainly be necessary to achieve this goal.

11. References

– Alley R., et al. (2015). Oceanic Forcing of Ice-Sheet Retreat: West Antarctica and More. Ann. Rev. Earth Planet. Sci. 43:207–231.

– Ault T.R., et al. (2016). Relative impacts of mitigation, temperature, and precipitation on 21st Century megadrought risk in the American Southwest. Science Advances 2(10): e1600873.

– Bahadur R., et al. (2012). Solar absorption by elemental and brown carbon determined from spectral observations. Proc. Nat'l. Acad. Sci. 109(43):17366–17371.

– Barriopedro D., et al. (2011). The Hot Summer of 2010: Redrawing the Temperature Record Map of Europe. Science 332(6026):220224.

– Bender F. A.-M., et al. (2012). Changes in extratropical storm track cloudiness 1983–2008: observational support for a poleward shift. Climate Dynamics 38:2037–2053.

– Bolch T., et al (2012). The state and fate of Himalayan glaciers. Science 336(6079):310–314.

– Boos W. R. and Storelvmo T. (2016). Near-linear response of mean monsoon strength to a broad range of radiative forcings. Proc. Nat'l. Acad. Sci. 113:1510–1515.

– Cai Y., et al. (2016). Risk of multiple climate tipping points should trigger a rapid reduction in CO_2 emissions. Nature Climate Change, 6: 520–525.

– Campos A., et al. (2012). Analysis of disaster risk management in Colombia: a contribution to the creation of public policies. Bogotá, Colombia: The World Bank and GFDRR.

– Climate and Clean Air Coalition (CCAC) (2016a). Integrated Assessment of Short-Lived Climate Pollutants in Latin America and the Caribbean: Summary for Decision Makers. Nairobi: UNEP.

– Climate and Clean Air Coalition (CCAC) (2016b) Short-lived Climate Pollutants in Countries' Intended Nationally Determined Contributions, A Scientific Advisory Panel Briefing Note.

– Dasgupta P., et al. (2015). Climate Change and the Common Good: A Statement of the Problem and the Demand for Transformative Solutions. The Pontifical Academy of Sciences and the Pontifical Academy of Social Sciences.

– DeConto R. M. and Pollard D. (2016). Contribution of Antarctica to past and future sea-level rise. Nature 531:591–597.

– Department of Defense (DOD) (2015) National Security Implications of Climate-Related Risks and a Changing Climate.

– Drijfhout S., et al. (2015). Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. Proc. Nat'l Acad. Sci. USA. 112:E5777–E5786.

– Dutrieux P., et al. (2014). Strong Sensitivity of Pine Island Ice-Shelf Melting to Climatic Variability. Science 343:174–178.

– Dutton A., et al. (2015). Sea-level rise due to polar ice-sheet mass loss during past warm periods. Science 349:aaa4019.

– E.U. (2014). Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated gases and repealing Regulation (EC) No 842/2006.

– Favier L., et al. (2014). Retreat of Pine Island Glacier controlled by marine ice-sheet instability. Nature Climate Change 4:117–121.

– Flynn H. C. and Smith P. (2010). Greenhouse Gas Budgets of Crop Production—Current and Likely Future Trends. International Fertilizer Industry Association, Paris, France.

– Francis J. and N. Skific (2015). Evidence linking rapid Arctic warming to mid-latitude weather patterns. Philos. Trans. Roy Soc. A 373(2045):20140170.

– Fujita K. and Nuimura T. (2011). Spatially heterogeneous wastage of Himalayan glaciers. Proc. Nat'l. Acad. Sci. 108(34):14011–14014.

– Fuss S., et al. (2014). Betting on negative carbon emissions. Nature Climate Change 4:851

– Ganguly D., et al. (2012). Climate response of the South Asian monsoon system to anthropogenic aerosol. Journal of Geophysical Research: Atmospheres 117(D13):2156–2202.
– Ganguly D., et al. (2012). Fast and slow responses of the South Asian monsoon system to anthropogenic aerosols. Geophysical Research Letters 39(18).
– Gardelle J., et al. (2012). Slight mass gain of Karakoram glaciers in the early twenty-first century. Nature Geoscience 5(5):322–325.
– Gardner A. S., et al. (2013). A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. Science 340(6134):852–857.
– Garschagen M., et al. (2016). WORLD RISK REPORT. UNU-EHS.
– Gertler C. G., et al (2016). Black carbon and the Himalayan cryosphere: a review. Atmospheric Environment 125:404–417.
– Goswami B. N., et al. (2006). Increasing Trend of Extreme Rain Events Over India in a Warming Environment. Science 314(5804):1442–1445.
– Guo W., et al. (2015). The second Chinese glacier inventory: data, methods and results. J. Glaciology 61(226):357–372.
– Gustafsson O. and Ramanathan V. (2016). Convergence on climate warming by black carbon aerosols. Proc. Nat'l. Acad. Sci. 113(16):4243–4245.
– Haberle S. G. and David B. (2004). Climates of change: Human dimensions of Holocene environmental change in low latitudes of the PEPII transect. Quaternary International 118119:165179.
– Hallegatte S., et al. (2013). Future flood losses in major coastal cities. Nature Climate Change 3:802–806.
– Hallegate S., et al. (2016). Shock Waves: Managing the Impacts of Climate Change on Poverty. World Bank.
– Hansen J., et al. (2016). Global Temperature in 2015.
– Hinkel J., et al. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise, Proc. Natl. Acad. Sci. 111(9): 3292–3297.
– Holland D. M., et al. (2008). Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters. Nature Geoscience 1:659–664.
– Hope C. and Schaefer K. (2016). Economic impacts of carbon dioxide and methane released from thawing permafrost. Nature Climate Change 6:56–59.
– Hu A., et al. (2013). Mitigation of short-lived climate pollutants slows sea-level rise. Nature Climate Change 3:730–734.
– Immerzeel W. W., et al. (2010). Climate change will affect the Asian water towers. Science 328(5984):1382–1385.
– Immerzeel W. W., et al. (2012). Hydrological response to climate change in a glacierized catchment in the Himalayas. Climatic Change 110(3-4):721–736.
– International Civil Aviation Organization (ICAO), Press Release (2016). Historic agreement reached to mitigate international aviation emissions.
– International Energy Agency (IEA) (2014). WORLD ENERGY OUTLOOK 2014.
– International Maritime Organization (IMO) (2015). INVESTIGATION OF APPROPRIATE CONTROL MEASURES (ABATEMENT TECHNOLOGIES) TO REDUCE BLACK CARBON EMISSIONS FROM INTERNATIONAL SHIPPING.
– IPCC (2001) CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS: CONTRIBUTION OF WORKING GROUP I TO THE THIRD ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Cambridge Univ. Press, Cambridge, 2001.
– IPCC (2007). CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS: CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE.
– IPCC (2011). MANAGING THE RISKS OF EXTREME EVENTS AND DISASTERS TO ADVANCE CLIMATE CHANGE ADAPTATION (SREX).
– IPCC (2013). CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS: WORKING GROUP I CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE.

– IPCC (2014). CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY: WORKING GROUP II CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE.

– Jacob T., et al. (2012). Recent contributions of glaciers and ice caps to sea level rise. Nature 482(7386):514–518.

– Jacobson M. Z., et al. (2015). 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States. Energy & Environmental Science 8:20932117.

– Ji Z., et al. (2015). Simulation of carbonaceous aerosols over the Third Pole and adjacent regions: distribution, transportation, deposition, and climatic effects. Climate Dynamics 45(9-10):2831–2846.

– Joughin I., et al. (2014). Marine ice sheet collapse potentially under way for the Thwaites Glacier basin, West Antarctica. Science 344:735–738.

– Kääb A., et al. (2012). Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas. Nature 488(7412):495–498.

– Kang S., et al. (2010). Review of climate and cryospheric change in the Tibetan Plateau. Environmental Research Letters 5(1):015101.

– Kang S., et al. (2015). Dramatic loss of glacier accumulation area on the Tibetan Plateau revealed by ice core tritium and mercury records. The Cryosphere 9(3):1213–1222.

– Kang S. C. and Cong Z. Y. (2016). Atmospheric black carbon and its effects on cryosphere. Advances in Climate Change Research.

– Kelley C. P., et al. (2015). Climate change in the Fertile Crescent and implications of the recent Syrian drought. Proc. Nat'l. Acad. Sci. 112(11):3241–3246.

– Kennett D. J., et al. (2007). Human responses to Middle Holocene climate change on California's Channel Islands. Quaternary Science Reviews 26(34):351367.

– Kreft S., et al. (2015). Global Climate Risk Index 2016: Who Suffers Most from Extreme Weather Events? Weather-related Loss Events in 2014 and 1995 to 2014.

– Kriegler E., et al. (2009). Imprecise probability assessment of tipping points in the climate system. Proc. Nat'l. Acad. Sci. 106:5041–5046.

– Lam N. L., et al. (2012). Household Light Makes Global Heat: High Black Carbon Emissions From Kerosene Wick Lamps. Envtl. Science & Technology 46(24):13531–13538.

– Lau K. M. and Kim K. M. (2006). Observational relationships between aerosol and Asian monsoon rainfall, and circulation. Geophysical Research Letters 33(21):L21810.

– Lau N.-C. and Nath M. J. (2014). Model Simulation and Projection of European Heat Waves in Present-Day and Future Climates. J. Climate 27:3713–3730.

– Lemoine D., and Traeger C. P. (2016). Economics of Tipping the Climate Dominoes. Nature Climate Change 6:514–519.

– Lenton T. M. (2012) Arctic climate tipping points. AMBIO 41:10–22.

– Lenton T. M., et al. (2008). Tipping elements in the Earth's climate system. Proc. Nat'l. Acad. Sci. 105:1786–1793.

– Levy H., et al. (2013). The roles of aerosol direct and indirect effects in past and future climate change. J. Geophysical Research: Atmospheres 118(10):4521–4532.

– Li C., et al. (2016). Sources of black carbon to the Himalayan–Tibetan Plateau glaciers. Nature Communications 7:12574.

– Li X., et al. (2015). Mechanisms of Asian Summer Monsoon Changes in Response to Anthropogenic Forcing in CMIP5 Models. J. Climate 28(10):4107–4125.

– Li Y., et al. (2016). Impacts of black carbon and mineral dust on radiative forcing and glacier melting during summer in the Qilian Mountains, northeastern Tibetan Plateau. The Cryosphere Discuss.

– Lin L., et al. (2016). Sensitivity of precipitation extremes to radiative forcing of greenhouse gases and aerosols. J. Geophysical Research Letters 43(18):9860–9868.

– Liu S. Y., et al. (2006). Glaciers in response to recent climate warming in Western China. Quaternary Sciences 26(5):762–771.
– Lontzek, T. S., et al. (2015). Stochastic integrated assessment of climate tipping points indicates the need for strict climate policy. Nature Climate Change 5:441–444.
– Lugber G. and McGeehin M. (2008). Climate change and extreme heat event. American Journal of Preventative Medicine 35(5):42935.
– Mayewski P. A., et al. (2013). West Antarctica's Sensitivity to Natural and Human-forced Climate Change Over the Holocene. J. Quaternary Science 28(1):40–48 (2013).
– McKay N. P., et al. (2011). The role of ocean thermal expansion in Last Interglacial sea level rise. Geophysical Research Letters 38(14):L14605.
– Meehl G. A. and Tebaldi C. (2004). More intense, more frequent, and longer lasting heatwaves in the 21st century. Science 305:994–997.
– Molina M., et al. (2009). Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions. Proc. Nat'l. Acad. Sci. 106(49):20616–20621.
– Neckel N. et al. (2014). Glacier mass changes on the Tibetan Plateau 2003–2009 derived from ICESat laser altimetry measurements. Environmental Research Letters 9(1):014009.
– Nitschke M., et al. (2011). Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. Environmental Health 10(42).
– Norris J. R., et al. (2016). Evidence for climate change in the satellite cloud record. Nature 536:72–75.
– OECD (2007). Ranking the World's Cities Most Exposed to Coastal Flooding Today and in the Future: Executive Summary. OECD, Paris, France.
– Pal, J. S. and Eltahir, E. A. B. (2015). Future temperature in southwest Asia projected to exceed a threshold for human adaptability. Nature Climate Change 6:197–200.
– Paolo F. S., et al. (2015). Volume loss from Antarctic ice shelves is accelerating. Science 348(6232):327–331.
– Pistone K., et al. (2014). Observational determination of albedo decrease caused by vanishing Arctic sea ice. Proc. Nat'l. Acad. Sci. 111(9):3322–3326.
– Pope Francis (2015). Laudato Si': On Care for Our Common Home [Encyclical].
– Qiu J. (2008). China: the Third Pole. Nature 454:393–396.
– Rahmstorf S. and Coumou D. (2011). Increase of extreme events in a warming world, Proc. Nat'l. Acad. Sci. 108(44):1790517909.
– Ramanathan V. and Carmichael G. (2008). Global and regional climate changes due to black carbon. Nature Geoscience 1:221–227.
– Ramanathan V. and Feng Y. (2008). On avoiding dangerous anthropogenic interference with the climate system: formidable challenges ahead. Proc. Nat'l Acad. Sci. USA 105(38):14245–14250.
– Ramanathan V., et al. (1985). Trace Gas Trends and Their Potential Role in Climate Change. J. Geophysical Research 90(D3):5547–5566.
– Ramanathan V., et al. (2001). Aerosols, Climate, and the Hydrological Cycle. Science 294(5549):2119–2124.
– Ramanathan V., et al. (2005). Atmospheric brown clouds: impacts on South Asian climate and hydrological cycle. Proc. Nat'l. Acad. Sci. 102(15):5326–5333.
– Ramanathan V., et al. (2015). BENDING THE CURVE: EXECUTIVE SUMMARY. University of California.
– Rignot E., et al. (2004). Accelerated ice discharge from the Antarctic Peninsula following the collapse of Larsen B ice shelf. Geophysical Research Letters 31: L18401.
– Rignot E., et al., (2011) Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. Geophysical Research Letters 38(5):L05503.
– Rignot E., et al. (2014). Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith and Kohler glaciers, West Antarctica, from 1992 to 2011. Geophysical Research Letters 41:3502–3509.
– Rogelj J., et al. (2015). Energy system transformations for limiting end-of-century warming to below 1.5°C.

– Nature Climate Change 5:519–527.
– Schleussner C.-F., et al. (2016a). Armed-conflict risks enhanced by climate-related disasters in ethnically fractionalized countries. Proc. Nat'l. Acad. Sci. 113(33):9216–9221.
– Schleussner C.-F., et al. (2016b). Differential climate impacts for policy-relevant limits to global warming: the case of 1.5C and 2C. Earth System Dynamics 7:327-351.
– Schoof C. (2007). Ice sheet grounding line dynamics: steady states, stability, and hysteresis. J. Geophys. Res. 112:F03S28.
– Schuur E. A. G., et al. (2015). Climate change and the permafrost carbon feedback. Nature 520:171–179.
– Serreze M. C. and Barry R. G. (2011). Processes and impacts of Arctic amplification: a research synthesis. Global Planetary Change 85–96.
– Shah N., et al. (2015). Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Air Conditioning. Lawrence Berkeley National Laboratory.
– Shindell D. and Faluvegi G. (2009). Climate response to regional radiative forcing during the twentieth century. Nature Geoscience 2:294–300.
– Shindell D., et al. (2012). Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security. Science 335(6065):183189.
– Sillmann J., et al. (2015). Climate emergencies do not justify engineering the climate. Nature Climate Change 5:290–292.
– Sinha A., et al. (2015). Trends and oscillations in the Indian summer monsoon rainfall over the last two millennia. Nature Communications 6:6309.
– Straneo F. and P. Heimbach (2013). North Atlantic warming and the retreat of Greenland's outlet glaciers. Nature 504:36–43.
– UNEP (2011). Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers.
– UNEP (2015). Decision XXVIII/1: Further Amendment of the Montreal Protocol.
UNEP-WMO (2011). Integrated Assessment of Black Carbon and Tropospheric Ozone. Nairobi: UNEP.
– UN Office for Disaster Risk Reduction (UNISDR) & Centre for Research on the Epidemiology of Disasters (CRED) (2015). THE HUMAN COST OF WEATHER-RELATED DISASTERS 1995–2015.
– UN Framework Convention on Climate Change (UNFCCC) (2015) Paris Agreement.
Velders G. J. M., et al. (2009). The large contribution of projected HFC emissions to future climate forcing. Proc. Nat'l. Acad. Sci. U.S.A. 106:10949–10954.
– Velders G. J. M, et al. (2012). Preserving Montreal Protocol Climate Benefits by Limiting HFCs. Science 335(6071):922–923.
– Velders G. J. M., et al. (2014). Growth of climate change commitments from HFC banks and emissions. Atmospheric Chemistry & Physics 14:4563–4572.
– Wang X., et al. (2012). Using remote sensing data to quantify changes in glacial lakes in the Chinese Himalaya. Mountain Research and Development 32(2):203–212.
– Watts N., et al. (2015). Health and climate change: policy responses to protect public health. The Lancet 386(10006):18611914.
– Webster P. J., et al. (1998). Monsoons: Processes, predictability, and the prospects for prediction. J. Geophysical Research 103(C7):14451–14510.
– Wheeler T. (2015). CLIMATE CHANGE IMPACTS ON FOOD SYSTEMS AND IMPLICATIONS FOR CLIMATE-COMPATIBLE FOOD POLICIES, Chapter in: Climate change and food systems: global assessments and implications for food security and trade, Aziz Elbehri (editor). Food Agriculture Organization of the United Nations (FAO), Rome, 2015.
– White House (2014). Climate Action Plan: Strategy to Reduce Methane Emissions.
– White House Office of the Press Secretary (2016). FACT SHEET: Nearly 200 Countries Reach a Global Deal to

– Phase Down Potent Greenhouse Gases and Avoid Up to 0.5°C of Warming.
– Winkelmann R., et al. (2015). Combustion of available fossil fuel resources sufficient to eliminate the Antarctic Ice Sheet. Science Advances 1:e1500589.
– World Bank (2013a). Building Resilience: Integrating Climate and Disaster Risk into Development.
– World Bank (2013b). TURN DOWN THE HEAT: WHY A 4°C WARMER WORLD MUST BE AVOIDED. Washington, DC.
– World Health Organization (WHO) (2014). Burden of disease from the joint effects of household and ambient air pollution for 2012.
– World Health Organization (WHO) (2016). Second Global Conference: Health and Climate, Conference Conclusions and Action Agenda.
– Xu, Y., et al. (2013). Estimating the radiative forcing of carbonaceous aerosols over California based on satellite and ground observations, J. Geophysical Research: Atmospheres 118(19):11148–11160.
– Xu Y., et al. (2013). The role of HFCs in mitigating 21st century climate change. Atmospheric Chemistry and Physics 13:60836089.
– Xu Y., et al. (2015). The importance of aerosol scenarios in projections of future heat extremes. Climatic Change 1–14.
– Xu Y., et al. (2016). Observed high-altitude warming and snow cover retreat over Tibet and the Himalayas enhanced by black carbon aerosols. Atmospheric Chemistry & Physics 16:1303–1315.
– Yao T., et al. (2012). Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings. Nature Climate Change 2(9):663–667.
– Yasunari T. J., et al. (2010). Estimated impact of black carbon deposition during pre-monsoon season from Nepal Climate Observatory–Pyramid data and snow albedo changes over Himalayan glaciers. Atmospheric Chemistry & Physics 10(14):6603–6615.
– You Q., et al. (2015a). Comparison of multiple datasets with gridded precipitation observations over the Tibetan Plateau. Climate Dynamics 45(3-4):791–806.
– You Q., et al. (2015b). Rapid warming in the Tibetan Plateau from observations and CMIP5 models in recent decades. International Journal of Climatology.
– Zaelke D., et al. (2012). Strengthening Ambition for Climate Mitigation: The Role of the Montreal Protocol in Reducing Short-Lived Climate Pollutants. Rev. Eur. Comp. & Int'l. Envtl. Law 231–242.
– Zhao L., et al. (2014). Glacier volume and area change by 2050 in high mountain Asia. Global and Planetary Change 122:197–207.