The Future of Democracy in the Face of Climate Change

Paper Four

Climate Change
An overview of science, scenarios, projected impacts and links to democracy

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About the author and acknowledgements

Halina Ward is Director of the Foundation for Democracy and Sustainable Development (FDSD). FDSD (www.fdsd.org) is a small charity, launched in September 2009, which works to identify ideas and innovative practices that can equip democracy to deliver sustainable development.

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This paper is a work in progress. It forms Paper Four of the Foundation for Democracy and Sustainable Development's project on *The Future of Democracy in the Face of Climate Change*, which aims to develop scenarios for the future of democracy and participatory decision-making in the face of climate change to 2050 and 2100. The project is funded by FDSD with the additional support of a Future of Humanity grant from the Foundation for the Future (www.futurefoundation.org).

Any mistakes or omissions are mine alone.

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Introduction

This is the fourth paper in the Foundation for Democracy and Sustainable Development's (FDSD) project on *The Future of Democracy in the Face of Climate Change*. The project aims to develop scenarios that can help to answer the question: *'How might democracy and participatory decision-making have evolved to cope with the challenges of climate change by the years 2050 and 2100*?'

In earlier papers, we outlined a range of issues and tensions at the interface of democracy and climate change (Paper One); reviewed approaches to defining or identifying 'democracy' in its various forms, and their implications for our project's central question (Paper Two); and reviewed relevant literature on the futures of democracy and sustainable development governance respectively, as well as a range of wider 'futures-oriented' literature relevant to the trajectories of democracy and of sustainable development (Paper Three).

In this final preliminary paper, Paper Four, we review the current state of climate science and some of its most closely associated tools and scenarios, focusing on the work of the Intergovernmental Panel on Climate Change (IPCC). Beyond Paper Four, the next step will be to develop an initial set of draft scenarios on the future of democracy in the face of climate change for discussion, testing, and refining.

The paper draws heavily on the IPCC's 2007 Fourth Assessment Report (AR4)[1], and in part on later analysis. For example, in November 2009, researchers at the University of South Wales Climate Research Centre issued their Copenhagen Diagnosis,[2] designed as an update to the science considered in AR4, and issued in the run-up to the December 2009 Copenhagen Climate Summit.[3] In 2010 the Royal Society published a collection of essays in a themed issue of its publication *Philosophical Transactions*, examining a variety of implications of a 4°C increase in temperature.[4] These later sources, and a small number of other post-AR4 journal articles and books are referred to as well, where appropriate.

Changes in the Earth's climate can happen for many reasons, including volcanic eruption, earthquake, changes in solar output, and the shifting trajectories of ocean currents and winds. For the purposes of our project on *The Future of Democracy in the Face of Climate Change*, however, what is most significant is scientific, political and public debate about anthropogenic global warming; i.e. warming which results from human activities.

The IPCC's most recent global review, its fourth (AR4), was published in November 2007. Its next, fifth (AR5), assessment report is due to be published in 2014.

AR4 concluded that "*warming of the climate system is unequivocal*".[5] In the period from 1906-2005, the average global temperature increased by 0.74°C; 0.8°C since 1880.[6] In AR4, the IPCC attributed much of the increase to human activity: *"most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic gas concentrations".*[7]

Today, scientists are nearly unanimous on the link between increased concentrations of greenhouse gases and global warming. Evidence relating to the possible range of impacts is less clear. Even so, climate science is developing rapidly as AR5 progresses towards its 2014 publication date. Perhaps most significantly, since the publication of AR4 in 2007, there has been a significant upward revision of estimates of global sea level rises. We consider this in more detail in a later section of this paper.

Climate change will profoundly affect patterns of human behaviour and social organisation, and the ecosystems of which all life forms part. Richard Matthew and Anne Hamill helpfully distinguish between two kinds of effects.[8] The first is connected to changes that have already begun to be felt; such as heatwaves, droughts and biodiversity loss. A second category of change is linked to currently unknown effects; including as a result of reaching various critical '*tipping points'* and the unknown '*feedback loops*' that could emerge between different effects. Both are considered in this report – but it is important to note that Working Group II (WGII) of the IPCC, in the Technical Summary of its report for AR4, notes that there has been little advance since the time of the IPCC's Third Assessment Report (TAR) in understanding of thresholds and tipping points.

The paper introduces the work of the IPCC, offers a basic introduction to essential scientific principles of climate change and the greenhouse effect, and then, in a series of separate sections, highlights key features of AR4, including significant subsequent research findings. Where there are clear links to democracy in the IPCC analysis, these are highlighted, and omissions or gaps discussed. The paper concludes with some brief reflections on the phenomenon of so-called '*climate scepticism*'.

The Intergovernmental Panel on Climate Change (IPCC): structure and procedures

The work of the IPCC is central to the global process of building consensus on climate science.

The IPCC was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) in 1988, (ahead of the 1992 United Nations Conference on Environment and Development), "*to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences*".[9]

Part scientific body and part intergovernmental body, the IPCC operates through three Working Groups and the voluntary contributions of thousands of experts around the world, producing periodic assessments of climate science and of the potential impacts of climate change. The IPCC includes representatives of 194 governments. It is a vast undertaking, even given the limit inherent in its mandate to review existing literature without carrying out substantive original research. In the periods 1991-1995 to 2001-2005, the number of relevant publications informing the drafting of an IPCC assessment grew from 5,000 to 19,000.[10]

In his accessible book *The Climate Files: the battle for truth about global warming*, respected UK science journalist Fred Pearce writes of the irony inherent in the creation of an *intergovernmental* body, rather than a process composed entirely of non-governmental scientists working under the auspices of an international organisation such as the UNEP or the WMO.[11] Pearce records the process leading up to and following a key 1985 meeting of 89 scientists from 23 countries in the Austrian town of Villach, at which the scientists called for the UN to ensure periodic assessments of the state of scientific understanding of climate change. Subsequently, the US government, under President Ronald Reagan, lobbied hard for the creation of an intergovernmental body whose activities would be approved by government delegates. The fear was that a small group of non-governmental scientists and their institutions could drive the climate agenda.

Bringing governments into the IPCC was a control mechanism. But it has also resulted in a body that is arguably more powerful in the political realm to which it is closely connected than one composed of independent experts would have been.[12]

In 2007, the IPCC and Al Gore were together awarded the Nobel Peace Prize for their work.[13] Since 2002 (i.e. for the duration of AR4 and the ongoing AR5 process to date), the IPCC has worked under the Chairmanship of Dr Rajendra K. Pachauri. Dr Pachauri is also Director General of the well-respected Indian non-governmental organisation TERI.[14]

The IPCC's work is not limited to climate change attributable to human activity. Rather, the IPCC uses the term '*climate change*' to refer to "*a change in the state of the climate that can be identified... by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in the climate over time, whether due to natural variability or as a result of human activity*".[15]

In this paper, we take AR4 as the basis for our review of climate science, supplemented where appropriate by significant later research findings. In all cases, we have relied principally on summaries of relevant primary research written for policymakers.

Grounding our analysis in the work of the IPCC is not uncontroversial; neither is our reliance on the AR4 Synthesis Report and summaries from the IPCC's three Working Groups. 2010 saw sustained attacks on the credibility of certain of the IPCC's findings. And our reliance on summaries means, in the context of the IPCC's operating procedures, that we are relying on text that has been negotiated and agreed by governments in an intergovernmental process, rather than text written by scientists alone.[16]

Intensification of controversy over climate change in the recent past may have resulted in a more cautious approach on the part of the IPCC in certain areas. Fred Pearce suggests that "*[s]ome of the more scary scenarios discussed by scientists in recent years, involving positive feedback and "tipping points" were left on the cutting room floor. Others appeared in muted form in the body of the report, but failed to reach the crucial summary for policy-makers. In the past the summary's authors had been accused of hyping the science for effect, but this time round it looked as if they were deliberately downplaying things.*"[17]

Some of the critiques of climate science raised by (so-called) 'climate sceptics' or 'climate deniers' are considered briefly in the final section of this paper. But for the time being, however much subsequent debate there has been over elements of AR4 - including very poorly supported and contradictory claims about the rate at which Himalayan glaciers could melt, or data relied upon by scientists at the UK's University of East Anglia (outlined briefly in Paper One) - the *overall* body of evidence on which the argument for global warming is based has not been seriously shaken.

A number of post-AR4 findings – including in relation to projected sea level rise (considered further below) – have, if anything, indicated that the physical processes of climate change could be associated with far more significant changes than those outlined in AR4. For example, amongst its other findings, the 2009 Copenhagen Diagnosis concluded that "*by 2100, global sea-level is likely to rise at least twice as much as projected by Working Group 1 of the IPCC AR4, for unmitigated emissions it may well exceed 1 meter. The upper limit has been estimated as 2 meters sea level rise by 2100.*"[18]

Since the publication of AR4, some projections of realistic global mean temperature increase within this century have also been revised upwards, and consequently indications of suggested *impacts* are also in some cases more serious.[19] The FDSD's starting point as an organisation is to find ways of enabling democracy to rise to the challenge of climate change. This worsening of projections in some key areas potentially therefore makes our task practically more difficult, accepting the assumption that democratic processes may be adversely affected by climate change.

The IPCC functions through three Working Groups. The first, Working Group I (WGI), focuses on the physical science basis for climate change, on which the other two Working Groups draw. Working Group II (WGII) focuses on the impacts of climate change, as well as identification of possible adaptation approaches and vulnerability to climate change. Working Group III (WGIII) documents trends in anthropogenic emissions since 1970, projecting emissions to the year 2100 under various scenarios and identifying the technical feasibility and cost of various mitigation measures.

The overall results of the IPCC's assessment are published in four volumes: three Working Group reports (each in turn containing chapters on individual topics, a Technical Summary and a Summary for Policymakers) and a separate Synthesis Report. The Synthesis Report for AR4 alone is 73 pages long. Adding in the reports from WGI, WGII and WGIII, AR4 totals almost 3000 pages.[20]

WGII and WGIII address questions that demand a greater degree of subjective judgment than those addressed by WGI because these two groups work to evaluate what could be the range of possible outcomes from (and therefore appropriate responses to) climate change *based on* the physical science base. This is where the work of the IPCC shifts from natural to social science.

A serious and credible attack on analysis from WGI would potentially undermine the fundamentals of climate science. An error in the analysis of WGII or WGIII does not, but rather raises questions about the IPCC's methodological and procedural approach, and potentially about the most appropriate policy responses to climate science.

The IPCC has drawn up detailed procedures for the conduct of its assessments. The depth of government engagement in the process may come as a surprise. It is the *government* representatives of the Panel who elect the IPCC's Chair and the Co-Chairs of the three Working Groups, and who, together with a group of some 80 intergovernmental and non-governmental organisations, nominate authors and reviewers. Subsequently, from amongst the nominated authors and reviewers, Working Group Co-Chairs and Vice-Chairs select Coordinating Lead Authors and Lead Authors responsible for the content of the Working Group reports.[21]

The IPCC works with the support of an elected Bureau. Its 31 members include the IPCC's Chair and Vice-Chairs, and Working Group Co-Chairs and Vice-Chairs. Additional players include authors, editors and government and expert reviewers. A Secretariat oversees and manages IPCC activities.[22]

Authors and Lead Authors draft Working Group reports, drawing on input from Contributing Authors as needed. Each report goes through two formal review processes and one or more informal reviews. When the second draft review process is reached, the reviewers include government representatives. Authors and review editors then prepare the final draft in light of comments received. Thereafter, a Summary for Policymakers is approved, line by line, in a session chaired by the Working Group Co-Chairs and attended by government representatives of all IPCC members. Sessions to approve a Summary for Policymakers typically last for several days.[23]

Preparation of an overall Synthesis Report begins whilst the Working Group report processes are still under way. Governments decide on the most policy-relevant topics for inclusion in the Synthesis Report. The writing team is led by the IPCC Chair and includes coordinating Lead Authors as well as other experts. A review process checks for consistency between the Synthesis Report and the

Working Group reports, and the Synthesis Report is approved section by section (but not line by line) in a plenary session of the Panel.[24] Not only peer-reviewed literature is considered, but IPCC procedures also require authors to critically assess non peer-reviewed or unpublished sources.

In a process that is politically charged because it is linked to an ongoing intergovernmental negotiating process under the United Nations Framework Convention on Climate Change (UNFCCC) – a process with very significant social, economic, environmental and geopolitical implications at that – the detail of IPCC procedures can make a considerable difference to perceptions of its outcomes. Alarmingly, given the potential for political judgment to clash with scientific judgment, Fred Pearce suggests that the "*IPCC requires that the chapters have to be made consistent with the summary, rather than vice versa. This is because the ultimate authors of the 'intergovernmental' reports are the governments. But they only get to read and approve the summary for policy-makers. So if the summary says something different from the chapter it supposedly summarises, then it is the chapter that has to be changed."*[25]

Pearce's summary is not borne out by a 2010 review of IPCC procedures.[26] On the contrary, the review report notes that "*Working Group Co-chairs and Lead Authors exercise the authority to reject proposed revisions they believe are not consistent with their underlying Working Group Report*".[27]

Pearce records controversy during the negotiating process surrounding the inclusion of the words *"the balance of evidence suggests a discernible human influence on global climate"* within the WGI Summary for Policymakers in the IPCC's Second Assessment Report in 1995, and the *subsequent* inclusion of those words within the chapter from which the relevant part of the Synthesis Report was drawn.[28] The detail is messy, and in any ordinary process of editing and report finalisation the to-ings and fro-ings that Pearce describes would be unremarkable; but in a politically charged process, any implication that scientific assessment *follows* rather than drives the detailed political process for wordsmithing of summary text is potentially damaging.

Criticism of the IPCC reached new heights in January 2010, in the wake of the so-called '*climategate*' email leak from the University of East Anglia (see Paper One). In November 2009, Dr Pachauri described as '*voodoo science*' an Indian scientist's report which dismissed the WGII claim that *"Glaciers in the Himalaya are receding faster than in any other part of the world... and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate. Its total area will likely shrink from the present 500,000 to 100,000 km^2 by the year 2035 (WWF, 2005)".* [29] Dr Pachauri defended the claim without investigating deeply its origin, despite the fact that the Indian scientist's report was referred to in a statement by his own (Indian) government's Environment Minister.[30]

Far from being based in robust, peer-reviewed scientific research, the WGII allocation of '*very high'* likelihood to the Himalayan glacier melt claim turned out to have been based on a report from the Indian branch of the environmental NGO multinational WWF. The term '*very likely'* is used by WGII to refer to a probability of 90-99%.[31] The WWF-India report in turn referred in error to a report that did not in fact support the claim, citing not the original scientific report but a claim made in an article in *Down to Earth* magazine, a publication of the Indian environment NGO Centre for Science and Environment.[32] Five cautionary review comments about the Himalayan glacier assertion during the preparation of the WGII report had not resulted in the amendment or removal of the assertion.[33]

In January 2010, the IPCC issued a formal statement defending a claim regarding Himalayan glacier melt in the AR4 Synthesis Report, but acknowledging that the relevant claim in the main WGII report refers to "*poorly substantiated estimates of rate of recession and date for the disappearance of Himalayan glaciers*". The IPCC added that "*[i]n drafting the paragraph in question, the clear and well-established standards of evidence, required by the IPCC procedures, were not applied properly. The Chair, Vice-Chairs, and Co-chairs of the IPCC regret the poor application of well-established IPCC procedures in this instance*".[34]

By late January 2010, after the story on origins of the Himalayan glacier statement broke in the international media, there were multiple calls from politicians and commentators[35] that Dr Pachauri resign from his role as Chair of the IPCC.

Resign Dr Pachauri did not, and in March 2010, Dr Pachauri and UN Secretary General Ban Ki-moon announced the launch of an independent review of IPCC procedures. The inquiry was carried out by a Committee convened by the InterAcademy Council (IAC), a body formed in 2000 by the world's science academies to mobilise the world's best scientists and engineers to advise international bodies and other organisations.[36] The IAC Committee reported at the end of August 2010.[37] Its report was considered at the IPCC's plenary in the Korean town of Busan in October 2010.[38]

The IAC's independent review potentially has implications for the balance between expertise and political input in intergovernmental processes – and hence for the future of global governance itself. At a headline level, it affirms the value of the IPCC generally, concluding that the IPCC assessment process has "*been successful overall and has served society well*".[39] But the review report recommends some 20 changes, most of which were subsequently accepted outright or in principle by the IPCC.[40]

The IAC's recommendations included strengthening the review process to ensure that review comments receive appropriate consideration and that controversial issues are reflected adequately in the report. It also recommended establishing a conflict of interest policy for application to individuals involved in preparing IPCC reports. Failures to follow the IPCC's guidance for addressing uncertainties in AR4 led to a series of recommendations: "*many statements in the Working Group II Summary for Policymakers... are assigned high confidence but are based on little evidence. Moreover, the apparent need to include statements of 'high confidence'... in the Summary for Policymakers led authors to make many vaguely defined statements that are difficult to refute, therefore making them of 'high confidence'*".[41]The IAC report recommends consistent use of a '*qualitative level-of-understanding*' scale in summaries, supplemented by a quantitative probability scale if appropriate. It also cautions that that the confidence scale should not be used to assign subjective probabilities to ill-defined outcomes.[42]

Other recommendations call for development of an effective communications strategy, enhanced transparency in the process of allocating roles within the process, strengthening of the procedure for the use of non peer-reviewed literature, and greater stakeholder (potentially to include the private sector, though without reference to ordinary public input) and regional balance in the IPCC process. In a hint at the potential for more wholesale changes in global governance processes generally, the report notes emerging approaches that merit attention, including the use of Wiki pages to supplement Working Group reports.[43]

On the key process for approving the Summary for Policymakers, the IAC simply recommends rather limply that the IPCC "*should revise its process for the approval of the Summary for Policymakers so that governments provide written comments prior to the Plenary*".[44] The report does not include any recommendation relating to the intergovernmental process for preparation of the overarching Synthesis Report.

By way of implicit response to the call for Dr Pachauri to resign, the IAC review suggests a limit of one term for key IPCC leaders, including the Chair and Working Group Co-chairs, to "*ensure the infusion of fresh perspectives on the assessments*".[45] In October 2010, the IPCC passed the issue to a Task Group for further consideration, with a view to reporting back in May 2011.[46] Dr Pachauri subsequently indicated that he intends to stay to oversee implementation of the IPCC reform process and the process leading to the publication of the IPCC AR5 in 2014.[47]

In its October 2010 response to the IAC review report, the IPCC accepted many of the recommendations immediately, and set up processes to respond fully in areas where further deliberation was needed before agreeing on ways forward. One exception to this general acceptance of the IAC report concerns the preparation of the Summary for Policymakers: the IPCC response simply concludes that no revisions to the process are required.[48]

In this paper, we rely generally on the Technical Summary and Summary for Policymakers from both WGI and WGII, as well as on the AR4 Synthesis Report. We readily acknowledge some of the shortcomings of this approach: the devil is often in the detail, and non-technical summaries of complex science for policymakers will inevitably be forced to generalise where there is nuance and detail.

For example, as the IAC review demonstrates, the application of the IPCC's uncertainty guidelines has resulted in some confusing juxtapositions, or misapplication, of qualitative (from 'high agreement limited evidence' to 'low agreement limited evidence'), quantitative (from 'virtually certain' to 'exceptionally unlikely'), and confidence (from 'very high confidence' to 'very low confidence') scales. This paper replicates, without investigating, the current mix of uses of these scales within AR4. In particular, WGI uses a combination of quantitative likelihood and quantitative confidence scales, whereas the WGII Summary for Policymakers primarily uses the quantitative confidence scale (intended for use when 'high agreement, much evidence' in terms of the confidence scale has been achieved within the literature). WGIII's Summary for Policymakers and Technical Summary rely extensively on the qualitative 'level of understanding' scale.[49]

Notwithstanding these weaknesses, we consider that at the level of detail that we are looking to achieve in developing scenarios on the future of democracy in the face of climate change to 2100, *general* reliance on IPCC summaries (themselves extensive) is appropriate.

We have considered more closely the detailed analysis of WGII of AR4 in some of those areas where its work has direct implications for links between democracy and climate change.

Climate change and the greenhouse effect

The greenhouse effect is central in both climate change and global warming. The effect results from the role played by the Earth's atmosphere (particularly so-called 'greenhouse gases' within it; including carbon dioxide (CO_2), methane (CH_4), and water vapour) in keeping solar heat within its bounds. If there were no greenhouse effect, scientists have calculated that the Earth ought in theory to be frozen.

French scientist Jean-Baptiste Joseph Fourier determined in the early 19th century that the Earth's atmosphere is responsible for keeping in a portion of the energy that reaches the Earth from the Sun, resulting in a 'greenhouse effect'. Some 30% of solar energy that reaches the Earth and its atmosphere is reflected back to space by clouds, gases and small particles in the atmosphere, and by parts of the Earth's surface. The remainder is either absorbed by the atmosphere or by the Earth's surface.[50]

The greenhouse effect increases when concentrations of greenhouse gases in the Earth's atmosphere increase. Greenhouse gases capture infrared energy radiated from the Earth's surface. Additionally, some greenhouse gases are responsible for depleting the Earth's ozone layer in a separate process which results in more ultraviolet energy reaching the Earth's surface from the Sun.

Concentrations of greenhouse gases in the Earth's atmosphere have increased very significantly as a result of human activities including the burning of fossil fuels, particularly since the industrial revolution. The increases can be deduced by examining ice cores spanning thousands of years. Human activities lead, in particular, to increases in the emissions of four *long-lived* greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons (a group of gases containing carbon bound to fluorine, chlorine, bromine or iodine). Of these, CO_2 is the most important anthropogenic greenhouse gas.[51] Annual emissions have grown by about 80% between 1970 and 2004, representing 77% of total anthropogenic greenhouse gas emissions in 2004.[52]

Climate change can result from processes that modify either how much energy is absorbed from the Sun, or how much infrared energy is emitted from the Earth to space. Among the factors that can have an impact in these processes are changes in the amounts of greenhouse gases, changes in aerosols (i.e. tiny particles in the air and atmosphere), changes in clouds, and changes in the overall reflectivity of the Earth's surface (e.g. as a result of snow or ice melting, which can reduce reflectivity). In the language of climate science, the difference, or imbalance, between the absorbed and emitted radiation flowing from these changes is referred to as '*climate forcing*' or '*radiative forcing*'. Positive radiative forcing will tend to cause warming, and negative forcing cooling.

Increases in greenhouse gas emissions and their concentrations in the Earth's atmosphere can in principle be balanced through the processes of a variety of natural sinks. These capture and store greenhouse gases at the surface of the Earth, thereby incidentally preventing them from exerting their greenhouse effect of trapping radiation in the Earth's atmosphere. Principal among these sinks are forests and other kinds of vegetation, soils and the Earth's oceans. In practice, increases in greenhouse gases in the Earth's atmosphere have not been balanced by the functioning of these sinks. Human interference in natural sinks – for example by cutting down forests – has the potential further to disturb the balance of the greenhouse process, by reducing the removal of greenhouse gases from the atmosphere, so that the Earth's land and sea areas become a net source of greenhouse gases rather than a sink.

Aside from the global warming effects of deforestation, scientists have a number of additional worries in relation to the processes of the Earth's sinks. One concerns the gradual acidification of the oceans that results from oceans absorbing increased levels of CO_2. Acidification (a process which is already under way[53]) could, scientists worry, have very significant impacts on marine life. However, the range of possible interactions is as yet by no means certain. Another potential process related to the functioning of sinks concerns the vast reservoirs of CH_4 stored in rotting vegetation and peat under the Earth's permafrost. Were permafrost to melt as a result of global warming, scientists fear, that could (among other effects) trigger a massive release of CH_4, with further knock-on effects on the Earth's climate – potentially on a huge scale. There is some evidence that already the permafrost '*lid*' is perforated, with extensive venting of CH_4 from the East Siberian Arctic Shelf, though it is not clear how long these emissions have been continuing.[54] The potential positive feedback effects of such releases are not assessed in AR4.[55]

Whatever the data or predictions about peak emissions, there will likely be a time-lag of several decades between any decrease in greenhouse gas emissions and stabilisation in global climate.[56] And AR4 also asserts that "*[e]ven if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1 degrees centigrade per decade would be expected*".[57]

There are various features of climate change that will take many decades, centuries or millennia to stabilise or materialise. A summary of climate science from the UK's Royal Society states that "*even if there was a complete cessation of emissions of CO_2 today from human activity, it would take several millennia for CO_2 concentrations to return to pre-industrial concentrations"*.[58] And AR4 points out that even if climate forcing (i.e. the imbalance between absorbed and emitted radiation resulting from processes that modify either the amount of energy absorbed from the Sun or the amount of infrared energy emitted to the atmosphere by the Earth) were stabilised in 2100, a further increase in global average temperature of around 0.5°C would still be expected by 2200.[59] Even beyond, AR4 notes that "*[b]oth past and future anthropogenic CO_2 emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for the removal of this gas from the atmosphere*".[60] Thermal expansion alone would likely lead to 0.3 to 0.8m of sea level rise by 2300, and would continue for many centuries due to the time required for heat to penetrate and warm the deep ocean.[61]

Climate feedbacks

Feedbacks explain the response of a system to a given perturbation (a disturbance, in everyday language) or to a climate (sometimes referred to as 'radiative') forcing mechanism.

A positive feedback means that the system responds in the same direction as the initial perturbation; whereas a negative feedback means that the system responds in the opposite direction. In relation to climate change, an example of a positive feedback is the impact of warming on Arctic ice. The overall reflectivity of a surface is known as its albedo. Because ice reflects sunlight and warming can cause ice to melt, one feedback set in motion is that as a result more solar heat is absorbed, rather than reflected. In the Arctic, this positive feedback process would lead in turn to increased ice melt. There are similar positive feedbacks at high altitudes, where temperature increases are amplified as a result of snow and ice albedo feedbacks.

Another example of a positive feedback lies with the risk that Arctic warming could cause vast quantities of CH_4 to be released from rotten vegetation currently locked into the Arctic permafrost. That in turn could lead to more heating, more melting of permafrost, and more releases of CH_4 into the atmosphere. This kind of positive feedback is also associated with one of the most feared climate 'tipping points', considered further in the next section.

The IPCC's AR4 notes that warming reduces terrestrial and ocean uptake of atmospheric CO_2, which in turn increases the anthropogenic emissions that remain in the atmosphere. This positive '*carbon* *cycle feedback*' in turn leads to larger atmospheric CO_2 increases and greater climate change for given emissions scenarios, but the strength of the feedback effect varies markedly among models.

An example of negative feedback lies with the fact that terrestrial ecosystems are currently absorbing more CO_2 than they are releasing – providing a net sink – though it is anticipated that this effect will decrease.[62]

The AR4 Synthesis Report notes that the greatest area of scientific uncertainty lies with cloud feedbacks: the implications of changing cloud cover for processes of heating and cooling.[63] Particles originating in human activities have the potential strongly to influence cloud properties; but scientific understanding of that effect is poor, and the interaction between clouds and climate (as opposed to weather) remains difficult to factor into models.[64]

Tipping points

The Earth's climate system is highly nonlinear, so that any given climate-altering input could potentially generate impacts – outputs – far out of proportion to the original input.

Various kinds of tipping points or critical thresholds in ecosystems could have dramatic and unforeseeable effects which are only incompletely factored into the emissions scenarios in which much of AR4 is grounded. Indeed, the AR4 Synthesis Report notes that "*understanding of low-probability/high-impact events and the cumulative impacts of sequences of smaller events, which is required for risk-based approaches to decision-making, is generally limited*".[65] A combination of better scientific understanding and new scenarios is needed.

Participants in a "*worst case scenario*" workshop organised by the US-based Foundation for the Future in 2008 argued that three tipping points have already been apparently irreversibly reached: winters are no longer cold enough to kill off the larvae of the pine bark beetles in the northern US and Canada, which are now killing vast areas of pine trees; oceans are acidifying, leading to massive changes in the lower levels of the food chain; and coral reefs in the Caribbean Sea have disappeared due to increasing temperatures.[66]

In 2009, the Copenhagen Diagnosis argued that "*Several vulnerable elements in the climate system (e.g. continental ice-sheets, Amazon rainforest, West African monsoon and others) could be pushed towards abrupt or irreversible change if warming continues in a business-as-usual way throughout this century. The risk of transgressing critical thresholds ("tipping points") increases strongly with ongoing climate change. Thus waiting for higher levels of scientific certainty could mean that some tipping points will be crossed before they are recognized*".[67]

One key possible tipping point for abrupt climate change would be the collapse of the North Atlantic Meridional Overturning Circulation' (MOC).[68] The possibility of large scale changes in the circulation of the North Atlantic Ocean remains an area of considerable scientific uncertainty. The issue is popularly referred to as a risk that the warm Gulf Stream (including the North Atlantic Drift Current) could weaken or reverse, bringing a mini ice age to countries in northwestern Europe, including the UK. The issue here concerns the risk that increase in the flow of freshwater into the North Atlantic from melting glaciers, rainfall and snowfall could have a braking effect on the Gulf Stream given the lower density of fresh, as opposed to salty, water. The overall effect would be to generate a net cooling of 1-3°C across the UK, Scandinavia, Greenland and the North Atlantic. Projections are made more difficult by evidence that natural cycles, too (as distinct from anthropogenic climate change), affect the speed of the Atlantic circulation system overall.[69]

Models in AR4 project a reduction of between zero to about 50% in the speed of the Gulf Stream during the 21st century. Overall, however, temperatures in the Atlantic region are still projected to increase despite these reductions. Even so, any slowing in the Gulf Stream could potentially reduce temperature increases in Europe.[70] But a mini ice age is very unlikely. The WGI Summary for Policymakers concludes that it is "*very unlikely that the [Gulf Stream system, referred to as the Meridional Overturning Circulation or MOC] will undergo a large abrupt transition during the 21st century*".[71]

On the other hand, were it to happen, rapid shutdown of the MOC (although assigned a 'low' probability) would be likely to have widespread severe impacts in Europe, especially western coastal areas. Impacts include reduced crop production, increased cold-related deaths and winter transport disruption, as well as population migration to southern Europe (Medium confidence).[72]

Other possible tipping points resulting from positive feedbacks include warming of the sea sufficient to release hundreds of gigatons of CH_4 from methane hydrates (sometimes referred to as '*clathrates*') on the sea floor. Another would be the potential for melting of the West Antarctic Ice Sheet, which currently sits on the (melting) Ross Ice Shelf. If the West Antarctic Ice Sheet melted into the sea, sea levels might rapidly rise by 16 ft (more than 5m).[73] And acidification of the world's oceans could trigger another tipping point. As oceans acidify, carbonate-forming organisms, such as many marine invertebrates, would be compromised and their existing structures might begin to dissolve, potentially causing the oceans to become net carbon sources, rather than sinks. There is already evidence that processes of acidification might have caused major extinctions in the past.[74]

A volume published by the Royal Society in late 2010 investigates tipping points associated with a global mean temperature increase of 4°C (itself a possibility as early as the 2060s-2080s under some scenarios).[75] In it, New *et al* suggest that *"[t]here are a range of other potential thresholds in the climate system and large ecosystems that might be crossed as the world warms from 2°C to 4°C and beyond. These include permanent absence of summer sea ice in the Arctic, loss of the large proportion of reef-building tropical corals, melting of permafrost at rates that result in positive feedbacks to greenhouse gas warming through CH_4 and CO_2 releases and die-back of the Amazon forest. While the locations of these thresholds are not precisely defined, it is clear that the risk of these transitions occurring is much larger at 4°C – and so the nature of the changes in climate we experience may well start shifting from incremental to transformative."*[76]

Emissions, concentrations, and *how much* global warming

A note on data presentation

Information about climate change is commonly presented in a number of ways, each of which is reflected in a different section of this paper, and each of which is relevant for different reasons.

A fundamental baseline is data on actual or projected emissions of greenhouse gases, which may be divided into data on each of the gases separately, or aggregated into a measure of the CO_2 equivalent of a basket of gases. Emissions data is generally presented in terms of gigatons (1 gigaton/Gt = 1 billion tons) of CO_2 or CO_2 equivalent (Co_2-eq) per year, and is commonly divided into emissions from energy (i.e. fossil fuel use), industry (i.e. emissions resulting from industrial processes aside from the burning of fossil fuels; cement production in particular), and land-based sources (e.g. as a result of deforestation).

Alternatively, the focus of analysis may be on identifying current or projected *concentrations* of greenhouse gases in the Earth's atmosphere. In that case, data is typically presented in parts per million (ppm) of CO_2 or other greenhouse gases or, in aggregate, ppm of CO_2-eq. By applying a variety of climate modelling approaches to projected concentrations of greenhouse gases, scientists derive estimates of the overall warming potential that can result. Here, at aggregate level, information tends to be presented in terms of global (or regional) mean temperature change against a given baseline (typically '*pre-industrial'* or a given date such as 1990). Increases (or decreases) in mean temperatures at global or regional levels can be modelled in terms of changes in the climatic system (e.g. melting ice caps, changes in precipitation or sea level rises) or in terms of the *impacts* that could flow from those changes (e.g. crop failure, inundation or increased incidences of malaria). Each of these kinds of information can be used for different policy-related purposes.

The remainder of this section makes use of these data to present an overall picture of key aggregate thresholds relevant for policy purposes.

Greenhouse gas concentrations, associated temperature rises and key thresholds

There is no time during the past 650,000 years when the CO_2 content of the Earth's atmosphere has been as high as it is today.[77]

Immediately before the industrial revolution, CO_2 concentrations in the Earth's atmosphere were about 280ppm (though indications are that they had previously been as low as 180ppm during the last ice age). By the end of 2009, concentrations of CO_2 in the Earth's atmosphere stood at 388ppm.[78] They are currently rising at about 2ppm annually.

Over the period from 1970 to 2004 alone, global greenhouse gas emissions due to human activities grew by 70%.[79] The largest growth has been from energy supply, transport and industry. With current (as at AR4 in 2007) climate mitigation policies and related sustainable development practices, global greenhouse gas emissions will continue to grow over the next few decades.

The responsiveness of the temperature of a climate system to changes in radiative forcing determines the '*climate sensitivity*' of the climate system. This is defined as the equilibrium global average surface warming following a doubling of CO_2 concentrations. The resulting global equilibrium temperatures, it should be noted, would not be reached until decades or even after greenhouse gas stabilisation.[80] Different starting points can be used, but the doubling of CO_2 since pre-industrial times is one convention.
Climate sensitivity is used widely to aid comparison across different climate models.[81] In AR4, the IPCC puts climate sensitivity, allowing for processes that amplify or reduce the size of the climate response[82] as *likely* to be in the range 2-4.5°C, with a best estimate of 3°C.[83]

AR4 concludes that climate sensitivity is *very unlikely* to be less than 1.5°C. "*Values higher than 4.5 degrees centigrade cannot be excluded*",[84] but the report notes that agreement of climate models with observations is not as good for those values.[85] Even without processes that amplify or reduce climate change, climate sensitivity would still be around 1°C for a doubling of CO_2 concentrations above pre-industrial levels.[86]

These climate sensitivities are *not* the same as an assessment of possible increases in temperatures to a given point in time (e.g. 2050 or 2100, for the purposes of our project): projected global mean temperatures reflect different considerations.

Projections of future warming are closely linked to projections of future greenhouse gas emissions. Models used in AR4 suggest that *if* the world continues to rely on carbon-based energy, *if* population growth continues at its current rate, and *if* 'dirty' technologies continue to be used, average global temperatures may increase by 6.4°C by 2100 (the end point for our current project) or 6.9°C relative to pre-industrial levels.[87]

Many scientists believe that warming by at least an additional 1°C is already wired in, and a summary of climate science from the Royal Society points out that even without a further increase in climate forcing, further warming would be expected as oceans slowly respond to existing forcing. That warming would amount to a further few tenths of a °C by the year 2100.[88]

It is also important to note that the range of temperatures represented by a *global* mean of, say, 2°C, may also mean dangerously high increases, significantly in excess of 2°C, in some parts of the world.

Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and the North Atlantic. In the outcome of a 2009 modelling exercise, researchers at the UK's Hadley Centre indicate that a 'plausible worst case scenario' of 4°C mean global rise might mean Arctic temperature increases of up to 15.2°C in a high greenhouse gas emissions scenario, and up to 10°C in parts of western and southern Africa.[89]

Currently, 400-600ppm of CO_2 is considered a 'red zone' of danger.[90] That level could potentially be reached by 2050 under AR4 scenarios. And the implications of unabated growth in carbon emissions up to 2100 are even more extreme. The implication of 1000ppm, argues NASA risk assessment expert Dr Feng Hsu, for example, is "*an unacceptable level of catastrophic risk that will likely lead to the extinction of humanity*".[91] Clearly, in such a situation, scenarios for the future of *democracy* in the face of climate change become meaningless: if all humanity is extinguished, democracy must go with it.

However, even environmental activist Mark Lynas, writing about a 'six degrees' world, considers it unlikely that all of humanity will become extinct: "*Even given the most dramatic rates of warming imaginable, somewhere, surely, it will still be possible to raise crops and grow food. Rainfall will not stop, and the melting ice sheets will provide plentiful supplies of water in polar regions... the idea that every single one of us could be wiped out strikes me as inconceivable*".[92]

350 has now become the emblematic number for a global campaign to commit the world to action to take concentrations of CO_2 below 350ppm – considered to be the upper 'safe' concentration by many climate scientists.[93]

The current widely accepted notional target of 450ppm also carries many uncertainties. It would, under AR4 scenarios, likely be associated with an average 2°C warming worldwide compared to pre-industrial levels. Even 2°C would mean large species loss, more severe storms, sea level rise, floods and droughts.

In practice, many policymakers see 550ppm as a more realistic goal given the major economic and lifestyle changes that are required to reduce overall concentrations of greenhouse gases in the atmosphere. But that could conceivably bring a global average temperature rise of 3°C by the end of the century compared to pre-industrial levels.

The Copenhagen Diagnosis points to surging greenhouse gas emissions which would mean that even if global emission rates were held at present-day levels, just 20 more years of increased emissions would give a 25% probability that warming exceeds 2°C, even if there were zero emissions after 2030.[94]

Scenarios have been developed for the point in time at which CO_2 emissions would need to peak (and decline thereafter) for various stabilisation levels of CO_2 concentrations to be reached. Overall findings from AR4 are summarised in *Table 1* below. WGIII warns that the emissions reductions to meet particular stabilisation levels might be under-estimated.[95] The WGIII Summary for Policymakers notes that for the majority of scenarios assessed, stabilisation of greenhouse gas concentrations occurs between 2100 and 2150.[96]

Anderson and Bows note that a flaw in some post-AR4 approaches is a failure adequately to factor cumulative emissions into trajectories and emission budgets associated with particular targets for global mean temperature increase (specifically the Copenhagen Accord's 2°C target). They conclude that "*while the rhetoric of policy is to reduce emissions in line with avoiding dangerous climate change, most policy advice is to accept a high probability of extremely dangerous climate change rather than proposed radical and immediate emission reductions*."[97]

Linkages between CO_2-eq concentrations in the atmosphere and equilibrium warming levels are by no means clear or linear. The CO_2-eq concentrations represent the concentrations of CO_2 that would have the same overall global warming potential as a basket of greenhouse gases. Since many greenhouse gases have a higher global warming potential than CO_2, CO_2-eq concentration is higher than CO_2 concentration at stabilisation. In AR4, WGI sets out seven levels of CO_2-eq concentration (as opposed to the concentration *ranges* shown in the WGIII table above), and gives 'best estimates' and 'likely ranges' of equilibrium warming for the different levels of CO_2-eq concentration as follows:

350 CO_2-eq ppm (the number of the global campaign): 1.0°C [0.6-1.4]
450 CO_2-eq ppm (a widely accepted notional target, *de facto* built into the Copenhagen Accord): 2.1°C [1.4-3.1]
550 CO_2-eq ppm (within the "*red zone*" of danger): 2.9°C [1.9-4.4]
650 CO_2-eq ppm: (within the "*red zone*" of danger): 3.6°C [2.4-5.5]
750 CO_2-eq ppm: 4.3°C [2.8-6.4]
1,000 CO_2-eq ppm ("*extinction*", according to some scientists): 5.5°C [3.7-8.3]
1,200 CO_2-eq ppm: 6.3°C [4.2-9.4][98]

Table 1: CO_2 stabilisation concentrations, their associated peak emissions years and temperature increases, and the extent to which they represent a change in global CO_2 emissions

CO_2 concentration at stabilisation (ppm)	**Peaking year for CO_2 emissions**	**Change in global CO_2 emissions in 2050 (% of 2000 emissions)**	**CO_2-equivalent[99] concentration at stabilisation (ppm)**	**Global mean temperature increase above pre-industrial at equilibrium, using "*best estimate*" climate sensitivity**	**Number of assessed scenarios**
350-400	2000-2015	-85 to -50	445-490	2.0-2.4	6
400-440	2000-2020	-60 to -30	490-535	2.4-2.8	18
440-485	2010-2030	-30 to +5	535-590	2.8-3.2	21
485-570	2020-2060	+10 to +60	590-710	3.2-4.0	118
570-660	2050-2080	+25 to +85	710-855	4.0-4.9	9
660-790	2060-2090	+90 to +140	855-1130	4.9-6.1	5

Source: adapted from WGIII Table TS.2[100]

It is worth reiterating that these estimates are for equilibrium warming – i.e. the total warming once the climate system has caught up with stabilised greenhouse gas levels in the atmosphere. They are different to the estimated ranges of global mean warming associated with a range of climate scenarios. These scenarios are considered further below. They range from a 1.1-6.4°C increase in global mean annual temperatures above 1980-1999 (*not* pre-industrial) baselines in the period to 2099. It should be noted further that neither equilibrium warming nor global average mean warming indicates the *point in time* at which equilibrium warming might be reached under different scenarios for current or projected future emissions.

Observed climate change

At smaller scales (e.g. in the case of individual storms or single seasons in a given region) it is difficult to attribute observed temperature changes or weather effects to climate change. As the IPCC puts it, "*[o]n these scales, natural climate variability is relatively larger, making it harder to distinguish changes expected due to external forcings*".[102] Furthermore, gaps and limitations *"currently prevent more complete attribution of the causes of observed natural system responses to anthropogenic warming. The available analyses are limited in the number of systems, length of records and locations considered."*[103]

More generically, the IPCC's conclusions allow little room for doubt. AR4 suggests that the number and quality of studies observing trends in the physical and biological environment's relationship to regional climate changes (since 1970) has greatly increased since the TAR.[104] However, the ability of current models to simulate some aspects of climate change is limited, and below the level of continental scale projections, there is little confidence in specific projections of future regional climate change.[105] This effectively means that any scenarios for the future of democracy in the face of climate change at a variety of country- (or political unit-) specific levels must be necessarily generic.

In the 12-year period to the end of 2006, 11 of 12 years rank among the 12 warmest in the record of global surface temperature since 1850. The decade 2000-2009 was, globally, about 0.15°C warmer than the decade 1990-1999.[106] The temperature increase is greatest at higher northern latitudes. Land regions have warmed faster than the oceans, despite oceans taking up over 80% of the heat added to the climate system.[107]

Sea level rise under warming is inevitable. Sea level rises to date are consistent with warming, progressing at an average rate of 1.8mm per year between 1961-2003, and then 3.1mm per year from 1993-2003; though the reasons for the increased rate of sea level rise over the latter period are unclear.[108] Thermal expansion of oceans is estimated to have contributed 57% to sea level rise, the decrease in glaciers and ice caps 28%, and losses from polar ice sheets the remainder.[109]

Annual average Arctic sea ice extent has shrunk by 2.7% per decade since 1978, with larger summer decreases of 7.4%. Mountain glaciers and snow cover on average have declined in both hemispheres. And the maximum area of seasonally frozen ground has decreased by around 7% in the Northern Hemisphere since 1900.[110]

Researchers involved in the Copenhagen Diagnosis highlight a rapid decline in Arctic sea ice (about 40% greater than the average prediction from models assessed in AR4), and a wide array of satellite and ice measurements which now demonstrate beyond significant doubt that both the Greenland and Antarctic ice sheets are losing mass at an increasing rate. Summer melting of Arctic sea ice, they note, has accelerated far beyond the expectations of climate models. The area of summer time sea ice during 2007-2009 was about 40% less than the average prediction from AR4 climate models.[111]

Other long term changes in some aspects of climate have also been observed. For example, over the period 1900-2005, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia; whereas precipitation declined in the Sahel, Mediterranean, southern Africa and parts of southern Asia.[112]

The intensity and/or frequency of extreme weather events have also changed over the last 50 years. AR4 considers it 'very likely' that cold days and nights and frosts have become less frequent, while hot days and nights have become more frequent. It is 'likely' that heat waves have become more frequent, 'likely' that the frequency of heavy precipitation events has increased, and likely that the incidence of extreme high sea level has increased since 1975.[113]

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since 1970. Average Northern Hemisphere temperatures during the second half of the 20th century were 'very likely' higher than during any other 50 year period in the last 500 years, and 'likely' the highest in the past 1300 years: *"Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases"*.[114] AR4 asserts with 'high confidence' that natural systems related to snow, ice and frozen ground are affected; for example, enlargement and increased numbers of glacial lakes, increasing ground instability in permafrost regions and rock avalanches in mountain regions, and changes in some Arctic and Antarctic ecosystems.[115]

AR4 also asserts with 'high confidence' that there has been *"increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers in many regions, with effects on thermal structure and water quality"*.[116] There is 'very high confidence' that recent warming is strongly affecting terrestrial biological systems and 'high confidence' that there has been a trend in many regions towards earlier greening of vegetation in the spring due to longer thermal growing seasons.[117]

There is 'high confidence' that observed changes in marine and freshwater biological systems are associated with rising water temperatures and related changes in ice cover, salinity, oxygen levels and circulation.[118]

AR4 also sets out emerging effects of regional climate changes on natural and human environments, noting however that *"many are difficult to discern due to adaptation and non-climatic drivers"*.[119] Consequently, the Synthesis Report expresses only 'medium confidence' of effects documented through:

- Changing practises of agricultural and forestry management at Northern Hemisphere higher latitudes, for example earlier spring planting of crops, and alterations in the disturbance of forests due to fires and pests.
- Certain aspects of human health for example heat-related mortality in Europe, changes in infectious disease vectors in parts of Europe, and earlier onset of/increased seasonal production of allergenic pollen in high and mid latitudes.

In other areas, the AR4 conclusions are expressed with even less confidence. For example: *"Sea level rises and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas. However, based on the published literature, the impacts have not yet become established trends"*.[120]

Some aspects of the Earth's climate appear not to have changed, but data inadequacies mean that AR4 was not able to determine whether that is in fact the case. For example, AR4 notes that there is no clear trend in annual numbers of tropical cyclones, and that Antarctic sea ice extent (as distinct from Arctic sea ice extent) does not show a statistically significant average multi-decadal trend (consistent with the lack of rise in near-surface temperatures).[121]

For all that these uncertainties remain, AR4 notes that: *"Changes in the ocean and on land, including observed decreases in snow cover and Northern Hemisphere sea ice extent, thinner sea ice, shorter freezing seasons of lake and river ice, glacier melt, decreases in permafrost extent, increases in soil temperatures and borehole temperature profiles, and sea level rise, provide additional evidence that the world is warming... Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming"*.[122]

Emissions scenarios: the IPCC SRES scenarios

In 2000, the IPCC published a Special Report on Emissions Scenarios (SRES) as input to the development of the TAR.[123] This grouped possible emissions trajectories into four 'families' and six 'groups' of scenarios – 40 in all – designed to explore the implications of alternative development pathways for emissions of greenhouse gases. The scenarios cover the entire 21st century, projecting emissions of major greenhouse gases, ozone and precursor gases, and sulphate aerosols.

The SRES scenarios were developed to take account of three external driving forces considered determinative of future greenhouse gas trajectories: demographic change, economic development and, to limited extent social development, and the rate and direction of technological change.

Consequently, they take as their starting point an assertion of strong links (or feedback loops) between environment and economy.

The families of scenarios were grounded in baselines which assumed no additional climate policy above those then (i.e. in 2000) in place. In particular, the scenarios do not assume implementation of the UNFCCC[124] or the emissions targets of the Kyoto Protocol.[125] However, the influence of other government policies on the drivers of emissions (such as demographic change, social and economic development, technological change, resource use, and pollution management) is broadly reflected.[126] Thus, for example, sulphur emissions projected in the SRES scenarios are generally below those projected in an earlier set of scenarios released in 1992,[127] reflecting adoption and implementation of sulphur control legislation in some parts of the world.[128]

The scenarios presented results for four reporting regions only (OECD (Organisation for Economic Co-operation and Development countries), Asia, eastern Europe and Former Soviet Union; Rest of the World) not for individual countries.[129] One consequence is that there are methodological challenges in 'downscaling' projections of population and GDP from the four SRES reporting regions to the national or subnational level.[130]

None of the SRES scenarios considered outlying 'surprise' or 'disaster' scenarios which appear in the climate change literature. None are assigned probabilities of occurrence indeed, the possibility that any one of the emission paths will unfold as described in the scenarios is highly uncertain. Together, the 40 scenarios describe divergent futures that are designed to encompass "*a significant portion of the underlying uncertainties in the main driving forces*". However, they are not comprehensive. For example, WGII itself recognised, in the Technical Summary of its input to AR4, that "*improved scenarios are required for poorly specified indicators such as future technology and adaptive capacity, and interactions between key drivers of change need to be better specified*".[131]

In 1998 the IPCC Bureau agreed to make preliminary descriptions and quantifications of the SRES scenarios available via the SRES website. This was done in order to make the scenarios available to climate modellers working to generate inputs for the TAR, and was in accordance with the SRES 'open process' which solicited wide participation and feedback. The publication of the scenarios was also intended to facilitate climate research beyond that of the IPCC. As stated in the SRES Summary for Policymakers: *"We recommend that the new scenarios be used not only in the IPCC's future assessments of climate change, its impacts, and adaptation and mitigation options, but also as the basis for analyses by the wider research and policy community of climate change and other environmental problems"*.[132]

Scenario family **A1** assumes a market-based, technology-driven world of very rapid economic growth, a global population that peaks at 8.7 billion mid-century decreasing to around 6.5 billion in 2100, and rapid introduction of new and more efficient technologies. Underlying themes are convergence among regions, capacity building, and increased cultural and social interactions. Population growth is assumed to be low "*because of the importance of development in bringing about the demographic transition from high to low fertility in developing countries*".

The **A1** scenario family is sub-divided into three groups describing alternative directions of technological change in energy systems: A1FI (fossil fuel intensive), A1T (non-fossil energy resources), and A1B (a balance across all energy resources).

Scenario family **A2** describes a very heterogeneous world characterised by high population growth, slow economic development and slow technological change. Globalisation, in this scenario, is weak, with economic development primarily regionally-oriented. Population growth is high (15 billion by 2100) "*because of the reduced financial resources available to address human welfare, child and reproductive health and education*".[133] The underlying theme is "*self-reliance and preservation of local identities*". Per capita economic growth and technological change are slower than in other scenario families.

Scenario family **B1** comes closest to a 'sustainable development future'. It has high economic growth (gross domestic product (GDP) projected to be £350 trillion in 2100), though not as rapid as A1. B1 describes a convergent world with the population of A1 (peaking mid-century and declining thereafter), but more rapid changes in economic structure towards a service and information economy, and introduction of clean and resource-efficient technologies and a reduction in material intensity. It is a world where the emphasis could be on education, equity and social welfare rather than on technological growth[134], and on global solutions to economic, social and environmental sustainability (but even so, without additional climate initiatives).

Scenario **B2** is in essence a less prosperous version of B1, with slower economic growth.[135] Like B1, it is also oriented towards environmental protection and social equity; but this is a world in which *local* solutions to economic, social and environmental sustainability are emphasised. The B2 scenario family is grounded in a continuously increasing global population but at a rate lower than A2. B2 is a world with intermediate population (10.4 billion in 2100) and economic growth (GDP of £250 trillion in 2100), and less rapid and more diverse technological change than that in the B1 and A1 scenario families. Both cultural pluralism and environmental protection are strong.

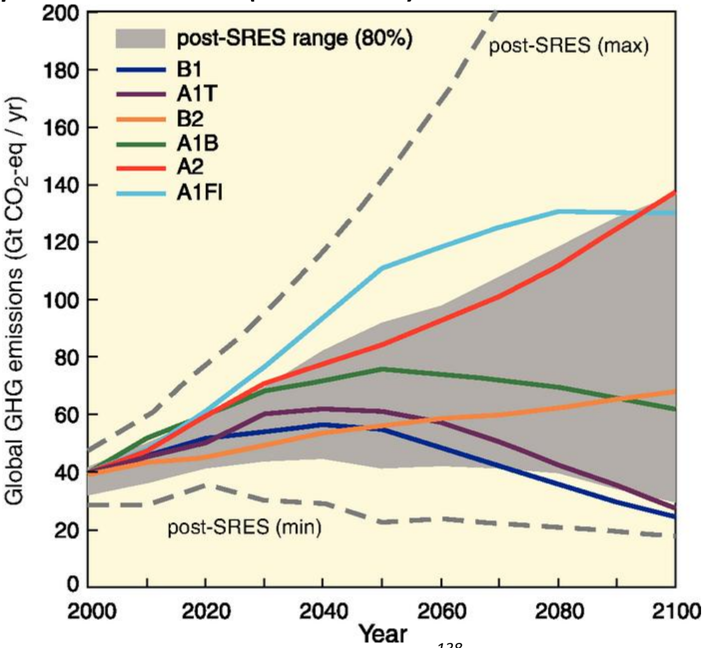
All of the scenarios describe futures more affluent than today, with gross world product (GWP) rising to 10 times today's value in the lowest scenarios, and to 26 times today's values in the highest scenarios by 2100. A narrowing of income differences among world regions is assumed in many SRES scenarios.

Uncertainties in the emissions scenarios are generally greater for non-CO_2 greenhouse gases (because their relationships to the driving forces are generally less studied) than for CO_2 from energy use.[136]

All six scenario groups (i.e. including the three sub-sets of scenario A1) cover wide and overlapping emission ranges. For each group there is a *"'marker*' scenario, described in the SRES report as follows: "*the markers are not necessarily the median or mean of a scenario family (nor would it be possible to construct such a median or mean scenario by taking all salient scenario characteristics and regional results into account). The markers are simply those scenarios considered by the SRES writing team as illustrative of a particular storyline. They are not singled out as more likely than alternative quantitative interpretations of a particular scenario family and its underlying storyline. Perhaps they may be best described as "first among equals"".*[137]

The emissions ranges of the six scenario groups, as summarised by the six marker scenarios, are broadly comparable with the 80th percentile range of emissions scenarios drawn up since the SRES report (i.e. '*post-SRES'* scenarios), as illustrated in *Figure 1* below.

Figure 1: Comparison of global greenhouse gas emissions for six SRES marker scenarios (coloured lines), the 80th percentile range of post-SRES scenarios (grey shaded area), and the full range of post-SRES scenarios (dashed lines)



Source: AR4 Synthesis Report, Figure 3.1[138]

The SRES scenarios have not been without their critics. For example, in a 2003 paper, Castles and Henderson[139] criticised the SRES scenarios on the basis that their economic development projections had been grounded in market exchange rates rather than purchasing power parity; a methodological approach which would have had the consequence of overstating gaps in income between high and low income countries, with the consequence of projecting rather optimistic growth figures and hence increased emissions. In the SRES scenarios, market exchange rates were used to compare GDP between different countries. This method, charged Castles and Henderson, is misleading because *price levels* are consistently many times higher in rich countries compared to poor countries. In consequence, poor countries appear to be considerably poorer, and hence the income gap between poor and rich countries appears greater. That is significant, in turn, because the SRES scenarios assume *"that a driving force in the economic growth process in the poorer parts of the world is a gradual catching up to the rich countries*".[140] If an income gap is initially exaggerated, that would also tend to exaggerate economic growth.

Subsequent exchanges between academic experts and analysts picked apart the relationship between economic growth and emissions growth. In practice, that relationship is not linear: emissions *intensity* per unit of GDP may in fact decrease over time. Under-estimating GDP could in practice also be associated with over-estimation of emissions intensities. Correcting for that under-estimate by using purchasing power parity would result in lowering of emissions intensities, so that over time, the actual emissions intensity of richer and poorer countries would tend to converge. In other words, whilst the SRES scenarios contained a methodological flaw, that flaw did not lead to significantly over-estimated per capita emissions.[141]

The SRES scenarios have also been criticised on grounds that they do not factor in the possibility of peak oil[142] or directly address resource depletion as a problem; assuming for most scenarios (e.g.

A1FI, which is grounded dominantly in a fossil fuel-based economy) that there are sufficient fossil fuels available to meet demand. One consequence might be, again, that the scenarios over-estimate economic growth.

AR4 compared SRES scenarios with studies published since the 2000 SRES report. It noted that some of these later studies used lower values for some emissions drivers – notably population projections. Overall, however, changes in other drivers – such as economic growth – resulted in little change in overall emissions levels, the IPCC concluded in 2007. Even those baseline studies and scenarios that factor in *'current'* climate change mitigation policies (as at the cut-off date for AR4) overall give rise to projected baseline emissions – for 2030 and 2100 – that are comparable in range to the initial 2000 SRES scenarios. In particular, economic growth projections for Africa, Latin America and the Middle East to 2030 in post-SRES baseline scenarios are lower than in SRES, but with only minor effects on overall emissions and global economic growth.[143]

Effectively, the beneficial effect of policy measures implemented since 2000 is cancelled out by changes in other drivers.[144]

For our purposes, these findings suggest that *in principle* the use of SRES scenarios is broadly speaking a suitable basis for our 'democracy and climate change' scenarios, assuming an AR4 baseline of 2007. However, it is also relevant to note that the economic growth predictions on which the SRES scenarios are based predate the 2008-9 financial crisis and the subsequent economic downturn in many parts of the world, which has been associated with a decline in the growth rates for greenhouse gas emissions, particularly those associated with energy.[145] There are many technical reasons to tread cautiously, in sum, when linking the SRES scenarios to democracy.

Equally importantly, a further drawback is that the SRES scenarios fail fully to account for social, cultural, political or ethical factors as driving forces of emissions. As the SRES notes, *"social, cultural, and institutional processes are hard to measure and often subjective. They tend to involve personal interactions among people, sometimes large numbers of people, over long periods... Storylines allow these issues to be addressed explicitly, even if current knowledge does not allow social, cultural, and institutional factors to be treated in a rigid, quantitative (not to mention deterministic) way*". [146] The IPCC recognises this as a weakness of the SRES scenarios when the WGII Technical Summary notes that scenarios are still required "*to describe the future evolution of the world under different and wide-ranging assumptions about how societies, governance, technology, economies will develop for the future*".[147]

An alternative approach would be to consider the likely relationship or correlation between various SRES scenarios and democracy. Some dimensions of the SRES scenarios could, for example, be weakly linked to democracy by means of such (limited) evidence as exists on links between preconditions for optimal effective democracy (e.g. relative income equality at the national level)[148] and democracy itself. One might also postulate a negative correlation between high emissions or severe climate impacts and the *'climate-readiness'* of democracy as a political system. Even this, however, demands a time disjuncture between the assessment of climate-readiness of any given political system on the one hand, and the corresponding climate impacts, which might not be felt until much later. Much depends on the point in time at which the assessment is made, and on the time delay between policymaking or public decision-making (the practice of democracy) on the one hand, and climate impacts on the other.

More fundamentally, since the SRES scenarios are rooted in an assumption of *no* additional climate mitigation policy measures (measures that would themselves be in part a function of politics and ethics), they are divorced from the social, cultural and political dimensions of climate mitigation and adaptation.

Based on the SRES scenario groups, AR4 reviewed scenarios to arrive at '*best estimates*' and '*likely*' ranges for global average surface air warming for the six SRES marker emissions scenarios, along with estimates of sea level rise. It is important to recognise that whilst the underlying methodological approaches and assumptions underpinning the SRES scenarios will almost certainly continue to evolve and improve, there appears to be little serious doubt that the *overall* parameters of the SRES emissions scenarios are currently appropriate.

Table 2 below shows projected '*best estimate*' and '*likely*' ranges of global mean temperature change and projected ranges for sea level rise at the end of the 21st century for each of the six SRES scenario groups.

The assessed upper ranges for the SRES projections are larger than in the IPCC's TAR, AR4 points out, because of the availability of a broader range of models which suggests stronger climate-carbon cycle feedbacks. For example, in the A2 family of scenarios, climate-carbon cycle feedback increases the corresponding global average warming at 2100 by more than 1°C.

Table 2: Projected global average surface warming and sea level rise at the end of the 21st century for six SRES marker scenarios

	Temperature Change (°C at 2090-2099 relative to 1980-1999)		Sea level rise (m at 2090-2099 relative to 1980-1999)
Case	Best estimate	*Likely* range	Model-based range (excluding future rapid dynamical changes in ice flow)
Constant year 2000 concentrations	0.6	0.3-0.9	Not available
B1 scenario	1.8	1.1-2.9	0.18-0.38
A1T scenario	2.4	1.4-3.8	0.20-0.45
B2 scenario	2.4	1.4-3.8	0.20-0.43
A1B scenario	2.8	1.7-4.4	0.21-0.48
A2 scenario	3.4	2.0-5.4	0.23-0.51
A1FI scenario	4.0	2.4-6.4	0.26-0.59

Source: AR4 Synthesis Report, Table 3.1[149]

Fung *et al* point to assessments which indicate that emissions commitments by the parties to the UNFCCC as at early 2010 will lead to a 50% chance of global warming peaking at 3.5°C over pre-industrial levels, though they do not investigate when that level might be reached.[150] And New *et al* also suggest that the likelihood of 3 or 4°C temperature rises this century needs to be contemplated.[151]

Betts *et al* consider the A1FI scenario in more detail.[152] Factoring complex ocean-atmosphere general circulation models (GCMs) into this scenario, and allowing for uncertainties in climate-carbon cycle feedbacks, the authors indicate that their best estimate is that the A1FI scenario would, in fact, lead to warming of 4°C above pre-industrial levels during the 2070s. However, with stronger carbon cycle feedbacks (less likely but still credible) that same level of warming could be reached by the early 2060s.[153] 4°C is roughly at the centre of the overall range of possible levels of warming envisaged by the SRES scenarios.

The SRES scenarios incorporate extensive uncertainties. As the AR4 Synthesis Report notes, projections of climate change and its impacts "*beyond about 2050*" are strongly scenario- and model-dependent, and improved projections would require improved understanding of sources of uncertainty and enhancements in systematic observation networks.[154]

WGIII of AR4[155] also draws on the SRES scenarios as 'non-mitigation' scenarios for future projected emissions. But the focus of WGIII's work is to inform efforts to model and negotiate mitigation options. Consequently, scenario data reviewed in WGIII extends to the emissions pathways of mitigation scenarios for six categories of overall CO_2 and CO_2-eq stabilisation levels. By summarising the modelled effect of different mitigation approaches, from changes in lifestyle and behaviour patterns to application of a range of mitigation technologies, WGIII provides a basis for policy decisions on mitigation options.

Projected climate impacts

Aggregate climate impacts

Climate change will have major impacts on the ability of the Earth to feed the inhabitants of an increasingly crowded planet, with some species becoming marginal or facing extinction, and access to water and to food becoming increasingly strained. Human health impacts will also be very significant; for example, as a result of increasingly frequent extreme weather events (including heatwaves, floods and droughts), shifts in incidence and spread of infectious diseases, and the mental health effects of increased social exclusion. And climate change will have wider social impacts too: not least as sea level rises generate major impacts on human settlements in coastal areas; as changes in agricultural productivity and practices force migration; and as the impacts of climate change begin to generate major shifts or shocks in the global economy.

AR4 documents the potential range of impacts of future climate changes. Much of the body of impacts evaluation considered in AR4 draws on the SRES scenarios groups and the work of WGII. But many of the statements made about projected impacts are difficult to evaluate. In the first place, AR4 makes assertions about possible impacts, but without analysis of which scenarios are most likely to materialise. Indeed, that analysis is explicitly excluded from the IPCC's overall framing of the SRES scenarios, all of which are to be considered equally sound.[156] Second, it is often unclear from AR4 summaries – and sometimes even from the original research on which they draw – which SRES scenarios have been considered in arriving at conclusions about possible impacts. Additionally, the SRES scenarios are 'non-mitigation' scenarios – that is, they assume no implementation of the UNFCCC or the emissions targets of the Kyoto Protocol. But the wide-ranging studies on which WGII draws are not all grounded in the same assumption. The report of WGII itself indicates that further scenarios are required to allow mitigation to be incorporated into climate change impact estimates.

All of this hampers efforts systematically to evaluate the relevance of AR4 statements about projected climate impacts.

With these cautionary notes sounded, one important overall message is that the resilience of many ecosystems is "*likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances... and other global change drivers... [T[here are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in* *species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services"*.[157]

New *et al* point to the dual stresses of climate change and population growth in the mid 21st century: "*Many population scenarios project that world population will peak at about nine billion in the 2050s, with the largest increases between now and then concentrated in emerging economies. Demand for food and water will rise (and possibly peak) in parallel with this. If climate warms rapidly – as might occur with a steep rise in emissions, with a high peak emissions rate... – a temperature of anywhere between 2°C and 4°C might be reached by the 2050s or 2060s, precisely at the time when vulnerability as a result of population demands for food and water is highest".*[158]

Overall, warming will be more pronounced in land areas than in oceans (which warm more slowly). On land, temperature increases are likely to exceed the global average by one-and-a-half times. Temperature increases at high latitudes will be amplified, with boreal summer temperatures likely to be at least twice the global average warming, and Arctic winter temperatures warming three times faster than average. And while global average precipitation is projected to increase, areas which are currently arid or semi-arid are likely to become even drier, while the moist tropics and mid-latitudes are projected to become wetter.[159]

Net carbon uptake by terrestrial ecosystems is likely to peak before mid-century (i.e. by the time of our initial mid-century staging post of 2050), weakening or reversing over the course of the 21st century, and amplifying the effects of climate change. 20-30% of plant and animal species assessed are likely to be at increased risk of extinction if global average temperature exceeds 1.5-2.5°C.[160] Already, writes Stewart Brand, warmer temperatures in Europe are moving North at "*25 miles a decade, whereas animals and plants are moving north at only 3.75 miles a decade*".[161]

Sea level rise is an inevitable outcome of a warmer world. The range of future sea level rise is, however, much less certain. Since the publication of AR4 in 2007 there has been a significant upward revision of estimates on global sea level rises, ranging from 0.75-2m by 2100 (an increase from the range of 18-59cm included in the AR4 scenarios).[162] The IPCC was unable to offer a best estimate or upper limit for sea level rise in AR4 because understanding of some effects driving sea level rise was too limited. In particular: "*Future changes in the Greenland and Antarctic ice sheet mass, particularly due to changes in ice flow, are a major source of uncertainty that could increase sea level rise projections. The uncertainty in the penetration of the heat into the oceans also contributes to the future sea level rise uncertainty*".[163]

There is currently insufficient understanding of "*the enhanced melting and retreat of the ice sheets on Greenland and West Antarctica to predict exactly how much the* ***rate*** *[emphasis added] of sea level rise will increase for a given temperature increase above that observed in the past century*".[165]

NASA's Jim Hansen has suggested that a sea level rise in the order of 5m during the course of the 21st century is yielded by revised modelling approaches that allow for non-linear rises resulting from melting of the Greenland and West Antarctic ice sheets.[166] And it has been suggested that the greenhouse gas tipping point for the collapse of the Greenland ice sheet is between 400 and 560ppm; currently at the low end of scenarios for 2100.[167]

More recently, Nicholls *et al* argue that were the world to warm by 4°C by 2100, a pragmatic estimate of sea level rise would be in the range of 0.5-2m. While an average global rise of more than 1m is much less likely (due to uncertainty over whether recent ice sheet melting will continue to accelerate), a rise of such magnitude could force up to 187 million people (up to 2.4% of the global population)to be displaced over the course of the century.[168]

Nicholls *et al* suggest that nations most at risk from sea level rise, such as Bangladesh, would face incremental adaptation costs of $25 billion (for a 0.5m sea level rise) to $270 billion (for a 2m sea level rise) a year to enhance and maintain defences in 2100. The authors suggest that the likelihood of adequate protection being successfully implemented is lowest in small islands, Africa and parts of Asia, making these regions the most likely to experience coastal abandonment.[169]

A significant loss of land in coastal areas could even give rise to ghost states whose governments-in-exile might rule over scattered citizens and land lost to rising seas, and in extreme cases might have to represent virtual states under the ocean.[170]

The social impacts of sea level rise clearly depend on what level of protection is given to coastal areas. Nicholls *et al* outline two distinct views concerning protection: *"The pessimists assume that protection is unaffordable and/or largely fails... This leads to an argument for stringent and immediate climate mitigation and preparation for environmental refugees. The optimists assume that protection will be widespread and largely succeed, and residual impacts will only be a fraction of the potential impacts. Hence, the main consequence of sea-level rise is the diversion of investment into new and upgraded coastal defences and other forms of adaptation (e.g. flood-warning systems)".*[171] The authors stress that, whilst even with adaptation some residual impacts remain, these are minor when compared with a 'no-protection' scenario. In the 'with protection' scenario, the number of displaced people also falls dramatically.

Food production to feed a rapidly growing population is projected to increase at mid to high latitudes with increases in *local* average temperatures over the range 1-3°C, but is likely to decrease for temperature increases above that range. At lower latitudes, however, even small local temperature increases (1-2°C) would likely lead to a decrease in crop productivity, and hence to an increased risk of hunger.[172]

In addition to the largely adverse effects of climate change on agricultural and food systems, Thornton *et al* highlight the effects of an increasing global population (an extra billion people are expected to populate Africa by 2050) and the increased demand for food that will go hand in hand with projected urbanisation and income growth. In order to meet this increased demand for food, huge infrastructural overhaul and investment in agricultural research and technology will be necessary.[173]

In a post-AR4 (2008) study of food security and sustainable agriculture,[174] researchers at the Austrian International Institute for Applied Systems Analysis (IIASA) suggest that developing regions, with the exception of Latin America, will face negative impacts on agricultural GDP. By 2080, climate change will reduce Asia's agricultural GDP by 4% and Sub-Saharan Africa's by up to 8%, they project. Under A2 scenarios, North America could gain 3-13% of agricultural value added, western Europe could lose 6-18%, and the former Soviet Union could gain 0-23%. The study indicates that there may be a considerable increase in the land suitable for cereal production in developed countries over the period 2008-2080. Increases would predominantly occur in North America (a potential 40% area increase of the currently 360 million hectares of cultivated land), in northern Europe (a potential 16% area increase of the 45 million hectares currently being cultivated), in the Russian Federation (a potential 64% area increase of the currently 245 million hectares), and in East Asia (a potential 10% area increase of the 150 million hectares presently under cultivation).

Turning to the overall impact of climate change on human settlements, industries, and societies, the AR4 Synthesis Report notes that *"[t]he most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with* *climate-sensitive resources and those in areas prone to extreme weather events, especially where rapid urbanisation is occurring"*.[175] These vulnerabilities potentially implicate vast numbers of people.

Coastal areas are likely to experience increased risks due to the effects of climate change and sea level rise, including from coastal erosion. *"By the 2080s, many millions more people than today are projected to experience floods every year due to sea level rise"*.[176] Small islands and people living in densely populated and low-lying megadeltas of Asia and Africa are especially vulnerable. The World Bank notes in a 2010 report that *"[t]hirteen of the world's 20 largest cities are located on the coast, and more than a third of the world's people live within 100 miles of a shoreline".* [177]

An assumed 2°C temperature rise usually leads to the projection that the areas most affected by future climate-induced population displacements will be low-lying islands, coastal and deltaic regions, and Sub-Saharan Africa.[178] However, in a +4°C world, the projected increases in extreme weather events, sea level rise and water stress are likely to disrupt existing patterns of migration, such as pastoralists' seasonal nomadic patterns of migration, or the seasonal labour migration to urban centres that Vietnamese rice farmers undertake during the flooding season.[179] For instance, flash floods that are more violent and frequent than they were previously are likely to disrupt traditional movements and severely limit peoples' migration options. Already, successive floods in Vietnam are causing agricultural destruction and have forced farmers to relocate permanently, rather than temporarily, in search of new livelihoods.[180] Permanent forced migration, particularly abroad, would be likely to affect peoples' rights and protection, for, as Gemenne puts it: *"no international protection regime exists for those displaced by environmental changes"*.[181]

Paradoxically, global mobility might decrease in a +4°C world. Gemenne points out that *"[n]umerous studies show that migration flows tend to decrease when environmental crises peak. This is especially true in the case of drought, as people tend to allocate their income primarily to meet their household's basic needs rather than to moving"*.[182] If poverty increases in the future, then in the event of environmental crisis an increasing number of people might find themselves forced to stay in one place.

In relation to health, climate change may bring some benefits such as fewer deaths from exposure to cold. The shifting range and transmission potential of malaria will generate mixed effects. But more negatively, *"[t] he health status of millions of people is projected to be affected through, for example, increases in malnutrition; increased deaths, diseases and injury due to extreme weather events; increased burden of diarrhoeal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some infectious diseases"*.[183]

To illustrate the potential scale of future health challenges in an established democracy, *Table 3* below summarises the anticipated health effects of climate change in the United States. The Table also highlights the non-climate determinants of effects, showing illustratively that these may also be quite significant in some cases.

Given the wide-ranging effects of climate change on human health, it will be particularly important in policy terms to consider factors shaping the overall health of populations, including, for example, education, infrastructure and economic development as well as health care and public health initiatives themselves.

Table 3: Anticipated health effects of climate change in the United States

Weather event	Health effects	Populations most affected	Non-climate determinants
Heat waves	Heat stress	The very old; athletes; the socially isolated; the poor; those with respiratory diseases	Acclimation; built environment
Extreme weather events	Injuries; drowning	Coastal, low-lying land dwellers; the poor	Engineering; zoning and land use policies
Winter weather anomalies (e.g. rain, ice)	Slips and falls; motor vehicle crashes	Dwellers in northern climates; elderly people; drivers	
Sea level rise	Injuries; drowning; water and soil salinisation; ecosystem and economic disruption	Coastal dwellers; those with low socio-economic status	Water pollution; storms; coastal development; land use policies
Increased ozone and pollen formation	Respiratory disease exacerbation (e.g. COPD, asthma, allergic rhinitis, bronchitis)	The elderly; children; those with respiratory diseases	Smoking; air quality; respiratory infections; industrial activity; electric demand and production mode; access to health care
Droughts, ecosystem migration	Food and water shortages; malnutrition	Those with low socio-economic status; the elderly; children	Population growth; food distribution systems; economic and trade issues; biotechnology; petroleum cost
Droughts, floods, increased mean temperature	Food- and water-borne diseases; vector-borne disease	Swimmers; multiple populations at risk depending on outcome of interest; outdoor workers; people pursuing outdoor recreation; the poor (without air conditioning/window screens)	Travel; land use; water treatment and quality; housing quality; food-handling practices; vector and animal host distribution; habitat change; land use
Extreme weather events; droughts	Mass population movement; international conflict	General population	Socio-political factors; resource use and conflicts; economic development
Climate change generally; extreme events	Mental health	The young; the displaced; those with depression or anxiety	Baseline mental health disease burden

Source: adapted from Frumkin et al[184]

Climate change will exacerbate stresses on water resources, as changes in precipitation and temperature lead to changes in runoff and water availability. Available research considered in AR4 suggests significant future increases in heavy rainfall events in many regions. AR4 adds that *"[i]t is likely that up to 20% of the world population will live in areas where river flood potential could increase by the 2080s"*.[185]

In a paper published in late 2010, Fung *et al* explore the relative significance of climate change and population change for water availability in a +2°C world consistent with the objective of the Copenhagen Accord,[186] and secondly a +4°C world more realistically aligned with the most recent scientific predictions.[187] They indicate that the spatial extent of water-stressed areas tends to be greater in a +4˚C world compared with a +2˚C world.[188] In all river basins studied (save for the tropical Amazon), the seasonality of surface run-off becomes stronger as one moves from a +2˚C to a +4˚C world: wet seasons become wetter and dry seasons drier. Wetter wet seasons are likely to give rise to flooding, rather than offering a means of alleviating water stress.[189]

The degree of future water stress will depend on the rate of global warming. Water stress will be considerably more severe if the planet warms quickly, with a +4˚C warming by around mid-century (when the global population is projected to peak). Conversely if global warming is more gradual, with a +4˚C temperature rise reached in 2100 or beyond, when global population is expected to be in decline, water stress will be considerably lower.[190]

Regional climate impacts

Introduction

There are considerable variations in climate impacts at different regional levels. AR4 includes summaries of main projected impacts on a regional basis. It is beyond the scope of the present paper to replicate the lengthy region-by-region summary. However, some of those impacts with greatest immediate potential to impact on democracy or governance are highlighted below for indicative purposes. It should be noted that there is little 'like for like' analysis across the regions, since the projected impacts reflect a combination of SRES scenarios (themselves highly aggregated into four, rather than the eight regions for which projections are offered) and review of available studies. This makes comparisons or firm conclusions difficult. Description (e.g. in relation to adaptation efforts) and projection are also frequently mixed up. This feature is particularly striking in the descriptions/projections for small islands.

In a contribution to the Royal Society's themed issue *Four Degrees and Beyond*", published online in late 2010[191], Sanderson *et al* examine regional climate change (specifically temperature and precipitation changes) in more depth, under high-end (at least 4°C) global warming.[192] Their research is based on the A2 SRES scenario. Their work confirms that the overall regional *patterns* of climate change and the impacts experienced by different regions when considered *relative* to one another are generally similar in high-end and non-high-end climate scenarios. In other words, the choice of high-end or non-high-end scenario does not appear to affect the *relative* distribution of impacts across regions. And in either set of scenarios, "*[m]any continental interiors actually warm approximately twice as fast as the global average, with this being particularly accentuated in boreal summer, and the winter-time Arctic Ocean temperatures rise more than three times faster than the global average. Larger temperature increases and precipitation decreases are projected in some of the regions that currently experience water resource pressures, including Mediterranean fringe regions, indicating enhanced pressure on water resources in these areas"*.[193]

Under high-end models (i.e. those generating the highest emissions and temperature rises) based on the IPCC's A2 scenario, northern Africa faces the greatest risk: it is projected to experience temperature increases greater than 6°C, as well as large precipitation decreases in both summer and winter.[194] In summer specifically, *"Southern Europe and the adjacent part of Central Asia are projected to warm by 6-8˚C, together with a decrease in precipitation of 10 per cent or more. This result suggests that drier soils, a consequence of the reduced precipitation, are the cause of the elevated temperatures, as the evaporative cooling effect will be smaller"*.[195] Parts of Brazil are also likely to experience major climatic changes during the summer. In winter, however, high northern latitude land areas, Mexico and parts of northern Africa are identified as those regions which could be most affected under high-end climate change scenarios.

Africa

The AR4 Synthesis Report indicates that in Africa, between 75 and 250 million people are projected to be exposed to increased water stress due to climate change by 2020.[196] In some African countries yields from rain-fed agriculture could be reduced by up to 50%.[197] It should be noted that both claims are disputed.[198]

In one of a number of post-AR4 studies evaluating the impact of climate change on agricultural revenues in different regions, Deressa and Hassan[199] consider the economic impact of climate change on Ethiopian farmers, and assess links between climate change and net revenues under temperature and precipitation projections for three climate models. They conclude that in every case, revenues per hectare will reduce in both 2050 and 2100. The negative impact of climate change on revenues increases with time, though its distribution is uneven. The findings are significant given the focus on a sector that supports 85% of the population in terms of employment and livelihood [200] and which is dominated by small-scale farming based on low inputs, low outputs, and rain-fed traditional practices. Major causes of underproduction already include drought and flood.[201] Another study shows that the marginal impacts of climate change on incomes from livestock farming in Kenya under A2 and B2 scenarios, modelled for 2050 and 2100, are also likely in the long run to give rise to increased poverty, vulnerability and loss of livelihoods. However, estimated marginal impacts suggest modest gains from rising temperatures and losses from increased precipitation.[202]

Any changes in the primary production of large lakes are also likely to have important impacts on local food supplies.

According to AR4, towards the end of the 21st century projected sea level rise will affect those African low-lying coastal areas with large populations, with adaptation costs of at least 5 to 10% GDP (high degree of confidence).[203] By 2080 an increase of 5 to 8% in arid and semi-arid land surface is projected under a range of climate scenarios (high degree of confidence).[204]

In a post-AR4 study, Thornton *et al*[205] argue that even small increases in global temperature could significantly reduce crop yields globally, due to increases in both heat and water stress. In much of Sub-Saharan Africa, where adaptive capacity is likely to be limited, negative impacts on agriculture are likely to be amplified. In another study, Shah *et al* suggest that southern Africa is the region that will suffer worst from loss of land for agricultural production, and that the region risks losing approximately 11% of its total land area (265 million hectares) for crop production in the 2080s due to environmental constraints induced by climate change.[206]

Thornton *et al* warn that in a +4˚C world *"current crop and livestock varieties and agricultural practices will often be inadequate, and food security will be more difficult to achieve because of commodity price increases and local production shortfalls"*.[207] Growing season length is likely to undergo at least a 20% reduction, though parts of East Africa might see a moderate increase. Season failure rates are projected to increase everywhere except central Africa, and in southern Africa they could increase to the extent that nearly all rain-fed agriculture below latitude 15˚S is likely to fail one year in two.[208]

In a post-AR4 paper focusing on links between eastern and southern African food security and warming of the Indian Ocean, Funk *et al*[209] argue that continued declines in rainfall and percapita agricultural capacity will produce increasing food insecurity, and may lead to a 50% increase in undernourished people in the eastern and southern African regions by 2030.[210] Using observations and climate model simulations, they argue that recent declines in eastern and southern African growing season rainfall are linked to anthropogenic warming in the Indian Ocean. The link to global warming would imply that declines in rainfall are likely to continue or intensify. For eastern Africa, this result is at odds with AR4, which anticipates precipitation increases, whereas for southern Africa the result is consistent with previous analyses which anticipate rainfall declines. The authors argue that recent climate change impact assessments based on optimistic precipitation simulations over eastern Africa may under-estimate yield reductions. However, there are also indications that impacts could be mitigated by agricultural development.

Shah *et al*[211] suggest that the cereal production potential of 16 Sub-Saharan African countries, with a projected population of 780 million in 2080, could drop by 7.9% due to climate change, while the cereal production potential of 14 Sub-Saharan African countries with a projected population of 580 million in 2080 could increase by 5.3%. Any domestic production losses resulting from climate change will further worsen the prevalence and depth of hunger. In all climate change scenarios considered in their study, the authors conclude that a number of countries in Sub-Saharan Africa will have lost their cereal production potential by the 2080s. They list Sudan, Nigeria, Senegal, Mali, Burkina Faso, Somalia, Ethiopia, Zimbabwe, Chad, Sierra Leone, Angola, Mozambique, and Niger. Together, these countries currently have an undernourished population of 87 million, equivalent to 45% of the total population in Sub-Saharan Africa suffering from undernourishment. In contrast, the cereal production potential of Zaire, Tanzania, Kenya, Uganda, Madagascar, Côte d'Ivoire, Benin, Togo, Ghana, and Guinea is projected to increase by the 2080s. These countries currently have a population of 73 million undernourished, equivalent to 38% of Sub-Saharan Africa's undernourished population.

At present, Sub-Saharan Africa's net cereal imports amount to approximately 7 million tons. The impact of climate change may result in a net import of roughly 143 million tons of cereal by 2080.[212] The regional macro-economic and food security implications, for some of the world's poorest countries, are potentially severe.

Asia

In Asia, AR4 indicates that freshwater availability in central, South, East and Southeast Asia is projected to have decreased by the 2050s; rapid urbanisation, industrialisation and economic development are projected to compound natural resource pressures; and endemic mortality and morbidity due to diarrhoeal disease associated with floods and droughts are expected to rise due to projected changes in the hydrological cycle. Crop yields could increase up to 20% in East and Southeast Asia, while they could decrease up to 30% in central and South Asia by the mid-21st century.

A 1m rise in sea level could lead to a loss of almost half of the mangrove area in the Mekong Delta (2,500km^2) while approximately 100,000 hectares of cultivated land and aquaculture would become salt marsh (medium confidence).

Coastal areas, especially heavily populated megadelta regions in South, East and Southeast Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, from rivers. For a 1m rise in sea level, 5,000km^2 of Red River Delta, and 15,000-20,000km^2 of Mekong River Delta are projected to be flooded, which could affect 4 million and 3.5-5 million people, respectively (medium confidence). Under the full range of SRES scenarios, between 120 million to 1.2 billion and 185 to 981 million people in Asia could experience increased water stress by the 2020s and the 2050s, respectively (high confidence).[213]

In a post-AR4 study, researchers forecast a risk of expansion of the range of the parasitic, highly debilitating and potentially fatal water-borne disease schistosomiasis into an additional area translating to 8.1% of the surface area of China by 2050.[214]

A study published in mid 2007 considers how climate change might interact with El Niño events and natural variability to impact on rice agriculture in populous Indonesia. Under SRES scenarios, the researchers foresee a 30-40% likelihood of a 30-day delay in the onset of the annual monsoon in 2050 (compared to 9-18% in 2007).A 30-day delay is selected as the threshold point beyond which significant impact on Indonesia's rice economy is likely.[215]A recent World Bank report, "*Climate Risks and Adaptation in Asian Coastal Megacities"*,[216] examines the impacts of climate change on the Asian megacity hotspots Bangkok, Ho Chi Minh City and Manila. The impacts on each city are based on two IPCC scenarios, a high- and a low-emissions scenario, through to 2050. For Bangkok and Manila the scenarios considered are A1FI (high) and B1 (low), whereas estimated impacts for Ho Chi Minh City are based on A2 (high) and B2 (low), in line with Vietnam's national target programme for responding to climate change. The report concludes that, even under low-emissions scenarios, these three coastal megacities will flood more often and on a larger scale in 2050, affecting millions more people and potentially crippling centres of national and regional economic growth. The cost of damage, particularly in the form of land subsidence and damage to buildings, could range from 2 to 6% respectively of Bangkok and Manila's regional GDP.

Australasia

In Australasia, by as early as 2020, significant biodiversity loss is projected, even under medium emissions scenarios. Among the most vulnerable areas are the Great Barrier Reef, Kakadu Wetlands, rainforests and alpine areas. By 2030, in southern and eastern Australia and in Northland and some eastern regions of New Zealand, water security problems are projected to intensify and production from agriculture and forestry projected to decline due to increased drought and fire. In relation to coastal development, by 2050 there is very likely to be loss of high-value land, faster road deterioration, degraded beaches, and loss of items of cultural significance (very high confidence). Production from agriculture and forestry by 2030 is projected to decline over much of southern and eastern Australia due to increased drought and fire. There will likely be an extra 3,200-5,200 deaths on average per year by 2050, allowing for population growth and ageing but assuming no adaptation (high confidence).[217]

Europe

In Europe, climate change is expected to magnify regional differences in natural resources and assets. Under the A1FI scenario, by the 2080s an additional 1.6 million people a year are expected to be affected by coastal flooding (high confidence). The number of additional people living in water-stressed watersheds in the countries of western Europe is likely to increase from 16 to 44 million under A2 and B1 emission scenarios, respectively, by the 2080s (high confidence). By the 2070s hydropower potential for the whole of Europe is expected to decline by 6%, with strong regional variations from a 20-50% decrease in the Mediterranean region to a 15-30% increase in northern and eastern Europe. A large percentage of European flora could become vulnerable, endangered, critically endangered or extinct by the end of the 21st century under a range of SRES scenarios (very high confidence). Mountainous areas will face glacier retreat, as well as reduced snow cover and winter tourism, with extensive species loss (up to 60% in some areas under high emissions scenarios by 2080). Forest fire risk is virtually certain to greatly increase in southern Europe (high confidence). By 2050, crops are expected to show a northward expansion in area, with the greatest increases in climate-related crop yields expected in northern Europe and the largest reductions in the South (high confidence).[218]

Latin America

In Latin America,[219] increases of 2°C and decreases in soil water are projected to lead to gradual replacement of tropical forest by savannah in eastern Amazonia (high confidence). By the 2020s, between 7 and 77 million people are likely to suffer from a lack of adequate water supplies. For the second half of the century these figures would increase to between 60 and 150 million (high confidence). The frequency and intensity of hurricanes in the Caribbean Basin are likely to increase (medium confidence). There is a significant risk of significant biodiversity loss through species extinction in many areas of tropical Latin America (high confidence). Crop and livestock productivity are projected to decline, with an impact on food security; and disappearing glaciers and precipitation pattern changes are projected to significantly affect the availability of water for human consumption. In a strangely specific projection, the WGII Technical Summary notes that "*cattle productivity is very likely to decline in response to a 4 degree Centigrade increase in temperatures"*.[220] Grain yield reductions could reach up to 30% by 2080 under the A1FI SRES scenario. The number of additional people at risk of hunger under the A2 scenario is likely to reach 5, 26 and 85 million in 2020, 2050 and 2080, respectively. However, if direct CO_2 effects are considered, yield changes could range between reductions of 30% in Mexico and increases of 5% in Argentina, and the additional number of people at risk of hunger under SRES A2 would increase by 1 million in 2020, remain unchanged in 2050 and decrease by 4 million in 2080.[221]

North America

In North America, warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows. In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5-20%; cities currently experiencing heatwaves can expect more, intense and longer heatwaves; and increased stress is likely to be inflicted on coastal communities. Competition for over-allocated water resources is likely to increase (very high confidence). Climate change in the first several decades of the 21st century is likely to increase forest production, but with high sensitivity to drought, storms, insects and other disturbances (high confidence). Warmer summer temperatures are projected to extend the annual window of high fire risks by 10 to 30%, and increase the area burned by 74 to 118% in Canada by 2100 (very high confidence). Ozone-related deaths are projected to increase by 4.5% from the 1990s to the 2050s (medium confidence).[222]

Polar regions

In polar regions, reductions in the thickness and extent of glaciers, ice sheets and sea ice are projected, along with changes in natural ecosystems that would give rise to detrimental effects on many living organisms, and mixed positive and negative effects on human communities in the Arctic.

By the end of the century, annually averaged sea ice is projected to show a reduction of 22-33%, depending on emissions scenario. In Antarctica, projections range from a slight increase to a near-complete loss of summer sea ice (high confidence). By the end of the century, 10-50% of Arctic tundra will be replaced by forest, and around 15-25% of polar desert will be replaced by tundra (medium confidence). In Siberia and North America, there may be an increase in agriculture and forestry as the northern limit of these activities shifts by several hundred kilometres by 2020 (high confidence). Northern Hemisphere permafrost extent is projected to decrease by 20-35% by 2050, and the depth of seasonal thawing is likely to increase by 15-25% in most areas by 2050, and by 50% or more in northernmost locations under the full range of SRES scenarios (high confidence). Over the next 100 years, AR4 notes that there will be important reductions in thickness and extent of ice from Arctic glaciers and ice caps, and the Greenland ice sheet (very high confidence), as a direct response to climate warming.

In Antarctica, losses from the Antarctic Peninsula glaciers will continue (high confidence) and observed thinning in part of the West Antarctic ice sheet, probably driven by oceanic change, will continue (high confidence). AR4 concludes that these contributions will form a substantial fraction of sea-level rise during this century (very high confidence). [223]

Small islands

In small islands, *"Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities"*. By mid-century climate change is expected to reduce water resources in many small islands to the point where they are insufficient to meet demand during low-rainfall periods. Without adaptation, agricultural economic costs from climate change are likely to reach between 2-3% and 17-18% of 2002 GDP by 2050 on high terrain and low terrain islands, respectively, under SRES A2 and B2 (high confidence).[224]

Oddly, the AR4 Synthesis Report notes that climate change might impact on tourism destination selection, but it does not specify the point at which entire island states may be completely inundated under different scenarios.

AR4 summaries of overall sectoral and regional climate impacts

AR4 gives examples of possible impacts of climate change due to changes in extreme weather and climate events, based on SRES projections for the mid to late 21st century (*Table 4* below).[225] The examples are not disaggregated by the six SRES groups.

Clear interpretation of the examples is further hampered by the fact that whilst future trends are allocated a '*likelihood*' based on SRES projections, SRES scenarios are all stated to be considered equally likely.[226] In other words, AR4 includes an assessment of the likelihood of future trends that arise out of scenarios the likelihood of which AR4 declines to assess.

Examples do not take into account any changes or developments in adaptive capacity, and they are highly aggregated, both geographically (the example impacts given are global) and sectorally (by water resources, agriculture, human health, etc.). Even so, the examples offer some indication of the kinds of impacts that democracies may have to contend with over the period 2050-2100. Warren implicitly confirms this when she warns that the interaction between different sectoral impacts and corresponding adaptation processes will likely make for impacts greater than the sum of the individual sectoral impacts to coasts, tropical forests, agriculture, water and migration.[227] Only a limited number of the interactions has thus far been captured by climate models.

Table 4: Examples of possible impacts of climate change

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems *{WGII 4.4, 5.4}*	Water resources *{WGII 3.4}*	Human health *{WGII 8.2, 8.4}*	Industry, settlement and society *{WGII 7.4}*
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	*Virtually certain*[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	*Very likely*	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	*Very likely*	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding: pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	*Likely*	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	*Likely*	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis)[c]	*Likely*[d]	Salinisation of irrigation water, estuaries and fresh-water systems	Decreased fresh-water availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

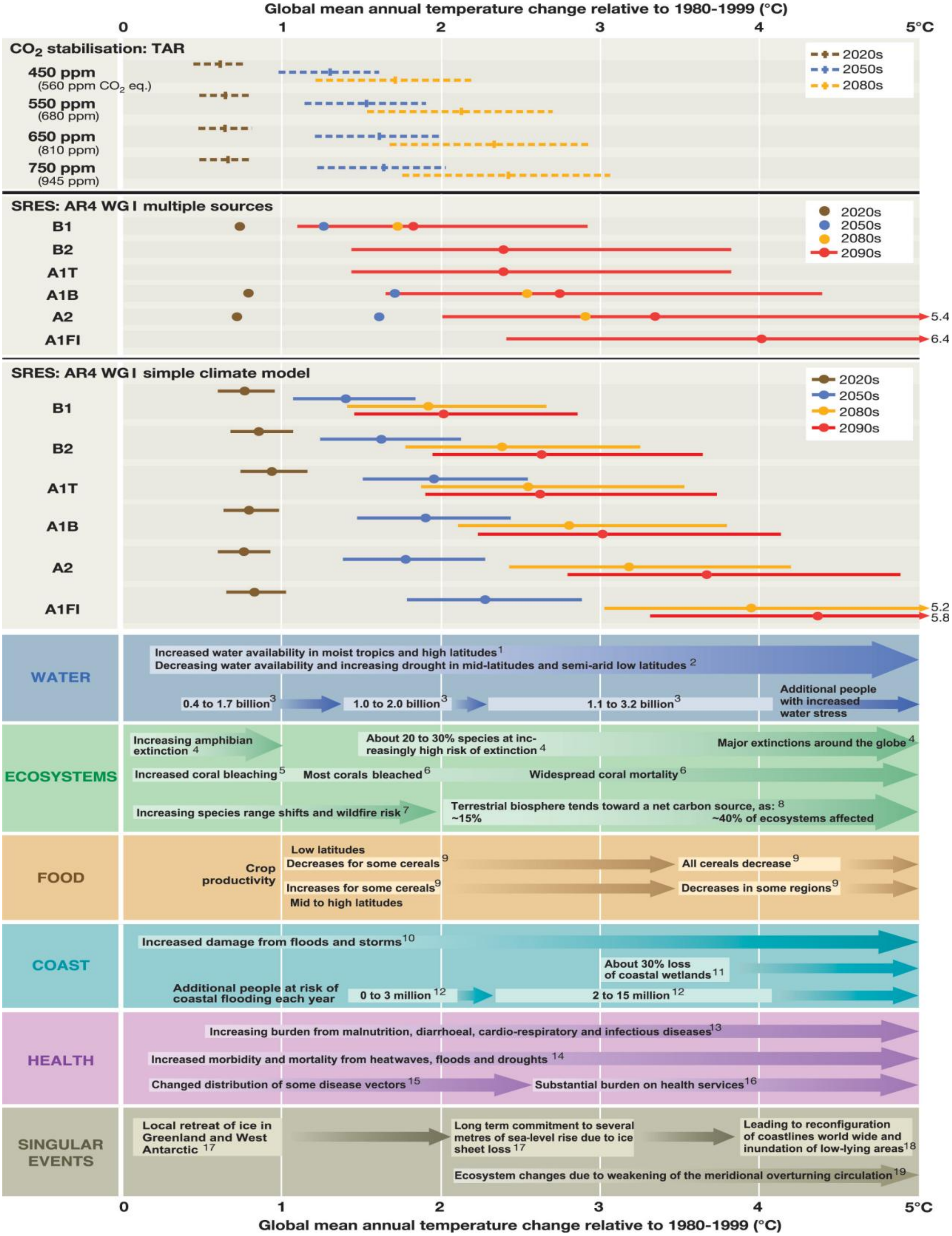
Source: AR4 Synthesis Report, Table 3.2[228]

WGII highlights some of the projected regional and global impacts of climate change in relation to global mean annual temperature change relative to 1980-99 (reproduced in *Figures 2* and *3* below), though it does not link these to individual SRES scenarios or groups of scenarios. CO_2 stabilisation projections in *Figures 2* and *3* are based on the TAR, since there were no comparable projections for AR4.

Plotting these changes in relation to scenarios for mean annual temperature change under different emissions projections allows rough plotting of impacts against timelines.

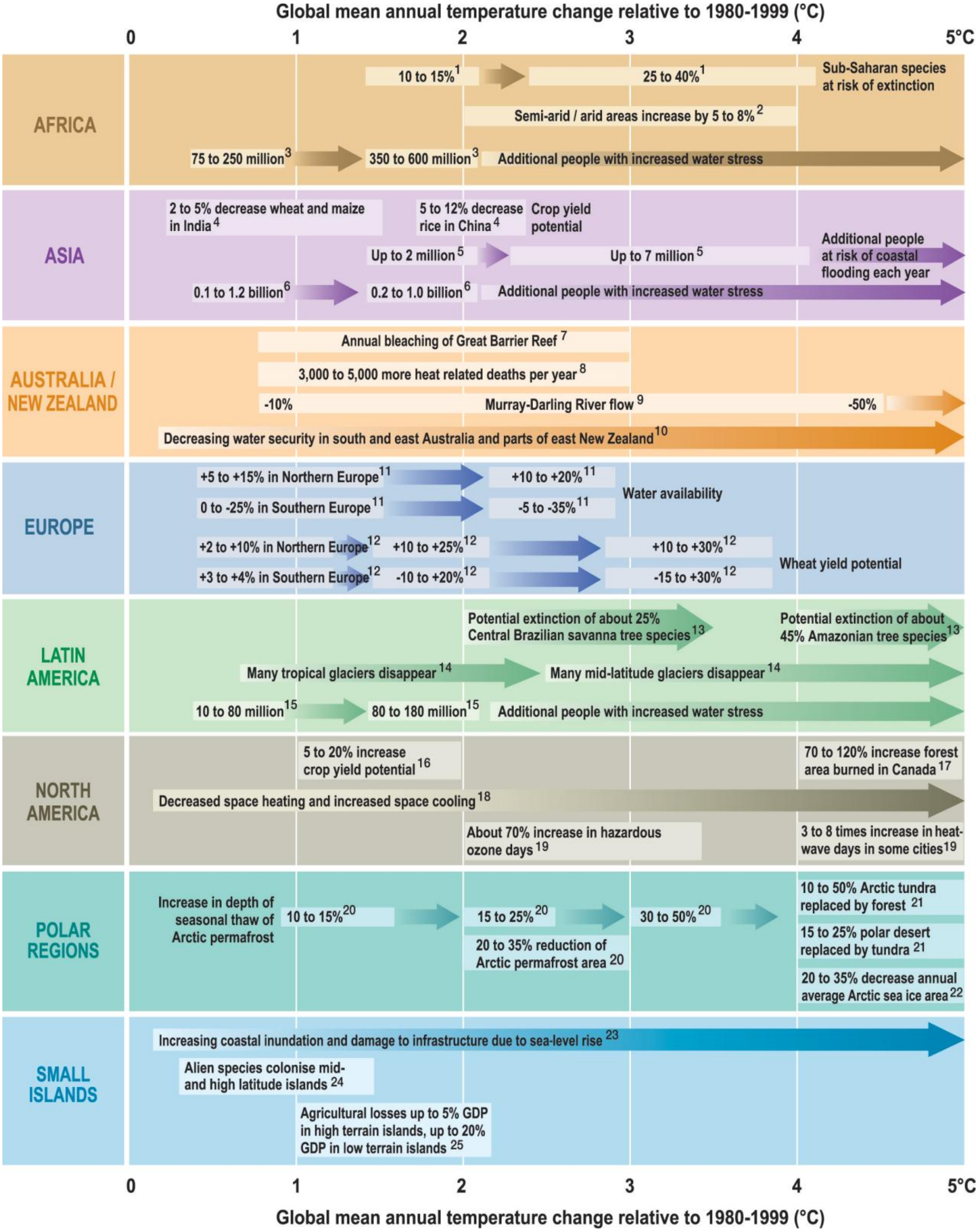
AR4 stops short of providing a comprehensive mapping of projected (or possible) impacts under different scenarios against time and against mean global temperature rise, providing only an indicative range of impacts for the 'high' and 'low' scenarios, B1 (with radiative forcing beyond 2100 kept constant at the 2100 level) and A2 (both reproduced in *Figure 4* below). For our purposes, this is a significant gap which makes it significantly more difficult to develop global scenarios for 2050 and 2100.

Figure 2: Global impacts of climate change in relation to global mean annual temperature change relative to 1980-1999



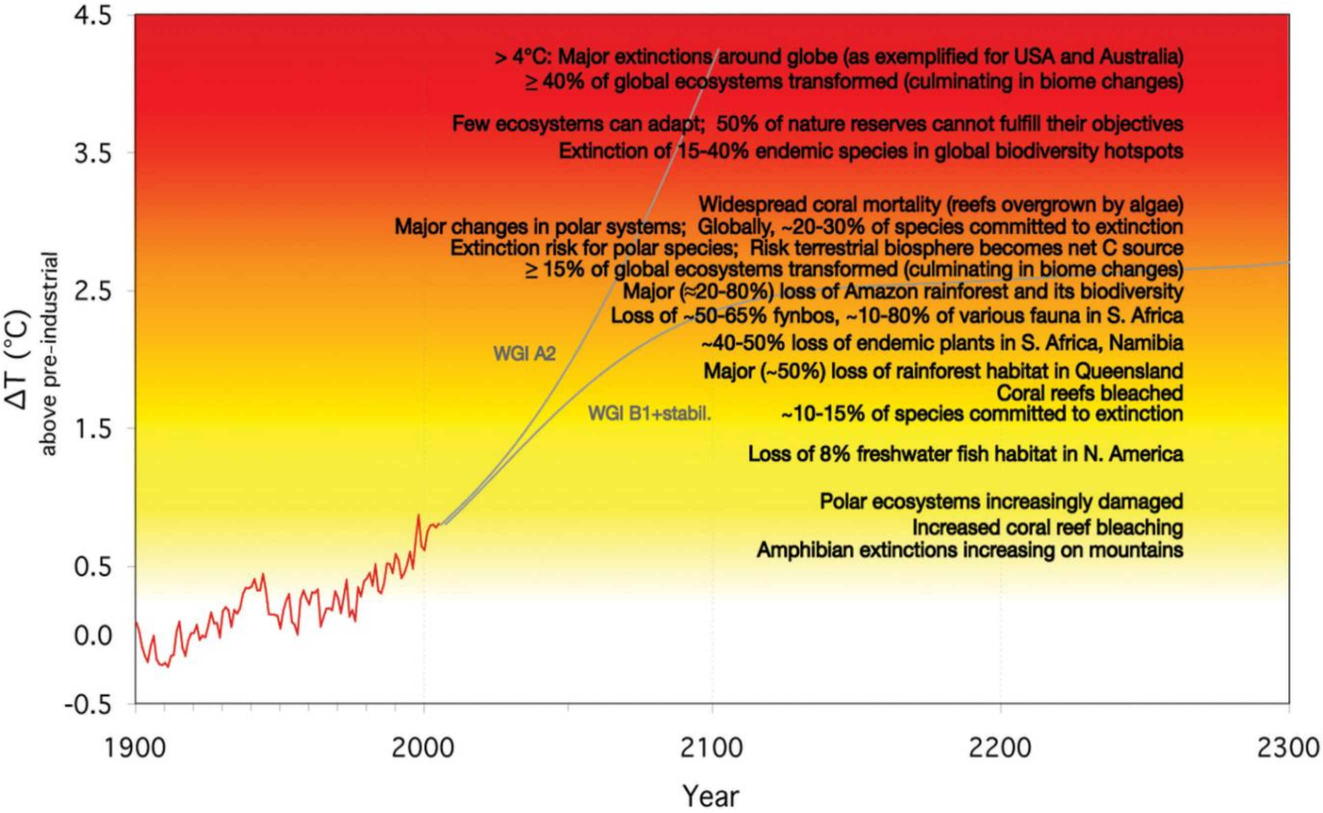
Source: WGII Table TS.3[229]

Figure 3: Regional impacts of climate change in relation to global annual temperature change relative to 1980-1999



Source: WGII Table TS.4[230]

Figure 4: Global and regional impacts of climate change, against time and mean global temperature rise, for scenarios A2 and B1



Source: WGII Figure TS.6[231]

Adaptation to climate change impacts and the relationship with democracy

Adaptation to the possible range of climate impacts will place considerable demand on stocks of social capital as people strive, for example, to organise alternative food production systems or human settlements in the face of climate change.

In the words of the AR4 Synthesis Report: *"Societies can respond to climate change by adapting to its impacts and by reducing GHG emissions (mitigation), thereby reducing the rate and magnitude of change... The capacity to adapt and mitigate is dependent on socio-economic and environmental circumstances, and the availability of information and technology. However much less information is available about the costs and effectiveness of adaptation measures than about mitigation measures"*.[232]

The vogueish word that is used to describe the qualities that are needed – a word that has resonance from the individual family or community level to the core attributes of democracy and political systems themselves - is '*resilience'*.

Resilience, according to a 2009 report for Oxfam America, *"speaks to the capacity of the population, system, or place to buffer or adapt to changing hazard exposures. Within the climate change community, resilience is used along with adaptation to gauge how society responds to this threat source".*[233] WGII defines it as "*the ability of a social or ecological system to absorb disturbance while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt naturally to stress and change*".[234]

Taking adaptive (as distinct from mitigation) capacity as an entry point, what are the indicators of vulnerability, and of potential for successful adaptation? Unsurprisingly, the literature leads to many of the issues that lie at the core of the relationship between democracy and sustainable development.

The vulnerability of any human system is determined partly by its physical properties (e.g. whether it is a large city in a coastal area), and partly by socio-economic context and social preferences.[235] WGII defines vulnerability as *"the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and the variation to which a system is exposed, its sensitivity and its adaptive capacity"*.[236] A 2009 literature review notes that there are many definitions of vulnerability, settling for describing it as "*the susceptibility of a given population, system, or place to harm from exposure to the hazard and directly affects the ability to prepare for, respond to, and recover from hazards and disasters".*[237]

Processes for developing adaptation options potentially provide a direct opportunity to strengthen public participation and draw on the knowledge of local people. For example, a 2009 study of possible adaptation measures of the agriculture sector of the Nile Delta to climate change impacts carried out by researchers affiliated with the Egyptian Ministry of Agriculture and Land Reclamation identifies a range of preferred adaptation measures. These draw on scientific evidence of projected climate changes. Importantly, however, the analysis draws on a (preset) questionnaire-based community level assessment to determine ground level perceptions and adaptive capacity. The Nile Delta is considered to be one of the most vulnerable regions in the world to climate change.[238]

The idea of adaptive capacity can help to identify the prerequisites of successful potential responses to climate change. The AR4 Synthesis Report notes that "*[a]daptive capacity is intimately connected* *to social and economic development, but it is not evenly distributed across and within societies*".[239] The capacity to adapt is influenced by "*a society's productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology. It is also affected by multiple climate and non-climate stresses, as well as development policy*".[240]

It is now clear – post Hurricane Katrina the more so – that even countries with notionally high levels of adaptive capacity may remain vulnerable to climate change in its various manifestations. WGII notes that "*within both developed and developing countries, some regions, localities, or social groups have a lower adaptive capacity*"[241], and also that "*adaptive capacity is not a concern unique to regions with low levels of economic activity*".[242] High income per capita is neither a necessary nor a sufficient indicator of the capacity to adapt to climate change, AR4 suggests. WGII concludes that one "*clear result from research on vulnerability and adaptive capacity is that some dimensions of adaptive capacity are generic, while others are specific to particular climate change impacts. Generic indicators include factors such as education, income and health. Indicators specific to a particular impact, such as drought or floods, may relate to institutions, knowledge and technology*".[243]

Roger Pielke Jr argues that the societal impacts of climate change are a joint product of climate phenomena and societal vulnerability.[244] He insists that it is the increasing vulnerability of human and environmental systems to climate change that is the primary cause of the growth in the magnitude of climate impacts, rather than changes in climate *per se*. From this perspective, it is social policy that must provide a significant part of the solution to both mitigation of and adaptation to climate impacts.

The outcome of local level decision-making will be a key determinant of impacts. Local decision-making and local level public participation in decisions on spatial planning, for example, potentially has significant implications for the cost, and the social impacts, of future climate impacts.

There are also public policy interventions that can help to mitigate some issues where climate change is also a factor in more powerful ways than policies designed simply to mitigate the incremental climate additionality of the projected increase. The projected increase in numbers of people at risk of malaria is an example offered by Pielke in his paper.

The twin challenges of adaptation and vulnerability therefore call for measures to improve *overall* societal responses to climate impacts. As Pielke argues *"even if energy policy could be used intentionally to modulate and control future climate, other factors will play a much larger role in creating future impacts and are arguably more amenable to policy change".* [245]

Pielke's argument might be criticised, to the extent that it could divert attention from the urgent need to take action to contain average global mean temperature rises and minimise the likelihood that the Earth's climate may reach one or more potentially catastrophic tipping points. But Pielke's paper also points to the value of more deliberative processes, and enhanced systems thinking and integrated approaches across different areas of social, economic and environmental policy.

When broader considerations of economic and social impacts are factored into decision-making about adaptation to climate change, it becomes apparent that democracy and democratic decision-making may play a larger role than commonly thought. And the broader context and policy goals of sustainable human development, rather than the mitigated or reduced costs of anthropogenic greenhouse gas-related climate change resulting from adaptation measures, offers a route to attaining the necessary integration.

Make democracy fit for purpose in terms of sustainable development, and we will likely also have generated potential to deliver a more socially just, and aware, approach to anthropogenic climate change and its impacts.

The IPCC stops short of investigating specifically the extent to which the characteristics of *democracy* themselves are significant determinants of adaptive capacity. But there are some links to democracy in the literature – both explicit and implicit. In a paper published in 2001, Yohe and Tol[246] propose eight determinants for adaptive capacity:

1. the range of available technological options for adaptation,

2. the availability of resources and their distribution across the population (in part an outcome of its political system),

3. the structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed (again, partly connected to the political system/s in play),

4. the stock of human capital including education and personal security (once more an outcome and, arguably, a prerequisite for effectively functioning democracy),

5. the stock of social capital including the definition of property rights,

6. the system's access to risk spreading processes,

7. the ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves, and

8. the public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

Yohe and Tol hypothesise that a weakness in one of these determinants could limit the adaptive capacity of the entire system. In a later study published in 2007[247] and designed to test this hypothesis, the authors group indicators of adaptive capacity (informed by TAR but in terms of the generic adaptive capacity of human systems to vectors of external stresses rather than climate-specific adaptive capacity) into five categories: political, cultural, religious (described as a "*dummy indicator*" category) economic, and education-related. The indicators are reproduced in *Table 5* below.

Political indicators include the nature of government and the nature of government intervention in society. Cultural indicators included average attitudes (e.g. to risk). A '*dummy indicator*' set gives the dominant religion in a country. And economic indicators were *per capita* income, income distribution, and poverty rates. Enrolment in education and literacy served as education indicators.

Many of these '*indicators*' are not in fact indicators, but rather themes. The desired direction of change is not evident from the indicators in their summary form. And no analysis is offered for how the indicator themes might be expressed *as* true indicators. Accordingly, we use the phrase "*potential determinants of adaptive capacity*" in *Table 5* below. Indeed, Tol and Yohe also use this language at times.

In their 2007 study, Tol and Yohe assess the relationship between these potential determinants of adaptive capacity and six alternative "*vulnerability*" (or in some cases "*invulnerability*") indicators.

Table 5: determinants of adaptive capacity

Theme	Description	Source
Institutions		
Accountability	Political, civil and human rights	Kaufmann et al. (1999)
Autocracy	Institutionalised autocracy	Marshall and Jaggers (2003)
Civil liberties	Freedom of expression, assembly, association, education and religion	Freedom House (2003)
Executive competition	Extent to which executives are chosen through competitive elections	Marshall and Jaggers (2003)
Corruption	Petty and grand corruption, and state capture	Kaufmann et al. (1999)
Democracy	Institutionalised democracy	Marshall and Jaggers Polity IV (2003)
Economic freedom	Corruption, barriers to trade, fiscal burden, regulatory burden (health, safety, environment, banking, labour)	Heritage Foundation (2003)
Government effectiveness	Competence of bureaucracy and quality of public service	Kaufmann et al. (1999)
Government quality	Quality of public institutions	Gallup and Sachs (1999)
Rule of law	Contract enforcement, quality of policy and judiciary, and crime	Kaufmann et al. (1999)
Political rights	Free and fair elections, competitive politics, opposition power, minority protection	Freedom House (2003)
Executive recruitment	Institutionalised procedure for the transfer of executive power	Marshall and Jaggers (2003)
Extent of regulation	Incidence of market-unfriendly policies	Kaufmann et al. (1999)
Political stability	Violent threats or changes in government	Kaufmann et al. (1999)

Religion		
Buddhism	Predominantly Buddhist	Adherents.com (2003)
Christianity	Predominantly Christian	Adherents.com (2003)
Hinduism	Predominantly Hindu	Adherents.com (2003)
Islam	Predominantly Moslem	Adherents.com (2003)
Yorubaism	Predominantly Yoruba	Adherents.com (2003)
Animism and spiritualism	Predominantly Animist	Adherents.com (2003)
Culture		
Individualism	Reinforcement of individual achievement and interpersonal relationships	Hofstede (2001)
Masculinity	Degree of gender differentiation and male dominance	Hofstede (2001)
Uncertainty avoidance	Tolerance of uncertainty and ambiguity	Hofstede (2001)
Power distance	Degree of inequality in power and wealth	Hofstede (2001)
Long-term orientation	Degree of orientation on the future	Hofstede (2001)
Trust	Degree of trust of others	WVS (2003)
Economics		
Gini coefficient	Degree of income inequality	WRI (2005)
Absolute poverty	Percentage of population living on less than $1/day	WRI (2005)
Relative poverty	Percentage of population below national poverty line	WRI (2005)
Per capita income	Per capita GDP, purchasing power parity exchange rate	WRI (2005)
Education		
Primary	Total enrolment relative to school-age population, primary education	WRI (2005)
Secondary	Total enrolment relative to school-age population, primary education	WRI (2005)
Tertiary	Total enrolment relative to school-age population, primary education	WRI (2005)
Literacy	Percentage of the population over 15 able to read and write	WRI (2005)

Source: Tol and Yohe[248]

The in/vulnerability indicators can readily potentially be linked to a variety of climate scenarios. They include the fraction of people affected by natural disasters normalised according to the size of the population; infant mortality; life expectancy at birth; nutrition reflected by the average calorie supply per person per day; the percentage of people with access to improved sanitation (pit latrines and better); and the percentage of people with access to an improved source of drinking water (rainfall collectors and better).

Tol and Yohe aimed to investigate whether the "*weakest link*" hypothesis held true; namely that "*the adaptive capacity of any system would, for all intents and purposes, be limited by the weakest of [the] underlying determinants [of adaptive capacity]"*.[249] Conversely, they investigated whether there were elements of adaptive capacity that might, or could not, be substituted. They concluded that for vulnerability to natural disasters, infant mortality and drinking water treatment, there is qualified support for the weakest link hypothesis: the weakest indicator plays an important role in determining the overall adaptive capacity, but it is not *the* essential determinant.

For life expectancy, sanitation and nutrition, Tol and Yohe found that the various determinants of adaptive capacity could potentially compensate each other. But they found no empirical support for the strongest link hypothesis, in which one single determinant dominates. Democracy is not an overarching determinant of adaptive capacity.

Although the weakest link hypothesis may well hold for specific hazards at micro-level, things *"get blurred for general hazards at macro-level"*, they note. Out of a list of 34 potential determinants, Tol and Yohe conclude that the list of potentially significant determinants of adaptive capacity includes: the fraction of people in absolute poverty, the average per capita income, income distribution, literacy, enrolment in secondary and tertiary education, democracy, religion, individualism, and uncertainty avoidance. The remaining 24 of the initial list of 34 potential determinants did not have a significant effect on alternative measures of vulnerability. They conclude that "*the statistically significant determinants of adaptive capacity are different for the different measures of vulnerability, which shows that there is no such thing as a general adaptive capacity. Rather, the factors from which systems draw to create adaptive capacity is [sic] different for different risks*".[250]

It is hard to know how best to apply Tol and Yohe's 2007 findings to climate change, given the highly aggregated "*indicators*" [sic] evaluated, and the lack of analysis of their relationship with climate-specific vulnerabilities and determinants of adaptive capacities proposed in their earlier work. Climate-specific analysis might have yielded different results. Clearly though, optimising adaptive capacity calls for investment in a range of its potential determinants. There is no silver bullet; rather a shifting mix of diverse antibodies.

Perhaps Tol and Yohe ultimately simply propose, as UNDP's work on adaptive capacity also suggests, that it is not possible to provide a list of off-the-shelf indicators to capture universal determinants of adaptive capacity. Appropriate indicators for assessing adaptive capacity must be tailored to each case.[251]

In AR4, WGII notes that studies carried out since TAR show that "*adaptive capacity is influenced not only by economic development and technology, but also by social factors such as human capital and governance structures*".[252] Generically, it appears that many of the core features of democracy as a political and social system explored in Paper Two are also potentially important factors in facilitating the emergence of strong adaptive capacities – though much is greatly context-specific. The examples given in *Box 1* below, taken from the WGII AR4 report, offer markers.

Box 1: Adaptative capacities in action

There are many examples where social capital, social networks, values, perceptions, customs, traditions and levels of cognition affect the capability of communities to adapt to risks related to climate change.

Communities in Samoa in the South Pacific rely on informal non-monetary arrangements and social networks to cope with storm damage, along with livelihood diversification and financial remittances through extended family networks.

Strong local and international support networks enable communities in the Cayman Islands to recover from and prepare for tropical storms.

Community organisation is an important factor in adaptive strategies to build resilience among hillside communities in Bolivia.

Recovery from hazards in Cuba is helped by a sense of communal responsibility.

Food-sharing expectations and networks in Nunavut, Canada, allow community members access to so-called country food at times when conditions make it unavailable to some.

The role of food sharing as a part of a community's capacity to adapt to risks in resource provisioning is also evident among native Alaskans.

Adaptive migration options in the 1930s USA Dust Bowl were greatly influenced by the access households had to economic, social and cultural capital.

The cultural change and increased individualism associated with economic growth in Small Island Developing States has eroded the sharing of risk within extended families, thereby reducing the contribution of this social factor to adaptive capacity.

Source: WGII, Chapter 17.3.1[253]

In another study considered by WGII for AR4, Malone and La Rovere set out headings for possible indicators of adaptative capacity in four overall clusters: demographic indicators, economic indicators, governance and policy indicators, and cultural indicators.[254] The challenge, as they say, is to *"develop adaptation strategies appropriate to the societies of the future"*.[255] However, it is striking that the examples of indicators for use in governance and policy analysis do not describe the political system in play, nor opportunities for public participation or access to information (the closest the examples come is to suggest consideration of "'*planned state reforms', e.g. privatisation, current and planned free-trade agreements*"[256]).

The state of research on adaptive capacity does not appear yet to lend itself to an assessment of correlation between determinants of democratic resilience (or '*strong*' democracy in its senses both as political system and system for social organisation) and determinants of adaptive capacity. But it seems clear from our work to date that this is an area where further research is justified.

Indicators or determinants of adaptive capacity do not have a clear read-across to notional indicators of effective mitigation capacity. Indeed, to our knowledge such indicators have not been developed. Mitigation capacity indicators might include for example uncontested science, wide public access to information (e.g. to maximise the potentially beneficial power of climate-sensitive consumer choice), strong public will for change (at least in democracies), and widespread technologically available alternative sources of energy and/or abatement. As we suggested in Paper One, mitigation presents greater challenges for established systems of democracy than adaptation.

For 'believers' in climate change, indicators of effective mitigation actions given the current low performance across these notional determinants, might be closely related to strong governance and top-down leadership. On the other hand, indicator sets or criteria developed in the adaptation literature are much more closely related to democracy and/or the features of good governance for sustainable development.

No wonder environmentalists are confused; hankering misty-eyed after benign dictators at the same time as renewed and strengthened systems of democracy and social interaction to deliver resilience and effective adaptive capacity at the local level. It seems very unlikely both could come about through a linear progression (from democracy now, to benign authoritarianism within the next 25 years so as to facilitate mitigation of the necessary intensity, to the kinds of democratic systems that could potentially maximise development of adaptive capacities).

With climate change potentially already hard-wired into the Earth's systems, adaptation actions are justified independently of mitigation actions. 'Democracy sceptics' within the environmental movement need to recognise that it is unlikely that benign authoritarianism could deliver effective adaptation capacity or local level resilience. But an open question is whether efforts to strengthen democracy in various ways at sub-national levels deliver dividends in terms of enhanced adaptive capacity, and if so, where and how.

Climate change mitigation and policy goals

Introduction

It can be hard to translate the sometimes bewildering body of scientific data and prognostication into hard behavioural or policy facts. Indeed, it is almost entirely unsurprising that it has proved difficult for countries to agree on targets and timetables for emissions reductions, even if the political challenges were removed.

We have already seen that there are substantial scientific uncertainties and methodological issues associated with current climate models and the scenarios data on which they are based. Disagreements over the pace of climate change – and how far temperatures or sea level might rise – will certainly continue.

One thing that is agreed by all is that CO_2 traps heat and that the burning of fossil fuels adds to CO_2 in the atmosphere. And it is equally clear, as Roger Pielke Jr argues, that "*accelerating decarbonisation of the global economy and improving adaptation to climate change make good sense quite independent of long-term predictions of the climate future*".[257]

The pressing need to decarbonise the global economy is given an added dimension by the peak oil agenda, with a growing consensus that peak oil was reached at some point between 2005 and 2008[258]. As such, the imperative for an effective shift towards sources of low-carbon energy is all the more clear. As the oil giant, Shell, puts it, *even if* it were possible for fossil fuels to maintain their current share of the energy mix and respond to increased demand, emissions of CO_2 would "*then be on a pathway that could severely threaten human well-being"*.[259]

Regrettably, however, for all the apparent synergy between the climate change and peak oil agendas, the two currently occupy distinct policy realms. Heinberg suggests that climate change activists are prone to quote overly robust estimates of remaining fossil fuel reserves. As a result, moderate climate activists, for example, might argue in favour of a switch to less carbon-intensive fuels such as natural gas, or might encourage investment in clean coal technologies. The result can be impenetrable argument over numbers, fuelled by what Heinberg considers to be *"unrealistic optimism on the part of official forecasting agencies"*[260].

As with the twin agendas of peak oil and climate change, the politics and the science of climate change are very far from aligned. Thus far, the global community of nations has consummately failed to agree on legally binding targets and associated timetables for reduction in greenhouse gas emissions to mitigate the potential impacts of climate change, much less to allocate carbon or greenhouse gas budgets as between developed and developing nations.

As emerging market economies rise in global economic significance, so too does their significance in terms of increases in global greenhouse gas emissions.

An old focus on the '*common but differentiated responsibilities'* of developed and developing nations respectively, taken in context of the history of colonisation and industrial development seems increasingly inappropriate. The old political economy of 'North and South' is shifting to accommodate new economic realities, including recession in many OECD countries following the financial crisis of 2008. AR4 notes that CO_2 emissions from energy use are projected to grow between 40 and 110% between 2000 and 2030, with two thirds to three quarters of the increase projected to come from non-Annex I regions.[261] China's CO_2 emissions from fossil fuel use had already overtaken those of the United States by 2006, by more than 8%.[262] Yet China, like other non-Annex I countries with rapidly growing emissions and large populations – such as Brazil and India, has no legally binding targets for its greenhouse gas emissions.

This crude overview represents just a fraction of the global governance challenge presented by climate change. The scope of the IPCC does not, of course, extend to an evaluation of the political science base for effective climate policy, nor political economy or political science scenarios for climate action. As the previous discussion of adaptive capacity suggests, it might be helpful if it did. But in considering issues surrounding adaptive capacity, the IPCC's work has arguably helped to give further impetus to the inclusion of adaptation within UNFCCC negotiations, providing a degree of empirical underpinning for the operation of the Kyoto Protocol Adaptation Fund[263] and negotiations on adaptation financing at the UNFCCC Conferences of the Parties in Copenhagen and Cancún in 2009 and 2010 respectively.[264]

Coordinated development of empirical analysis that is more closely linked to the political science, governance, political economy and behavioural economics and psychology implications of climate adaptation and mitigation could help to provide a more systematic grounding for intergovernmental reflection and negotiation on policy responses to climate change.

Human systems of political and social organisation – their current shape, and how they could evolve or be shaped - remain an unacknowledged elephant in the IPCC room. The shape of the elephant is discernable in the multiple analytical gaps that we have identified concerning the application of the SRES scenarios within the IPCC. Its shadowy form can be clearly seen in the IPCC's work on adaptation. And it can also be made out in IPCC work on mitigation, which we consider further in this section.

Mitigation scenarios and policy options in AR4

WGII of AR4 considers the mitigation potential, relative to emission baselines, for a given level of carbon price. Mitigation potential is further divided into "*market*" potential and "*economic*" potential.[265]

Market potential is essentially the mitigation potential which might be expected to occur under forecast market conditions (including – unlike SRES scenarios – policies and measures currently in place), whilst noting that barriers limit uptake of the potential.

Economic potential is the mitigation potential taking into account social costs and benefits of mitigation, and assuming that market efficiency is improved by policies and measures and that barriers are removed. Economic potential is therefore likely to be greater in most cases than market potential.[266] In both cases, models factor in a range of assumptions on technological and structural changes.

Bottom-up studies of mitigation options take macro-economic circumstances as a given, and assess specific technologies and regulations. Top-down studies assess the economy-wide potential of mitigation options. WGIII notes that bottom-up studies are useful for assessment of specific policy options at the level of particular economic sectors, whilst top-down studies are useful for assessing cross-sectoral and economy-wide climate change policies such as carbon taxes and stabilisation policies.[267] Both approaches incorporate only limited consideration of lifestyle choices, and have only limited representation of some regions, countries, sectors, gases and barriers.

WGIII concludes from both bottom-up and top-down studies that there is substantial economic potential for mitigation of global emissions in the period to 2030, sufficient to "*offset the projected growth of global emissions or reduce emissions below current levels*".[268]

Estimated global economic mitigation potential for top-down and bottom-up models as assessed in AR4 is summarised below for a range of carbon prices. As a point of reference, actual emissions in 2000 were 43GtCO_2-eq.

Table 6: Global economic mitigation potential in 2030 estimated from bottom-up studies

Carbon price (US$/t$CO_2$-eq)	**Economic potential** (GtCO_2-eq/yr)	**Reduction relative to SRES A1B** (68 GtCO_2-eq/yr in 2030) (%)	**Reduction relative to SRES B2** (49 GtCO_2-eq/yr in 2030) (%)
0	5-7	7-10	10-14
20	9-17	14-25	19-35
50	13-26	20-38	27-52
100	16-31	23-46	32-63

Source: WGIII, Table SPM 1[269]

Table 7: Global economic mitigation potential in 2030 estimated from top-down studies

Carbon price ($US\$/tCO_2$-eq)	**Economic potential** ($GtCO_2$-eq/yr)	**Reduction relative to SRES A1B** (68 $GtCO_2$-eq/yr in 2030) (%)	**Reduction relative to SRES B2** (49 $GtCO_2$-eq/yr in 2030) (%)
20	9-18	13-27	18-37
50	14-23	21-34	29-47
100	17-26	25-38	35-53

Source: WGIII, Table SPM 2[270]

Overall economic potentials for top-down and bottom-up models are broadly congruent, though there are considerable differences at the sectoral level.

WGIII also reviews macro-economic costs for multi-gas mitigation to 2030. These top-down economic cost models to 2030 are derived from stabilisation scenarios summarised in *Table 8* below. Overall, the range of macro-economic costs for multi greenhouse gas mitigation that is consistent with emissions trajectories towards stabilisation at between 445 and 710ppm CO2 equivalent lies in the range between 3% decrease of global GDP to a small increase when compared to a the various baselines used in the studies assessed.

Table 8: Estimated global macro-economic costs in 2030 for least-cost trajectories towards different long-term stabilisation levels

Stabilisation levels (ppm CO_2-eq)	**Median GDP reduction (%)**	**Range of GDP reduction (%)**	**Reduction of average annual GDP growth rates**
590-710	0.2	-0.6-1.2	<0.06
535-590	0.6	0.2-2.5	<0.1
445-535	Not available	<3	<0.12

NB: studies vary in the point in time when stabilisation is achieved. Generally it is 2100 or later
NB: studies use various baselines
NB: GDP is global GDP based on market exchange rates
Source: WGIII, Table SPM.4[271]

Technological changes interact with structural changes in virtually all stabilisation scenarios. WGIII notes that baseline scenarios usually assume significant technological change and diffusion of new and advanced technologies – with some mitigation scenarios then inducing additional technological changes through the introduction of different policies and measures to achieve emissions reduction. Newer literature goes beyond exogenous technology improvement and use of advanced technologies to incorporate learning by doing and endogenous technological change. WGIII notes that the newer scenarios show higher benefits of early action, as models assume that early deployment of technologies leads to benefits of learning and cost reduction.[272]

The range of stabilisation levels and associated climate and human impacts shown in *Table 8* above is surprisingly wide given the relatively short timescale (to 2030) of the studies assessed. Taking the data at face value, macro-economic costs[273] to mitigation portfolios and with universal emissions trading (even assuming transparent markets and no transaction costs),[274] could still lead to stabilisation levels that are associated with climate impacts ranging from the threshold between "*dangerous*" and "*extremely dangerous*" (445ppm CO_2-eq) and to an upper stabilisation level associated, even at the time of AR4, with a global mean temperature rise of 4°C.

WGIII notes that costs may be lower under an assumption that revenues from carbon taxes or auctioned permits under an emission trading system are used to promote low-carbon technologies.[275] Equally, studies that assume that climate change policy induces enhanced technological change also give lower costs. GDP *gains* result in some models that assume that technological change may be induced by mitigation policies. Importantly, the inclusion of multiple greenhouse gases (not limited to CO_2 alone) and carbon sinks generally reduces costs substantially when compared to CO_2 abatement alone.

WGIII also suggests that the near-term health co-benefits from reduced air pollution as a result of action to reduce greenhouse gas emissions may offset a substantial fraction of mitigation costs.[276] And in addition to mitigation technologies and practices that are linked to particular economic sectors and currently commercially available or to be commercialised by 2030, WGIII notes potential for changes in lifestyle and behaviour patterns to contribute to climate change mitigation. In a significant gap, for purposes of our project on the relationship between democracy and climate change, these are not quantified, nor is their impact on the feasibility of other mitigation options assessed. In Paper Three, we highlighted the potential for behavioural changes to drive new forms of democratic engagement and public participation better attuned to the achievement of sustainable development outcomes. And it is behavioural patterns, along with current economic growth models, that present the most significant '*democracy*' obstacles to effective climate action. The omission of any serious analysis of behavioural or lifestyle change from the IPCC is therefore a significant gap.

Key sectoral options identified in WGIII for sector-specific mitigation are highlighted in *Table 9* below.

Climate mitigation is strongly (though not exclusively) technology-dependent, with the availability of technologies itself closely linked to the overall enabling environment for technology investment and development. Aside from the range of already-existing mitigation technologies, WGIII notes the potential of geoengineering options such as ocean fertilisation to remove CO_2 directly from the atmosphere, or blocking sunlight, but stresses that these options remain speculative and unproven, with the risk of unknown side effects. Further, reliable cost estimates for these options have not been published.[277]

WGIII notes that limited results from integrated analyses of costs and benefits of mitigation do not as yet permit unambiguous determination of the emissions pathway or stabilisation level where benefits exceed costs.[278] At the same time, choices about the scale and timing of greenhouse gas mitigation involve "*balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay*".[279]

Table 9: Key mitigation technologies and practices by sector

Sector	Key mitigation technologies and practices currently commercially available	Key mitigation technologies and practices projected to be commercialized before 2030
Energy supply	Improved supply and distribution efficiency; field switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of Carbon Capture and Storage (CCS, e.g. storage of removed CO_2 from natural gas)	CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and solar PV.
Transport	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land use and transport planning.	Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries.
Buildings	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases.	Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar PV integrated in buildings.
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions; and wide array of process-specific technologies.	Advanced energy efficiency; CCS for cement, ammonia, and iron manufacturer; inert electrodes for aluminium manufacture.
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertilizer application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency.	Improvements of crops yields.
Forestry/forests	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use.	Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing technologies for analysis of vegetation/soil carbon sequestration potential and mapping land use change.
Waste management	Landfill methane recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimization.	Biocovers and biofilters to optimize CH_4 oxidation.

Source: WGIII, Table SPM. 3[280]

WGIII also considers the range of measures, policies and instruments to mitigate climate change and outlines (very) general findings about the performance of eight policy and instrument types. The eight are: integration of climate policies into broader development policies; regulations and standards; taxes and charges; tradable permits; financial incentives – subsidies and tax credits; voluntary agreements; information instruments; and research and development.[284] Evaluation criteria applied by WGIII include institutional feasibility, but not social acceptability. The latter would have provided the basis for an assessment of the interaction of particular policy types with some of climate policy's democracy challenges.

Highlights from the WGIII evaluation of policies and instruments that are relevant to the relationship between democracy and climate change, or to the feasibility of achieving meaningful mitigation, include that:

- Information instruments may positively affect environmental quality by promoting informed choices and possibly contributing to behavioural change. However, their impact on emissions has not been measured yet.
- Voluntary agreements between industry and governments are politically attractive, but the majority of agreements has not achieved significant emissions reductions beyond business as usual.
- A wide range of voluntary actions may limit emissions, stimulate innovative policies and encourage the deployment of new technologies. However, on their own, they generally have limited impact on national or regional level emissions.

In a finding that is particularly worrying given the major remaining uncertainties surrounding climate science, WGIII notes that government funding in real absolute terms for most energy research programmes is now about half of the 1980 level.[285]

WGIII places a strong emphasis on carbon pricing and market-based approaches to climate mitigation, noting that an effective carbon price signal could realise "*significant*" mitigation potential in all sectors. The report suggests, however, that barriers to implementation of mitigation options are manifold and varied.[286]

Assessing the gap between current government commitments and a 2°C warming target

The goal of confining global warming to an average of 2°C (implicitly over pre-industrial levels) is acknowledged in the 2009 Copenhagen Accord. But even that level of average warming may be insufficient to prevent dangerous consequences.

Anderson and Bows suggest that it is now more appropriate to consider 2°C as the threshold between dangerous' and 'extremely dangerous' climate change, rather than between 'acceptable' and 'dangerous' climate change as previously thought.[287]

Researchers engaged in the Copenhagen Diagnosis give a clear estimation of the scale of the decisions required of people and policymakers: "*If global warming is to be limited to a maximum of 2°C above preindustrial values, global emissions need to peak between 2015 and 2020 and then decline rapidly. To stabilize climate, a decarbonized global society – with near-zero emissions of CO_2 and other long-lived greenhouse gases – needs to be reached well within this century. More specifically, the average annual per-capita emissions will have to shrink to well under 1 metric ton CO_2 by 2050. This is 80-95% below the per-capita emissions in developed nations in 2000*".[288]

Clearly, for all that they are inadequate, pledges made under the Copenhagen Accord are nonetheless significant in setting up emissions trajectories for the future. According to a recent preliminary assessment of pledges made by countries to reduce their emissions under the Copenhagen Accord carried out by the UNEP, and of the variety of studies of emissions pathways that might be consistent with various limits, the pledges that are already in place leave a significant gap if the aspiration of a 2 (or ideally 1.5)°C rise is to be realised.[289]

UNEP concludes (with a number of caveats on areas of uncertainty) that:

> *"[i]f we start at the level of emissions expected from the Copenhagen Accord pledges in 2020 and then follow the range of these pathways through to 2100, we find that they imply a temperature increase of between 2.5 to 5° C before the end of the century (see Figure 2). The*

> *lower bound is the case in which emissions are fairly stringently controlled after 2020, and the upper in which they are more weakly controlled. In other words, emission levels in 2020 implied by current pledges do not seem to be consistent with 2° C or 1.5° C temperature limits. To stay within these limits, emission levels would have to be lower in 2020 and then be followed by considerable reductions".* [290]

Emission pathways consistent with a 'likely' chance of meeting the 2° C limit "*generally peak before 2020, have emission levels in 2020 around 44 $GtCO_2e$ [$GtCO_2$-eq](range: 39-44 $GtCO_2e^7$), have steep emission reductions afterwards and/or reach negative emissions in the longer term*". "*2020 emission levels with a "likely" chance of staying within the 2° C limit can be about the same as those with a "medium" or lower chance of meeting the 1.5° C target. However, to have a higher chance of meeting the 1.5° C target the emission reduction rates after 2020 would have to be much faster*".[291]

Taking Copenhagen Accord pledges as a starting point, the study suggests that *"[o]n one hand, emissions in 2020 could be as low as 49 $GtCO_2e$ (range: 47-51 $GtCO_2e$) when countries implement their conditional pledges with "strict" accounting rules. On the other hand, they could be as high as 53 $GtCO_2e$ (range: 52-57 $GtCO_2e$) when countries implement unconditional pledges with "lenient" accounting rules*".[292] UNEP emphasises that a range of other factors could also combine to make eventual emissions lower or higher than these estimates, including risks associated with double counting and the availability of climate finance.[293]

Given the existence of the '*pledge*' and '*emissions*' gap, UNEP notes that "*if the aim is to have a "likely" chance (greater than 66 per cent) of staying below the 2° C temperature limit, the gap would range from 5-9 $GtCO_2e$, depending on how the pledges are implemented".*[294]

AR4 is clear that whatever mitigation measures are undertaken over the next two to three decades, additional adaptation measures will be required at regional and local levels to reduce the adverse impacts of projected climate change and variability.[295]UNEP's assessment underscores this insight. And it also points to an urgent need for enhanced understanding of adaptation capacities and the kinds of governance systems that are best equipped to optimise adaptation capacities at local and national levels. Comparative and context-specific assessment of different systems of different social and political organisations and their potential contribution to climate change should become a more important ingredient in the IPCC mix.

Climate sceptics and climate 'denial'

The evidence of human-induced climate change is far from uncontested. But the major controversies of the blogosphere have not always matched the areas of uncertainty highlighted in the reports of the IPCC. Like the many differences of opinion that exist between those who argue the case for human-induced climate change, there are complexities regarding 'climate sceptics'. Indeed, the binary characterisation of (to use equally disparaging terms) so-called 'warmists' and 'sceptics' does a significant disservice to the wide range of debate. For example, some on the sceptic side of the spectrum argue that climate change is not anthropogenic. Others deny its existence entirely. *Fully* accommodating scepticism within public policy processes would therefore entail a negation of the precautionary approach.[296] And it would also mean far less, and slower, action to tackle climate change.

One warmist website documents a total of 142[297] sceptic arguments, responding to each under the heading "*what the science says*". Among them are the arguments that "*an ice age was predicted in the 70s*"; that "*it's the sun*"; that the Earth is actually cooling; that "*it's just a natural cycle*"; that "*global warming is good*"; that "*Antarctica is gaining ice*"; that "*it's El Niño*"; or that "*it's aerosols*".[298]

Many of the claims are easily refuted – as one would expect given the diversity in the sources, knowledge, and interests of those expressing their scepticism. But in other areas, the concerns of individuals and scientists sceptical about particular areas of scientific investigation of climate change have helped to strengthen the methodological robustness of climate science.

Fred Pearce narrates the story of the people and the issues behind three particular areas of controversy:[299]

- the '*hockey stick'* graph produced by Mike Mann and others, which shows through a range of proxies how global temperatures hardly changed over the first millennium until a major rise in the 20th century which resulted in a graph of temperature changes which formed the shape of a hockey stick that was then included within the AR2;
- the use of evidence of past temperatures gathered from the proxy evidence before temperature records began some 160 years ago; particularly proxy data offered by tree rings, and the methods employed to select and profile data sets from different tree ring sources;
- controversy over the extent to which different temperature data sets account for the possible warming effect of increased urbanisation and the resulting '*heat islands'* in the vicinity of some weather stations.

In all of these areas the close scrutiny of scientific findings that resulted from the activism of so-called sceptics appears to have served in part to secure greater clarity and more robust methodological approaches on the part of climate scientists. We might speculate, too, that climate scepticism has served in part to advance the cause of scientific expert accountability. But the interaction between adversaries – as revealed by Pearce's account and, in part, the documentary evidence of the '*climategate*' email revelations (as to which, see Paper One) – also shows defensiveness.

Pearce's tale shows scientists taking on advocacy roles. It demonstrates a lack of deep understanding on the part of climate scientists of the wider connection between their work and an approach to democracy based on deep rather than shallow transparency (e.g. of data sets), as well as deliberation about and accountability of expert inputs into processes that are inherently '*public*' in nature (as to which, see further Paper Three). And it reveals the political nature of the academic peer review and journal publication process; with impacts on the overall body of work that is available to the IPCC's periodic assessment processes.

One issue is the scientific debate. And another, as we have seen with the controversy of so-called '*glaciergate*', is how the IPCC then filters it – for example, in its profiling of grey literature or the 'hockey stick' graph, or its adoption of almost meaningless vague statements of probability.

The detail is beyond the interest of most ordinary people. But its effects have lasting impact. There is little evidence that climategate, for example, had any significant impact on proceedings at the Copenhagen Climate Summit. But tension between warmists and sceptics and the associated battle of words has continued unabated since the climategate controversy.

In the period since we completed a draft of Paper One in this research project, in March 2010, three inquiries into climategate – one of them carried out by UK Members of Parliament – have reported, and have largely upheld the integrity of the University of East Anglia researchers. But public opinion in some parts of the world – on whether climate change is caused by human activities; whether global warming is happening; and the urgency of the need to take action to mitigate its risks – has moved away from concern about the climate since the dismal Copenhagen Climate Summit.[300] The polling data – for what it is worth - does not provide evidence of a massive shift towards scepticism. But there is still evidence in the UK, for example, that 40% of the population in June 2010 thought that the seriousness of climate change was exaggerated.[301]

The bond of assumed trust between a vast body of expert scientific research and the world of policy has been broken for significant parts of the population in countries like the UK and the US. The IAC's IPCC report confirms this: *"public opinion polls in the United States and United Kingdom showed that public confidence in climate science has waned".*[302] The internet, social media and the blogosphere, have been brokers of the breach. And whilst that brokering process has sometimes been to the overall benefit of scientific accuracy, it has as often (if not more often) been to the detriment of rational, or non-ideological, discussion of the issues.

Today, environmentalists, or simply people concerned about climate change, are frequently referred to in the western blogosphere as '*eco-fascists*' or '*green nazis*',[303] So too are journalists or broadcasters who present the views of warmist climate scientists or fail to report on predictions of cold winters. There is a nastiness in the social media debate about climate change that had not previously been so visible. And here, it is sceptics, rather than environmentalists, who are on the attack.

But then the stakes are getting higher. And the use of shocking media tactics is also intensifying within the environmental movement and even government. Red buttons that explode people who don't take action to reduce their carbon emissions.[304] Scary bed-time stories.[305] Pale-faced, haunting children.[306]

Richard Feinberg writes that peak oil authors have pointed to Kübler-Ross's five-stage model of grief.[307] People who have been informed that they have a fatal illness typically go through five stages, he suggests: denial, anger, bargaining, depression and acceptance. Could climate denial – in its most visceral forms – perhaps be a symptom of a deeper collective grieving process; a natural psychological response to a diagnosis of potentially terminal illness?

What happens next will depend in part on what hard evidence continues to emerge as climate science evolves. As we have seen, there is a great deal more that the IPCC could do to offer greater clarity in the process. But what happens next will depend as much on how democracy – as both political and social system – evolves.

Climate change impacts on democracy. And it is also clear from this review of AR4 and key associated reports – though the IPCC does not spell this out explicitly – that shifts in the practice of democracy will potentially have major impacts on climate change.

As we conclude Paper Four and begin the process of developing scenarios for the future of democracy in the face of climate change, we have raised many questions that remain unanswered by the work of the IPCC.

Without a detailed knowledge, down to the level of original source documents, of the academic and other analytical materials considered by the IPCC, it is virtually impossible to make robust assertions on the potential evolution of climate impacts to 2050 and 2100, let alone the relationship with democracy. The IPCC offers both a great deal and very little to aid the exercise, even though its substantive core – the evolving relationship between democracy and climate change – may have profound impacts on the future shape of social and political systems and our ability as humans to deliver globally made promises on sustainable development.

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