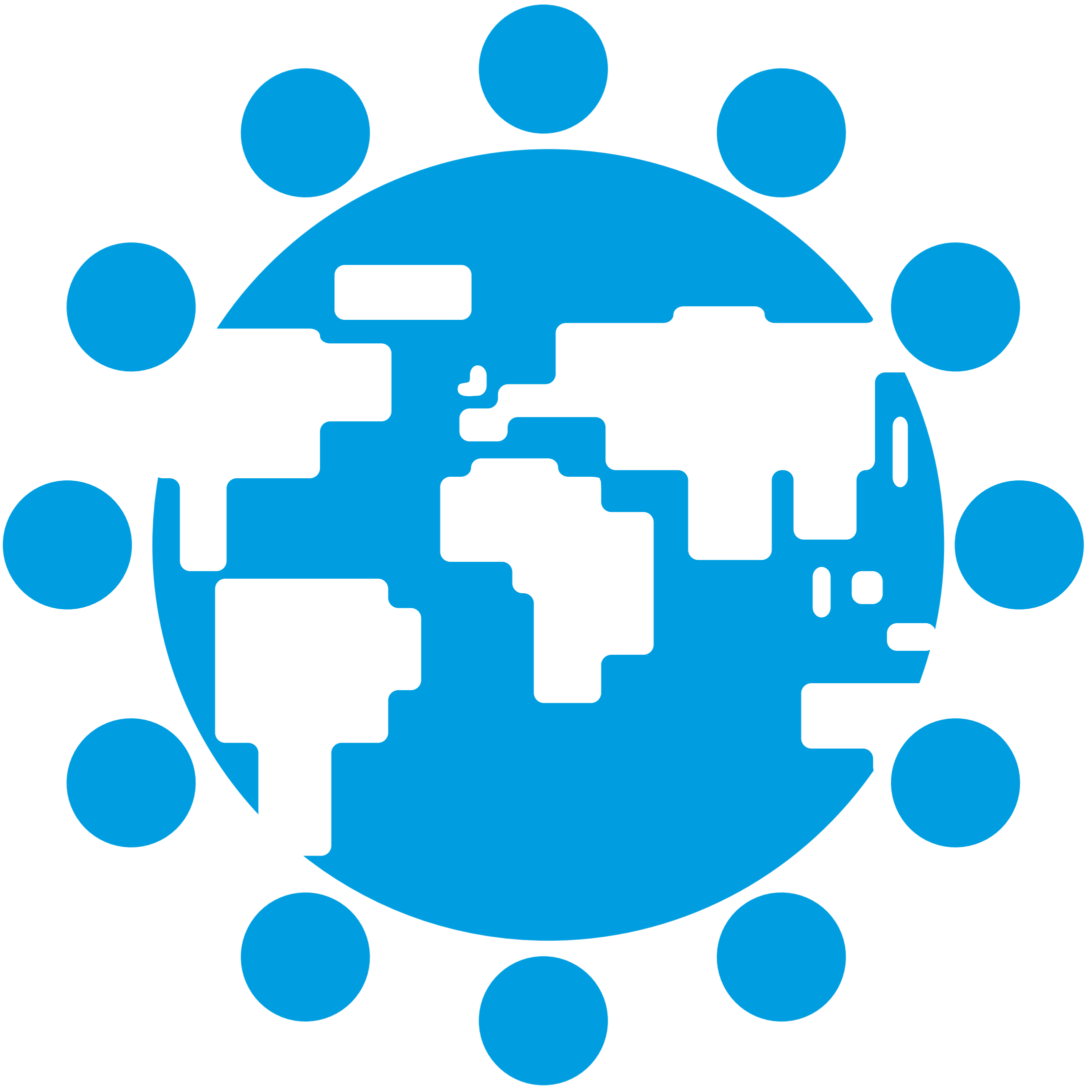


Science of Climate Change

Bill Hare
Potsdam Institute for Climate Impact Research

THE °CLIMATE GROUP

Breaking the Climate Deadlock
Briefing Paper

About the 'Breaking the Climate Deadlock' Initiative

'Breaking the Climate Deadlock' is an initiative of former UK Prime Minister Tony Blair and independent not-for-profit organisation, The Climate Group. Its objective is to build decisive political support for a post-2012 international climate change agreement in the lead up to the 2009 UN Climate Change Conference in Copenhagen. Its particular focus is on the political and business leaders from the world's largest economies, particularly the G8 and the major developing countries. The initiative builds on Mr Blair's international leadership and advocacy of climate change action while in office, and The Climate Group's expertise in building climate action programmes amongst business and political communities.

This briefing paper and its companions were commissioned by the Office of Tony Blair and The Climate Group to support the first Breaking the Climate Deadlock Report – 'A Global Deal for Our Low Carbon Future' – launched in Tokyo on June 27th 2008. Written by renowned international experts and widely reviewed, the papers' purpose is to inform the ongoing initiative itself and provide detailed but accessible overviews of the main issues and themes underpinning negotiations towards a comprehensive post-2012 international climate change agreement. They are an important and accessible resource for political and business leaders, climate change professionals, and anyone wanting to understand more fully, the key issues shaping the international climate change debate today.

The views expressed and information provided in this paper are the sole responsibility of the author. The Climate Group, the Office of Tony Blair and the staff of Breaking the Climate Deadlock Initiative accept no responsibility for any errors of fact or the opinions contained herein.

For further information see: *www.breakingtheclimatedeadlock.com*

Executive Summary

- Climate risks are larger, at lower temperatures, than previously assessed
- Actual increases in emissions, temperature and sea levels are at top of the range forecast by the Intergovernmental Panel on Climate Change (IPCC) in its scenarios
- High oil prices and coal intensive development since 2000 point to a risk of higher emissions unless urgent action is taken
- Lowering of emissions will lower temperature and reduce risks and damages
- Limiting global warming to below 2°C is critical to prevent dangerous climate changes – significant damages and risks would remain even at warming of 2°C
- To have more than a 50 percent chance of limiting warming to 2°C, carbon dioxide (CO_2) emissions will need to peak by 2020, and drop to well below 50 percent of 2000 levels by 2050
- This will require developed ('Annex I') countries' greenhouse gas emission allocations to be reduced by 20-45 percent from 1990 levels by 2020, and by 80-95 percent from 1990 levels by 2050

Recommendations

- Agree to a goal of limiting warming to 2°C or lower in the long term
- Agree to a goal of bringing global emissions growth to a halt no later than 2020
- Agree that Annex I countries set targets that would collectively reduce their emissions by 20-45 percent from 1990 levels by 2020

Science of Climate Change

This paper on the science of climate change is written around a set of questions:

- What is the international scientific consensus on climate change?
- Why does the science tell us we need to act now?
- What does the science tell us the overall goal should be in terms of atmospheric concentration of greenhouse gases (GHGs) and temperature rise – and what the effects will be of overshooting this?
- What does this imply for when global emissions should peak, and for the level they would need to be at in 2020/2030 and in 2050?
- What, in turn, does this imply for the trajectories of emissions required in industrialised and developing countries respectively?
- How will different decisions about targets and timings affect our ability to reach our concentration and temperature goals?
- How should we seek to balance and optimise the costs of mitigation, adaptation and damages?
- What are the other likely impacts of decisions about targets and timing – for example, on technological lock-in, likely adaptation requirements, and irreversibility thresholds?
- What climate impacts can we expect even if we act decisively now?

In framing policy-relevant responses to these questions, this paper draws heavily on the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), and in particular from its Synthesis Report[1]. The paper also takes account of science published since the AR4, and offers additional perspectives beyond the findings of the IPCC.

The international climate science consensus

The international scientific consensus on climate change is clear. In 2007 the IPCC stated that "warming of the climate system is unequivocal"; and that there was a greater than 90 percent probability that most of the warming since the mid-20th century had been caused by the rapid increase in greenhouse gas (GHG) concentrations due to human activities since the start of the industrial revolution. In addition, the IPCC found that climate change had influenced an increase in ocean temperatures, widespread melting of snow and ice, and a rising global average sea level; and that it had affected many natural systems across all continents.

The IPCC found that concentrations of GHGs, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), had increased markedly due to human activities, and were far above levels that prevailed in pre-industrial times. It found with certainty that CO_2 and CH_4 now far exceed levels that occurred naturally over the last 650,000 years; and that the increases in CO_2 concentrations were due primarily to emissions from fossil fuel use, with deforestation and other land use activities contributing significantly.

The IPCC found that GHG emissions had risen by 70 percent between 1970 and 2004, and that: "There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades."

While there remains uncertainty over the exact scale and speed of future changes in the world's climate, there is no disagreement about the direction of change, or about humanity's influence on elevated GHG levels. The IPCC found that: "Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century".

Literature published in the past two years has identified several specific cases of higher risk than that assessed in the IPCC's AR4, including for sea level rise, food production, and loss of Arctic sea ice. In the judgement of this author, this literature is sufficiently important, credible and robust to justify presenting a view that adds to, and in some cases differs from, the IPCC assessment. The reader should be aware, also, that this paper presents the science of climate change from a risk perspective, in terms of which low-probability, high-consequence events merit the attention of policymakers at the highest level.

The need to act now

The science of climate change provides compelling evidence that early action is needed to limit the growth of GHG emissions. Ten lines of evidence from the present state of scientific knowledge point to the need to act now:

1. Global fossil fuel emissions trends are higher than expected
2. Unless policies are changed, emissions will continue to grow rapidly
3. Observed warming and sea level rise are at the upper end of expected range
4. Significant impacts of human-induced climate change on human and natural systems are already being observed
5. The climate system is more sensitive to the effects of increasing greenhouse gas concentrations than previously estimated
6. Warming is bringing the climate system closer to tipping points, and projected unmitigated warming this century would probably trigger tipping points
7. Significant additional warming and sea level rise are already committed due to historic emissions; the inertia of the climate system and carbon cycle mean that very large emission reductions are needed to halt the warming and substantially slow sea level rise
8. The scale and magnitude of projected impacts is higher than previously assessed, and in some regions it is severe at low levels of warming
9. The scale and magnitude of adaptation action required is enormous, even if strong mitigation actions are taken
10. There is growing risk of ice sheet disintegration or rapid decay with increasing warming

Each of these lines of evidence is outlined in turn.

1 Global fossil fuel emissions trends are higher than expected

Energy-related CO_2 emissions are at the top of, or may exceed, the ranges forecast in IPCC scenarios[2], and are indicative of a recarbonisation of the energy system globally, as well as economic growth in China and India that is more rapid than expected[3]. CO_2 is the most important greenhouse gas influenced by human activities. The increase in concentration of this gas from around 280 parts per million by volume (ppmv) in the preindustrial period to around 381 ppmv in 2006 has, unambiguously, been caused by human activities. The rate of increase in CO_2 concentration is growing, and is now around 2ppm/year[4]. A significant fraction of present emissions of fossil carbon will remain in the atmosphere for hundreds and even thousands of years[5].

2 Unless policies are changed, emissions will continue to grow rapidly

In its AR4, the IPCC found that unless current policies were changed, emissions would continue to grow rapidly. High oil prices and energy security concerns are encouraging a shift towards carbon intensive liquid fuels (coal to liquid technologies, tar sand and oil shale technologies), which will very probably have an adverse effect on future levels of CO_2 emissions. Emissions of CO_2 from China have grown rapidly in recent years as economic growth has been maintained at high levels – a trend that could continue for several decades, in the absence of technological shifts in China's power and heavy industry sectors[6].

It is important to note the risk of "lock in" of carbon intensive energy systems. As the IPCC AR4 Working Group III concluded: "Delayed emission reductions lead to investments that lock in more emission intensive infrastructure and development pathways" and this "significantly constrains the opportunities to achieve lower stabilization levels ... and increases the risk of more severe climate change impacts"[7]. A degree of carbon intensive "lock in" is already happening as a consequence of investments over recent decades. Unless action is taken – through policy signals such as a carbon price – this problem could worsen substantially, making it much more expensive to reduce emissions deeply in the future[8].

3 Observed warming and sea level rise are at upper end of expected range

Observed global mean warming and sea level rise are at the upper end of the ranges previously projected by the IPCC[9]. Changes in extremes are being observed, such as increased heat waves, droughts and more intense precipitation events, that are consistent with projected effects of global warming[10] and in many cases appear to be occurring significantly earlier than projected[11].

4 Significant impacts of human-induced climate change on human and natural systems are already being observed

Impacts of climate change on human and natural systems are already being observed at scale[12]. For example, the European heat wave of 2003, which caused more than 45,000 excess deaths, demonstrated that human systems, even in wealthy regions, are more vulnerable to extreme climate events than was previously estimated by the scientific community[13]. That heat wave was found to be more than twice as likely to occur than in preindustrial times, due to human-induced warming of the climate system[14].

The impacts on human and natural systems have been wide-ranging. Agricultural production in India has been adversely affected due to climate change and air pollution[15]. Glaciers appeared to be losing mass and melting faster than anticipated, with consequential adverse effects on water supply availability[16]. Widespread coral bleaching has been observed in most ocean basins and is being associated with global warming . Water supply impacts are being observed from unusual droughts in Australia and other regions and are consistent with projected effects of climate change in the future .

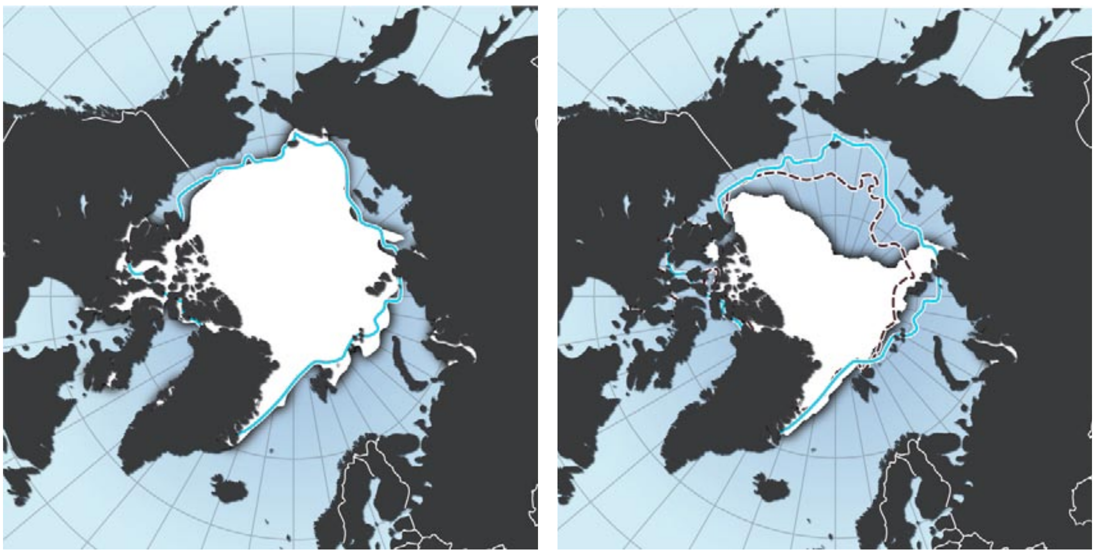
Observed loss of Arctic summer sea ice is more extensive than expected in nearly all of the IPCC AR4 climate models, with loss rates increasing over recent decades to about 9.1 percent per year for the 1979-2006 period[20] (see Exhibit 2). The IPCC AR4 projected that sea ice would decrease in both the Arctic and Antarctic under all of the unmitigated emissions scenarios examined, with summer sea ice almost entirely disappearing towards the end of the 21st century[21]. There are indications that the loss of Arctic summer sea ice in the future could be faster than projected in the IPCC AR4[22]. Loss of sea ice would have far reaching adverse consequences for ice-dependent species and ecosystems[23].

Exhibit 1

Arctic sea ice trends

Source
UNEP/GRID-Arendal

Median minimum extent of ice cover (1979 – 2000)
Minimum extent of ice cover 2005

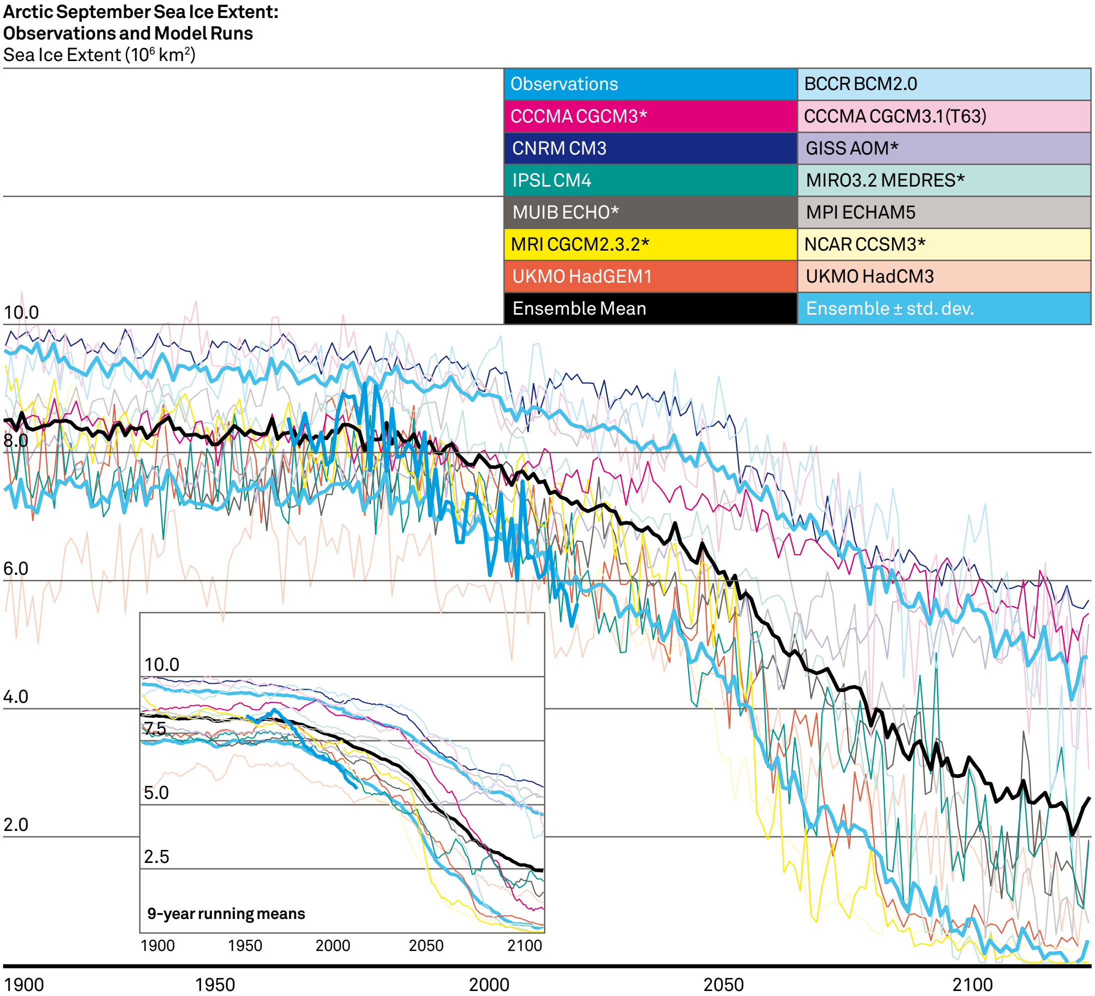


1982 **2007**

Figure 2

Observed vs projected changes in Arctic September sea ice extent[25]

Source
Stroeve, Holland et al. (2007)



Observations are shown with thick red line, with the solid black line being the multi-model ensemble mean of 13 IPCC AR4 climate models. The inset graphs shows the same results as a 9-year running which smoothes the data.

5 Climate system is more sensitive to the effects of increasing greenhouse gas concentrations than previously estimated

The sensitivity of the climate system to the effects of increasing greenhouse gas concentrations may be higher than previously estimated. The IPCC AR4 found that a doubling of CO_2 concentrations above the preindustrial level[26] would cause a temperature increase of 2°C at the lower bound, up from the 1.5°C previously estimated, with the best estimate increased from 2.5°C to 3°C. While the upper bound of 4.5°C has not been changed, there is nonetheless a small but significant probability that the climate sensitivity could be higher than this[27].

6 Warming is bringing the climate system closer to tipping points, and projected unmitigated warming this century would probably trigger tipping points

Tipping points in the climate system are levels of warming which can trigger changes in large-scale components of the climate system[28]. Examples of elements of the climate system which are susceptible to “tipping” include Arctic summer sea ice (possible complete loss); Greenland ice sheet (meltdown raising sea level 6-7 metres over many centuries); West Antarctic ice sheet (disintegration raising sea level 4-5 metres over several centuries); Atlantic thermohaline circulation (risks of abrupt shutdown); and the Amazon rainforest (risk of collapse due to warming and rainfall reductions). A recent assessment of “tipping elements”[29] indicates that a significant number of tipping points could be approached for warming levels above 3°C over preindustrial levels, and some could be approached already at warming levels of 1.5- 2°C, or at lower levels in the case of Arctic summer sea ice. Limiting warming to below the levels that would approach these tipping points will require efforts to reduce emissions in the short term rather than the longer term.

7 Significant additional warming and sea level rise are already committed due to historic emissions; the inertia of the climate system and carbon cycle mean that very large emission reductions are needed to halt the warming and substantially slow sea level rise

Substantial inertia exists in the climate system due to the long time scales of the heat uptake by the ocean[30] and the very long lifetimes of important carbon pools, particularly those involved in taking up carbon from the atmosphere into the oceans and ultimately into sedimentary deposits on the seabed[31]. Even rapidly reduced emissions will not stop a significant fraction of the warming already "loaded" into the system, but not yet seen in observations, from occurring. As a consequence, many of the impacts projected to occur within the next 20 years or so are already committed, almost irrespective of the scale of emission reductions undertaken over that time frame. In order to reduce impacts over periods beyond the next 20 years, very substantial emission reductions are needed in the short term (2015) and medium term (2020s and 2030s). The inertia of sea level rise is an enormous problem, as the present level of greenhouse gases could cause sea level rise of up to 2m over the next few thousand years[32].

8 Scale and magnitude of projected impacts higher than previously assessed and in some regions severe at low levels of warming

The scale and magnitude of projected impacts and risks at the different levels of warming is higher than previously assessed in many cases. For a number of regions, particularly in sub-Saharan Africa and the small island states, projected effects on food production, water supply and ecosystems are substantial to severe at warming levels above 1.5°C higher than preindustrial[33].

9 Scale and magnitude of adaptation action required is enormous, even with strong mitigation actions

The scale and magnitude of the required adaptation to human-induced climate change is enormous, including over the next 20 to 30 years. Beyond this timeframe, adaptation costs and challenges increase very substantially with further warming. In Africa, for example, in the absence of mitigation to reduce greenhouse gas emissions, sea level rise by the 2080s could threaten large population centres, requiring expenditures of the order 5-10 percent of gross domestic product to defend them[34]. To lower this longer term adaptation task, successful mitigation must be achieved in the near term.

10 Growing risk of ice sheet disintegration or rapid decay with increasing warming

Disintegration of the West Antarctic ice sheet, and/or the rapid loss of the Greenland ice sheet due to global warming leading to significant sea level rise has long been recognised as a low-probability, high-consequence risk[35]. The resulting sea level rise from complete loss of the Greenland ice sheet could be up to 6-7 metres and from the West Antarctic 5-6 metres[36]. Sea level rise of these magnitudes would transform the face of the planet, whether they occurred over half a millennium in the most extreme scenarios, or over several thousand years based on ice sheet model projections[37]. The IPCC AR4 noted that recently observed dynamical processes could increase the future rate of ice loss from ice sheets. It found that "the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales"[38].

The lines of evidence for risk of more rapid ice sheet loss and consequential sea level rise are drawn from observations of ice sheet response to recent surface and ocean warming; evidence from the last interglacial period; and from ice sheet models. A recent review by Alley and colleagues found that: "Contrary to prior expectations that warming would cause mass addition averaged over the Greenland and Antarctic ice sheets and over the next century, the ice sheets appear to be losing mass, at least partly in response to recent warming.... With warming projected for the future, additional mass loss appears more likely than not."[39]

For the Greenland ice sheet, the level of warming that could trigger irreversible meltdown could be as low as 1.9-4.6°C[40] above preindustrial, leading to widespread, or near total, deglaciation. This would raise sea levels 2-7 metres over centuries or millennia[41]. Evidence from the last interglacial or warm period before the present, 125,000 years ago, indicates that levels of local warming over Greenland comparable to that expected in the 21st century led to major deglaciation of this ice sheet, and was associated with a sea level rise of the order 4-6 metres[42]. Work published since the cutoff date for the AR4 assessment indicates that average rates of sea level rise in this period were rapid, around 1.6 metres per century[43], which these authors argue "inform the ongoing debate about high versus low rates of sea-level rise in the coming century". Warming to date is already leading to significant loss of ice from Greenland at a faster rate than models estimate[44]. Loss rates have doubled in the last decade[45]. An observed process, whereby surface melting induces a speed-up of discharge glaciers from the ice sheet, appears likely to have a substantial effect on future loss rates from the ice sheet[46].

The risk of disintegration of the West Antarctic ice sheet is hard to quantify, and there is a range of opinions and ongoing debate about it in the scientific community. A recent assessment by Lenton and others[47], places this tipping point risk at a global warming of around 3.5-5.5°C above preindustrial. The Chapter 19 writing team of the IPCC AR4 Working Group II estimated that a warming of 2.5°C above preindustrial could lead to a "commitment to partial deglaciation with 1.5-5 m of sea-level rise over centuries to millennia". The likelihood of near-total deglaciation of this ice sheet is estimated to rise with increases in temperature[48]. Accelerating losses of ice from parts of the West Antarctic ice sheet have been observed; appear to be associated with ocean warming[49]; and are occurring in a region long identified as a possible locus of instability in this ice sheet[50].

Overall goals required for atmospheric concentration of greenhouse gases, and temperature rise

Science cannot define what the goal of policy should be, as this is a political and normative judgement. Nevertheless, science can provide information and analyses useful, if not critical, to informed judgements and decisions.

Global goal for prevention of dangerous climate change requires an evaluation of risks of both high- and low-probability outcomes

It is important to acknowledge that the evaluation of what to do about climate change is ultimately a risk assessment issue. Risk for these purposes can be defined as the probability of an outcome, multiplied by its consequence: low-probability events with a high consequence can therefore correspond to a high risk. The establishment of an overall global goal for climate change requires an evaluation of both high- and low-probability outcomes against their consequences.

Reducing level of global mean warming reduces level of risks and damages to many sectors and regions

The IPCC AR4 provides an assessment of risks to sectors and regions, with these risks evaluated at different levels of global mean temperature increase. What this assessment shows is that lowering the level of global mean warming is likely or very likely to lower the level of risks and damages to many sectors and regions. The figures below illustrate this.

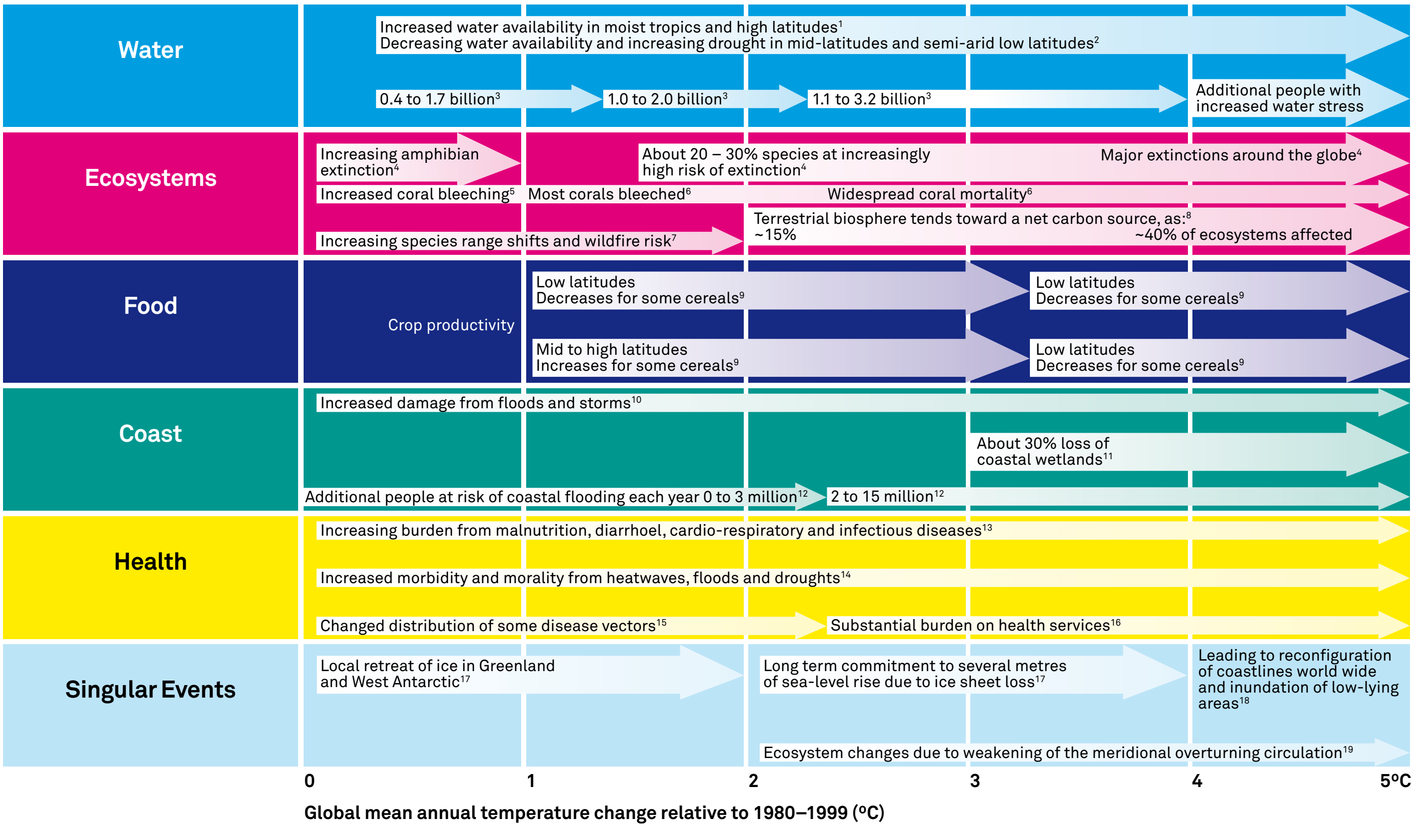
Risks rise rapidly with increasing global mean temperature for a wide range of systems and regions

Risks often rise rapidly with increasing global mean temperature, for a wide range of systems and regions. Reducing warming avoids or limits risks and damages: reducing the temperature increase from 4°C to 2°C (above preindustrial) reduces risks, impacts and vulnerabilities very substantially in most cases. For example, the risk to food production is decreased from potential global decreases, to decreases in some cereal production in the tropics (low latitudes). For ecosystems, the risk of "widespread coral reef mortality" is reduced to a lesser, but still significant risk, where "most coral reefs" are bleached. For species, the risk of "major extinctions" globally is reduced to a risk of regional extinctions at around 2°C warming. For large-scale system changes such as ice sheet loss, lowering the warming level reduces the risk, but does not eliminate it.

Exhibit 3

Sectors – lower temperature reduces risks and damages

Source
IPCC AR4 WGII Table TS.3[51]

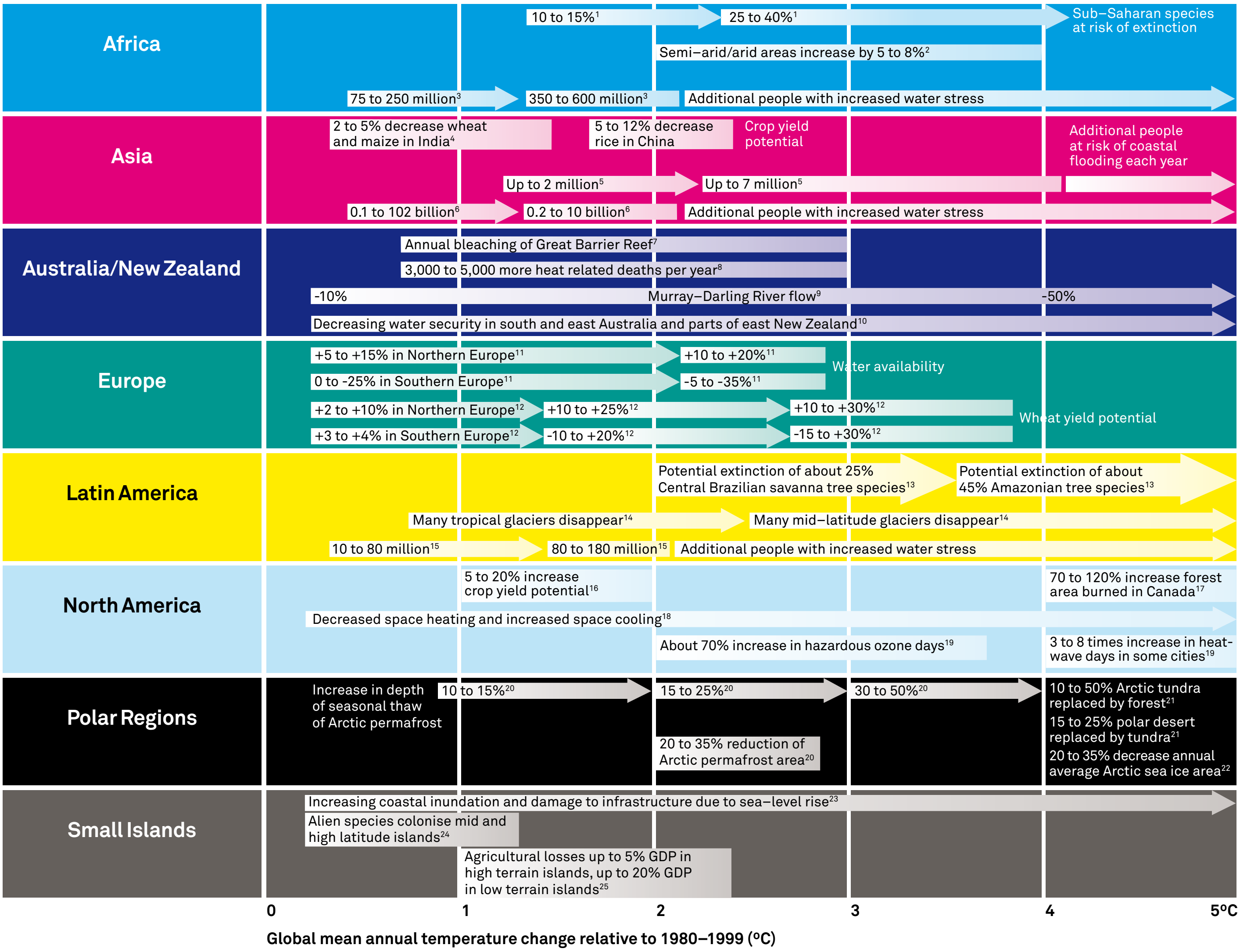


Temperature levels are shown with respect to 1980-1999. Add about 0.6°C to convert to temperatures above preindustrial. 2°C above preindustrial corresponds to around 1.4°C above 1980-1999.

Exhibit 4

Regions – lower temperature reduces risk and damages

Source
IPCC AR4 WGII Table TS.4[52]



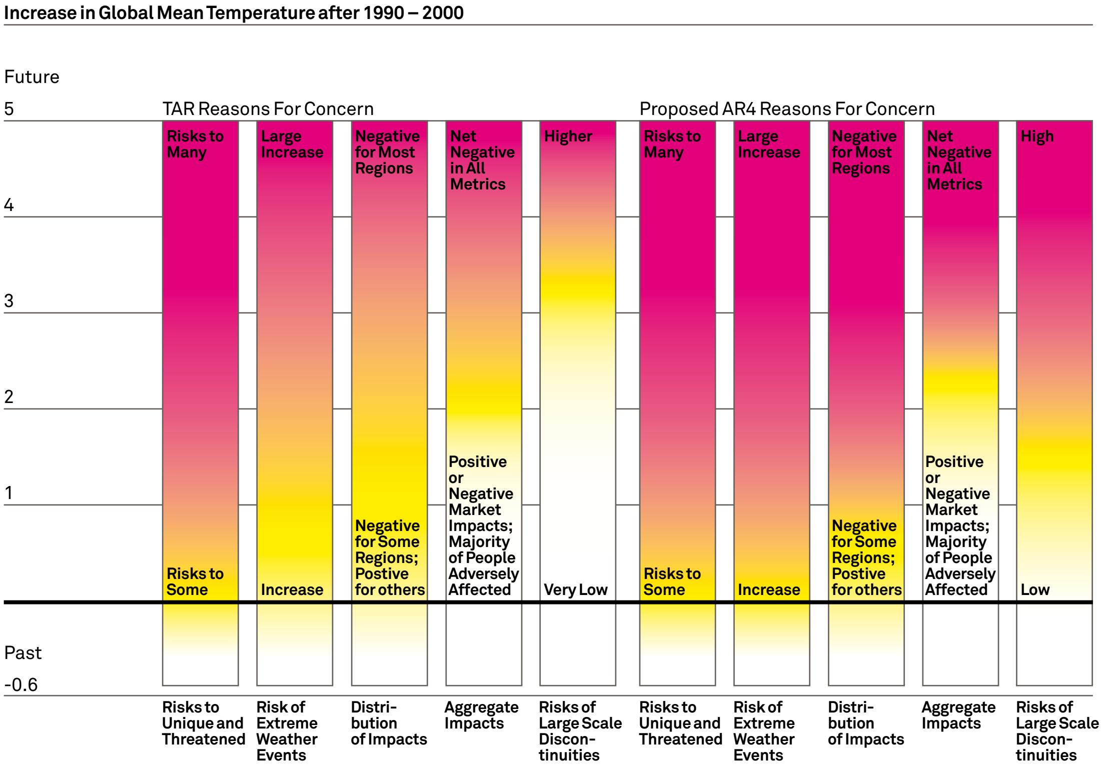
Temperature levels are shown with respect to 1980-1999. Add about 0.6°C to convert to temperatures above preindustrial. 2°C above preindustrial corresponds to around 1.4°C above 1980-1999.

Regionally, the IPCC AR4 shows that reducing warming from around 4°C (above preindustrial) reduces the number of people at risk of water stress very substantially and also reduces the area of increased aridity significantly (Exhibit 4). For Asia, reducing warming from 4°C to 2°C (above preindustrial) reduces the damage to crop production very substantially. In Latin America the risk to ecosystems is reduced significantly but not eliminated – in this region reducing warming from 4°C to 2°C probably would not prevent the loss of important glacial systems in the tropical and near tropical regions, whose extinction is predicted in the next few decades. More generally, the loss of glacial mass in regions such as the Himalayan, Hindu Kush and Central Asian Mountain regions poses a substantial threat to water supply and agriculture in many countries and is likely to affect water security for billions of people. Projections are not available for all regions, but the indications are that reducing warming from 4°C down to 2°C would prevent the total loss of glaciated basins in these mountain regions.

IPCC AR4 "reasons for concern" are greater at lower levels of global mean temperature increase than in the 2001 Assessment

A group of authors involved with the Third and Fourth IPCC Assessment reports attempted to synthesise the relative change in assessed climate risks and key vulnerabilities across the five "reasons for concern", which were identified in the IPCC's Third Assessment Report (TAR) in 2001 and updated in the AR4 Synthesis Report[53]. The figure below illustrates the initial findings from this work, which is drawn entirely from the literature of the AR4 and in particular Chapter 19 of IPCC AR4 WGII. This figure shows that, for all of the "reasons for concern", many risks and vulnerabilities are greater at the lower levels of global mean temperature increase than was found to be the case in 2001.

Exhibit 5



IPCC AR4 finds greater risks at lower temperatures

Source
Dangerous Climate Change: An Update of the IPCC Reasons for Concern, December 30, 2007: Smith, Schneider, Oppenheimer, Yohe, Hare, Patwardhan, Mastrandrea, Burton, Corfee-Morlot, Magadza, Füssel, Pittock, Rahman, Suarez, van Ypersele, in review PNAS

Individual scientific studies and judgements of risk also give an indication of the risk assessment by individual scientists or groups of scientists in areas of their expertise. It needs to be recognised that individual studies such as those cited below do not provide as robust an assessment of risk as those deriving from large-scale, multi-author assessments of the literature. Nevertheless, there are important new findings, viewpoints and judgements of risk in the scientific literature, which supplement and add to the assessments made by the IPCC, and which add richness to the assessments of climate risks and vulnerabilities described here. Some of the more important of these, as judged by this author, are described below. They range from global-scale risks down to individual species and systems.

Warming above around 2°C above preindustrial has the possibility of "seeding irreversible catastrophic effects"

On global scale risks, Jim Hansen's group has published a number of papers over the last few years outlining the level of acceptable warming that they see based on a consideration of the likelihood of major changes to the Earth System, including the risks of ice sheet disintegration, loss of Arctic sea ice, increased tropical storm intensity, loss of ecosystems and loss of alpine and mountain glaciers. They argue essentially for a temperature limitation of not more than 1.5°C above the present level (around 2°C above preindustrial) and consequently call for stabilisation of atmospheric carbon dioxide at an "initial" level of 350 ppm CO_2[54]. In their most recent paper they argue that: "If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm."

They go on to observe that "if the present overshoot of this target CO_2 is not brief, there is a possibility of seeding irreversible catastrophic effects".[55]

On more specific systems, individual scientific groups have indicated specific levels of risk, implying or stating what they consider to be acceptable.

Risk of more rapid sea level rise in 21st century than projected in the IPCC AR4

The IPCC was unable to estimate fully all of the contributions to sea level rise due to global warming, due to the inability of ice sheet models to describe adequately the response of ice sheets to warming[56]. The AR4 model based range for sea level rise, excluding future rapid dynamical changes in ice flow from the ice sheets of Greenland and Antarctica, was 0.18m to 0.59m by 2090-2099 above 1980-1999 levels[57]. If the recent rate of sea level rise for the 1993-2003 period of 3.1mm/year continued to the end of the 21st century, the sea level increase would be around 0.3 m. The IPCC also found that "dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise". As a consequence the IPCC found that larger values of sea level rise "cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise".[58]

A different approach to estimating future sea level rise based on the observed relationship between sea level and temperature over the last century has been developed by Rahmstorf[59]. This semi-empirical sea level rise model projects a sea level rise of 0.5-1.4 by 2100 over 1990 levels for a similar range of emission scenarios as used in the AR4. This approach points to a risk of metre scale sea level rise by 2100, far above the upper end of the IPCC projection range for this time period[60]. More recent work indicates a more sensitive relationship between temperature increase and sea level than that established by Rahmstorf, with the implication that sea level rise could be even higher than his estimate by 2100.[61]

Southern Ocean sink for carbon dioxide has weakened, probably due to human induced climate changes

The global oceans are a major sink for fossil carbon dioxide emissions and their continuing ability to take up carbon from the atmosphere is critical to future levels of atmospheric CO_2 concentrations. Recently it has been observed that the Southern Ocean sink for CO_2, which is the largest, has weakened due to the observed increase in southern ocean winds.[62] There are suggestions that at least part of the cause for the observed increase in wind speeds in the Southern Ocean is increased greenhouse gas concentrations and stratospheric ozone depletion resulting from human activities[63]. Some models project wind speeds to increase in the future due to warming[64]. If so, the fraction of CO_2 emissions that the oceans absorb would probably decrease, and the level at which atmospheric CO_2 will stabilise for a given set of emissions will probably be higher than presently estimated[65].

CO_2 concentrations above 500 ppm appear extremely risky for coral reefs

A recent review paper published in Science by Hoegh-Goldberg and others[66], examining the projected effects of global warming and ocean acidification on the health and viability of coral reef systems globally, concluded by that "contemplating policies that result in CO_2 above 500 ppm appears extremely risky for coral reefs and the tens of millions of people who depend on them directly, even under the most optimistic circumstances".

Greater risk to food production than assessed

Recent work[67] suggest greater risk to food production and food security than were found in the IPCC AR4[68].

Main body of scientific evidence and opinion points to an acceptable level of warming being well below a 4°C increase above preindustrial levels

In summary, the main body of scientific evidence and opinion points to an acceptable level of warming being well below a 4°C increase above preindustrial levels. Where researchers have expressed specific opinions about acceptable levels are warming these generally are in the range of 1.5°C to about 3°C above preindustrial levels. While the IPCC has found that reducing warming reduces risks substantially, its mandate does not permit it to recommend acceptable levels of warming[69]. In the judgement of this author the IPCC AR4, and science published after the close-off dates for literature for that assessment (around mid-2006), provide evidence that strongly supports the EU's 2°C warming limit goal. There is little in the literature that would indicate that warming levels higher than this are in any sense "safe" for any of the systems examined. If anything, the literature points to even lower levels being required to protect critical systems or to reduce substantially the risk of major system changes. Some systems, such as the Arctic summer sea ice, may already be close to thresholds of irreversible change.

When global emissions should peak, and where they would need to be in 2020/2030 and 2050

Limiting warming to levels around 2°C above preindustrial requires very substantial emission reductions. In its AR4, the IPCC reviewed the published literature on mitigation scenarios and categorised them into six ranges, the lowest of which stabilised CO_2e concentrations of greenhouse gases in the range 445 to 490 ppm CO_2e.

These stabilisation levels would correspond in the long term (centuries to millennia) to a global mean temperature increase in the range 2- 2.4°C. The table below, extracted from the IPCC WGIII summary for policymakers, shows the CO_2 profiles corresponding to different stabilisation levels. For the lowest stabilisation level, global CO_2 emissions in these scenarios peak in the period 2000 and 2015, and reduce to 50 to 85 percent below 2000 levels by 2050.

There are several caveats in interpreting these results.

The first is that the results summarise a set of emission stabilisation scenarios in the literature, and therefore do not explore a full range of possibilities. The peak in the period 2000-2015 is based on the scenario literature published up until the beginning of 2007. If emissions do not peak in this period, this does not mean that the stabilisation levels corresponding to these scenarios cannot ultimately be achieved; however, it does mean that the rate of subsequent emission reduction would need to be faster by 2050 than the range indicated at present.

Second, these results are for CO_2 only and do not account for emission reductions required for the other gases. The emission profiles that would result from a multi-gas assessment would differ in detail from this, although the broad reduction ranges required would not change much.

Exhibit 6

CO_2 emission profiles for different GHG concentration stabilization levels

CO_2e Stabilization level (2005 = 375 ppm CO_2e)	Global Mean temperature increase at equilibrium (ºC)	Global average sea level rise at equilibrium from thermal expansion only	Year global CO_2 needs to peak	Reduction in 2050 global CO_2 emissions compared to 2000
445 – 490	2.0 – 2.4	0.4 – 1.4	2000 – 2015	-85 to -50
490 – 535	2.4 – 2.8	0.5 – 1.7	2000 – 2020	-60 to -30
535 – 590	2.8 – 3.2	0.6 – 1.9	2010 – 2030	-30 to +5
590 – 710	3.2 – 4.0	0.6 – 2.4	2020 – 2060	+10 to +60
710 – 855	4.0 – 4.9	0.8 – 2.9	2050 – 2080	+25 to +85
855 – 1130	4.9 – 6.1	1.0 – 3.7	2060 – 2090	+90 to +140

Source
IPCC AR4 Synthesis Report Table 5.1 Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only

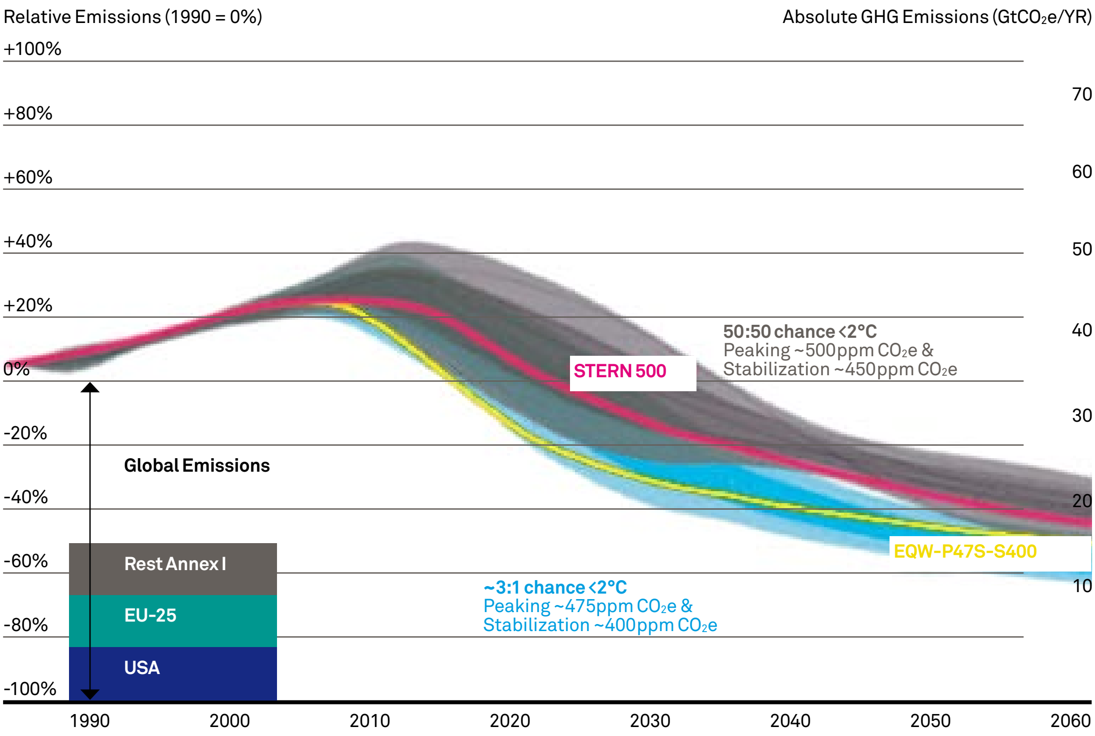
Work done by Meinshausen and colleagues[70], evaluating multigas emission pathways that can limit warming to 2°C or below, supports the need to peak emissions before 2020, and for global emissions to be at least 50 percent below 1990 levels by the 2050s. The figure below shows that the emission pathways that have around a 75 percent chance of limiting warming to a 2°C increase require that global emissions are reduced at least 50 percent below 1990 levels in 2050 (top of green shaded area), and more likely of order 60 percent (middle of green shaded area).

Exhibit 7

Emission pathways for limiting warming to 2˚C 50 percent chance (grey) and with 75 percent chance.

Source
Meinshause, M. pers. Comm.

Global & Annex I GHG emissions (with LULUCF)



Notes:
(a) Historic 1990-2003 GHG emissions including LUCF/LULUCF for annex 1 country groups based on Table II-7 in UNFCCC (2005) "Key GHG Data".
(b) Shown are various multi-gas FAIR-SimCaP (den Elzen & Meinshausen, 2006) and EQW pathways (Meinshausen et al 2006) relative to 1990 for peaking at approximately 500 ppm and stabilizing at 450ppm CO_2e (grey pathways) and peaking at 475 with subsequent stabilization at 400ppm CO_2e (green pathways).
(c) The here shown pathways comprise the SRES country groups OECD90 and REF (Economies in Transition). Note that the absolute GHG emission data is (-15%) higher compared to absolute Annex 1 emissions reported to the UNFCCC, partially due to non-reported sources, as landuse related emissions and slight differences in countries (Turkey, some REF).
(d) The probabilities are given to stay below 2ºC global-mean warming relative to preindustrial levels, assuming an IPCC consistent climate sensitivity pdf with a 90% confidence that climate sensitivity lies between 1.5ºC and 4.5ºC (for details see Chapter 28 in Schellnhuber et al. "Avoiding Dangerous Climate Change", 2006).
(e) The light and dark patches show the mean plus / minus one and two standard deviations, respectively, for the set of analysed FAIR-SIMCaP and EQW pathways.
(f) The calculations imply default MAGICC carbon cycle feedbacks, comparable to approximately the mean across the C_4MIP studies (Friedlingstein et al. 2005).

Scientific developments since the conclusion of the AR4, particularly in relation to the effects of black carbon (a form of air pollution), indicate that reductions of these aerosols could help to reduce warming significantly. If verified, this may assist in achieving the warming limits assessed here. Reduction of black carbon emissions would also have large benefits in terms of avoided health and agricultural damages.

Required trajectories of emissions in industrialised and developing countries

The IPCC AR4, in its Working Group III report, provided a survey of the emission reductions corresponding to different stabilisation levels for industrialised (Annex I) and developing (Non-Annex I) country groups[72]. The chart below, Box 13.7 from IPCC WGIII, shows the range of emission reductions within the Annex I group for a 450 ppm CO_2e stabilisation scenario. The Kyoto Protocol parties have drawn upon the scenario range to establish indicative reduction ranges to be discussed in the course of the work of the Ad Hoc Working Group (AWG) on the review of the Annex I emission commitments. However, specific details were not provided for the non-Annex I countries.

For the Annex I group, the required GHG emission reduction ranges in 2020 are 25 to 40 percent below 1990 levels, and by 2050, 80 to 95 percent below 1990 emissions. The exact number for each country depends on the emission allocation system used or assumed in the different models.

Exhibit 8

Emission reduction ranges for Annex I countries
The range of the difference between emissions in 1990 and emission allowances in 2020/2050 for various GHG concentration levels for Annex 1 and non-Annex 1 countries as a group [a]

Scenario category	Region	2020	2050
A-450 ppm CO_2e[b]	Annex 1	-25% to -40%	-80% to -95%
	Non-Annex 1	Substantial deviation from baseline in Latin America, Middle East, East Asia and Centrally-Planned Asia	Substantial deviation from baseline in all regions
B-550 ppm CO_2e	Annex 1	-10% to -30%	-40% to -90%
	Non-Annex 1	Deviation from baseline in Latin America and Middle East, East Asia	Deviation from baseline in most regions, especially in Latin America and Middle East
C-650 ppm CO_2e	Annex 1	0% to -25%	-30% to -80%
	Non-Annex 1	Baseline	Deviation from baseline in Latin America and Middle East, East Asia

Source
IPCC WGIII Chapter 13, Box 13.7

Notes:
(a) The aggregate range is based on multiple approaches to apportion emissions between regions (contraction and convergence, multistage, Triptych and intensity targets, among others). Each approach makes different assumptions about the pathway, specific national efforts and other variables. Additional extreme cases - in which Annex 1 undertakes all reductions, or non-Annex 1 undertakes all reductions - are not included. The ranges presented here do not imply political feasibility, nor do the results reflect cost variances.
(b) Only the studies aiming at stabilization at 450 ppm CO_2e assume a (temporary) overshoot of about 50 ppm (See Den Elzen and Meinshausen, 2006).

Two examples of specific allocation systems applied to the goal of limiting GHG concentrations to 400 ppm CO_2e or 450 ppm CO_2e, are shown in the figures below, which are drawn from the Dutch FAIR model. The first shows the emission allowances resulting from the application of a per capita convergence goal, whereby each country's emissions converged to the same level over time. This produces the most stringent reductions for the Annex I group.

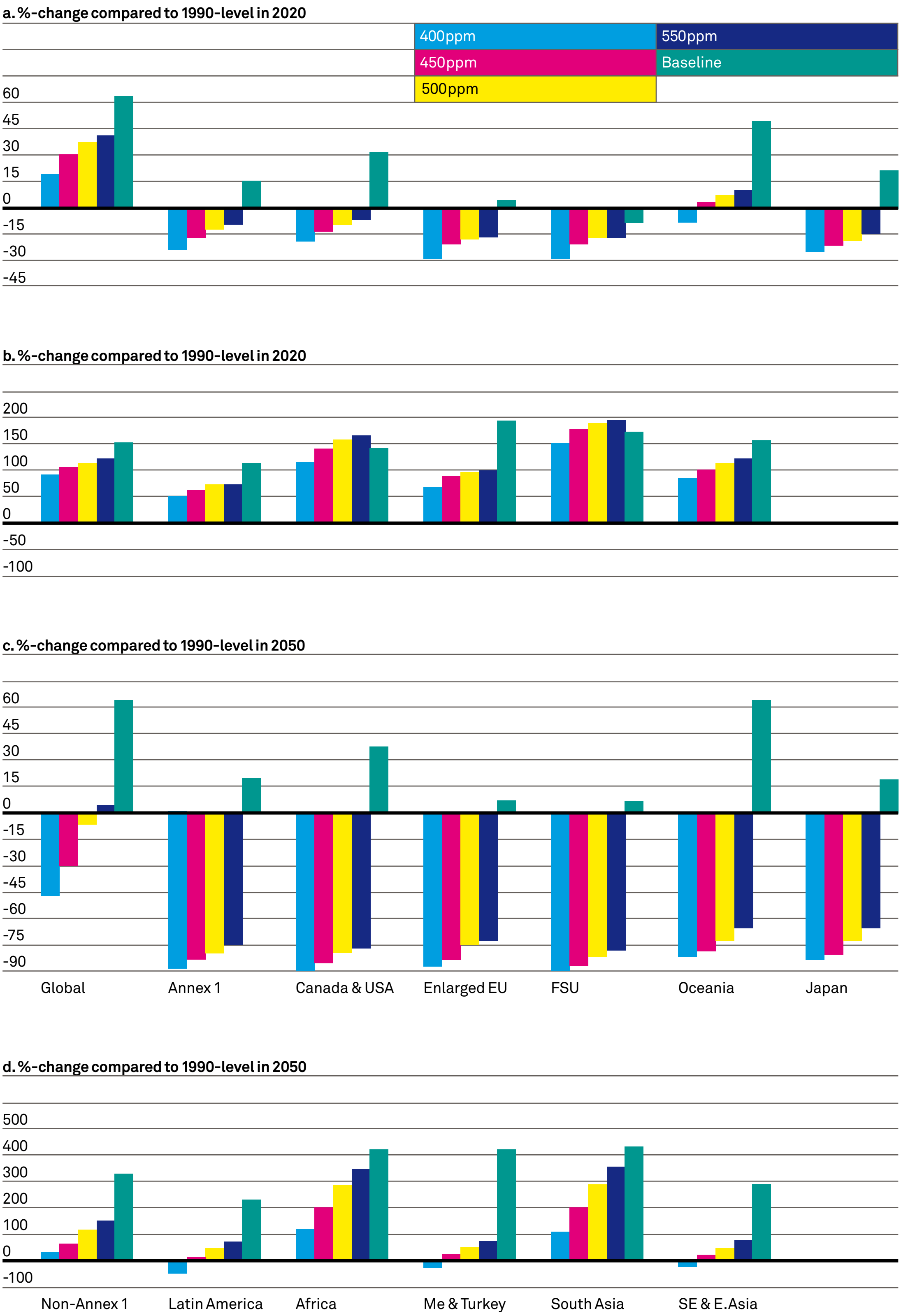
In this study the Annex I emission reductions need, in aggregate terms, to be 25 percent below 1990 levels. The South-North proposal shows quite similar reductions, except for the EU, which has an allocation some 40 percent below 1990 levels.

For the Non-Annex I group substantial reductions below business as usual emissions are required by 2020, in each of the cases examined; the reduction varies by group or country and method of allocation. In general, the least developed countries of Africa and the countries of South Asia need to do the least, and Latin America and East Asia the most.

In the South-North proposal all developing countries, except the least developed, need to reduce the growth in their emissions significantly by 2020. For the Newly Industrialised Countries the reduction in growth is quite significant by 2020. For the Rapidly Industrialising Countries (including China) the reduction in growth is less pronounced but nevertheless significant, while for other developing countries (including India) the reduction in emissions growth is small. By 2050 the Newly Industrialised Countries and Rapidly Industrialised Countries must reduce their emission allocation below 1990 levels.

Exhibit 9

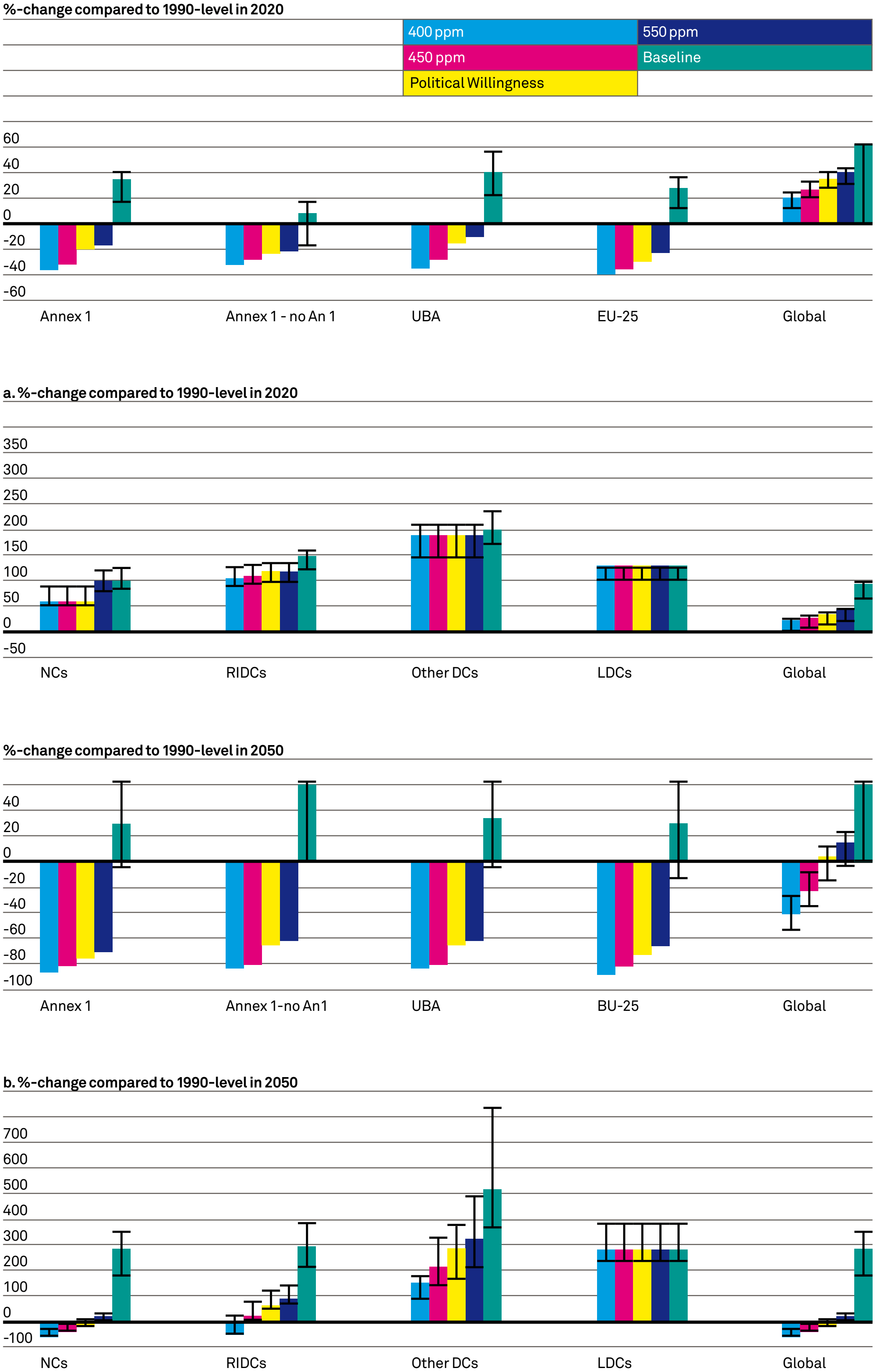
Emission Allocations: Contraction and Convergance



Change in Kyoto-gas emission allowances (excluding land use CO_2 emissions) before emissions trading compared to 1990 levels in 2020 (upper) and 2050 (lower) for the Annex I regions (a,c) and non-Annex I regions (b,d) for the Contraction & Convergence approach for the stabilization pathways at 550, 500, 450 and 400 ppm CO_2e concentrations under the CPI tech scenario[72].

Exhibit 10

Emission Allocations: South-North Dialogue Proposal



After [73]: Change in emission allowances compared to 1990 levels in 2020 (a) and 2050 (b) under the 400,450, 500 (Political Willingness) and 550 ppm CO_2e ppm scenario compared to the baseline emissions for the country groups (including the USA and EU-25). The bars represent the median over the six IMAGE IPCC SRES scenarios, while the error bars are the full range of the scenarios[74].

Impact of target and timing decisions on reaching concentration/ temperature goals

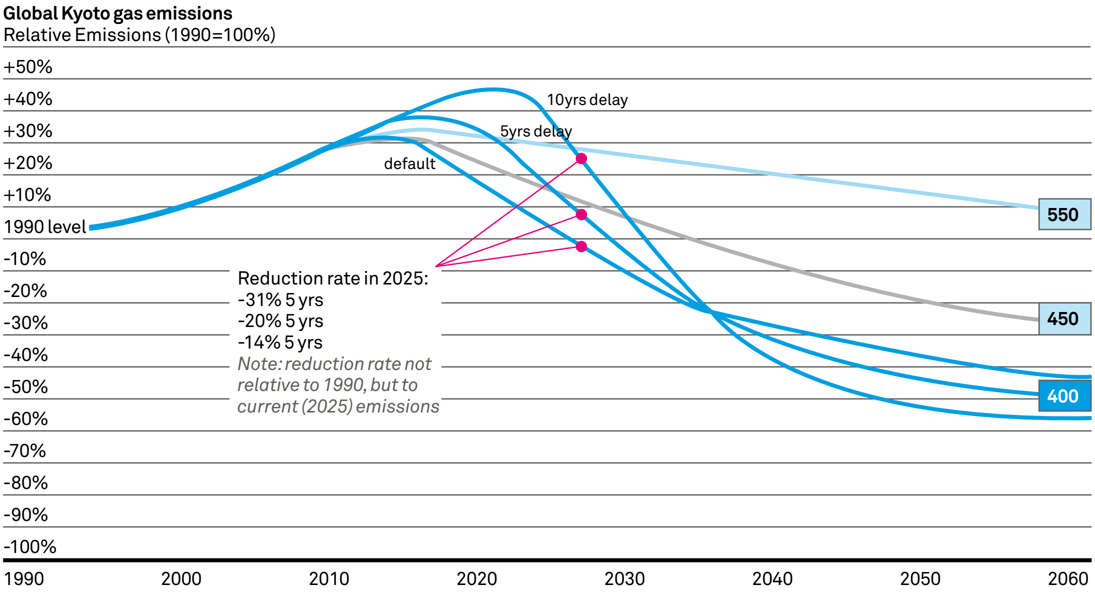
Delaying decisions to reduce emissions has consequences for the rate and magnitude of emission reductions required in the future to achieve a specific concentration or temperature goal. One measure of the increased efforts required as a consequence of delay is the increased rate of emission reduction required. It has been estimated that every five years in peaking global emissions increases the rate of required emission reductions by 1 percent per year (see Exhibit 11 below).

As reported above, the IPCC AR4 found that delay in reducing emissions risked carbon intensive technological lock in and larger and more severe climate damages.

Exhibit 11

Effects of delay
Emission pathway stabilizing CO_2e greenhouse gas concentrations at 400 ppmv CO_2e

Source
Meinshausen, M. pers. Comm.



Note:
(a) The S550Ce, 54550Ce, and S400Ce stabilization scenarios are based on the EQW multi-gas emissions pathways method which builds on the gas-to-gas correlations within the pool of S4 SRES and Post-SRES scenarios (Meinshausen et al submitted).
(b) Landuse CO_2 emissions are sharply decreasing in the default scenarios. If constant CO_2 emissions from the landuse sector were assumed, the emission reductions of the Kyoto-gases (fossil CO_2, Methane, N_2O, HFCs, PFCs, SF_6) have to be more pronounced. Alternatively, if emission allowances were given to avoided landuse emissions, overall emission allowances for the Kyoto-gases would have to be reduced accordingly (solid line).
(c) Delay profiles were calculated by assuming a 5 or 10 delay in global action. In the illustrative default scenarios, OECD and REF regions are assumed to enter stringent emission reductions by 2010, and ASIA and ALM by 2015.

Balancing and optimising the costs of mitigation, adaptation and damages

There is little agreement on whether one can in reality optimise across these different variables. The IPCC AR4 produced in effect an open finding on the question:

> *"Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilization level where benefits exceed costs."*[75]

Because the damages of climate change are felt in countries and regions remote from the primary causes of the damage, and many damages are felt over long timeframes, substantial ethical, moral and intergenerational issues are raised in deciding about the level of risk to be accepted and transmitted to future generations as a consequence of mitigation choices made at present.

Given the potentially catastrophic character of a number of the risks it can be argued that a more appropriate framework is to establish mitigation policies that limit those risks as far as possible. As Stern has argued, investment in mitigation now may be a small insurance premium to pay for avoided risks in the future.

Further impacts of target and timing decisions: technological lock-in, adaptation, irreversibility

What are the other significant impacts of decisions over targets and timing? Several findings from the IPCC AR4 Synthesis Report are relevant to this question:

- Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts
- Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels
- Even though benefits of mitigation measures in terms of avoided climate change would take several decades to materialise, mitigation actions begun in the short term would avoid locking in both long-lived carbon intensive infrastructure and development pathways; reduce the rate of climate change; and reduce the adaptation needs associated with higher levels of warming
- Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt
- Reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is not possible, or will only be available at very high social, environmental and economic costs.

Expected climate impacts if we do act now

The climate impacts that can be expected as a result of the most aggressive emission reductions scenarios reviewed by the IPCC in its AR4 can be seen from Exhibit 3 and Exhibit 4 above. The lowest scenarios would limit temperature to around 2°C above preindustrial. At this temperature increase during the 21st century, up to a billion additional people could be at risk of water stress; some 10 – 20 percent of species could be at increasing risk of extinction; substantial and widespread increases in coral reef bleaching would expected along with reduced agricultural production from crops in the tropics and low latitude regions; increased damages from floods and storms in would be expected in coastal regions; and there would be increased health risks and deaths from diarrhoeal diseases, heat stress and other climate change induced problems. The threshold for the irreversible meltdown of the Greenland ice sheet could be approached or crossed.

Exhibit 12 summarises the impacts for a temperature increase of 2 – 2.4°C above pre-industrial (1.4-1.8°C above 1980-1999) from Exhibit 3 and Exhibit 4 above. This does not, however, directly show the impacts that would follow from the most stringent mitigation scenarios examined, as the temperature range for these scenarios is in equilibrium (after the 21st century at 2-2.4°C). The IPCC AR4 provided no information on the 21st century warming to be expected from these low stabilization scenarios; however, it could be anticipated that in general temperatures would not rise as high as the long term warming levels for these scenarios. Nevertheless, the kind of scenarios shown above Exhibit 7, which are consistent with the pathways shown in Exhibit 6 for the low scenarios, have about a 10-40 percent chance of exceeding 2°C in the 21st century. The table below can therefore be seen as the upper edge of the likely damages and risks to be faced under the most stringent mitigation scenarios in the IPCC AR4.

Exhibit 12

Summary of impacts, risks and damages for warming of 2-2.4˚C above preindustrial

Sector/Region	Risk or damage for 2-2.4˚C warming
Water	1-1.5 billion additional people with water stress, increasing drought in mid and low latitudes
Ecosystems	ca. 20% of species at increasingly high risk of extinction, most corals bleached, increasing wild fire risks
Food	Decreases in cereal production for some crops in low latitude regions
Coast	Increased damages from storms and floods, up to 3 million additional people at risk of coastal flooding
Health	Increasing burden from malnutrition and diarrhoea, infectious and cardiovascular diseases; increased mortality from heat waves, floods and droughts.
Singular events	Continuing retreat of Greenland and West Antarctic and approach to threshold for irreversible loss
Africa	10-15% of sub Saharan species at risk of extinction, 350 million additional people at risk of water stress
Asia	Decreases of crop production of order 5% in wheat and maize in India and rice in China, up to 2 million additional people at risk of coastal flooding, of order 0.5 billion additional people with water stress
Australia/New Zealand	Annual bleaching of Great Barrier Reef, of order 3-5,000 additional deaths from heat waves, reduction in flow of Murray Darling River of greater than 10%, decreasing water security in southern Australia
Europe	Significant decreases in water availability and crop production (wheat) in Southern Europe
Latin America	Increasing risk of extinctions, 80-180 million additional people with water stress
Small Islands	Increasing coastal inundation and damage to infrastructure, agriculture loss of up 20% of GDP in low lying islands

Glossary of Terms

This glossary defines words and phrases used in this paper on climate science. The text is drawn from the “Glossary of Terms used in the IPCC Fourth Assessment Report”[74] and is shortened, abridged or used verbatim, as appropriate for this paper.

Adaptation:	Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
Aerosols:	A collection of airborne solid or liquid particles that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in several ways: directly through their effects on radiation transfer in the atmosphere and indirectly by helping to form clouds or modifying properties and lifetime of clouds.
Annex I:	The list countries in Annex I to the UNFCCC.
Atlantic thermohaline circulation:	North-south overturning circulation in the Atlantic ocean which is more accurately termed the Atlantic Meridional Overturning Circulation (MOC).
AR4:	IPCC Fourth Assessment Report
AWG:	Ad Hoc Working Group
Back carbon:	Aerosol species that absorb light and can have a warming effect, and consists of soot, charcoal and/or possible light absorbing organic matter.
Carbon cycle:	The term used to describe the flow of carbon (in various forms, e.g., as carbon dioxide) through the atmosphere, ocean, terrestrial biosphere and lithosphere.
CO_2:	Carbon dioxide
Carbon dioxide equivalent (CO_2e):	The concentration of carbon dioxide that would cause the same amount of radiative forcing as a given mixture of carbon dioxide and other greenhouse gases.
Climate forcing agents:	An agent that causes change in the climate system such as volcanic eruptions, solar variations and anthropogenic changes in the composition of the atmosphere (including changes to greenhouse gas concentrations and aerosols) and land use change.
Climate projection:	A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/ radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised and are therefore subject to substantial uncertainty.

Climate sensitivity: Equilibrium climate sensitivity refers to the equilibrium change in the annual mean global surface temperature following a doubling of the atmospheric equivalent carbon dioxide concentration.

Climate scenario: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models.

Climate system: The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, and the interactions between them. The climate system evolves in time under the inflence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and changes in greenhouse gas concentrations.

Emission scenario: A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.

FAIR: The policy decision-support-tool FAIR aims to assess the environmental and abatement costs implications of climate regimes for differentiation of future commitments.

Greenhouse gases: Greenhouse gases (GHG) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O3) are the primary greenhouse gases in the Earth's atmosphere.Moreover, there are a number of entirely human made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

IMAGE: Integrated Model to Assess the Global Environment

IPCC: Intergovernmental Panel on Climate Change

Multigas: Next to CO_2 the other greenhouse gases (methane, nitrous oxide and fluorinated gases) are taken into account in e.g. achieving reduction of emissions (multi-gas reduction) or stabilization of concentrations (multi-gas stabilization).

Non-Annex I: Countries that do not appear in Annex I of the UNFCCC.

Ocean acidification: Increased concentrations of CO_2 in sea water causing a measurable increase in acidity (i.e., a reduction in ocean pH). This may lead to reduced calcification rates of calcifying organisms such as corals, molluscs, algae and crustacea.

Palaeoclimate: Climate during periods prior to the development of measuring instruments, including historic and geologic time, for which only proxy climate records are available.

PPM: parts per million

Projections: Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised, and are therefore subject to substantial uncertainty. See also Climate projection;

Radiative forcing: Change in the net, downward minus upward, irradiance (expressed in W m–2) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.

Scenarios: A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a 'narrative storyline'.

Sink: Any process, activity, or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere.

SRES: The storylines and associated population, GDP and emissions scenarios associated with the Special Report on Emissions Scenarios (SRES)[75], and the resulting climate change and sea-level rise scenarios. Four families of socio-economic scenario (A1, A2, B1 and B2) represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns, and global versus regional development patterns.

TAR: IPCC Third Assessment Report

UNEP: United Nations Environment Program

UNEP/GRID-Arendal: Official UNEP Centre in Southern Norway

Vulnerability: 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 variation to which a system is exposed, its sensitivity, and its adaptive capacity.

WGII: IPCC Working Group II

WGIII: IPCC Working Group III

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