Climate Change - Global Risks, Challenges & Decisions

Synthesis Report

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UNIVERSITY OF COPENHAGEN

SYNTHESIS REPORT

CLIMATE CHANGE

Global Risks, Challenges & Decisions

COPENHAGEN 2009, 10-12 March

www.climatecongress.ku.dk

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2. Professor Lord Nicholas Stern, IG Patel Professor of Economics and Government, London School of Economics
3. Mr. Anders Fogh Rasmussen, (Former) Prime Minister of Denmark
4. Mrs. Connie Hedegaard, Danish Minister for Climate and Energy
5. Mr. Helge Sander, Danish Minister for Science, Technology and Innovation
6. Mr. John Ashton, Special Representative for Climate Change, United Kingdom Foreign & Commonwealth Office
7. Professor Amanda Lynch, School of Geography and Environmental Sciences, Head of the Monash University Climate program, Monash University
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14. Professor Qingchen Chao, Deputy Director General, Department of Science & Technology Development, China Meteorological Administration
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PREFACE

The United Nations Framework Convention on Climate Change (UNFCCC) meeting to be held in Copenhagen in December 2009 (the 15th Conference of the Parties, COP15) will be a critical step in developing a global response to the threat of climate change caused by human activities. The primary scientific input to those negotiations is the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), published in 2007[1]. The IPCC report has already been instrumental in increasing both public and political awareness of the societal risks associated with unchecked emission of greenhouse gases.

Since the production of the IPCC report, new knowledge has emerged that furthers understanding of the impacts of human influence on the climate and the response options and approaches that are available to tackle this complex issue. To bring this new knowledge together, the International Alliance of Research Universities[i] organised an international scientific congress on climate change, *Climate Change: Global Risks, Challenges and Decisions*, which was held in Copenhagen from 10-12 March 2009. Participation in the Congress was open to all. Most of the approximately 2500 people attending the Congress were researchers, many of whom have also been contributors to the IPCC reports. Participants came from nearly 80 different countries and contributed with more than 1400 scientific presentations. Abstracts for all of the scientific presentations made can be found at www.iop.org/EJ/volume/1755-1315/6, and a transcript of the closing plenary session can be found at environmentalresearchweb.org/cws/article/opinion/39126.

This synthesis report presents an up-to-date overview of a broad range of research relevant to climate change – including fundamental climate science, the impacts of a changing climate on society and environment, and the many tools and approaches available to deal effectively with the challenge of climate change. The report has been produced by a writing team comprised of members of the Scientific Steering Committee for the IARU Congress and individuals invited to give the writing team academic and geographic breadth. It is based on the 16 plenary talks given at the Congress as well as input from over 80 chairs and co-chairs of the 58 parallel sessions held at the Congress. The names of the plenary speakers and the chairs and co-chairs of the parallel sessions can be found on the inside cover of this volume. The writing team has, in addition to presentations at the Congress, drawn upon recent publications in the scientific literature to create this synthesis.

This report has been critically reviewed by representatives of the Earth System Science Partnership (ESSP)[ii], by the parallel session chairs and co-chairs, and by up to four independent researchers from each IARU university. This extensive review process has been implemented to ensure that the messages contained in the report are solidly and accurately based on the new research produced since the last IPCC Report, and that they faithfully reflect the most recent work of the international climate change research community.

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[i] IARU (International Alliance of Research Universities): (http://www.iaruni.org/)
Australian National University, University of California - Berkeley, University of Cambridge, University of Copenhagen, ETH Zürich, National University of Singapore, University of Oxford, Peking University, The University of Tokyo, Yale University.

[ii] The ESSP (www.essp.org) is a partnership of the international research programmes World Climate Research Programme (WCRP), International Geosphere Biosphere Programme (IGBP), International Human Dimensions Programme for Global Change Research (IHDP) and DIVERSITAS, an international programme of biodiversity science.

EXECUTIVE SUMMARY

Past societies have reacted when they understood that their own activities were causing deleterious environmental change by controlling or modifying the offending activities. The scientific evidence has now become overwhelming that human activities, especially the combustion of fossil fuels, are influencing the climate in ways that threaten the well-being and continued development of human society. If humanity is to learn from history and to limit these threats, the time has come for stronger control of the human activities that are changing the fundamental conditions for life on Earth.

To decide on effective control measures, an understanding of how human activities are changing the climate, and of the implications of unchecked climate change, needs to be widespread among world and national leaders, as well as in the public.

The purpose of this report is to provide, for a broad range of audiences, an update of the newest understanding of climate change caused by human activities, the social and environmental implications of this change, and the options available for society to respond to the challenges posed by climate change.

This understanding is communicated through six key messages:

KEY MESSAGE 1:
CLIMATIC TRENDS

Recent observations show that greenhouse gas emissions and many aspects of the climate are changing near the upper boundary of the IPCC range of projections. Many key climate indicators are already moving beyond the patterns of natural variability within which contemporary society and economy have developed and thrived. These indicators include global mean surface temperature, sea-level rise, global ocean temperature, Arctic sea ice extent, ocean acidification, and extreme climatic events. With unabated emissions, many trends in climate will likely accelerate, leading to an increasing risk of abrupt or irreversible climatic shifts.

KEY MESSAGE 2:
SOCIAL AND ENVIRONMENTAL DISRUPTION

The research community provides much information to support discussions on "dangerous climate change". Recent observations show that societies and ecosystems are highly vulnerable to even modest levels of climate change, with poor nations and communities, ecosystem services and biodiversity particularly at risk. Temperature rises above 2°C will be difficult for contemporary societies to cope with, and are likely to cause major societal and environmental disruptions through the rest of the century and beyond.

KEY MESSAGE 3:
LONG-TERM STRATEGY: GLOBAL TARGETS AND TIMETABLES

Rapid, sustained, and effective mitigation based on coordinated global and regional action is required to avoid "dangerous climate change" regardless of how it is defined. Weaker targets for 2020 increase the risk of serious impacts, including the crossing of tipping points, and make the task of meeting 2050 targets more difficult and costly. Setting a credible long-term price for carbon and the adoption of policies that promote energy efficiency and low-carbon technologies are central to effective mitigation.

KEY MESSAGE 4:
EQUITY DIMENSIONS

Climate change is having, and will have, strongly differential effects on people within and between countries and regions, on this generation and future generations, and on human societies and the natural world. An effective, well-funded adaptation safety net is required for those people least capable of coping with climate change impacts, and equitable mitigation strategies are needed to protect the poor and most vulnerable. Tackling climate change should be seen as integral to the broader goals of enhancing socioeconomic development and equity throughout the world.

KEY MESSAGE 5:
INACTION IS INEXCUSABLE

Society already has many tools and approaches – economic, technological, behavioural, and managerial – to deal effectively with the climate change challenge. If these tools are not vigorously and widely implemented, adaptation to the unavoidable climate change and the societal transformation required to decarbonise economies will not be achieved. A wide range of benefits will flow from a concerted effort to achieve effective and rapid adaptation and mitigation. These include job growth in the sustainable energy sector; reductions in the health, social, economic and environmental costs of climate change; and the repair of ecosystems and revitalisation of ecosystem services.

KEY MESSAGE 6:
MEETING THE CHALLENGE

If the societal transformation required to meet the climate change challenge is to be achieved, then a number of significant constraints must be overcome and critical opportunities seized. These include reducing inertia in social and economic systems; building on a growing public desire for governments to act on climate change; reducing activities that increase greenhouse gas emissions and reduce resilience (e.g. subsidies); and enabling the shifts from ineffective governance and weak institutions to innovative leadership in government, the private sector and civil society. Linking climate change with broader sustainable consumption and production concerns, human rights issues and democratic values is crucial for shifting societies towards more sustainable development pathways.

LIVING WITH ENVIRONMENTAL CONSTRAINTS

The Earth is approximately five billion years old. Humans, however, have been on the planet for only 0.004% of that history; modern *Homo sapiens* evolved around 200,000 years ago. Dramatic climate changes have occurred in the Earth's long history. Early humans experienced, and a fraction of them survived, some of these dramatic climate events. However, only during the last 12,000 years, a period in which the Earth's climate has been comparatively warm and stable, have humans really thrived.

During the stable climate conditions of this period, humans discovered how to cultivate plants and domesticate animals. These discoveries, which occurred about 10,000 years ago and ultimately led to modern agriculture, dramatically changed the relationship between humans and the planet. They broke an early natural constraint on human numbers, and enabled many more people to thrive simultaneously on Earth than was possible without control over food availability.

Presumably, the first farmers were free to farm wherever they wanted to. However, when society – many thousands of years later - recognised that unchecked agricultural practice and development could be harmful for society as a whole, local rules were developed to govern how and where agriculture could be carried out. In the same manner, our early ancestors probably experienced no restrictions on where they could dispose of their waste. When human numbers increased to a certain level and the accumulation of waste was recognised as a health or pollution problem, rules and technologies were established to manage waste disposal. A contemporary example of globally enforced regulation is the Montreal Protocol, where the international community in 1987 agreed to act on scientific evidence that certain industrial gases can lead to dangerous depletion of the Earth's ozone layer.

In all of these cases, control was only established when there was the general acceptance in society that a continued state of non-regulation would lead to unacceptable costs. Thus, the history of humanity's relationship with the environment shows that when society learns that a certain practice may jeopardise the well-being of its members, rules, regulations, and other strategies are established to control the offending practice.

The scientific evidence today overwhelmingly indicates that allowing the emission of greenhouse gases from human activities to continue unchecked constitutes a significant threat to the well-being and continued development of contemporary society. The knowledge that human activities are influencing the climate gives contemporary society the responsibility to act. It necessitates redefinition of humanity's relationship with the Earth and - for the sake of the well-being of society – it requires management of those human activities that interfere with the climate. To support development of effective responses, however, this knowledge should be widely disseminated outside of the scientific community. The purpose of this report is to communicate to a broad range of audiences the research community's most up-to-date understanding of climate change, its implications, and the actions needed to deal with it effectively.

KEY MESSAGE 1

CLIMATIC TRENDS

Recent observations show that greenhouse gas emissions and many aspects of the climate are changing near the upper boundary of the IPCC range of projections. Many key climate indicators are already moving beyond the patterns of natural variability within which contemporary society and economy have developed and thrived. These indicators include global mean surface temperature, sea-level rise, global ocean temperature, Arctic sea ice extent, ocean acidification, and extreme climatic events. With unabated emissions, many trends in climate will likely accelerate, leading to an increasing risk of abrupt or irreversible climatic shifts.

The Intergovernmental Panel on Climate Change (IPCC) concluded in 2007[2] that climate change is, without doubt, occurring and that the Earth is warming. More importantly, the IPCC concluded that there is over 90% probability that this global warming is primarily caused by human activities – the most important of these being the emission of greenhouse gases and the clearing of natural vegetation. Since 2007, reports comparing the IPCC projections of 1990 with observations show that some climate indicators are changing near the upper end of the range indicated by the projections or, as in the case of sea level rise (Figure 1), at even greater rates than indicated by IPCC projections. Grasping the significance of such observations requires an understanding of climate change that goes beyond the warming of the atmosphere.

The climate is largely controlled by the flows of heat entering and leaving the planet and the storage of heat in the various compartments of the Earth System - ocean, land, atmosphere, snow/ice. This heat ultimately comes from the sun. Only a very small amount of the heat is stored in the atmosphere (Figure 2); by far the largest amount of heat stored at the Earth's surface is found in the ocean. The heat flux into the ocean proceeds more slowly than into the atmosphere. However, given that the ocean stores so much heat, a change in ocean temperature, which reflects a change in the amount of heat stored in the ocean, is a better indicator of change in the climate than changes in air temperature.

Figure 3 shows the trend in surface air temperature in recent decades. 2008 was comparatively cooler than the immediately preceding years, primarily because there was a minimum in the cycle of the sun's magnetic activity (sun spot cycle) and a La Niña event in 2007/2008. Nevertheless, the long-term trend of increasing temperature is clear and the trajectory of atmospheric temperature at the Earth's surface is proceeding within the range of IPCC projections.

Since the last IPCC report, updated trends in surface ocean temperature and heat content have been published[4,5]. These revised estimates show (Figure 4) that the ocean has warmed significantly in recent years. Current estimates indicate that ocean warming is about 50% greater

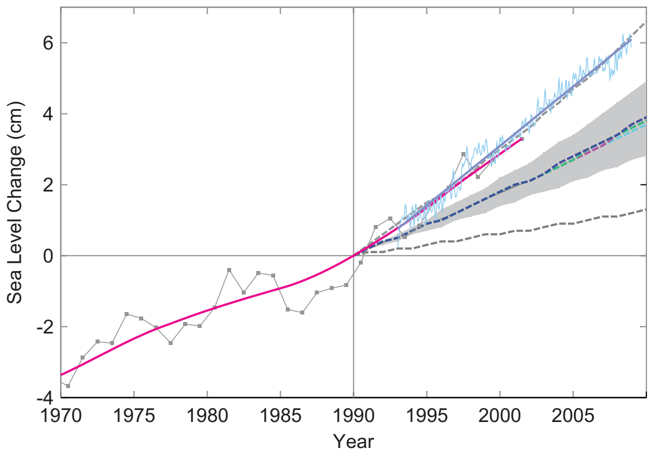


Figure 1
Change in sea level from 1970 to 2008, relative to the sea level at 1990. The solid lines are based on observations smoothed to remove the effects of interannual variability (light lines connect data points). Data in most recent years are obtained via satellite based sensors. The envelope of IPCC projections is shown for comparison; this includes the broken lines as individual projections and the shading as the uncertainty around the projections[3].

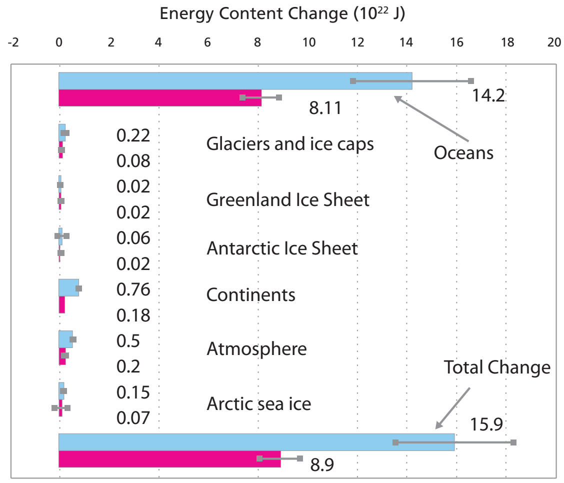


Figure 2
The change in energy content in different components of the Earth System for two periods: 1961-2003 (blue bars) and 1993-2003 (pink bars)[2] (figure 5.4).

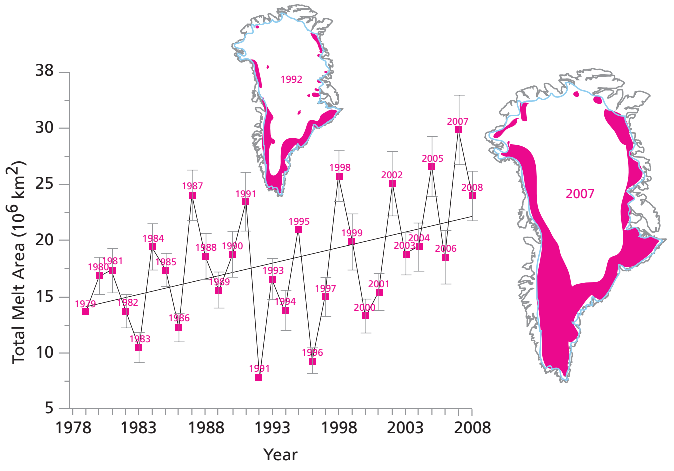
BOX 1

Changes in the Greenland Ice Sheet

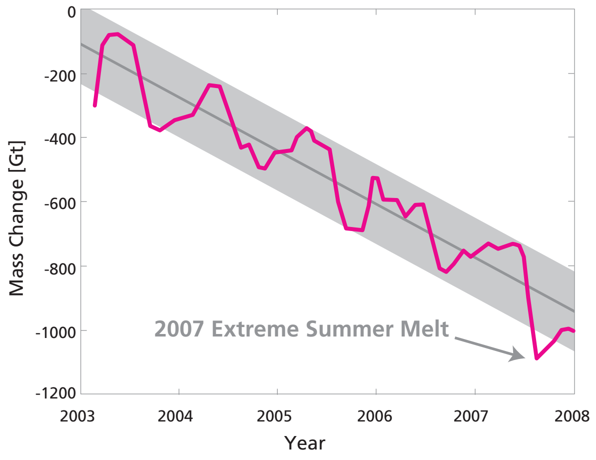
Prof. Dorthe Dahl Jensen, ddj@gfy.ku.dk & Dr. Konrad Steffen, Konrad.Steffen@colorado.edu

Increased melting of the large polar ice sheets contributes to the observed increase in sea level. Observations of the area of the Greenland ice sheet that has been at the melting point temperature at least one day during the summer period shows a 50% increase during the period 1979 to 2008[6] (see figure). The Greenland region experienced an extremely warm summer in 2007. The whole area of south Greenland reached the melting temperatures during that summer, and the melt season began 10-20 days earlier and lasted up to 60 days longer in south Greenland[7].

In addition to melting, the large polar ice sheets lose mass by ice discharge, which is also sensitive to regional temperature. Satellite measurements of very small changes in gravity have revolutionised the ability to estimate loss of mass from these processes. The second figure shows that the Greenland ice sheet has been losing mass at a rate of 179 Gt/yr since 2003. This rate of loss corresponds to a contribution to global mean sea level rise of 0.5 mm/yr; the current total global mean sea level rise is 3.1 mm/yr[8]. As for melt area, the mass loss for the exceptionally warm year of 2007 was very large. The new observations of the increasing loss of mass from glaciers, ice caps and the Greenland and Antarctic ice sheets lead to predictions of global mean sea level rises of 1 m (±0.5 m) during the next century. The updated estimates of the future global mean sea level rise are about double the IPCC projections from 2007[28].



Area of surface melting across the Greenland Ice Sheet, as inferred from satellite observations of the surface temperature[6].



Change in the mass of the Greenland ice sheet from 2003 to 2008, as estimated from satellite measurements of changes in the gravitational field. The grey shaded area shows the 90% confidence level of the fitted straight line. The vertical axis is set to an arbitrary value of zero at the beginning of the observational period[8].

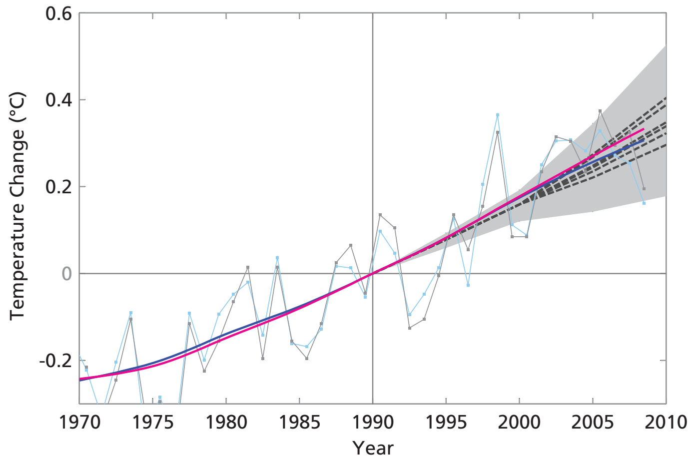


Figure 3

Changes in global average surface air temperature (smoothed over 15 years) (corrected from 11 in the first version og this report) relative to 1990. The blue line represents data from Hadley Center (UK Meteorological Office); the red line is GISS (NASA Goddard Institute for Space Studies, USA) data. The broken lines are projections from the IPCC Third Assessment Report, with the shading indicating the uncertainties around the projections[3] (data from 2007 and 2008 added by Rahmstorf, S.).

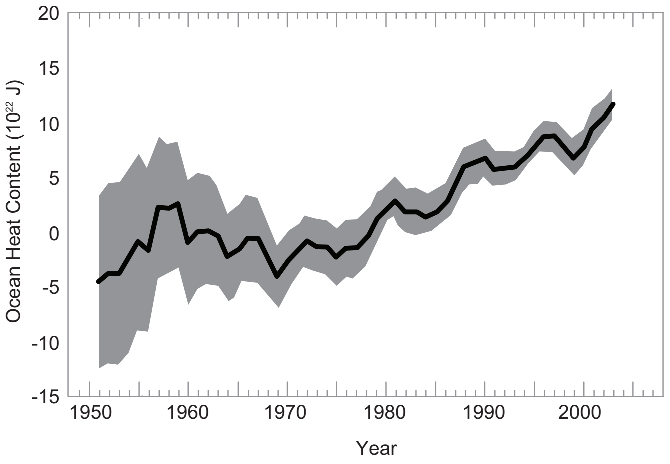


Figure 4

Change in ocean heat content since 1951 (observations - black line) with uncertainties (in grey shading), relative to the ocean heat content in 1961[4].

than had been previously reported by the IPCC[2]. The new estimates help to better explain the trend in sea level that has been observed in recent decades as most of the sea-level rise observed until recently has been the result of thermal expansion of seawater.

The rate of sea-level rise has increased in the period from 1993 to the present (Figure 1), largely due to the growing contribution of ice loss from Greenland (Box 1) and Antarctica. However, models of the behaviour of these polar ice sheets are still in their infancy, so projections of sea-level rise to 2100 based on such "process models" are highly uncertain. An alternative approach is to base projections on the observed relationship between global average temperature rise and sea-level rise over the past 120 years, assuming that this observed relationship will continue into the future. New estimates based on this approach suggest a sea-level rise of around a metre or more by 2100[16] (Opening Session (S. Rahmstorf) and session 1).

Sea-level rise will not stop in 2100. Changes in ocean heat content will continue to affect sea-level rise for several centuries at least. Melting and dynamic ice loss in Antarctica and Greenland will also continue for centuries into the future. Thus, the changes current generations initiate in the climate will directly influence our descendents long into the future. In fact, global average surface temperature will hardly drop in the first thousand years after greenhouse gas emissions are cut to zero[9,10].

One of the most dramatic developments since the last IPCC Report[1] is the rapid reduction in the area of Arctic sea ice in summer. In 2007, the minimum area covered decreased by about 2 million square kilometres as compared to previous years. In 2008, the decrease was almost as dramatic[11]. This decreasing ice coverage is important for climate on a larger scale as ice and snow reflect most of the radiation from the sun back into the atmosphere while seawater absorbs most of the radiation reaching it from the sun. Thus, an ice-free ocean absorbs more heat than an ice-covered ocean, so the loss of Arctic sea ice creates a "feedback" in the climate system that increases warming.

The major cause of the increasing heat content of the planet's surface is the increasing concentrations of greenhouse gases in the atmosphere[2, 12] (Figure 5). These gases enhance the "greenhouse effect", which is a well documented and understood physical process in the Earth System - like gravity or tides - and which has been known since the 19th century. The natural greenhouse effect makes Earth habitable in the first place. Greenhouse gases, such as water vapour, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere absorb the heat leaving the Earth's surface, thus retaining more heat near the Earth's surface - in the ocean, land, and atmosphere. Without the existence of the natural greenhouse effect, the average temperature on Earth would be about -19ºC, that is, about 34ºC colder than it is today. All planets with heat absorbing gases in their atmosphere experience a greenhouse effect; the extreme surface temperature (440ºC) of Venus, for example, can only be explained by the high concentration of CO_2 there.

Changing the amount of greenhouse gases in the atmosphere alters the magnitude of the greenhouse effect. Water vapour is the most abundant greenhouse gas and makes the greatest contribution to the natural greenhouse effect on Earth. Because the atmosphere's ability to contain water vapour is strongly dependent on temperature, the amount of water vapour in the atmosphere is regulated by the Earth's temperature itself, increasing as warming occurs. This means that water vapour follows and amplifies changes in global temperature that are induced by other causes. Human activities have not had a significant direct effect on net global flows of water vapour to/from the atmosphere[16] (session 3), although locally they have changed these flows by, for example, felling forests or establishing irrigation.

The situation is very different for some of the other greenhouse gases where human emissions do have a direct impact. Atmospheric CO_2 as well as methane and nitrous oxide concentrations have increased dramatically over recent decades as a result of human activities. Ice core and sediment records show that the concentration of all of these gases in the atmosphere is now higher than it has been since long before modern humans evolved. In fact, the CO_2 concentration in the atmosphere has not been substantially higher than it is now for at least the last 20 million years of the Earth's history[17].

The initial warming from increased greenhouse gas concentrations is amplified by reinforcing feedbacks. These are processes that are induced by climate change and that subsequently drive further warming. In addition to the Arctic sea ice and water vapour feedbacks described above, a very important feedback is related to natural "carbon sinks" - processes that absorb CO_2 from the atmosphere. Not all of the CO_2 released into the atmosphere through human activities remains there. Over half of the CO_2 emitted to the atmosphere by fossil fuel combustion and land use change is removed by land and ocean CO_2 sinks. The fraction of human-driven CO_2 emissions removed by these sinks has decreased over the last 50 years[12], with some evidence that the fraction will decrease further over coming decades under high future emissions scenarios[12] (Box 2). If this weakening of natural CO_2 sinks continues, a greater fraction of emissions will remain in the atmosphere, requiring a greater reduction in emissions to achieve specific targets for the concentration of CO_2 in the atmosphere.

At smaller scales, one of the most important changes in climate is the observed increase in extreme events – heat waves, storms and floods[2]. In addition, regional climate is often directly related to the behaviour of specific patterns of climate variability, such as the monsoon systems, and these patterns may themselves be influenced by the warming climate[16] (session 3),[19]. Changes in extreme events and in the patterns of natural variability can have dramatic consequences for human societies that have become used to or dependent upon long-established patterns of temperature, wind and rainfall in specific regions. The next section deals with some of the consequences and risks that interference with the climate poses for society.

BOX 2

The Global Carbon Cycle

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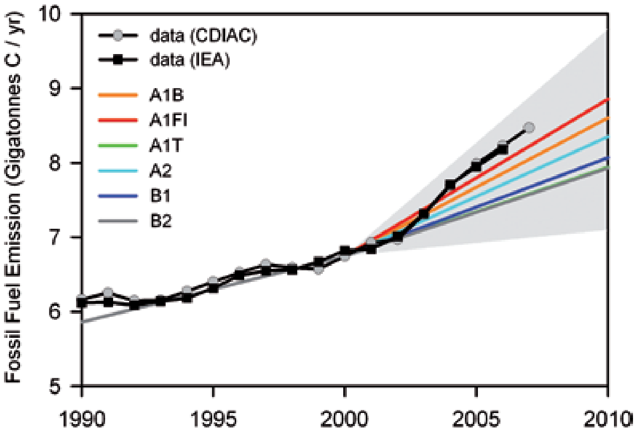
The global carbon cycle is in strong disequilibrium because of the input of CO_2 into the atmosphere from fossil fuel combustion and land use change. Fossil fuels presently account for about 85% of total emissions, and land use change for 15%. Total emissions have grown exponentially at about 2% per year since 1800. However, fossil fuel emissions have accelerated since 2000 to grow at about 3.4% per year, an observed growth rate that is at the upper edge of the range of growth rates in IPCC scenarios. Total CO_2 emissions are responsible for 2/3 of the growth of all greenhouse gas radiative forcing.

Without CO_2 sinks, which remove and store CO_2 from the atmosphere, the total human CO_2 emissions since 1800 would have caused atmospheric CO_2 to increase from its pre-industrial value of 280 ppm to nearly 500 ppm. However, the disequilibrium of the carbon cycle causes the vast human input of CO_2 to be repartitioned between the carbon stores in the atmosphere, land, and oceans. Consequently, land and ocean CO_2 sinks have consistently taken up more than half of total CO_2 emissions since 1800 and the actual CO_2 accumulation in the atmosphere has raised the CO_2 concentration to only 385 ppm (growing at about 2 ppm per year). However, these natural CO_2 sinks are vulnerable to climate and land use change: they are highly likely to weaken in the future because of several effects including increasing ocean acidification, ocean circulation changes, and water, temperature, and nutrient constraints on land CO_2 uptake. Also, previously inert carbon pools can be mobilised and released into the atmosphere either as CO_2 or methane, a more potent greenhouse gas. Pools of concern include tropical peatland carbon, which is vulnerable to land clearing and drainage, and the large stores of organic carbon in Arctic permafrost, which are vulnerable to warming.

Recent work is starting to quantify the amplifying effect of these vulnerabilities on climate change. There is increasing confidence that their net result will be to amplify the atmospheric CO_2 and methane increases to 2100, thence amplifying climate change. The amplification factor is ill constrained, and best current estimates range from near zero to over 50%. Under the IPCC[1] A2 emissions scenario, which predicts global warming of about 4°C without carbon-climate feedbacks, an additional 0.1 to 1.5°C is predicted from the vulnerability of land and ocean sinks. The additional effect of accelerated methane and CO_2 emissions from thawing permafrost is potentially very significant but is not yet quantified.



Observed global fossil-fuel and industrial CO_2 emissions[18], compared with averages of 6 scenario groups from the IPCC Special Report on Emissions Scenarios (coloured lines) and range covered by all individual scenarios (grey shading). Emission data are from two sources: The Carbon Dioxide Information and Analysis Center (CDIAC) and the International Energy Agency (IEA). Figure updated using the latest available data (www.globalcarbonproject.org) since the original publication of this report.

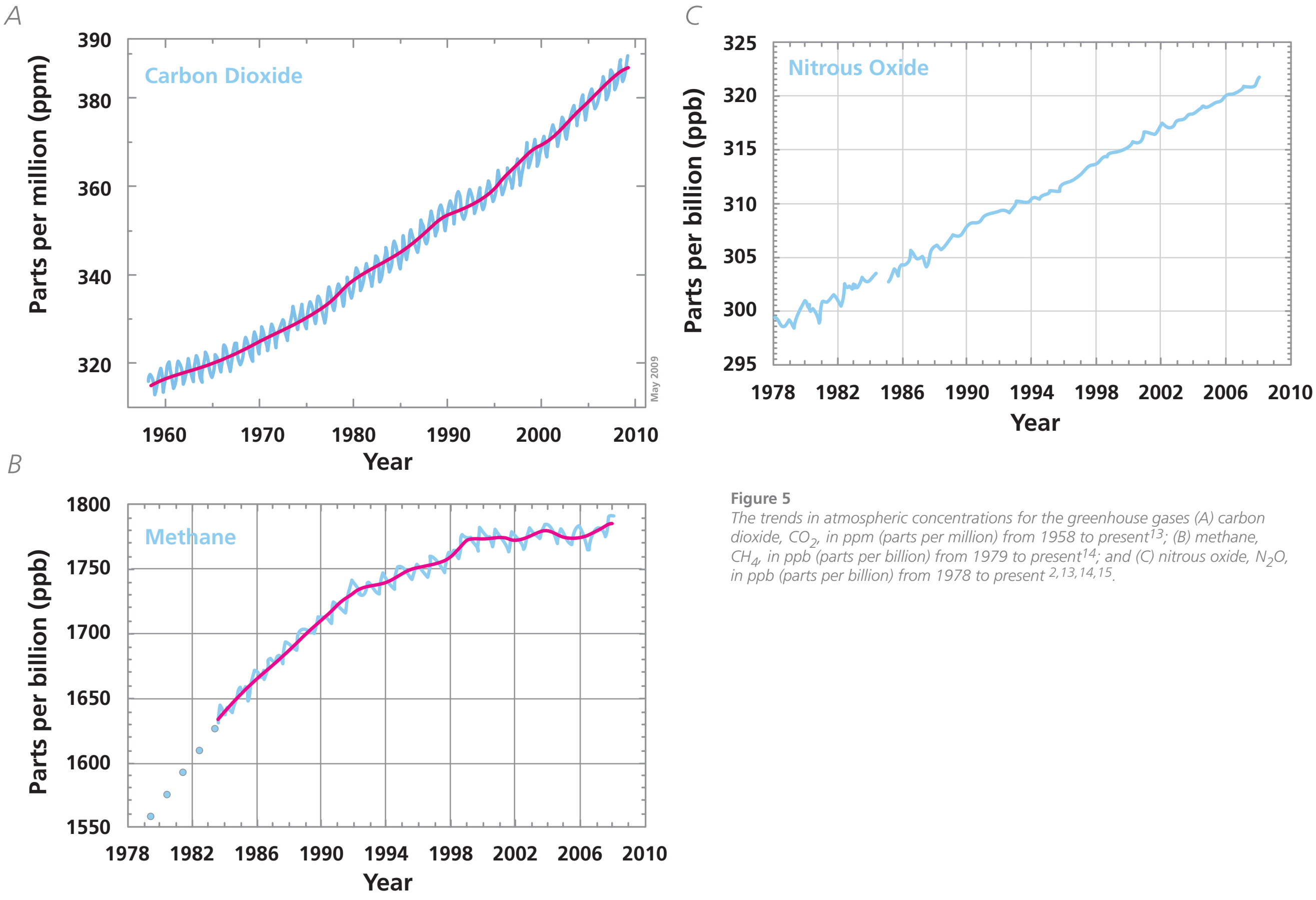


Figure 5
The trends in atmospheric concentrations for the greenhouse gases (A) carbon dioxide, CO_2, in ppm (parts per million) from 1958 to present[13]; (B) methane, CH_4, in ppb (parts per billion) from 1979 to present[14]; and (C) nitrous oxide, N_2O, in ppb (parts per billion) from 1978 to present [2,13,14,15].

KEY MESSAGE 2

SOCIAL AND ENVIRONMENTAL DISRUPTION

The research community provides much information to support discussions on "dangerous climate change". Recent observations show that societies and ecosystems are highly vulnerable to even modest levels of climate change, with poor nations and communities, ecosystem services and biodiversity particularly at risk. Temperature rises above 2°C will be difficult for contemporary societies to cope with, and are likely to cause major societal and environmental disruptions through the rest of the century and beyond.

Defining "dangerous climate change" is ultimately a value judgement to be made by societies as a whole. At least three different kinds of considerations are important: (i) the negative effects to humans and ecosystems that occur at various levels of climate change; (ii) the levels of negative impacts that societies are willing to tolerate; and (iii) the levels of climate change at which so-called tipping points might be crossed, where change is no longer linear and reversible, but abrupt, large, and potentially irreversible in time frames relevant for contemporary society. At present, there seems to be little such discussion and debate[16] (session 39) despite the fact that scientific research provides a wealth of critical information relevant to such discussion.

While there is not yet a global consensus on what levels of climate change might be defined to be "dangerous", considerable support[20] has developed for containing the rise in global temperature to a maximum of 2°C above pre-industrial levels. This is often referred to as "the 2°C guardrail". IPCC[21] as well as more recent scientific research[31] indicate that even with temperature rises less than 2°C, impacts can be significant, although some societies could cope with some of these impacts through pro-active adaptation strategies. Beyond 2°C, the possibilities for adaptation of society and ecosystems rapidly decline with an increasing risk of social disruption through health impacts, water shortages and food insecurity.

One of the best indicators of the impacts of climate change on societies is human health and well-being (Box 3). The observed temperature rise to date, about 0.7°C, is already affecting health in many societies; the increasing number of extreme weather events, such as heat waves, floods, and storms, is leading to a growing toll of deaths and injuries from climate-related natural disasters[1]. Beyond the direct impacts on health, climate change also affects the underlying determinants of health – quantity and quality of food, water resources, and ecological control of disease vectors[16] (session 14).

The nexus between climate change, human health and water systems is particularly strong. As for health, the impacts of climate change on water systems are already apparent in many parts of the world, with accelerating impacts likely for several decades irrespective of future agreements to abate emissions of greenhouse gases (Box 4). For example, droughts and drying are leading to social instability, food insecurity and long-term health problems in some regions now as livelihoods are damaged or destroyed[16] (session 14). Such impacts often drive a strategy of short-term survival at the expense of longer-term

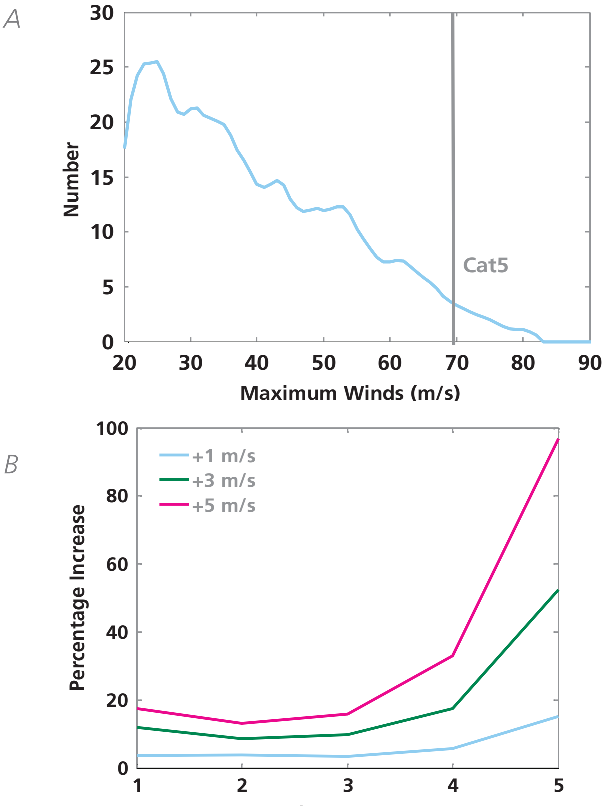


Figure 6

(A) The numbers of North Atlantic tropical cyclones for each maximum wind speed shown on the horizontal axis. The most intense (Category 5) tropical cyclones have maximum wind speeds of 70 m/s or greater. (B) The proportional increase by cyclone (hurricane) category (1 – least intense; 5 – most intense) arising from increases in maximum wind speeds of 1, 3 and 5 m/s. Note the disproportionately large increase in the most intense tropical cyclones with modest increases in maximum wind speed, compared to the increase in less intense cyclones[23].

Effects of Climate Change on Human Health and Well-Being

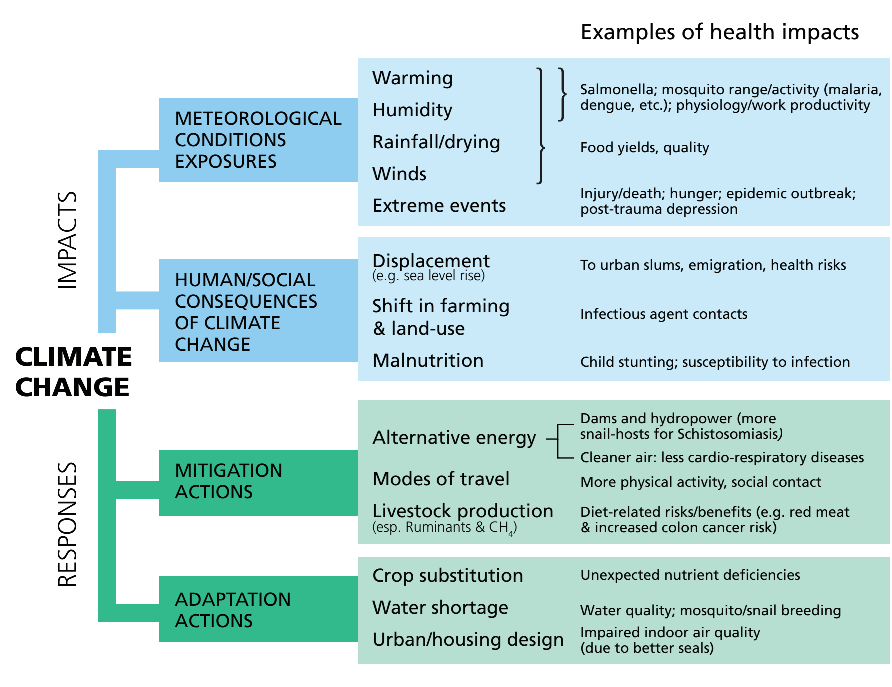
BOX 3

Prof. Anthony McMichael, Tony.McMichael@anu.edu.au *& Dr. Roberto Bertollini,* Bertollinir@who.int

The serious, increasingly evident, risks to human health from climate change underscore the potentially profound impact on Earth's 'life-supports'. This 'vital sign' should help motivate government action. Low-income and geographically vulnerable populations are at greatest risk. These populations contributed little to the problem, yet incur much of the health risk.

The risks arise from direct stresses (e.g. heat-waves, weather disasters, workplace dehydration), from ecological disturbance (e.g. altered infectious disease patterns), and disruptions of ecosystems on which humanity depends (e.g. health consequences of reduced food yields), from population displacement and conflict over depleted resources (water, fertile land, fisheries). Melting ice-sheets may mobilise ice-bound chemical pollutants into the marine food web.

Many specific impacts can be anticipated or, in some cases, observed now. Modelling studies indicate that a 2ºC rise could cause 5-20% reductions of cereal grain yields in South Asia, South East Asia and Sub-Saharan Africa, significantly exacerbating under-nutrition and adverse health outcomes (especially child physical and intellectual development). In many urban populations, a 2ºC rise would increase the annual death rate from heat-waves by an estimated doubling or more. A 2ºC rise would allow a 50-100% increase in the geographic range of potential transmission of (water snail-hosted) schistosomiasis in China, endangering many tens of millions of people. Recent experience from coastal Alaska shows that a 1ºC rise in water temperature has, by passing a threshold, enabled summer-long bacterial proliferation in shellfish and consequent gastroenteritis in consumers.



Health-protecting adaptive strategies are already needed, both for current and anticipated future risks. The World Health Organization is supporting member states in their activities, leading to formal standardised country-level health risk assessment and adaptive strategy planning in relation to climate change. Meanwhile, positive health-promoting benefits can flow from many mitigation activities, via enhanced air quality, physical activity patterns, and dietary balance[16] (session 14).

Water Resources and Climate Change: Building Resilience Towards a Sustainable Future

BOX 4

Prof. Maria Carmen Lemos, lemos@umich.edu *and Prof. Torkil Jønch Clausen,* tjc@dhigroup.com

Climate change often affects human societies through the water system, directly and indirectly, by a combination of changes in water availability, accelerating floods and droughts, and sea level rise and storms. These impacts are already occurring, affecting the poorest and disadvantaged people and countries the most. Many of these impacts will accelerate irrespective of future agreements and actions to reduce emissions. Enough is known now to start building adaptive capacity among vulnerable populations and ecosystems. However, improvement is required in our knowledge and modelling capabilities of the physical, social and environmental processes that affect the resilience of water systems to ensure sustainable solutions for tomorrow. Good governance is key to successful adaptation, building on integrated and adaptive approaches from the community level to trans-boundary river basins. The need for open and transparent sharing of data, information and knowledge among all stakeholders is crucial[16] (session 29).


Photo: John McConnico

adaptation. Nevertheless, adaptation measures to lessen the impacts of climate change are urgently needed now. Given the considerable uncertainties around projections of climate impacts on water resources at local and regional scales, building resilience, managing risks, and employing adaptive management are likely to be the most effective adaptation strategies[16] (session 29). Even with effective adaptation, the impacts on water resources in many parts of the world will be severe with climate change associated with only 1.0 to 1.5ºC rises in temperature[23].

Water resources are a growing problem for urban areas also. Lack of clean water in many of the new mega-cities, where ten million or more, often poor, inhabitants live, is already an issue of serious concern. In many cases, pressure on water supplies is exacerbated by changes in rainfall patterns and water availability resulting from climate change. A continuing flux of people into these new mega-cities, some of whom are escaping drying areas in the surrounding regions, adds further to the water stress.

Many of the most damaging effects of climate change are associated with extreme events – high intensity, relatively rare events such as cyclones and storms – rather than slow increases in average values

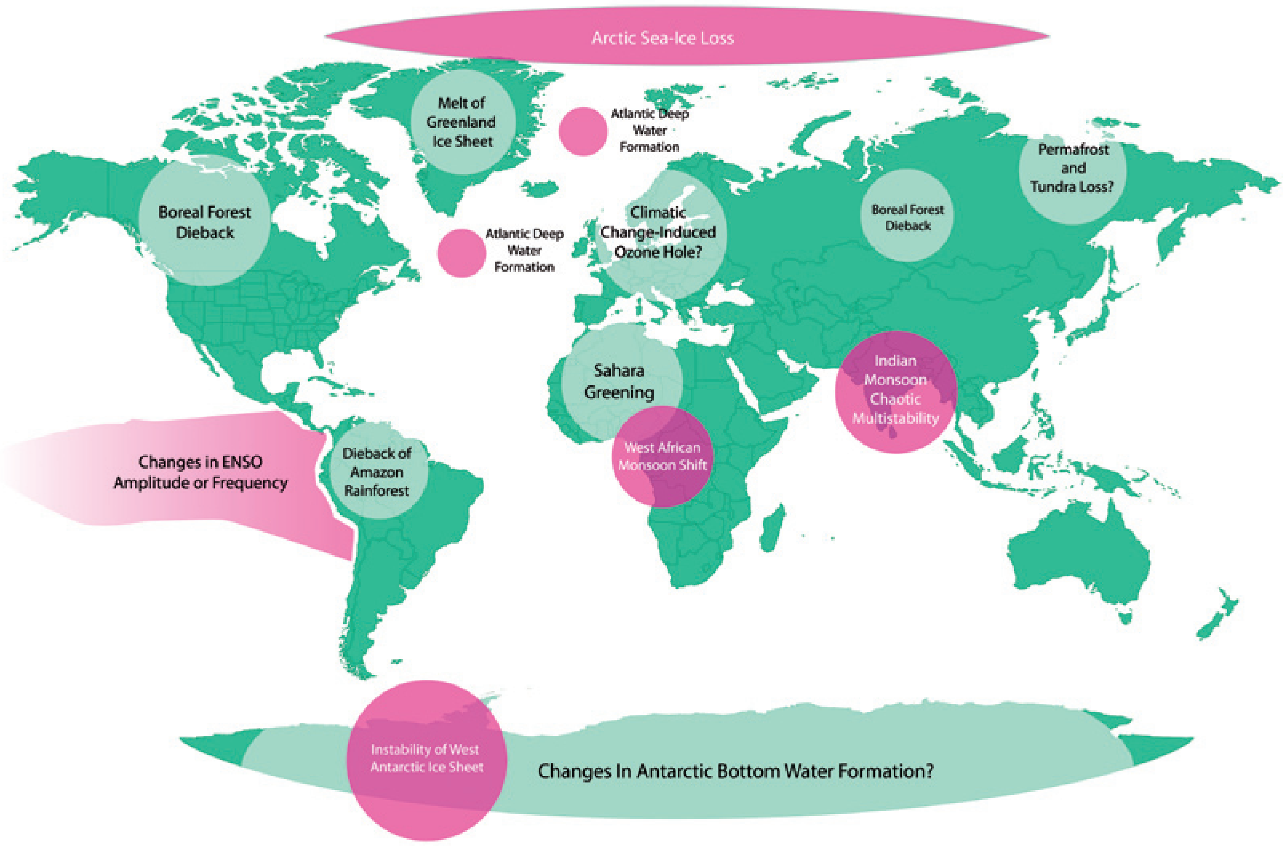


Figure 7
Map of potential climatic "tipping elements" . Tipping elements are regional-scale features of the climate that could exhibit threshold-type behaviour in response to human-driven climate change – that is, a small amount of climate change at a critical point could trigger an abrupt and/or irreversible shift in the tipping element. The consequences of such shifts in the tipping element for societies and ecosystems are likely to be severe. Question marks indicate systems whose status as tipping elements is particularly uncertain[27,30].

of climatic parameters. Furthermore, extreme events may respond to climate change by becoming even "more extreme". For example, even with a modest increase in surface wind speed of 5 metres per second in tropical cyclones, possible with just a 1°C rise in ocean temperature, the number of the most intense and destructive cyclones (Category 5) may double while the incidence of less intense cyclones would experience much smaller increases (Figure 6). Observations from the last decade in the North Atlantic, in which the number of Category 5 cyclones has increased by 300-400%, support this analysis[24]. The consequences of these events for coastal communities around the world, from small fishing villages on Pacific atolls to mega-cities on Chinese river deltas, are potentially severe, particularly when coupled with sea-level rise and a range of local factors that increase vulnerability.

The increasing accumulation of CO_2 in the atmosphere is important for marine ecosystems as it increases ocean acidity (Box 5). While the precise effects of ocean acidification are not yet clear, those organisms which produce calcium carbonate are expected to be especially vulnerable. Animals such as corals may be particularly threatened – possibly even to extinction – within the next century if atmospheric CO_2 concentrations continue to rise unchecked. The geologic record indicates that ecosystem recovery from such a change in ocean acidity would likely take hundreds of thousands, if not many millions, of years, although true recovery is impossible because extinctions are irreversible[10].

Climate change has consequences for biodiversity, more generally, and for the many services that humans derive from diverse and well-functioning ecosystems. There is a looming biodiversity catastrophe if global mean temperature rises above the 2°C guardrail, ocean acidification spreads and sea-level rise accelerates[26]. These climate-related stressors will interact with a wide range of existing stressors on biodiversity. The catastrophe will be expressed as the extinction of a significant fraction of biological species within the next 100 years, a substantially reduced range and higher risk of eventual extinction for other species, and the degradation of ecosystem services (Box 6). Limiting temperature rise to 2°C or less and rapidly implementing strong and proactive adaptation in conservation policy and management can limit the magnitude of the crisis but not entirely eliminate it[16] (session 31).

Estimates of the impacts of climate change on critical sectors such as water resources and biodiversity, and on more integrative measures of well-being such as health, are common approaches to defining dangerous climate change. More recent research on tipping elements in the Earth System provides another measure of potentially dangerous consequences for humanity of unabated climate change[27]. Tipping elements occur when a small change in an important variable, such as temperature, causes a rapid and unexpectedly large change in a feature of the climate, altering its condition or pattern of behaviour.

Figure 7 shows the location of a number of such tipping elements, any one of which, if triggered, would lead to societal disruption for very large numbers of people. Tipping elements shown could be triggered this century by human-made climate change, and would show a significant change at time scales ranging from a decade or less, as for

The Acidification of Planet Earth

BOX 5

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Acidification of Planet Earth's terrestrial and oceanic biospheres is happening now and caused by two very different anthropogenic sources.

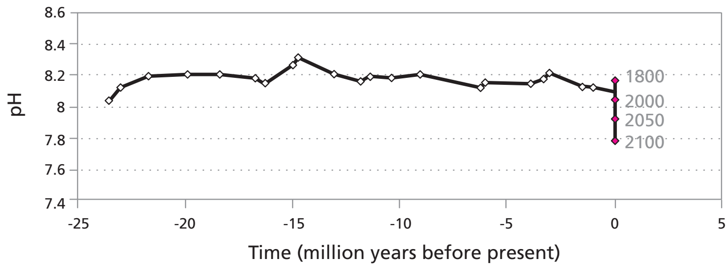
Land acidification is caused by nitric and sulphuric acids and whilst its significance emerged during the 1970s, it is still an issue in the developed world and a growing issue in developing countries. Land acidification results in changes to species diversity, net primary productivity, an imbalance of inorganic nitrogen ions in the soil, and eutrophication of fresh water bodies. Feedbacks between the land and aquatic systems are not well understood or researched.

Ocean acidification is a direct and certain consequence of CO_2 emissions to the atmosphere; its consequences on the global ocean are only now emerging. The oceans have already taken up around 27-34% of the CO_2 produced by humankind since the industrial revolution. Whilst this has limited the amount of CO_2 in the atmosphere, it has come at the price of a dramatic change to ocean chemistry. In particular, and of great concern, are the observed changes in ocean pH and carbonate and bicarbonate ion concentrations.

Evidence indicates that ocean acidification is a serious threat to many organisms and may have implications for food webs and ecosystems and the multi-billion dollar services they provide. For instance, erosion is likely to outpace growth of tropical coral reefs at 450-480 ppm CO_2; there are already reports of a 19% decrease in growth of Great Barrier Reef corals.

When atmospheric CO_2 reaches 450 ppm, large areas of the polar oceans will likely have become corrosive to shells of key marine calcifiers, an effect that will be strongest in the Arctic. Already, loss of shell weight in planktonic Antarctic calcifiers has been observed. Decreasing pH could also make oceans noisier in the audible range with potential implications for marine life, as well as for scientific, commercial, and naval applications using ocean acoustics.

The rate of change in ocean chemistry is very high (see figure), faster than previous ocean acidification-driven extinctions in Earth's history, from which it took hundreds of thousands of years for marine ecosystems to recover. Ocean acidification will continue to track future CO_2 emissions to the atmosphere so urgent and substantial emission reductions are the only way of reducing the impact of ocean acidification.



Ocean acidity (pH) over the past 25 millions years and projected to 2100[25]. The lower the pH, the more acidic the ocean becomes.

Biodiversity and Climate Change: Findings of the Millennium Ecosystem Assessment

BOX 6

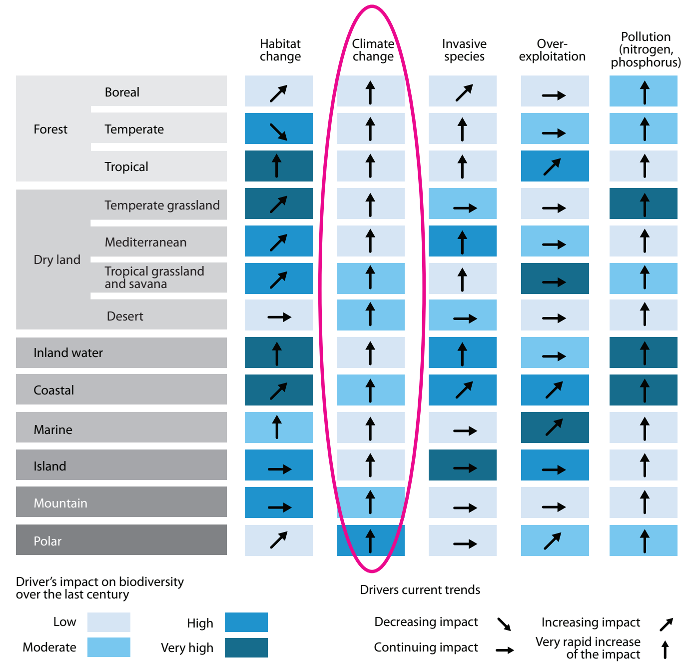
Prof. Harold Mooney, hmooney@stanford.edu & Dr. Anne Larigauderie, anne@diversitasinternational.org

Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth. The distribution of species on Earth is becoming more homogenous, as a result of both the prevalence of disturbed ecosystems and the proliferation of exotic invasive species. At the same time, humans have increased the species extinction rate by as much as 1,000 times over background rates typical over the planet's history, as a result of direct use and of indirect impacts of land use such as habitat loss and landscape fragmentation. For example, 10–30% of mammal, bird, and amphibian species are currently threatened with extinction. Overall, changes being made in ecosystems are increasing the likelihood of nonlinear changes with important consequences for human well-being. Beyond species introductions and losses, these include fisheries collapse, eutrophication and hypoxia in freshwater systems, disease emergence, and regional climate change.

The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of the degradation of many ecosystem services. Specifically, increase in a number of production services (especially crops, livestock and aquaculture) has come at a great cost to some other products such as wood fuel and freshwater, and to critical regulation services including regional and local climate regulation, air quality regulation, natural hazard regulation, and many spiritual, cultural, and aesthetic values. The degradation of ecosystem services often causes significant harm to human well-being and represents a loss of a natural asset or wealth of a country. Unless addressed, these impacts will also substantially diminish the benefits that future generations obtain from ecosystems.

The degradation of ecosystem services could grow significantly worse during the first half of this century. Among other causes, direct contributions of climate change include:

- Potential future impacts on biodiversity: By the end of the century, climate change and its impacts may be the dominant direct driver of biodiversity loss and changes in ecosystem services globally.
- Net harmful impact on ecosystem services: The balance of scientific evidence suggests that there will be a significant net harmful impact on ecosystem services worldwide if global mean surface temperature increases more than 2°C above pre-industrial levels.



		Habitat change	Climate change	Invasive species	Over-exploitation	Pollution (nitrogen, phosphorus)
Forest	Boreal	↗ Low	↑ Low	↗ Low	→ Low	↑ Moderate
	Temperate	↘ High	↑ Low	↑ Low	→ Moderate	↑ Moderate
	Tropical	↑ Very high	↑ Low	↑ Low	↗ High	↑ Low
Dry land	Temperate grassland	↗ Very high	↑ Low	→ Moderate	→ Low	↑ Very high
	Mediterranean	↗ High	↑ Low	↑ High	→ Moderate	↑ Low
	Tropical grassland and savana	↗ High	↑ Moderate	↑ Low	→ Very high	↑ Moderate
	Desert	→ Low	↑ Moderate	→ Moderate	→ Low	↑ Low
Inland water		↑ Very high	↑ Low	↑ High	→ Moderate	↑ Very high
Coastal		↗ Very high	↑ Moderate	↗ High	↗ High	↑ Very high
Marine		↑ Moderate	↑ Low	→ Low	↗ Very high	↑ Low
Island		→ High	↑ Low	→ Very high	→ High	↑ Low
Mountain		→ High	↑ Moderate	→ Low	→ Low	↑ Low
Polar		↗ Low	↑ High	→ Low	↗ Moderate	↑ Moderate

Driver's impact on biodiversity over the last century

Low	High
Moderate	Very high

Drivers current trends

Decreasing impact	↘	Increasing impact	↗
Continuing impact	→	Very rapid increase of the impact	↑

Current impacts and trends of different drivers on major global biomes. Climate change impacts are highlighted as currently low to moderate, with expected increasing importance over the next 50 years. This importance is tightly linked with the ability to keep temperatures below a 2°C increase[26].

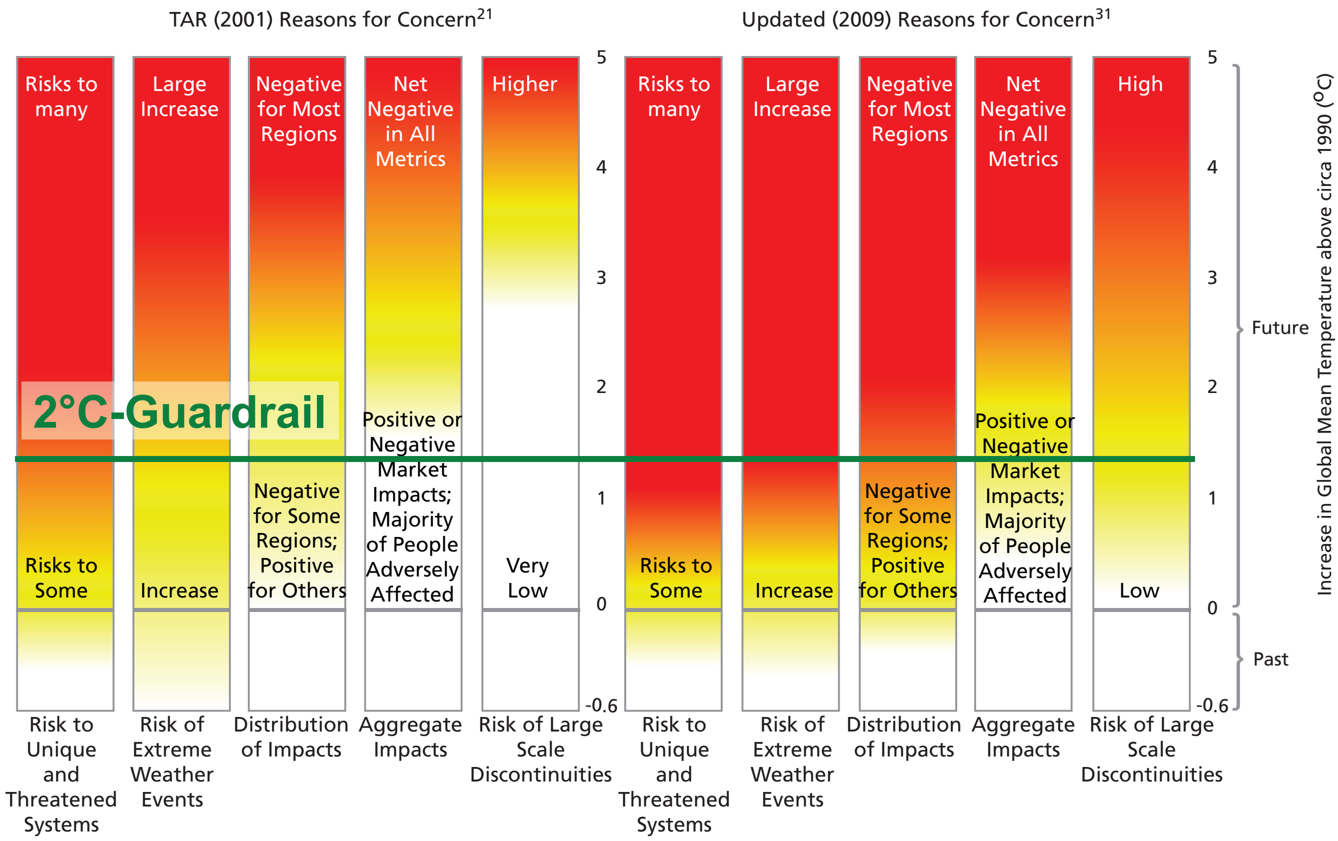


Figure 8

Diagram relating the potential impacts of climate change to the rise in global average temperature. Zero on the temperature scale corresponds approximately to 1990 average temperature, and the bottom of the temperature scale to pre-industrial average temperature. The level of risk or severity of potential impacts increases with the intensity of red colour. The 2°C guardrail is shown for reference.

Arctic summer sea ice and the Asian monsoon, to several centuries or a millennium, as for the Greenland ice sheet. For two of the tipping elements – Arctic summer sea ice and the Greenland ice sheet – a rise in global average temperature of 1-2°C would possibly be enough to trigger them[27] although another study[28] indicates that a global average warming of 3.1°C would be the threshold for the Greenland ice sheet. The magnitude of warming required to trigger most of the other tipping elements, however, is not well known but even a small risk of triggering them would be considered dangerous[24]. It is not only temperature increases that may trigger tipping events. Recent studies suggest that ocean acidification (Box 5) may cause the creation of areas in the ocean with reduced levels of oxygen – "marine oxygen holes" - with devastating consequences for marine life[29].

One of the most common human responses to severe environmental stress, such as deterioration in water resources or food supply, is to move to places where conditions are better. The abrupt change of a tipping element such as the Asian monsoon to a substantially drier state, or the eventual loss of water storage capacity in Himalayan glaciers, would lead to environmental stress of profound proportions by reducing water availability in the Indo-Gangetic plain. The possibility of large numbers of forced migrants as a result of severe climate impacts has raised concerns that climate change may soon become a major issue (Box 7).

The IPCC in 2001[21] synthesised the types of analyses described above using the best scientific evidence available at the time in terms of "reasons for concern". The resulting visual representation of that synthesis, the so-called "burning embers diagram", shows the increasing risk of various types of climate impacts with an increase in global average temperature. Using the same methodology, the reasons for concern have been updated based on the most recent research[31].

Several insights relevant to the definition of dangerous climate change are obvious from a comparison of the 2001 and 2009 diagrams (Figure 8). First, risks of deleterious climate change impacts now appear at significantly lower levels of global average temperature rise in the more recent analysis. Second, a 2°C guardrail, which was thought in 2001 to have avoided serious risks for all five reasons for concern, is now inadequate to avoid serious risks to many unique and threatened ecosystems and to avoid a large increase in the risks associated with extreme weather events. Third, the risks of large scale discontinuities, such as the tipping elements described above, were considered to be very low in 2001 for a 2°C increase but are now considered to be moderate for the same increase.

In summary, although a 2°C rise in temperature above pre-industrial remains the most commonly quoted guardrail for avoiding dangerous climate change, it nevertheless carries significant risks of deleterious impacts for society and the environment.

BOX 7

Security Implications of Climate Change

Prof. Ole Wæver, ow@ifs.ku.dk

Climate change can create strains that increase the frequency of violent conflicts between societies, typically where the main causes are ethnic or political tensions but where added burdens from climate change weaken societies' ability to handle tensions. Changing conditions for settlement, agriculture, mining, transportation, diseases and disasters lead to local conflicts due to competition, and to international conflicts mainly through migration or power shifts.

Historically, the major human response to climatic changes beyond local adaptation capacity was migration. When human communities in the past occasionally weathered comparably large changes this way, the world was not yet carved up into tightly regulated territorial states, and climate changed much more slowly than now. Today, large scale migration is usually resisted by states and becomes a conflict issue between them[39,40].

Some researchers emphasise that a correlation between climate change and conflict is not documented in quantitative data[41]; others point out that this would in any case be unlikely given both the nature of these data sets and the relatively recent materialisation of the impacts of accelerating climate change on societies[42,43]. Much research is currently aimed at producing data better focused on measuring these relationships, thereby also preparing international society for managing the resulting conflicts. Meanwhile, non-public analyses abound. Intelligence services and militaries place climate change ever more centrally in their preparations for future conflicts[44,45]. If major powers become involved in conflicts, political cooperation on climate policy will become much more difficult.

If international climate policy comes to be seen as manifestly failing, unilateral attempts to deal with the emergency situation can lead to conflicts, for example, over geo-engineering. Also climate change policy and the lack thereof can itself become the object of international conflict or justify dramatic measures, as in the famous characterisation by Ugandan President Yoweri Museveni of climate change as "an act of aggression by the rich against the poor".

Generally, when issues are cast in security terms, leaders get increased latitude for dramatic measures. It is crucial that this 'security driven empowerment' in the case of climate change gets 'channelled' into strengthening of international institutions, and not unilateral emergency acts[42,43,46].

Factoring security into the climate change equation runs the risk of escalating vicious circles. In the parts of the world where health and well-being are most negatively impacted by climate change, the likelihood of conflict will increase most, and these conflicts will further reduce living standards. More privileged parts of the world are likely to first feel the spill-over effects from these conflicts, such as refugees and diseases, and at higher temperature increases see their own security agenda re-organised around climate change.

Photo: John McConnico

KEY MESSAGE 3

LONG-TERM STRATEGY: GLOBAL TARGETS AND TIMETABLES

Rapid, sustained, and effective mitigation based on coordinated global and regional action is required to avoid "dangerous climate change" regardless of how it is defined. Weaker targets for 2020 increase the risk of serious impacts, including the crossing of tipping points, and make the task of meeting 2050 targets more difficult and costly. Setting a credible long-term price for carbon and the adoption of policies that promote energy efficiency and low-carbon technologies are central to effective mitigation.

The goal of constraining warming to an average global temperature increase of no more than 2°C above preindustrial levels plays a central role in current discussions about appropriate climate policies. As described in the previous section, a 2ºC warming would, in itself, introduce considerable risk to human society and natural ecosystems. Nevertheless, the facts that global average temperature has already risen by about 0.7°C and that greenhouse gas emissions from human activities are still increasing (Box 2) render the achievement of a more ambitious goal very difficult. Due to inertia in the climate system alone, the 2007 IPCC Report[2] argues that a global temperature increase of about 1.4°C above pre-industrial levels is inevitable. There is also inertia in human systems but this is harder to quantify and it is not known how quickly or dramatically society can or will reduce greenhouse gas emissions.

What level of emission reductions is needed to retain climate change on the right side of the 2°C guardrail? The IPCC[1] estimated the level of atmospheric concentrations of greenhouse gases at which the global average temperature rise would be contained within various ranges (Table 1). The concentrations are given both as CO_2 and CO_2-equivalents. CO_2-equivalents include the combined warming effects of CO_2 and the non-CO_2 greenhouse gases (excluding water vapour) as well as the net cooling effect of aerosols in the atmosphere. CO_2-equivalents are expressed as the equivalent amount of CO_2 required to give the same net warming as that created by these other gases and aerosols. Aerosols are small particles suspended in the atmosphere that reflect the sun's incoming radiation and thus have a cooling effect. As air pollution regulations become more stringent and the amount of particles emitted to the atmosphere from human activities decreases, the cooling effect of aerosols in the atmosphere will also be reduced.

According to the IPCC analysis, atmospheric CO_2 concentration should not exceed 400 ppm CO_2 if the global temperature rise is to be kept within 2.0 – 2.4°C. Today, the CO_2 concentration is around 385 ppm[33], and is rising by 2 ppm per year. The 2007 concentration of all greenhouse gases, both CO_2 and non-CO_2 gases, was about 463 ppm CO_2-equivalents. Adjusting this concentration for the cooling effects of aerosols yields a CO_2-equivalent concentration of 396 ppm[34]. A recent study[35] estimates that a concentration of 450 ppm CO_2-equivalents (including the cooling effect of aerosols) would give a 50-50 chance of limiting the temperature rise to 2°C or less.

Thus, atmospheric CO_2 concentrations are already at levels predicted to lead to global warming of between 2.0 and 2.4°C (Table 1). If society wants to stabilise greenhouse gas concentrations at this level, then global emissions should, theoretically, be reduced by 60-80% immediately, the actual amount being dependent upon the amount that will be taken up by oceans and land. Given that such a drastic immediate reduction is impossible, greenhouse gas concentrations will continue to rise over the next few decades. An overshoot of the atmospheric greenhouse gas concentrations needed to constrain global warming to 2ºC is thus inevitable. To limit the extent of the overshoot, emissions should peak in the near future. Recent studies[22,36,37] suggest that if peak greenhouse gas emissions are not reached until after 2020, the emission reduction rates required thereafter to retain a reasonable chance of remaining within the 2°C guardrail will have to exceed 5% per annum. This is a daunting challenge when compared to a long-term average annual increase of 2% in emissions (Box 2). The conclusion from both the IPCC and later analyses[38] is simple – immediate and dramatic emission reductions of all greenhouse gases are needed if the 2ºC guardrail is to be respected.

Short-term financial concerns, political and institutional constraints and lack of public awareness and concern are the greatest barriers to immediately initiating ambitious emission reduction. There is still disagreement in the economics community as to whether climate change is simply an externality like any other or is fundamentally different from anything humanity has ever faced[38,39]. There is also disagreement about how to appraise the costs of mitigation as compared to the future costs of inaction, and how to evaluate the risks of climate change. Nevertheless, a growing number of analyses indicate that the costs of both adapting to and mitigating climate change will increase if action is postponed[16] (sessions 32 & 52), (Box 8). Generally, economic analysts agree that the uncertainty about the extent of future climate change is not a rational reason for delaying programs to curb emissions. Existing economic structures and interests, however, can often prevent effective climate policy action.

The Costs of Delaying Action

BOX 8

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Postponing emission reductions is potentially very costly. It implies:

- More emissions now leading to greater and more rapid temperature increases and, therefore, greater impacts and adaptation costs.
- Locking in high-carbon infrastructure and delaying 'clean' technological development.
- More drastic cuts in emissions are required later on.

Greater near-term emissions lock us into greater climate change requiring greater costs from climate impacts and more investment in adaptation. Furthermore, they lead to a faster rate of climate change with greater challenges for adaptation. There is a greater risk of crossing tipping points and, if dictated by emerging evidence, problems in changing to more ambitious targets.

Different emission trajectories will have different impact and adaptation implications but also different mitigation costs. Drastic emissions reductions would mean prematurely retiring productive capital stock (physical investments like cars and power stations) and is potentially very costly. They raise costs of new investments either through early use of developing technologies or earlier retirement **of existing investments*** ~~using older technologies~~ particularly in capital intensive sectors with durable investments, such as power generation, where plants are often expected to last 40-50 years.

While deploying technologies before they have matured incurs higher costs, these technologies will not mature without investment and clear policy signals. Developing new technologies lowers costs for future emissions reductions. Relying on greater emission reduction in the future depends on innovation delivering cost effective low-carbon approaches in sectors that would currently be expensive to decarbonise like aviation and agriculture. For a given level of emissions, the longer the delay in action on relatively low-cost emissions such as energy efficiency and deforestation, the greater the reductions that will be required in these high cost sectors. While there are risks on both sides, the available evidence suggests that it is the cost of doing too little that dominates most current proposals[39].

**The words "using older technologies" have been removed at the request of the author*

Photo: John McConnico

Temperature rise	CO_2	CO_2-eq.	Year of peak emissions	% change in global emissions
Global average temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity	CO_2 concentration at stabilisation (2005 = 379 ppm)	CO_2 -eq. concentration at stabilisation including GHGs and aerosols (2005 = 375 ppm)	Peaking year for CO_2 emissions	Change in CO_2 emissions in 2050 (percent of 2000 emissions)
°C	ppm	ppm	year	percent
2.0 - 2.4	350 - 400	445 - 490	2000 - 2015	-85 to -50
2.4 - 2.8	400 - 440	490 - 535	2000 - 2020	-60 to -30
2.8 - 3.2	440 - 485	535 - 590	2010 - 2030	-30 to +5
3.2 - 4.0	485 - 570	590 - 710	2020 - 2060	+10 to +60
4.0 - 4.9	570 - 660	710 - 855	2050 - 2080	+25 to +85
4.9 - 6.1	660 - 790	855 - 1130	2060 - 2090	+90 to +140

Table 1
Characteristics of various emission trajectories to achieve stabilisation of atmospheric greenhouse gas concentrations, in CO_2 and CO_2-eq. The equilibrium global average temperature increase above pre-industrial is given for each stabilisation target. Only the first scenario, shown in the first row, has a possibility to meet the 2°C guardrail. Note that current atmospheric greenhouse gas concentrations are about 385 ppm CO_2 and 396 ppm CO-eq (including the cooling effect of aerosols). Modified from[1] (table 5.1, p. 67).

Although it can be politically difficult, a critical step in curbing emissions is that businesses and consumers face an appropriate price for emitting greenhouse gases[38,39]. Emissions pricing can be done either through emissions targets and trading, through harmonised taxes and fees on emissions, or through a combination of these approaches. In any case, other policies and programmes to address additional externalities and market failures will likely be required (Box 9). If ambitious mitigation goals are to be achieved, then emissions reductions programmes and carbon pricing should be implemented as quickly as possible, and within stable policy frameworks. This will provide signals to investors, consumers, and innovators about the future market environment and thus encourage investments and ultimately reduce the cost of attaining a given mitigation goal. In concert with carbon pricing, adoption of policies and regulations that promote energy efficiency - for example, establishment of energy standards for appliances, housing and transport[32,48,49] - and the widespread uptake of low-carbon technologies are also critical for rapid and effective mitigation[50].

Without global cooperation, ambitious climate protection will be virtually impossible. To achieve ambitious mitigation goals, it is critical to move as quickly as possible to achieve widespread participation of all major countries in comprehensive mitigation action[16,51,52,53] (sessions 32 & 52). However, the current global economic crisis suggests that it would not be wise to build an intricate, highly connected global system in which collapse of a single element in the system leads to collapse of the whole[16] (session 23). Nevertheless, a global action plan, global commitments and a global framework are necessary prerequisites to build an appropriate level of coordination of measures at all scales including the local, national and regional[16] (session 58).

In addition to the economic and political constraints on reducing greenhouse gas concentrations, technical bottlenecks are also important. Stabilising atmospheric concentrations at any level will require emissions to be reduced to near-zero levels in the long term[54]. Some of the projected pathways that give a reasonable chance of staying within the 2°C guardrail (Figure 9) suggest that global society may need to develop the capacity to remove carbon from the atmosphere[55]. Although some promising technologies - for example, Carbon Capture and Storage, CCS – are under development[56], they are still some way from being deployed commercially and on a large-scale[16] (session 17).

Given the enormity of the mitigation challenge, increasing attention is being given to aggressive mitigation portfolios and their practical implementation. Analyses range from the potential of energy efficiency measures[16] (session 20) and technical innovation in renewable energy systems[57] to integrated assessments of the technical feasibility and economic affordability of emission pathways to stabilise greenhouse gas concentrations at 400, 450 and 550 ppm CO_2-equivalents, respectively (Figure 9). The 400 ppm CO_2-equivalents target, about the same as today's concentrations, is estimated to give a 75% chance of confining global warming to less than 2°C[22,35]. Energy-environment-economy modelling suggests that such a low-carbon pathway is feasible at moderate costs if the full suite of technologies is developed and employed, including large-scale biomass use and options to capture and store CO_2[16] (session 27),[60].

Others argue that the mitigation challenge might be much greater than currently envisaged, and that the innovation strategies required might hit technical, social, and ecological barriers. This line of argument points towards geo-engineering, in which humanity deliberately manipulates global-scale climate processes to achieve planetary cooling, as being a potential option in addition to mitigation strategies[61]. Social acceptance of geo-engineering approaches, however, has yet to be demonstrated[62].

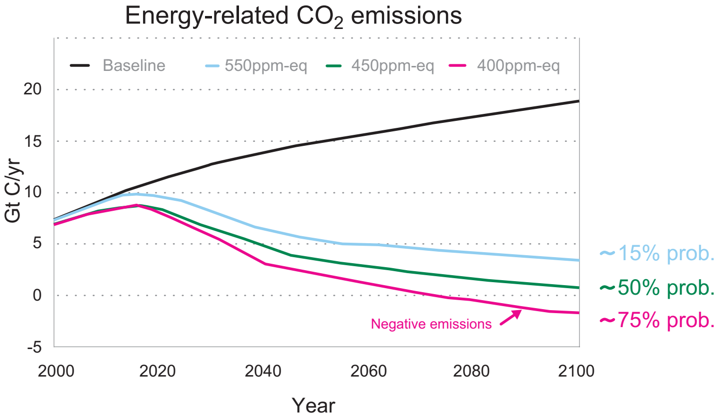

Figure 9
Energy-related emission trajectories from 2000 to 2100 to achieve stabilisation of greenhouse gases in the atmosphere at three different targets (coloured lines). The black line is a reference trajectory based on no climate policy. Estimated (median) probabilities of limiting global warming to maximally 2°C are indicated for the three stabilisation targets [35,58,63].

Economic Tools to Meet the Mitigation Challenge

BOX 9

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Emissions pricing is the main economic tool for controlling greenhouse gas emissions. The two main pricing instruments are a carbon tax (setting the price), and emissions trading (setting the quantity, 'cap and trade'), with hybrid schemes also possible. Most schemes planned and in place use emissions trading, sometimes with elements of price control. Taxes and trading perform differently under uncertainty, and debates continue among economists over which approach is preferable, but the fundamental principle is the same: a financial penalty is placed on emitting greenhouse gases and transmitted through markets, creating an incentive to cut emissions. Businesses and consumers shift to lower-emissions processes or products because it saves them money. The overall response is cost effective because the lowest cost options are used first.

Subsidies for low-carbon technologies are another critical tool to address externalities and market failures that may persist under emissions pricing. Examples include knowledge spillovers in research and development (R&D), credit constraints for investment, and misaligned incentives for end users. In many countries, fiscal stimulus packages to counter the recessionary effects of the Global Financial Crisis include public investment in low-carbon technology and infrastructure. Sector-specific regulatory approaches are also part of the climate economic toolbox, for example mandating that utilities buy a minimum share of electricity supplied by renewable energy sources. Such regulation can also include market mechanisms, like trading of renewable quotas between utilities.

The central considerations in choosing and designing economic policies for greenhouse gas mitigation are their cost effectiveness and political sustainability. The key is to create stable price signals and long-term expectations of rising carbon prices, in order to support long-lived investments in mitigation measures; and to implement the policies widely across sectors and countries to maximise the incentives for reducing emissions and minimise the aggregated economic costs.

KEY MESSAGE 4

EQUITY DIMENSIONS

Climate change is having, and will have, strongly differential effects on people within and between countries and regions, on this generation and future generations, and on human societies and the natural world. An effective, well-funded adaptation safety net is required for those people least capable of coping with climate change impacts, and equitable mitigation strategies are needed to protect the poor and most vulnerable. Tackling climate change should be seen as integral to the broader goals of enhancing socioeconomic development and equity throughout the world.

Equity considerations are prominent in the origins and consequences of climate change, and especially important in developing solutions to climate change. The climate is not changing uniformly around the world. Temperature is rising faster near the poles than at the equator, rainfall is changing in complex ways in which some regions are becoming wetter while others are drying, and extreme events are becoming more frequent in some locations compared to others. Inequities are also prominent in the human dimensions of climate change. In general, developed countries are most responsible for climate change up to now while developing countries suffer the majority of the impacts. For example, the impacts of climate change on health are profoundly unequal; the poor, the marginal, the uneducated and the geographically vulnerable are at greatest risk of injury and death[16] (session 14). In general, the poor have the least capacity to adapt to climate change. Any lasting and widely accepted solution to the climate change challenge should recognise and account for these equity dimensions in negotiations and agreements.

Vulnerability to the impacts of climate change varies widely around the world, with ethics and justice issues emerging as key factors in adaptation approaches. Discussions of the inequalities surrounding adaptation commonly involve the interaction of adaptation with national poverty, regional imbalances in adaptive capacity, adaptation in the context of colonial histories, responsibility for financing adaptation and the ethics of imposing the adaptation burden on an already unequal world[16] (sessions 10 & 11). A number of models have been proposed for addressing these equity issues, often oriented around the concept of a well-funded adaptation safety net for the most vulnerable (Box 10).

Global analyses of hot spots for water scarcity and vulnerability of agriculture and food systems can identify the people and places most vulnerable to food shortages (Figure 10), helping to direct resources and expertise towards reducing these vulnerabilities. To date, there has been surprisingly little research specifically on maintaining or enhancing the productivity of food systems under a changing climate or on the vulnerability to climate change of other aspects of food systems such as distribution networks and food quality. This lack of research focus is a common problem in many developing regions of the world, where pressures for survival in the near term dominate over long term adaptation to climate change. Nevertheless, as climate change impacts increase in importance, additional resources will be required for both research and action to reduce the vulnerability of the most food-poor parts of the world[64,65].

Equity issues have temporal as well as spatial dimensions. There has been much discussion about the obligations of the current generation to future generations and, although there is vigorous debate on many aspects of intergenerational equity, some areas of agreement have emerged. First, standard economic approaches employing cost-benefit analysis and standard discounting fail to reflect the diversity of perspectives on obligations to future generations. Second, many different philosophical perspectives lead to the same conclusion – maintaining a business-as-usual approach to climate change is unjust to future generations, who have a fundamental right to an environment they can live in. In summary, the current generation is managing Earth's natural capital so that a substantial environmental debt will be passed on for the next generations to repay[16] (session 12).

The unfolding biodiversity catastrophe raises not only concerns about the provision of ecosystem services to humans[26], but also ethical issues regarding the relationship between humanity and the rest of nature. While contemporary society often views the natural world as a vast array of resources for exploitation, the recreational and spiritual values of nature remain important for many people. Thus, the potential extinction of charismatic species, such as Emperor Penguins, or iconic ecosystems, such as coral reefs or rainforests, as a consequence of climate change is regarded as unacceptable by many people. Biocentric and ecocentric ethical perspectives confer moral status on plants, animals and ecosystems, and thus climate change-driven extinctions are viewed as matter of injustice when equity between humanity and the rest of nature is considered[16] (session 13).

Equity issues are also prominent in mitigation of climate change, and invariably enter discussions of differential responsibilities for emission reductions across countries. The scientific basis for the equity dilemma regarding mitigation is the so-called stocks and flows problem[18]. The climate responds to the amount of greenhouse gases in the atmosphere – the stocks. Because of the long lifetime of CO_2 and some other greenhouse gases in the atmosphere, the stocks are dominated by the historical emissions from developed countries. Thus, the level of climate change being experienced in 2009 is largely caused by the historical emissions from wealthy countries (Figure 11). However, the

Funding for Adaptation

BOX 10

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The world's poorest are usually the most vulnerable to the impacts of climate change but least responsible for them. The UNFCCC and Kyoto Protocol have both stated that substantial funding should flow from those with the "capability" to cope with and manage climate change to those without. Agreeing to that principle was the easy part; a global pact, however, must address a series of crucial questions. How much funding is needed for adaptation and how do we know and estimate these costs, both for the near and longer term? Who should pay for adaptation and how much should each country pay? How can adequate payments be reliably and justly raised? How can international funds for adaptation be fairly distributed and effectively put to use?

Estimates of the amount of funds required for developing nations to adapt to the likely impacts of climate change currently range from eight to over one hundred billion dollars a year, but it is clear that tens of billions of dollars may be needed to be mobilised annually, starting now. Current voluntary funds are grossly inadequate. As in most disasters, despite significant efforts, many of the impacts and disaster losses are never repaired or repaid. The Polluter Pays Principle, however, suggests that those who created the need to adapt should pay for it. It is crucial that these payments be considered obligatory restitution for damages done, and not treated as optional or charity.

The UNFCCC specifies that action on climate change should be based on responsibility and capability. The most promising approaches utilise revenues generated in wealthier nations in driving their emissions reductions (by carbon taxes or permit auctioning revenues) to address the needs of poorer nations to adapt. International levies on carbon trading or transportation have advantages over funding raised through national taxes, which risk being captured by national politicians under pressure to address other local priorities. Finally, careful attention must be paid to fair and effective distribution of adaptation funds: participatory processes, transparency of delivery, and independent evaluation of their use will all be needed to maintain broad confidence.

Photo: John McConnico

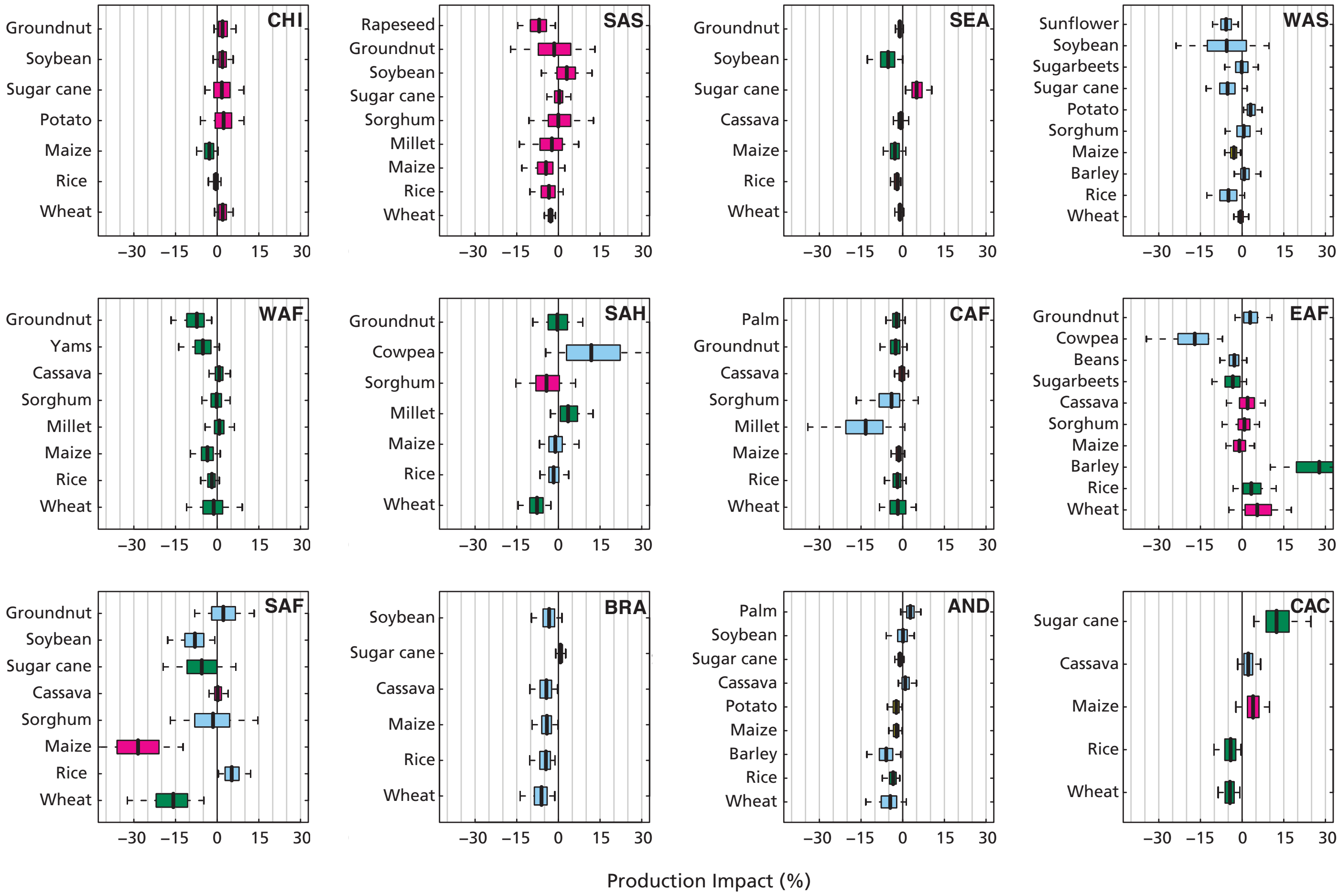

Figure 10

Projected climate change impacts on agricultural production in 2030, expressed as a percentage change relative to 1998-2002 average yields. Pink, green and blue indicate a "hunger importance ranking" of 1 to 30 (more important), 31 to 60, and 61-94 (less important), respectively. Dashed lines extend from 5th to 95th percentile of projections, boxes extend from 25th to 75th percentile, and the middle vertical line within each box indicates the median projection. Region codes are: CHI – China; SAS – South Asia; SEA – Southeast Asia; WAS – West Asia; WAF – West Africa; SAH Sahel; CAF – Central Africa; EAF – East Africa; SAF – Southern Africa; BRA – Brazil; AND – Andean Region; CAC – Central America and Caribbean[64].

origins of human emissions of greenhouse gases into the atmosphere are changing rapidly. The rate of increase in emissions is now dominated by developing countries, and the large Asian economies, in particular, have become significant emitters of CO_2 into the atmosphere in terms of annual flows. However, on a per capita basis, developed countries still dominate emissions and will continue to do so in the foreseeable future.

In a 2050 world of 9 billion people, to meet the emission reduction targets to avoid dangerous climate change (Key Message 2), per capita emissions will need to be about 2 tonnes of carbon dioxide per annum or less. As noted, per capita emissions at present vary widely from country to country – for example, in the USA, they are over 20 tonnes, in the Nordic countries about 11 tonnes, and in China, under 4 tonnes[66]. To convert the required per capita average into a binding emissions entitlement per person across the world is a complex issue, involving issues of historical responsibility (Figure 11) as well as the time required to eliminate the current differences between countries.

Mitigation approaches in a national context are also beset with equity challenges. They invariably intersect with structural inequalities in complex ways, often to disadvantage economically and politically weaker sub-populations. Energy policies to limit emissions should be sensitive to specific patterns of energy consumption that vary across households and individuals in terms of income, urban vs. rural locations, gender and age. Dealing with these challenges requires the increased participation of and consideration of all social groups in policy design and implementation[16] (session 10).

Development, deployment and diffusion of low- or no-carbon technologies are critical aspects of the mitigation efforts that also intersect strongly with equity issues, especially for developed-developing country interaction. The introduction of a mix of different non-fossil fuel energy sources to reduce emissions is sometimes argued to slow poverty alleviation in the developing world due to its high requirement for investment[16] (session 21) although it can have the opposite effect when appropriately designed and implemented. Some key principles when introducing non-fossil fuel energy sources are: (i) explicitly plan for spill-over and diffusion to developing countries when demonstration projects are carried out in a developed country; (ii) design co-benefits for other aspects of socio-economic development and include explicit incentives to support low-carbon energy systems; and (iii) technologies do not have to be the most advanced and costly to be effective in the developing world[16] (sessions 21 & 27). An example of the last principle is the rapid diffusion of low cost, low maintenance solar cell technology in Kenya[57] (Figure 12).

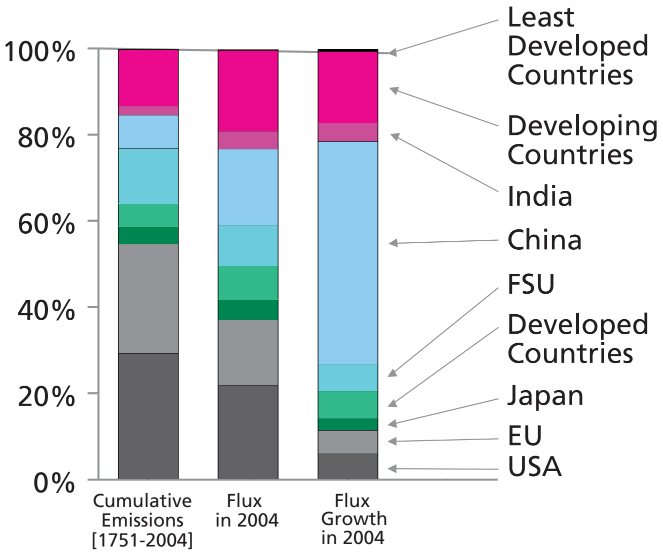

Figure 11
Various aspects of human carbon emissions by country/region, highlighting the so-called stocks and flows problem. The first column shows the cumulative emissions from the beginning of the industrial revolution to 2004. It is these stocks of carbon in the atmosphere that are largely driving observed climate change. The second column shows the flow rate of human carbon emissions into the atmosphere in 2004. The third column shows the annual rate in 2004 by which the flows of carbon into the atmosphere are growing[18]. FSU is the Former Soviet Union.

Using biological systems to store carbon and reduce emissions is a potential mitigation approach for which equity considerations are complex and contentious. Changes in forest land cover are responsible for about 15% of human global greenhouse gas emissions[1]. Approaches to reducing emissions from deforestation and forest degradation are gaining support as a potentially effective and efficient mitigation strategy (Key Message 5), but challenges remain to ensure that such strategies are equitable, especially the need to protect the rights and livelihoods of forest-dependent populations. To achieve widespread acceptance, such projects should avoid the mistakes and build on the successes of previous attempts to control deforestation, which implies


Photo: Arne Jacobson

Figure 12
Small-scale photo-voltaic cells (average system – 18 watts) as used in Kenya. The rate of uptake of this technology is higher in Kenya than in any other country in the world[57].

that policy tools need to address the true drivers of deforestation. These are often cross-sectoral and outside of the traditional forestry sector. Furthermore, forest protection approaches need to accommodate diverse local situations, both in political economy and in ecology[16] (session 25).

Other biology-based mitigation approaches include the development and use of biofuels. These, however, also involve equity considerations. The 2008 spike in food prices, which was at least in part attributable to competition with biofuels for land, has highlighted the potential conflict driven by the demand of wealthy countries for liquid fuels and the need of the poor in developing countries for food security. Second-generation biofuel systems are designed to remove this potential conflict by using non-food feedstocks and by using land unsuitable for food production[16] (session 18).

Equity issues pervade virtually all aspects of the climate change challenge. Attempts to separate or compartmentalise emission reduction and adaptation activities from the broader goals of socio-economic development in many parts of the world are doomed to failure. The twin challenges of the 21st century – avoiding dangerous climate change and poverty alleviation – should and can be tackled together[67,68].

KEY MESSAGE 5

INACTION IS INEXCUSABLE

Society already has many tools and approaches – economic, technological, behavioural, and managerial – to deal effectively with the climate change challenge. If these tools are not vigorously and widely implemented, adaptation to the unavoidable climate change and the societal transformation required to decarbonise economies will not be achieved. A wide range of benefits will flow from a concerted effort to achieve effective and rapid adaptation and mitigation. These include job growth in the sustainable energy sector; reductions in the health, social, economic and environmental costs of climate change; and the repair of ecosystems and revitalisation of ecosystem services.

Any societal response to human caused climate change should be a combination of ***mitigation***, whereby active measures are taken to reduce or change the human activities that are driving climate change, and ***adaptation***, whereby society increases its capacity to cope with the impacts of climate change, so far as possible. Mitigation and adaptation are closely related as response strategies. Adaptation is essential, as even a massive mitigation effort initiated today would be unable to eliminate the impacts of the climate change that are already occurring and those to which society is committed in the future owing to the inertia in the climate. At the other extreme, if no mitigation is initiated and human caused climate change is allowed to continue unabated, the risk of the most dangerous or catastrophic impacts associated with a global warming of several degrees is large (Key Message 2). Even the wealthiest of societies, with the best and most well-resourced adaptation activities, would probably not be able to completely adapt to such levels of climate change. This simple reality underscores the fact that effective climate policies should combine both adaptation measures and mitigation activities.

A reduction of human emissions of greenhouse gases to the level necessary to stay within the 2°C guardrail cannot happen unless a very much larger percentage of societal energy demands is met by non-fossil fuel sources. Developing an economy less dependent on fossil fuels is referred to as "decarbonising the economy". Many renewable energy technologies that can contribute to decarbonising the global economy have been under development in recent years (Box 11). Although there is no "silver bullet" – no single renewable technology that can replace fossil fuels in their totality – a mix of technologies can allow different countries and regions to develop their own renewable energy combinations to meet their own needs. Technologies are already available that, in combination with changes on the demand side - reduced energy usage and improved energy efficiency – give the potential to achieve a 50% greenhouse gas emission reduction by 2050 and, in some regions, to reduce emissions to virtually zero by that time[16] (session 19). Reaching such goals, however, requires rapid, substantial build-up of production capacity through concerted investments; a stable policy framework; and research, development and demonstration to facilitate technology learning and reduce production costs (Figure 13).

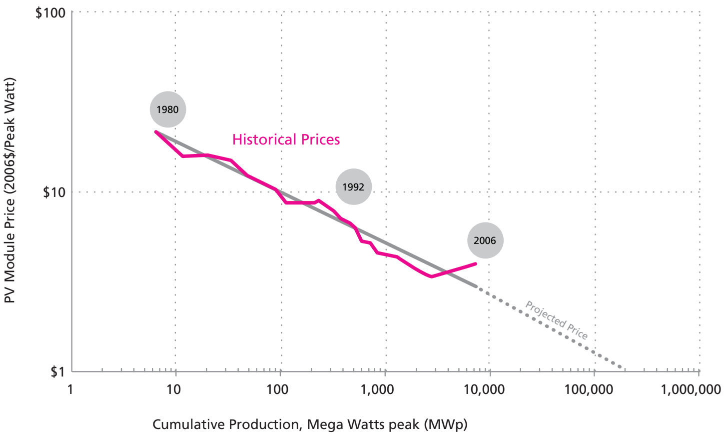

Figure 13
The drop in module price of thin-film photo-voltaic (PV) solar cells as the cumulative production increases, a reinforcing feedback loop which shows that early, significant investment in renewable technologies will increase their rate of uptake, further lowering unit costs[69]. The solid line shows historical data and the broken line shows the projected trajectory based on a continuation of historical trends.

"Smart grids", where different elements of the energy system, including production, flexible demand, storage and energy conversion, interact to provide a stable and efficient energy system, will be essential to integrate large fractions of renewable energy. The development of "super-grids" - regional energy supply systems providing energy over large geographical areas - may also be necessary to facilitate integration of wind, solar and other renewable energy technologies together with large-scale energy storage facilities, such as hydroelectric power facilities. Such grids can help to balance loads and moderate fluctuations in production[16] (session 19).

In some cases, renewable technologies may actually be more immediately applicable to developing country requirements than more traditional fossil fuel based energy systems because they can work in remote areas on smaller scales and may need less maintenance and local technical capacity (Key Message 4). Some technologies, such as early solar technologies, that may not be appropriate for power generation in countries that already have a modern and reliable energy distribution system, may nevertheless be well suited for power generation in developing communities that do not have access to reliable electricity systems. In other words, when climate considerations are integrated into development activities, the goals of climate change mitigation and development can be strongly synergistic.

In addition to the development of renewable energy technologies, the management of biological systems has considerable potential as a tool for mitigation. Forests, for example, can remove significant amounts of CO_2 from the atmosphere, as trees (like all plants) capture CO_2 through photosynthesis and convert it to biomass. Because plant communities consisting of many species generally take up more carbon from the atmosphere than communities consisting of just one or a few species[70], the preservation of biodiverse natural forests has come into sharp focus as a mitigation tool through the REDD (Reducing Emissions from Deforestation and forest Degradation) initiative[16] (session 25), (Figure 14). Its aim is to significantly reduce the emissions of greenhouse gases associated with the conversion of natural forests to other land uses.

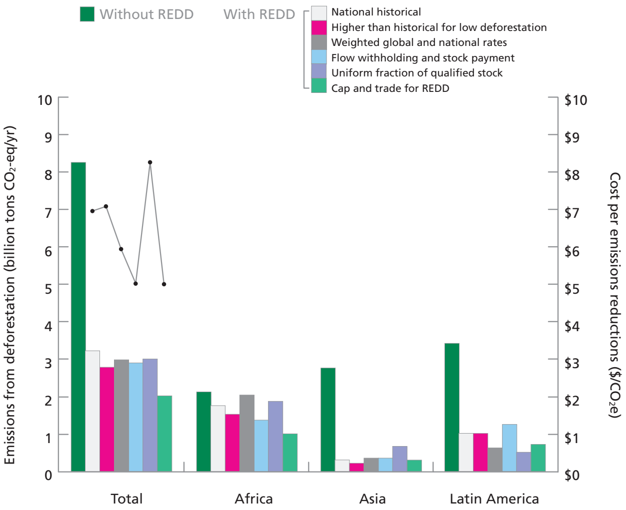

Figure 14

Modelled emissions from deforestation under seven REDD design options, by region. The different design options are based on varying approaches for defining the baseline from which additional deforestation would be measured, the nature of financial mechanisms, measures to control internal "leakage" of deforestation to countries with historically low deforestation rates, and other factors[16] (session 25). The results of the analysis show that regardless of the details of the particular design, the REDD approach can reduce emissions from deforestation to less than half. The results vary strongly by region, with Asia and Latin America showing very large emission reductions via REDD, while the gains are very small in Africa. Thus, the results are far more sensitive to regional differences than they are to the nature of the REDD design[71].

While REDD has much appeal, it also presents enormous challenges: how can baselines be established from which increases or decreases in deforestation can be measured? What are the conditions and mechanisms - financial and other - that best support REDD? How can local populations be fairly compensated for dedicating "their" land and its carbon values for a global purpose (Key Message 4)? Furthermore, if temperature increases by 2°C or more, there is a risk that land ecosystems, including forests, may become a net source of carbon to the atmosphere due to increases in respiration and in disturbances such as fire. The loss of carbon-regulating services of forests would seriously accelerate climate change[16] (session 38), (Box 2).

Agriculture is the most widespread and fundamentally important of all human land uses but it is also a significant emitter of greenhouse gases to the atmosphere. On the other hand, very significant and cost effective greenhouse gas reductions can be made in modern agriculture, primarily through altered management practices. Enhanced soil carbon storage has, in particular, large emission reduction potential in the short-term, while offering long-term increases in sustainability of farming systems. This mitigation potential, however, is unlikely to be achieved unless a realistic price is put on greenhouse gas emissions. There are also other barriers - structural, institutional, financial and educational - to altering agricultural management practices to become more climate friendly[16] (session 24), (Figure 15).

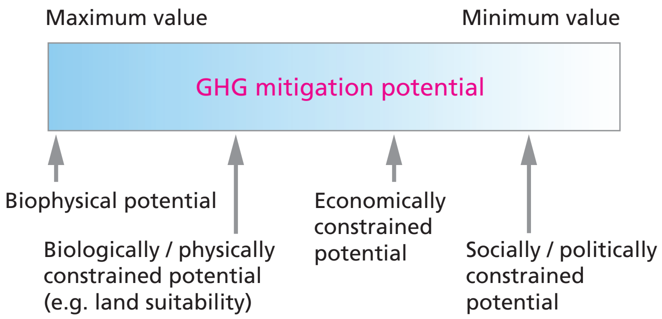

Figure 15

Impacts of different constraints on reducing greenhouse gas mitigation potential from its theoretical biophysical maximum to the lower achievable potential[72]. Ecological constraints, such as nutrient or water limitations, can significantly reduce the theoretical biological potential for carbon uptake in production systems. Economic, social and political considerations can provide further constraints, which results in a realised level of carbon uptake that is far less than the theoretical maximum.

Technology	Feedstocks	Process technology	Potential competition with food production	Conversion efficiency	Level of feed by-products
1st generation bioethanol	*Cereals, sugar cane, tubers*	*Fermentation*	*Low to high*	*30-65%*	*High*
2nd generation bioethanol	*Residues, waste, bioenergy crops*	*Fermentation*	*Low*	*30-75%*	*Low to high*
Biogas (methane)	*Manure, energy crops, organic waste*	*Mesophilic fermentation*	*Low to high*	*60-80%*	*None*
Biodiesel	*Oil crops, food & animal waste*	*Extraction & transesterification*	*Low to high*	*85%*	*Low to high*
Biomass to Liquid (diesel)	*Any biomass, preferably wood*	*Thermochemical*	*Low*	*50-60%*	*None*
Biomass for heat and power	*Any biomass, preferably waste and residues*	*Thermochemical*	*Low*	*50-65%*	*None*
3rd generation biofuels	*Algae, halophytes, waste and residues*	*Thermochemical, biological, extraction*	*None*	*< 65%*	*Unknown*

Table 2
Comparison of biomass to energy conversion technologies. Note the large variation in conversion efficiencies. This reflects the difference between earlier technologies and the current state of the art. The conversion efficiency for biomass for heat and power is based on the average annual efficiency[73-84].

Perhaps the most controversial of all biology-based mitigation tools are biofuels, which are produced from plant biomass and can be combusted to generate heat and power so that they can substitute for fossil fuels (Table 2). Ultimately, a transport sector less dependent on fossil-derived liquid fuels is necessary. In the short term, biofuels are important to reduce the use of fossil fuels for cars; in a longer timeframe they will likely replace fossil fuels for airplanes and ships[16] (session 18). The limiting factor is the amount of land that can be devoted to the production of biofuels. Therefore, much effort is currently being devoted to the development of 2nd generation biofuel systems that are based on "waste" plant material rather than on crops cultivated for the sole purpose of energy production. Based on this reasoning, as well as on a comparison of the total energy required for production compared to the total energy yield, the use of the oil crops - oil palm, rape, sunflower and soy - is not sustainable and should therefore be avoided[16] (session 18).

With respect to adaptation, sectors that are already tightly managed by humans - food systems, forestry, and water systems - can most readily be adapted to the impacts of climate change[16] (session 38). Agriculture and forestry can, for example, change to alternative crops or tree species that require less or tolerate more water, or that remain productive under higher temperatures.

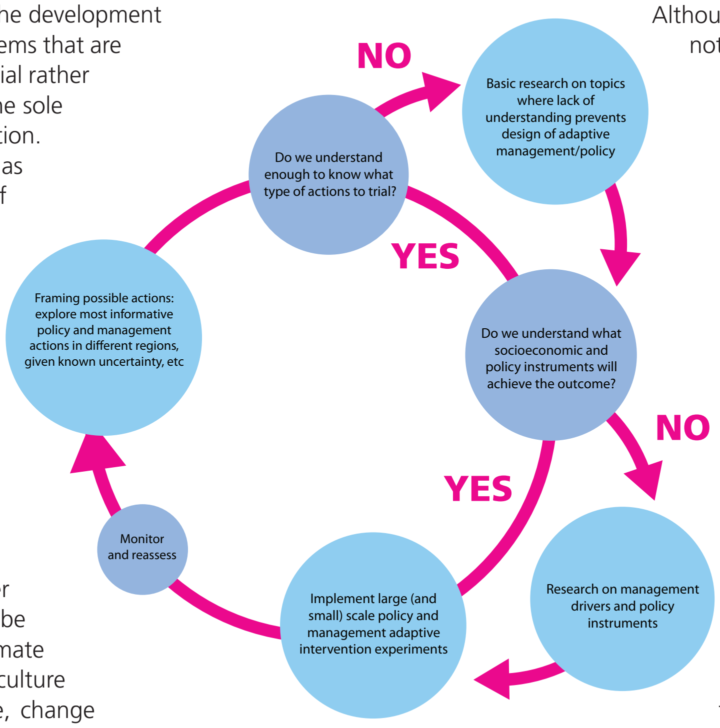

Figure 16
A visual representation of active adaptive management, an iterative approach built around explicit, experimentally based development of plausible management options[72,86].

However, there are limits to such adaptations if the climate changes too much or too fast. In agriculture, mitigation and adaptation often involve the same management strategies and can thus be achieved at the same time, giving synergistic outcomes[85].

It is more difficult to develop adaptation strategies for natural systems, which provide the indirect ecosystem services that ultimately underpin human well-being. A new paradigm for nature conservation would be more appropriate in the face of climate change[16] (sessions 31 & 38). This paradigm should concentrate primarily on enhancing the resilience of well functioning ecosystems. Appropriate adaptation strategies include the expansion and connection of protected area networks, the control of alien species, and the use of active adaptive management (Figure 16). Some presently used conservation tools, such as static red species lists, small unconnected protected areas and political borders as boundaries for declaring threatened species, are not effective adaptation tools with respect to climate change[16] (session 31).

Even with the most effective adaptation approaches, very large numbers of species will not survive with unabated climate change (Key Message 2). To avoid a worsening extinction crisis, there is no alternative to rapid, effective mitigation. In addition, investment in *ex situ* conservation – that is, keeping organisms in captivity or maintaining seed banks - could be made in the hope that these organisms, one day, can be released back into the wild should a suitable climate be recovered[86]. At best, however, *ex situ* measures will be feasible for only a few species.

For the developing world, in particular, perhaps the most important message emerging from current adaptation efforts is that climate considerations should be included in both domestic policies and foreign assistance. Adaptation to climate change cannot be successfully implemented if treated as an "add on" and implemented separately from other initiatives aimed at fostering economic and social development and increasing the resilience of societies. Although the full impact of future climate change is not yet known, some current trends are becoming apparent - changing access to fresh water, increased frequency of storms and floods, and drought-affected agricultural areas. Many 'no regrets' adaptations - for example, those that sustain water supplies or secure dwellings - can be implemented now and will build societal resilience towards further climate change[66].

As part of building effective adaptation, research is urgently required into the implications of existing policies and potential future policies with regard to adaptation: do they support or hinder adaptation, and how do they need to be changed? Investment for infrastructure also needs to be considered in a climate adaptation context: which projects have the best benefit-cost ratio and when should investment decisions be taken? Furthermore, because climate is tracking near the upper range of projections, societies require adaptation policies, practices

The Benefits of Decarbonising the Economy

BOX 11

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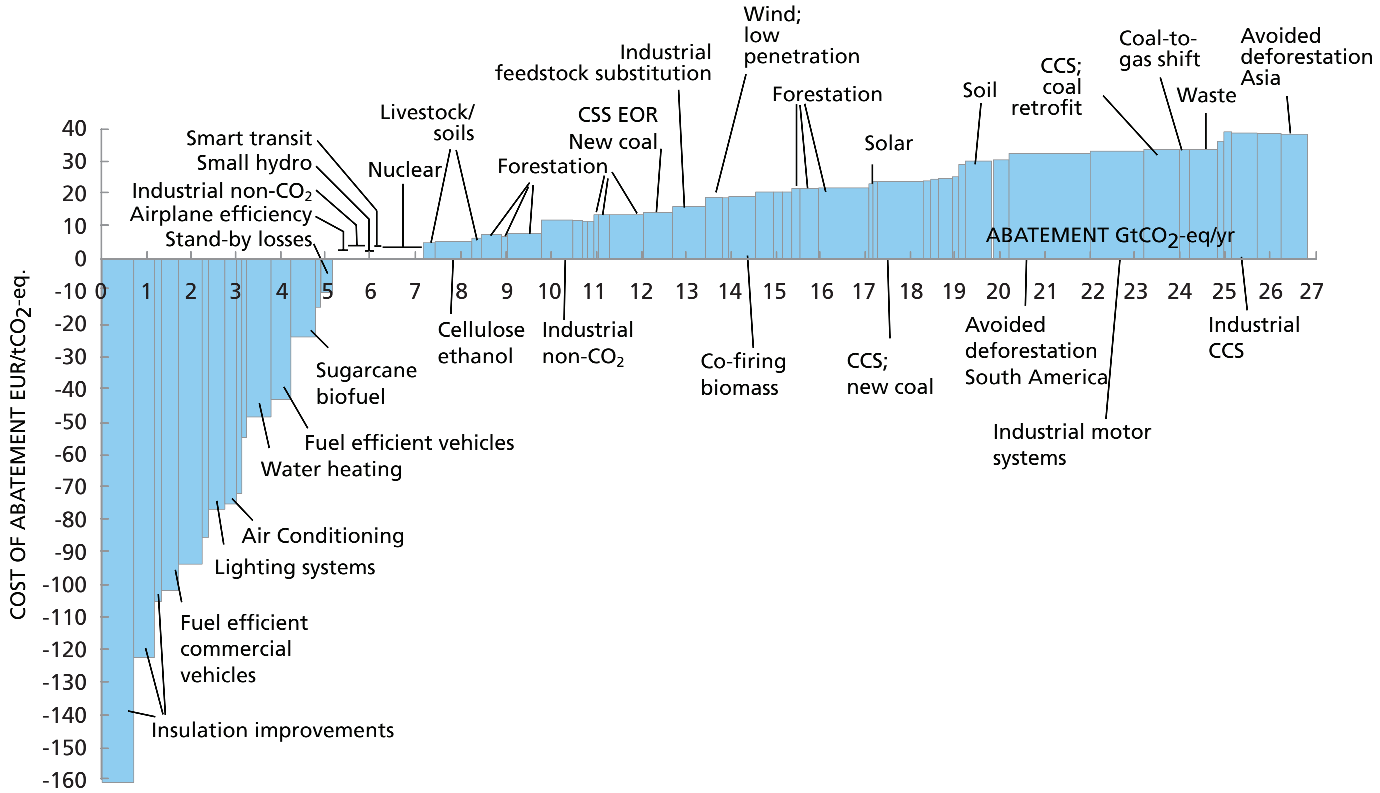

One of the most important lessons of the rapidly-expanding mix of energy efficiency, solar, wind, biofuels, and other low-carbon technologies is that the costs of deployment are lower than many forecasts, and at the same time, the benefits are larger than expected. This seeming 'win-win' claim deserves examination, and continued verification, of course.

Over the past decade, the solar and wind energy markets have been growing at rates over 30% per year, and in the last several years growth rates of over 50% per year have taken place in the solar energy sector[91]. This rapid and sustained growth has meant that costs have fallen steadily, and that an increasingly diverse set of innovative technologies and companies have been formed. Government policies in an increasing number of cities, states, and nations are finding creative and cost-effective ways to build these markets still further.

At the same time that a diverse set of low-carbon technologies are finding their way to the market, energy efficiency technologies (e.g. 'smart' windows, energy efficient lighting and heating/ventilation systems, weatherisation products, and efficient appliances) and practices are all in increasingly widespread deployment. Many of these energy efficiency innovations demonstrate negative costs over time, meaning that when the full range of benefits (including improved quality of energy services, improved health, and worker productivity) are tabulated, some energy efficiency investments are vehicles for net creation of social benefits over time.

The cost of carbon abatement curves have become famous since the Swedish power company Vattenfall collaborated with the McKinsey Company to develop a set of estimates on the costs to deploy and operate a range of energy efficiency, land use, and energy generation technologies. These costs of conserved carbon curves depict the costs (or savings, in the case of a number of 'negative cost' options such as building efficiency) as well as the magnitude (in giga-tonnes) of abatement potential at a projected future time. The most common plots are for 2030.

The figure shows the famous 'Vattenfall, or McKinsey curves', which provides one set of such cost/reward estimates that integrates both energy efficiency and clean energy generation technologies, in this case presented as a snapshot for the year 2030.

Many more innovations are on the near-term horizon, including those that use innovative municipal financing to remove entirely the up-front costs of energy efficiency and renewable energy investments through loans that are repaid over the duration of the services provided by clean and efficient energy products[92].

and infrastructure that can cope with extreme events at the severe end of the probability distribution. Thus, adaptation strategies should include a strong component of disaster preparedness, placing even more emphasis on emergency management services[16] (session 32).

As effective and necessary as these mitigation and adaptation approaches are individually, the integration of adaptation and mitigation activities in a systems framework is now becoming paramount in order to capture synergies that enhance the effectiveness of each and to avoid perverse outcomes in which mitigation activities could have deleterious outcomes for adaptation and *vice versa*. Nowhere is the need for integrative, systems-level approaches more pressing than in land use. One of the greatest challenges facing human society as population continues to grow is prioritising land use to balance local needs, such as food production and space for dwellings and businesses, and global needs, such as the removal of CO_2 from the atmosphere, production of biomass for energy and biofuels, and protection of biodiversity.

Today, approximately 12% of the Earth's land area is under intensive crop production[88,89] and much more is pasture and rangeland used for livestock production. About 70% of the freshwater co-opted for human use is allocated to agriculture[90]. With the demand for food continuing to increase as population grows, coupled with an escalating demand for land-based mitigation activities as well as a growing need for "land for nature", society is under pressure to equitably manage an unprecedented competition for land and water at all scales, from local to global.

Much of the change to the Earth's land surface is driven by the provision of ecosystem services for an increasingly urban population. Just over half of humans now live in cities, but urban areas account for approximately 75% of humanity's greenhouse gas emissions, either directly or indirectly[16] (session 33). Many cities are also particularly vulnerable to the effects of climate change, such as extreme weather events and rising sea-level. This has prompted the UN to declare that the battle against climate change will be won or lost in cities[16] (session 33), and makes an integrated approach to adaptation and mitigation in urban areas particularly important (Box 12).

In summary, society has many tools to facilitate both mitigation of climate change and adaptation to the impacts that cannot be avoided, but debates still surround the ways to further develop and apply these tools[16] (sessions 40, 41 & 43). Society also has a number of economic approaches to promote the adoption of these tools and encourage the energy transition necessary to constrain global warming (Box 8). The critical missing ingredients to achieve the societal transition that climate change demands are the political will and the social acceptance of the need for change.

Climate Change and Urban Areas

BOX 12

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Climate change is more than an environmental problem; it is also a major development challenge for urban areas. Urban areas are highly vulnerable to crises and disasters associated with climate variability and climate change. Their cumulative impacts have severe economic and human costs; quickly lead to serious bottlenecks or emergencies in the supply of key resources such as water, energy and food; and affect the living conditions for a vast number of people. The UN estimates that a total of 2.5 billion people were affected by disasters between 1995 and 2004, 75% of which were related to weather extremes.

Reducing social and urban vulnerability and enhancing adaptation to the impacts of climate change offer extended social, economic, health, and environmental benefits for local and national governments. Important elements in adaptation strategies include poverty alleviation, improvement of livelihood strategies, building human capital, protection of environmental assets, enhancing public health, and creating opportunities for sustainable development. There is also an urgent need to incorporate adaptive criteria in the design and planning of the built environment - urban infrastructure, buildings, and transportation.

The life span of infrastructure is often over 75 years and structures being built now will operate under different climatic conditions in the coming decades. Current investments seldom take into account the potential impacts of climate change that could cause significant dysfunctions in their operation.

Incorporating multidimensional adaptive strategies into current urban development strategies will make an efficient use of scarce financial, technical, human, and natural resources, particularly in poor countries and emerging economies. A critical step in this direction is assisting policy makers, urban planners, and stakeholders to incorporate adaptation strategies and define alternative and sustainable paths of urban growth. There is a tremendous opportunity to integrate development, mitigation, and adaptation strategies to create more resilient urban areas. Further delays in developing and implementing adaptation strategies will have severe consequences for millions of urban inhabitants and ultimately local and national economies.

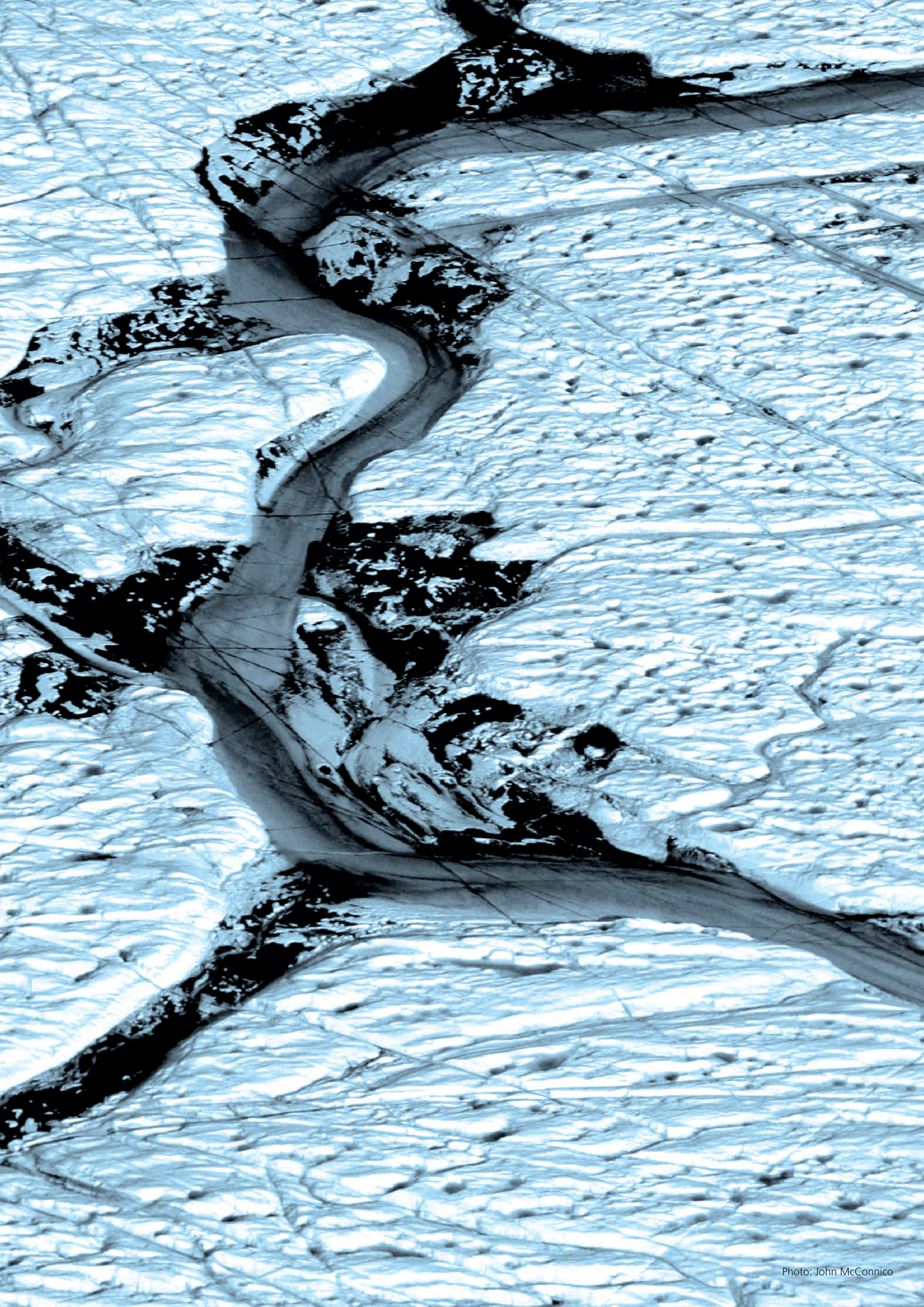

Photo: John McConnico

KEY MESSAGE 6

MEETING THE CHALLENGE

If the societal transformation required to meet the climate change challenge is to be achieved, a number of significant constraints must be overcome and critical opportunities seized. These include reducing inertia in social and economic systems; building on a growing public desire for governments to act on climate change; reducing activities that increase greenhouse gas emissions and reduce resilience (e.g., subsidies); and enabling the shifts from ineffective governance and weak institutions to innovative leadership in government, the private sector and civil society. Linking climate change with broader sustainable consumption and production concerns, human rights issues and democratic values is crucial for shifting societies towards more sustainable development pathways.

The evidence presented earlier on the nature of dangerous climate change (Key Messages 1 and 2), the emission reduction pathways needed to avoid dangerous climate change (Key Message 3) and the need to meet this challenge in an equitable way (Key Message 4) together send a clear, strong message – "business-as-usual is dead"[39]. Marginal changes to the current socio-economic and technological trajectory of contemporary society will not be sufficient to facilitate the societal transition required to keep climate change within a 2°C guardrail. Many technological and managerial tools and policy approaches are available now to drive the required transformation (Key Message 5). The ultimate challenges are to trigger, facilitate and support the transition – removing the constraints and seizing the many opportunities that such a societal transformation offers.

The research required to inform and support a major societal transformation lies primarily in the domains of the humanities and social sciences, which have been much less prominent in the climate change discourse than natural sciences and economics. Nevertheless, their insights into human cultures, behaviours and organisation are crucial to meeting the climate change challenge.

Transitioning contemporary society to a more sustainable future must occur at many scales – from individual to institutional and governmental – and at many levels – from changes in everyday behaviour to a re-examination of core values, beliefs and worldviews (Box 13). Indeed, the language used to discuss human caused climate change often reflects underlying worldviews. For example, a focus in the political process on greenhouse gas "reductions" and "sharing the burden" reinforces the view that climate change mitigation is an evil that should be avoided as much as possible. On the other hand, a focus on the benefits derived from avoiding the serious impacts of unabated climate change or on the economic and employment opportunities provided by decarbonising the economy (Box 11) builds worldviews that are much more positive and optimistic.

Many worldviews emphasise the importance of governmental actions in dealing with climate change, yet much can be achieved by recognizing and encouraging a wide range of non-state actors that use "social-practice" approaches to build on the voluntary actions of individuals and small groups[16] (session 48). Behavioural change is at the centre of any transformation, and experience and social learning offer much hope for the future (Box 14).

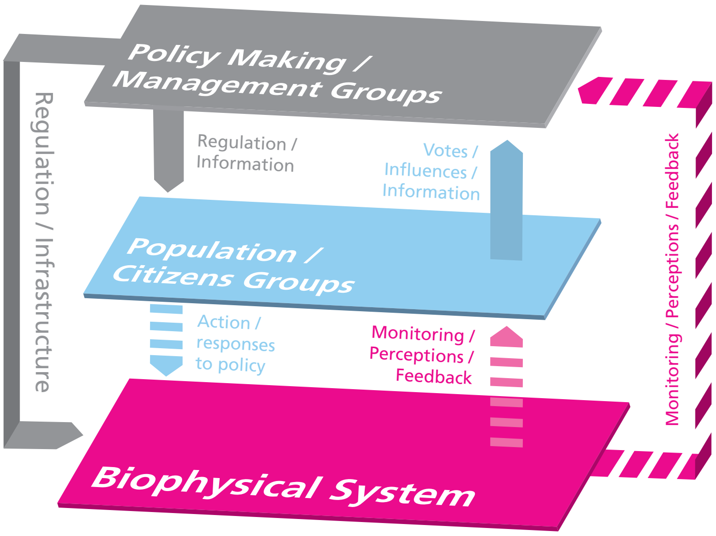

Figure 17

Typical interactions in multi-level governance systems, in which citizens groups can play a key role in mediating between policymaking that operates at regional or national scales, and the on-ground management of biophysical systems, which often occurs at the local scale. Such professionally organised multi-level processes can help to reduce scale mismatches and policy incoherence, and to support integrated social and regulatory changes[93].

Individuals alone cannot solve the climate change problem, nor can national governments on their own. A wide range of other organizations – multinational corporations and other business groups, environmental NGOs, scientific research organizations and sub-national governmental bodies – are crucial to developing a societal response. The business community, in particular, is increasingly insistent on the need for policy frameworks that create a positive environment for investment and change. Some features of this environment are: (i) partnerships for action that build a common strategy even if underlying motivations

Cultures, Values & World Perspectives as Factors in Responding to Climate Change

BOX 13

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No climate change policy will receive the support it needs, either formally in the political arena or at the pragmatic day-to-day level, unless cultures, values and world perspectives are taken into account from the outset. The reasons are simple. First, not even the most sophisticated science-based information and risk assessments are necessarily received in the same sense as they are understood by those who produce them. Second, policies, in order to be effective, need to take into account the socio-culturally shaped setting that pre-dates the attempt to implement the policies. The following points underscore the significance of this main finding:

- Information about climate change and local interpretations of risk assessments are culturally mediated through particular emotional ways of reasoning, typical meaning-making processes, specific conceptions of landscape and climate variability and change, and idiosyncratic notions of mitigation of risk.
- Local religious and spiritual beliefs, knowledge systems, understanding of nature-society relationships, and values and ethics influence how individuals and communities perceive and respond to climate change. Climate change science must recognise these local and indigenous cultural and experiential contexts, and attempt to relate to them when fostering societal mitigation and adaptation activities.
- The implementation of adaptation strategies can raise issues that cut across power relations in existing situations of inequality, which may have unforeseen long-term effects for individuals and communities. This calls for approaches that foster deliberation in open, democratic decision-making contexts. In other words, the social and cultural consequences of climate change responses must be assessed, including the question of "whose values count?"

Research on the role of culture, values, and worldviews in both the generation of and responses to climate change should become a top priority. The cultural and experiential dimensions of climate change must be integrated with more standard, systems-oriented research on climate change, and need to be included in both mitigation and adaptation research and implementation programs. This conclusion argues for a new, larger role for the social sciences and humanities in addressing the challenges of climate change, and suggests the need for a truly interdisciplinary and integrated research agenda that places climate change in a much richer and deeper societal context.

The Importance of Behavioural Change

BOX 14

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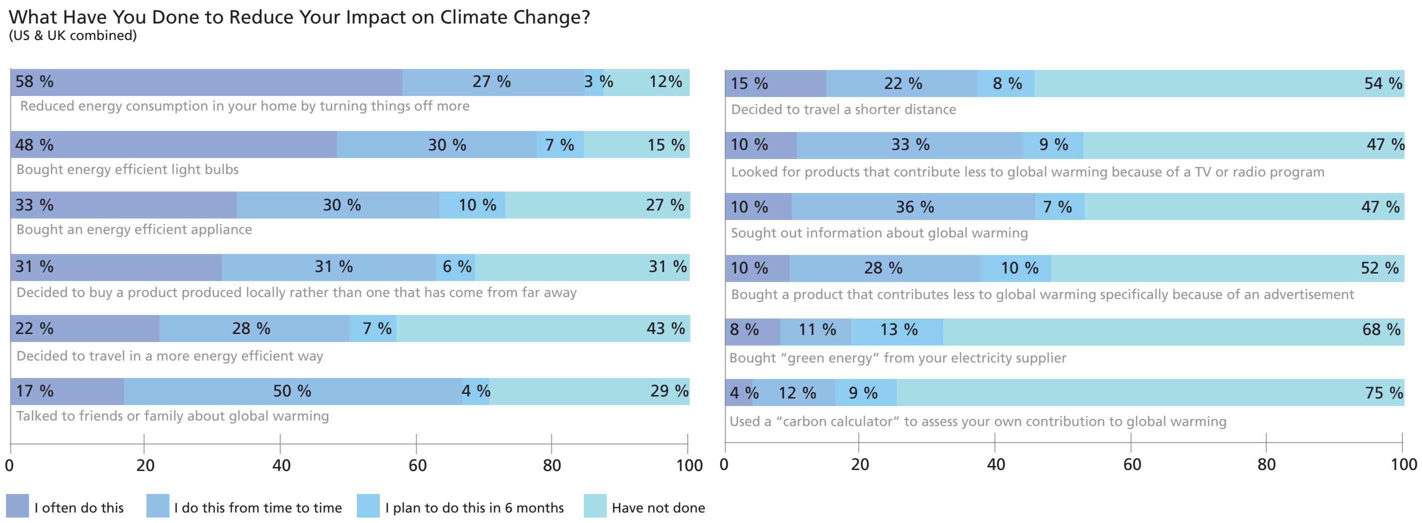


Actions taken by Individuals to reduce their contribution to climate change. The data are based on a survey of 2734 citizens in the US and UK by Accountability, June 2007, What Assures Consumers on Climate Change? [94].

Individual citizens can play an important role in the response to climate change, especially when they make decisions to reduce their greenhouse gas emissions or adapt to climate change. Public support is also critical in the success of national and regional government actions, and public perceptions can impede the acceptance of mitigation technologies. There is considerable evidence that individual behavioural change can contribute to reductions in emissions, especially from households and transportation and when supported by government policies, incentives and private sector activities (see figure). Many of the lowest cost reductions in greenhouse gas emissions are in the residential sector, where the use of insulation, efficient appliances and lights, and information feedback from smart meters and utility bills can produce rapid reductions in energy demand at a net financial saving rather than cost (see Box 11).

Behavioural and attitudinal changes are also important in terms of political and corporate leadership where, for example, business leaders and city mayors have made significant commitments to emission reductions that go far beyond national political obligations or simple cost-benefit analysis. In terms of adaptation, millions of farmers and herders have adjusted their practices to past climate shifts and are already making decisions in response to the onset of warming and other shifts associated with climate change. International policy needs to support, and be sure not to constrain, the agency of individuals to respond to climate change, and to recognise the importance of providing relevant information to citizens so that they can make informed decisions about supporting policies and changing their own behaviour[16] (session 20)[62,95].

are not aligned; (ii) trust-building between business and civil society; and (iii) leadership that empowers people and supports learning and adaptive management[16] (sessions 48 & 54).

Civil society – communities and stakeholders – engages with climate policy in a multitude of ways (Figure 17). Central to many of the approaches are stakeholder consultations or engagements. Engagement needs to be two-way – not only imparting information from experts but getting information back from the community[16] (session 39). Information exchange via the media presents significant challenges, however, as the climate change issue is often presented as one "great global warming debate" rather than a depiction of the convergent agreement in science and the complexities and subtleties in the science-policy interface[16] (sessions 53 & 54).

Community-level responses to the climate change challenge can often be most effective if they are a blend of local knowledge and experience and expert input. Empowerment is a key concept, and is best achieved by carefully defining the purpose of stakeholder engagement and structuring the processes to allow full participation by community members. Moving from community engagement to community action – a common outcome of effective engagement – requires proactive considerations of the institutions, resources, and the technical assistance required to support action[16] (session 54).

At national and global scales, economic instruments such as emissions pricing, and market-based approaches more generally, are centrally important. Additional approaches, however, may be required. For example, a nationally driven but globally coordinated investment strategy, perhaps building on the opportunity provided by the global financial crisis, could actively promote climate-friendly development pathways and achieve technology diffusion and emission reductions faster than would be achieved by market instruments alone. Given the urgency of the climate change challenge (Key Message 1), "front-loading" – for example, a big, immediate push for investment in efficiency and renewable energy systems – will likely be more effective than adopting a more gradualist approach[16] (session 55). Other visionary approaches at the large regional or global scale may be required to transform the management of our relationship with the planetary environment. One such approach could be to consider a novel global division of land-use activities that would significantly improve the geographical pattern of food and fibre production, biodiversity protection, infrastructure and energy generation (Box 15).

The challenge is equally great to transform the current international governance landscape from a set of individual regimes or governance systems to an innovative, integrated institutional architecture for Earth System governance. A successful strategy to build such an architecture should be multi-dimensional and carefully coordinated, building on a number of existing institutional arrangements: (i) other environmental regimes, such as the Convention on Biological Diversity, CBD; (ii) international trade and financial mechanisms, such as the World Trade Organization, WTO, and the World Bank; and (iii) development-oriented organisations aimed at alleviating poverty, such as the Global Environmental Facility, GEF, and regional development banks. Ultimately, meeting the climate change challenge will require a mosaic of approaches designed to build an integrated system of governance[16] (session 48).

In democratic political systems, individual voters will only drive such transformative change – from pragmatic changes in neighbourhood practices to the construction of new multi-national energy and transport systems and the building of new institutional regimes – if their values are deep and strong enough to make hard, long-term decisions (Box 13). Thus, no climate change policy will ultimately succeed unless cultures, worldviews and core values change in ways that support the development of effective policy and its implementation[16] (sessions 54 & 57) .

Scientific information, technologies and economic instruments are all part of the solution, but their interpretation and application are mediated through the cultures and worldviews of individuals and communities (Figure 18). Religious and spiritual beliefs, indigenous knowledge systems, understandings of nature-society relationships, values and ethics influence how individuals and communities perceive and respond to climate change[16] (session 57). Ultimately these human dimensions of climate change will determine whether humanity eventually achieves the great transformation that is in sight at the beginning of the 21st century or whether humanity ends the century with a "miserable existence in a +5ºC world"[101].

POLITICIANS / LOCAL GOVERNMENTS
- Seek voters´ support, dependent on media, next election is the reference point
- Have more interest in structural adaptation options because they are easier to "sell" to the electorate.

PUBLIC OPINION / MEDIA
- Allocates responsibility to the government
- Seen as not aware of climate change impacts, not aware of their choices.

ADVOCACY / INTEREST GROUPS
- Normative points of view (e.g. "space to rivers", "plant trees in each unused space")
- Supported by facts or beliefs ("water is from God")

ADMINISTRATION / BUREAUCRACY
- Focuses on implementation, engineering approaches
- Hierarchical, often follows outdated procedures
- Does not directly respond to pressure from other groups;
- Often involved in power and competencies conflicts

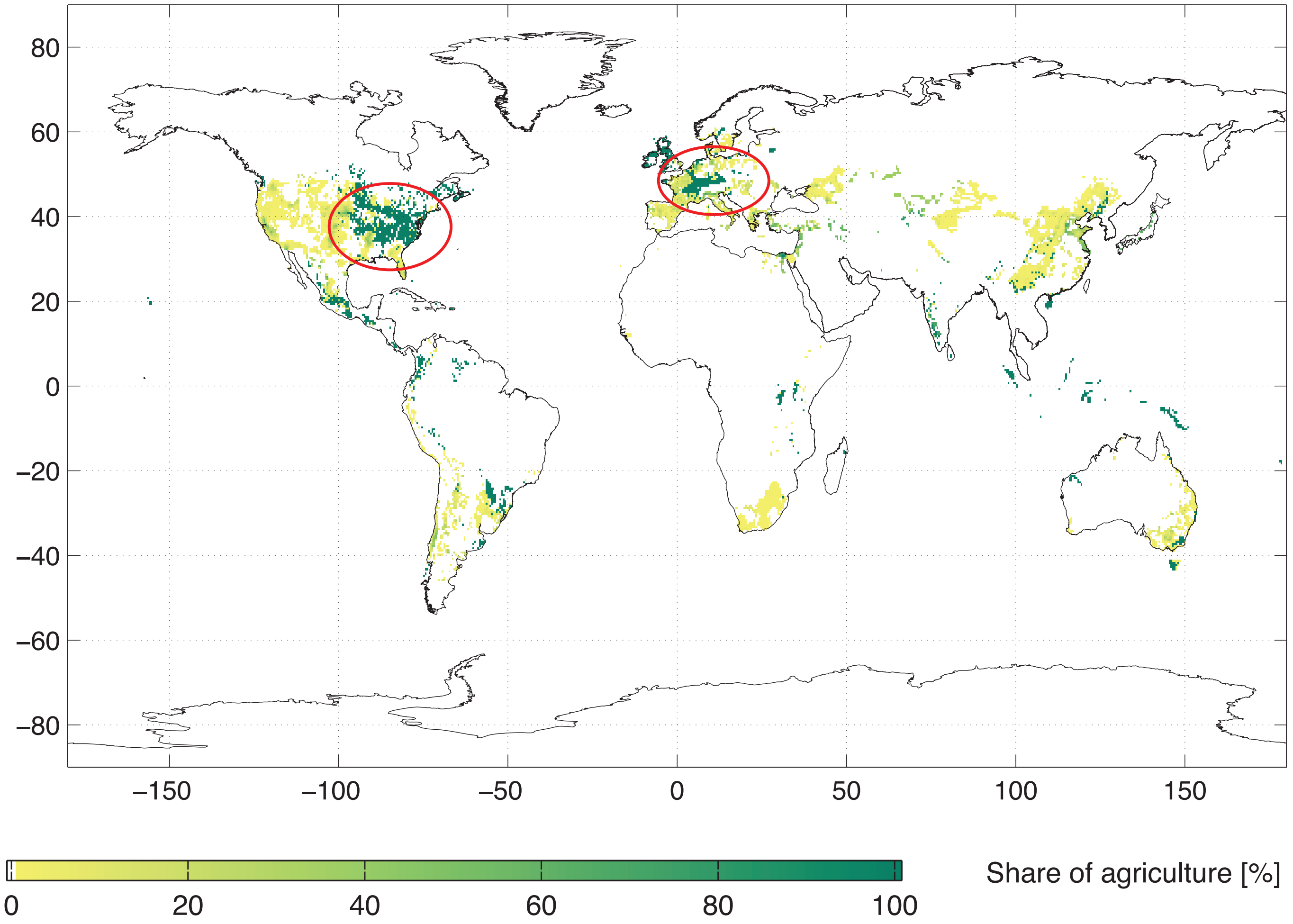
RESEARCHERS
- Theoretically oriented, not practical, not aware of local condition or social dynamics
- Often function only within one discipline, pursue only their discipline's point of view ("free trade and putting price on scarce resources can solve all problems")

Figure 18
Groups of shared mental models. Mental models vary across different groups in society and affect how people perceive the climate change issue; they are hard to change and can create barriers to communication and action[99]. Thus, a critical challenge to dealing effectively with climate change is to build consensus across society on the nature of the climate change threat and the overall strategy to deal with it. In effect, a single, high-level mental model – or perspective – needs to be achieved. Without it, effective climate and policy action will be unlikely.

Towards a Great Land-Use Transformation?

BOX 15

Prof. Hans Joachim Schellnhuber, John@pik-potsdam.de & Veronika Huber huber@pik-potsdam.de



Ranking of world-wide locations according to suitability for food production under current management practices (adopted from[98]). The red ellipses mark the prime regions to be considered as "global agricultural commons".

Keeping global warming below 2°C will require all our ingenuity for the climate-smart evolution of existing structures, yet large-scale transformational measures will also be needed. In particular, the current planetary land-use pattern may have to change fundamentally, as it is the sub-optimal result of erratic historical processes that were blind to global sustainability considerations. Future land-use on Earth must accommodate multiple competing demands for food and fibre, energy, services, infrastructure and conservation by some 9 billion people – on a non-expandable global surface. Novel challenges like the creation of artificial carbon sinks through bio-sequestration may have to be met in order to avoid dangerous climate change[96].

Science needs to demonstrate (i) what an "optimal" land-use pattern might look like; (ii) that this pattern would warrant the generation of sufficient quantities of the desired functions and resources; and (iii) which sociopolitical strategies can realise the envisioned transformation in good time. The international research community is just beginning to address such issues, yet certain insights concerning the first two aspects are already available.

For instance, the German Global Change Advisory Council (WBGU) has recently published various reports that identify those areas on Earth that should be dedicated to biodiversity support, biomass production, and renewable energy harvesting, respectively[97]. One important conclusion is that the afforestation of degraded land can tap a sustainable bioenergy potential of around 100 Exajoules. Analyses led by the Potsdam Institute[98] also indicate that 12 billion people with 1995 dietary habits could be nourished on less than one third of the present agricultural area – if the best sites were used for the most appropriate crops and if world food trade would operate undistorted by protectionism. This bold approach would only become feasible, however, if the prime locations (as shown in the figure) would be reclaimed/reserved for agriculture as part of a long-term global deal – in the same way as the tropical rainforests hopefully will be earmarked for conservation as part of the global commons.

THE PATH AHEAD

Many past environmental problems were solved when humans realised that their own activities were leading to consequences deleterious to their health and well-being. They responded by changing behaviour and developing new technologies. Will our contemporary society respond in a similar way to the climate change challenge now facing us? Climate change is fundamentally different from the environmental problems humanity has dealt with until now. The risks, scales and uncertainties associated with climate change are enormous and there is a significant probability of a devastating outcome at the global scale.

The nature of the climate change challenge demands visionary and innovative thinking. The planetary boundaries concept[100], which aims to define the "safe operating space" for humanity, draws on the earlier experience of societies that regulated their own behaviour when knowledge of undesirable consequences became available. Planetary boundaries are defined with respect to biophysical thresholds of the Earth, the crossing of which would lead to catastrophic outcomes for societies (see tipping elements, Key Message 2). The scientific evidence strongly suggests that there is an upper limit for the concentration of greenhouse gases in the atmosphere, or a "climate change boundary", within which humanity should operate to reduce the risks of catastrophic outcomes. Although the precise position is not yet known, current evidence indicates that humanity is fast approaching or may even have exceeded the boundary[16]. Thus, the need for rapid and drastic reductions in the emissions of greenhouse gases is urgent if serious climate impacts are to be avoided.

Living within a challenging climate change boundary can often seem overwhelmingly difficult. There is no single treaty or technological "silver bullet" that will quickly and painlessly transform contemporary society. A transformation to a society living within the climate change boundary will take time and will require commitment from all levels and members of society. As a starting point, long-term targets for emission reductions are essential if society wishes to reduce the risk of dangerous climate change to acceptable levels. Trajectories provide guideposts along the way to meeting the targets, but there are many possible pathways that humanity could follow which would allow it to remain within the overall climate change boundary.

Thus, in 2009 society cannot precisely determine the "right" or the "best" pathway all the way to 2050 and beyond. There will be technological, societal and value changes in the future that will cause the trajectory to change. There should be no penalty for not getting it absolutely right the first time. The most important task is to start the journey now. The first steps are to generate a broad dialogue at all levels of society and to build a consensus on the need to act. Quite probably, when it comes to responding to human-made climate change, the "only action that is inexcusable is to take no action at all"[101].

This synthesis, which is based on the discussions at and outcomes of the IARU International Scientific Congress *Climate Change: Global Risks, Challenges & Decisions*, summarises the most up-to-date knowledge on climate change from the research community – natural scientists, social scientists, economists, engineers and humanities scholars. The evidence that human activities are changing the fundamental conditions for life on Earth is overwhelming, and the challenges presented by these changes are daunting. Postponing action will only increase the risks to future generations. While no single meeting can transform our society to one living within the climate change boundary, the United Nations Climate Change Conference, COP15, to be held in December 2009 offers a unique and timely opportunity to start such a transformative journey. Many are hoping that if society is successful in meeting the climate change challenge, future generations will read in their history books that COP15 was where the journey really began.

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