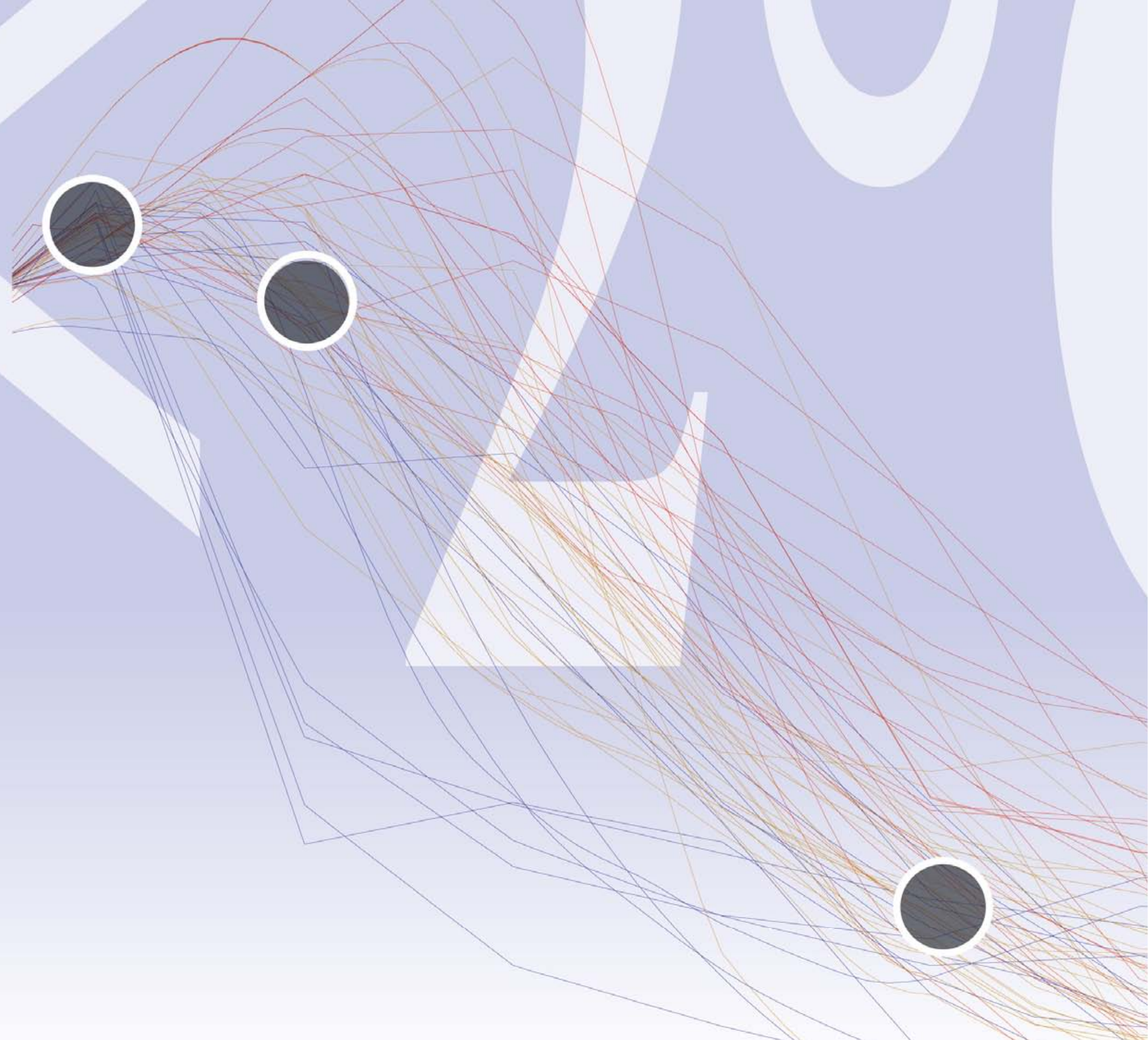

Scientific Perspectives after Copenhagen

Information Reference Document

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This Information Reference Document was commissioned by the EU's Climate Change Science Experts on behalf of EU member states. The paper was prepared by scientists throughout Europe and is based on an ongoing project, conducting a more detailed analysis and review of literature in which external experts have also been consulted.

It is an advisory document, which has been written to inform climate change negotiators and policymakers of the most relevant up-to-date scientific knowledge on climate change.

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Acknowledgments

The Spanish and Belgian Presidency thank the Writing Team, the members of the Steering Group and the members of the EGSci for their valuable comments and guidance and the UK Department of Energy and Climate Change (DECC) for providing financial support for project management.

Scientific Perspectives after Copenhagen

Information Reference Document, October 2010

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Preface

Climate change presents a growing social, economic and political threat for all countries and one which requires urgent international concerted action. The challenge facing governments is to develop the international mechanisms required to tackle this common problem whilst at the same time recognising the diverse capabilities and responsibilities of each country.

The Copenhagen Conference did not reflect the EU's expectations and ambitions, but did raise climate change to the highest level of government policy and mobilised public opinion in an unprecedented manner. The outcome established our common long-term goal of limiting warming to below 2°C. However, a number of questions remain to be answered. For example, what is needed for a reasonable chance of achieving a 2°C limit to global temperature rise? Where would different reduction options lead us? What if we do not attain an emissions peak within the next decade? How do the pledges relate to the 2°C limit?

It is important that policymaking is advised by the best relevant and up-to-date scientific information available. The IPCC continues to be the most authoritative body to provide us with policy-relevant information from the scientific literature. Since 2007, new studies have confirmed and complemented IPCC AR4 findings. This paper is an EU contribution to the scientific understanding of the nature of the problems we face and aims to guide us in the development of an effective solution. It is to a large extent an update of the previous Information Reference Document - The 2°C target (2008). The work was commissioned from a number of scientists across Europe following the Copenhagen Conference of the Parties and addresses a number of key scientific and technical issues relevant to the international efforts to combat climate change, including the Copenhagen Accord.

The paper indicates that the reduction pledges that Parties have offered in association with the Copenhagen Accord are indeed a step in the right direction. However, they are likely to be insufficient to achieve the 2020 milestone required to keep open the possibility of limiting global temperature rise to 2°C, the goal of the Copenhagen Accord. Thus, for aligning actions with the long-term goals, and for designing a viable future climate change regime, the first step has been taken. Yet more needs to quickly follow, in order to achieve an emissions peak soon enough so that 2020 emissions become reduced to a level which allows for feasible and sufficient reduction rates thereafter. The longer the delay in action, the more difficult it will become to limit global warming to less than 2°C.

We commend this paper to you as a contribution to the ongoing negotiations and to their successful conclusion.

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Belgian Minister for Environment and Climate

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Summary

The Copenhagen Accord sets a goal of limiting average global surface warming to 2°C to achieve the ultimate objective of the United Nations Framework Convention on Climate Change. It further calls for Parties to submit their 2020 emission reduction pledges in order to begin achieving this goal. Additionally, it allows for the review of a limit of 1.5°C in 2015.

To ensure a likely (>66%[1]) chance of achieving the common goal of limiting global warming to less than 2°C above pre-industrial temperatures:

- ***A peak in emissions is required by approximately 2015.*** The later the peak occurs, the steeper the decline in emissions would need to be in the subsequent decades. Delaying the emissions peak past this window will result in annual reduction rates that potentially exceed feasibility while substantially raising the costs of mitigation.

- ***A decrease in emissions of 50-70% relative to 1990 levels is necessary by 2050.*** This assumes further emission reductions after 2050.

- ***Reductions of long-lived greenhouse gases, such as carbon dioxide are essential.*** In addition reductions of the short-lived greenhouse gases, black carbon aerosol, tropospheric ozone, and aviation-induced cloudiness could also make an important contribution by lowering the rates of temperature increase in the near term. It would also counteract the warming resulting from reductions in sulphate aerosol concentrations due to reduced fossil-fuel use and air quality policies. Thus, ***reducing all constituents contributing to global warming may be necessary.***

- ***Technologies that achieve negative CO_2 emissions may be necessary in the long term (post 2030).*** Many studies suggest biomass energy with carbon capture and storage may be crucial for maintaining a 2°C limit.

[1] In this document "likely" means that with the given emission path (of which we do not judge the probability that it will occur), there is at least a 66% chance that the warming will be below the stated level, considering uncertainties in the response of the climate system.

The current emissions reduction pledges associated with the Copenhagen Accord fall short of a 2020 milestone that maintains a likely chance of achieving a 2°C limit without requiring potentially infeasible post-2020 reduction rates. Even the most optimistic interpretation of the current pledges leaves a gap of 2-6 Gigatonnes of CO_2 equivalents. Excluding the conditional pledges and other optimistic hypotheses, the gap in 2020 is approximately 10 Gigatonnes of CO_2 equivalents.

The main conclusions in this report are based on a probability of at least 66% that temperature increase is limited to below 2°C. If a higher probability of staying below 2°C is required then greater emission reductions would be needed. If a lower probability is considered acceptable (for instance 50%) then emission reductions could be lower. However, our analysis of the current Copenhagen Accord pledges shows that, ***even allowing a 50% probability of limiting warming to below 2°C, the required post-2020 emission reduction rate may not be feasible.***

The achievement of the large reductions in anthropogenic greenhouse gases required to maintain the 2°C limit highly depends upon the implementation of effective policy instruments. This includes targeting as many emissions sources as possible with cost effective policies which are perceived as fair. Cost effectiveness can only be achieved by giving long-term signals that enhance necessary investments and by making emitting of greenhouse gases costly. Well-attuned development can also contribute to mitigation and improve adaptive capacity by shifting to more sustainable development pathways. Sustainable development paths may also reduce the potential negative side effects of mitigation efforts, such as negative impacts of increased biomass production on food security, biodiversity and deforestation.

Recent literature reinforces the evidence provided by the IPCC AR4 that limiting warming to less than 2°C above pre-industrial temperatures considerably reduces the risk of triggering accelerated or irreversible changes in the climate system as well as large-scale adverse impacts. Nevertheless, significant risks do still remain. Impacts of climate change will, in addition, not be the same everywhere and some regions or sectors might experience a disproportionate amount of adverse impacts.

The Copenhagen Accord also calls for a review, in 2015, of a potential 1.5°C limit. Research in relation to this is expected to be synthesised in the upcoming IPCC 5th assessment report. The few limited assessments currently available give preliminary evidence that such a goal might only be possible by allowing temperatures to initially exceed 1.5°C, followed by temperature reductions towards the end of the century or later (overshooting).

1. Introduction

This paper presents a scientific assessment of the implications of the 2020 emission reduction pledges associated with the Copenhagen Accord and provides an update of the recent scientific evidence of direct relevance to these. It is intended to provide Parties with information on the implications of these pledges with relevance to a post-2012 agreement.

The Copenhagen Accord (CA) established a goal to limit global average surface warming to less than 2°C (hereafter referred to as the 2°C limit). A review is also envisaged for 2015 to consider a lower temperature limit of 1.5°C. In support of the 2°C limit, national pledges to reduce emissions by 2020 are given in the appendices of the Copenhagen Accord. There are, however, many open questions as to how a 2°C limit is to be achieved in light of the current pledges. This paper aims to improve the understanding of the ramifications these mitigation pledges have in respect to the 2°C limit.

The 2008 EU 2°C Target Paper (EG Science 2008), based largely upon the IPCC Fourth Assessment Report (AR4), catalogued a range of evidence as to why an increase of more than 2°C in global average near-surface temperature compared to pre-industrial temperatures is expected to be undesirable on a global scale. Since the AR4, the understanding of climate system components and processes has continued to improve, although considerable uncertainties remain. Recent evidence reinforces the importance of maintaining 2°C as an upper limit to temperature increases.

In this paper we present an assessment of a range of different emission pathways and an evaluation of the technical and economic feasibility of achieving large emission reductions. We then discuss the implications of emission reduction pledges associated with the Copenhagen Accord and present actions required for achieving stringent targets. We finish with an update of recent findings regarding changes in the climate system and their impacts in relation to a goal of limiting warming to below 2°C.

How certain are we about limiting warming to an acceptable level?

Projections of future climate have some uncertainty associated with them. This means that when we talk about limiting warming below a particular temperature, such as 2°C, we are really specifying the probability of keeping the temperature below the chosen limit. Clearly, there remains some chance that the limit will still be exceeded.

The probability with which we should aim to keep warming below 2°C is not specified in the Copenhagen Accord, which simply states that the global temperature increase shall remain below 2°C. It remains an open question for negotiators and policy makers to decide what level of certainty they are willing to work with.

In this document, for much of our analysis and when forming our main conclusions, we have chosen to use a probability level of at least 66% (defined by the IPCC as "likely"). Requiring at least a 66% chance of limiting global temperature rise to below 2°C implies there is up to a 34% chance of exceeding this temperature limit.

A lower probability level (of at least 50%) for limiting warming to below a given temperature is also commonly used in the published literature. When comparing results from a range of different studies it is vital to establish what probability level has been used in each case.

2. Stabilisation targets

How do choices in emission pathways affect future temperature?

The total emissions over the entire time span in question are important due to the strong correlation between cumulative emissions and temperature outcomes (e.g. Allen et al. 2009, Meinshausen et al. 2009). Setting global emission milestones in specific years, namely in 2020 and 2050, does constrain cumulative emissions to a certain degree and can therefore help indicate whether a 2°C limit can be maintained. This is because there are a limited number of feasible pathways that can occur between these milestones.

A later peaking date requires a higher rate of emissions reduction after the peak, or lower (or even negative) emissions in the long term to achieve the same probability of limiting warming to below a particular level. As a consequence, later and/or higher peaks increase the required speed at which a transition to a low carbon economy must occur after peaking. The interplay between emissions peak year and post-peak reduction rate from one particular study is illustrated in Figure 2.1.

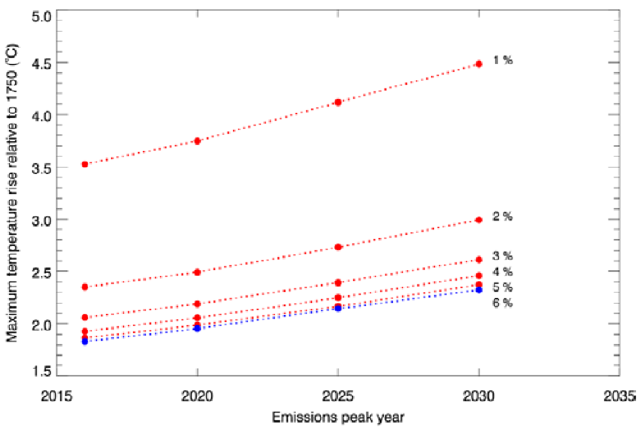


Figure 2.1: Illustrative example: Projected maximum global average surface temperature reached with a 50% probability for a range of emissions pathways. Results are presented for emission peak years ranging from 2016 to 2030 and post peak emission reduction rates of from 1% per year to 6% per year compounded (Gohar and Lowe 2009). Uncertainty in the climate projections was determined following Lowe et al. (2009) (see endnote 1).

For a given warming target, early peaking reduces the subsequent rate of emission reductions that are needed for a given temperature target. As expected, it can also be seen from these results that, given the same long-term emission reduction rates, early peaking gives a higher chance of limiting warming to lower temperature levels. For post-peak emission reduction rates of 2% per annum or greater (see endnote 2), each decade of delay in the peaking date increases the peak warming level by between 0.2 and 0.5°C given the same rate of decline in post peak emissions, as displayed by the sloping red lines in Figure 2.1.

Significant reductions in temperature will require net removal of emissions from the atmosphere.

Recent literature (Matthews and Caldeira 2008; Solomon 2009; Lowe et al. 2009) suggests that if emissions are reduced to very low levels (or zero) in the long term, the decline in atmospheric CO_2 concentrations are likely to occur slowly and temperatures would not decline, but would stabilize. A decline in temperatures could be achieved, albeit the extent is uncertain, by globally net negative CO_2 emissions (e.g. Biomass Energy with Carbon Capture and Storage – BECCS), supported by a vigorous abatement of non-CO_2 greenhouse gases (see section 5).

This has two major implications: Firstly, if global warming progressed to a level that is found to produce unacceptable consequences it remains uncertain how quickly, or even if, it can be brought back to a safer, lower level. Secondly, even for a 2°C limit, net emissions of greenhouse gases, particularly CO_2, have to be at least close to zero towards the end of the 21st century. It is also important to note that, a stabilisation of temperature will not lead to an immediate stabilisation of other aspects of the climate system - particularly sea level rise and possibly large-scale components of the system, such as the Amazon forest (Jones et al. 2009).

3. Setting the milestone for 2020 emissions

This section focuses on how to set the emission target milestones in 2020 (and 2050) in order to effectively plan a journey towards a low or zero-carbon economy with a sufficiently small probability of exceeding the 2°C limit. Higher emission levels in 2020 imply steeper subsequent reduction rates, as discussed in Section 2. Furthermore, increased mitigation effort between now and 2020 avoids locking into carbon intensive infrastructure, making it easier to manoeuvre in the future.

We have collected more than 100 emission pathways available from a range of climate mitigation studies (specifically EMF-22, ADAM and RECIPE inter-comparisons) and, using established techniques (Meinshausen et al. 2009), estimated their probability of exceeding a warming limit of less than 2°C in a consistent way (see endnote 3).

Many of the pathways peaking between 2010 and 2020 display a likely (>66%) probability of achieving the 2°C limit whereas those peaking later have a more limited chance of this. This is consistent with recent estimates of a global emission level of 44 $GtCO_2eq$/yr by 2020 (± 2 $GtCO_2eq$) being used as an indicator of whether global emissions are on the right track for avoiding warming of more than 2°C (Tirpak et al. 2009; Stern 2009; EU Commission 2010). Current levels of total anthropogenic emissions are estimated at 48 $GtCO_2eq$/yr (van Vuuren and O'Neill 2006; Manning et al. 2010). Thus, today's emission levels exceed those envisaged as being desirable in 2020 by roughly 4 $GtCO_2eq$/yr (±2 $GtCO_2eq$), requiring the peaking of global emissions by approximately 2015 in order to achieve at least a likely chance of limiting warming to below 2°C.

Our analysis quantifies the implications of 2020 emission levels with regards to the stringency of post-2020 mitigation efforts (see Figure 3.1) and the achievement of the 2°C limit with a specific probability. In practice, there will be limitations in the socially-acceptable and politically-feasible future reduction rates, even if they are technically feasible. In addition to raising issues of intergenerational equity and economic optimality, a delay of decisive mitigation actions would also result in a high 2020 global emission level which might also lead to higher temperature levels. In other words, delayed mitigation in the near-term might practically foreclose the option for mid-course corrections after 2020 to achieve the 2°C limit, if it turns out that more pessimistic estimates about climate system behaviour and/or diffusion rates of carbon neutral technologies were to come true.

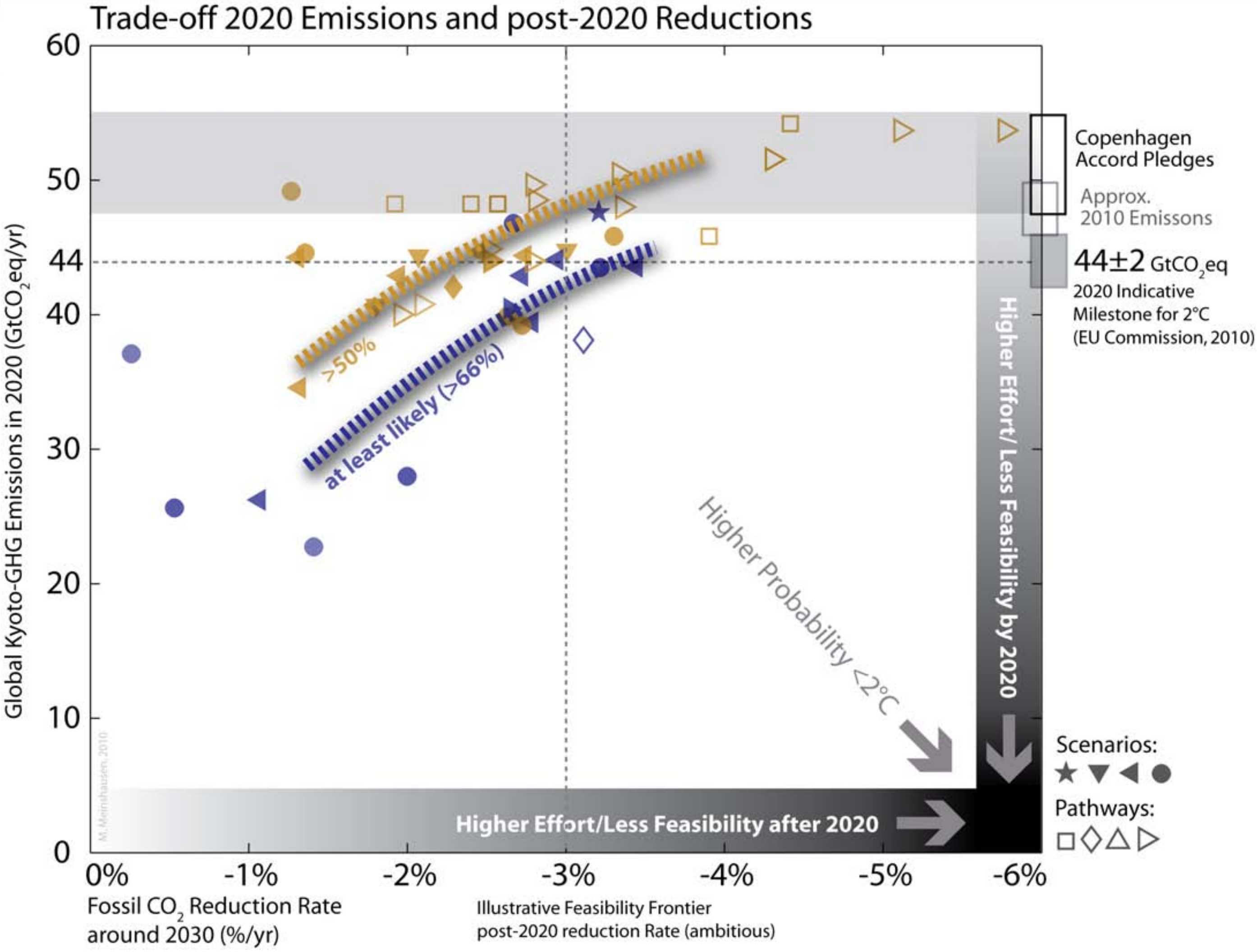


Figure 3.1 *Relationship between 2020 emission levels and post-2020 reduction rates. Each marker represents one scenario, with 2020 GHG emission levels on the vertical and 10-year average fossil CO_2 reduction rates in 2030 on the horizontal bottom axis. The yellow markers are associated with a >50% probability of staying below 2°C warming, whilst the blue markers are associated with a likely or >66% probability. Dashed bold lines illustrate the trade-off between higher efforts to reduce emissions up to 2020 and thereafter in the two different likelihood classes of scenarios. Reduction rates are given in % of year-2000 global emission levels per year (see endnote 1).*

For a 44 $GtCO_2eq$ (± 2 $GtCO_2eq$) emission level in 2020, our analysis finds that annual reduction rates of around 3% are required for a pathway with at least a likely chance (66% or greater) of limiting global warming to below 2°C. Although consideration of 2050 emissions is absent from the Copenhagen Accord it is discussed further in negotiating texts on the “Shared Vision”. We find that most scenarios suggest a 50 to 70% reduction in emissions relative to 1990 to maintain at least a likely chance of limiting warming to below 2°C.

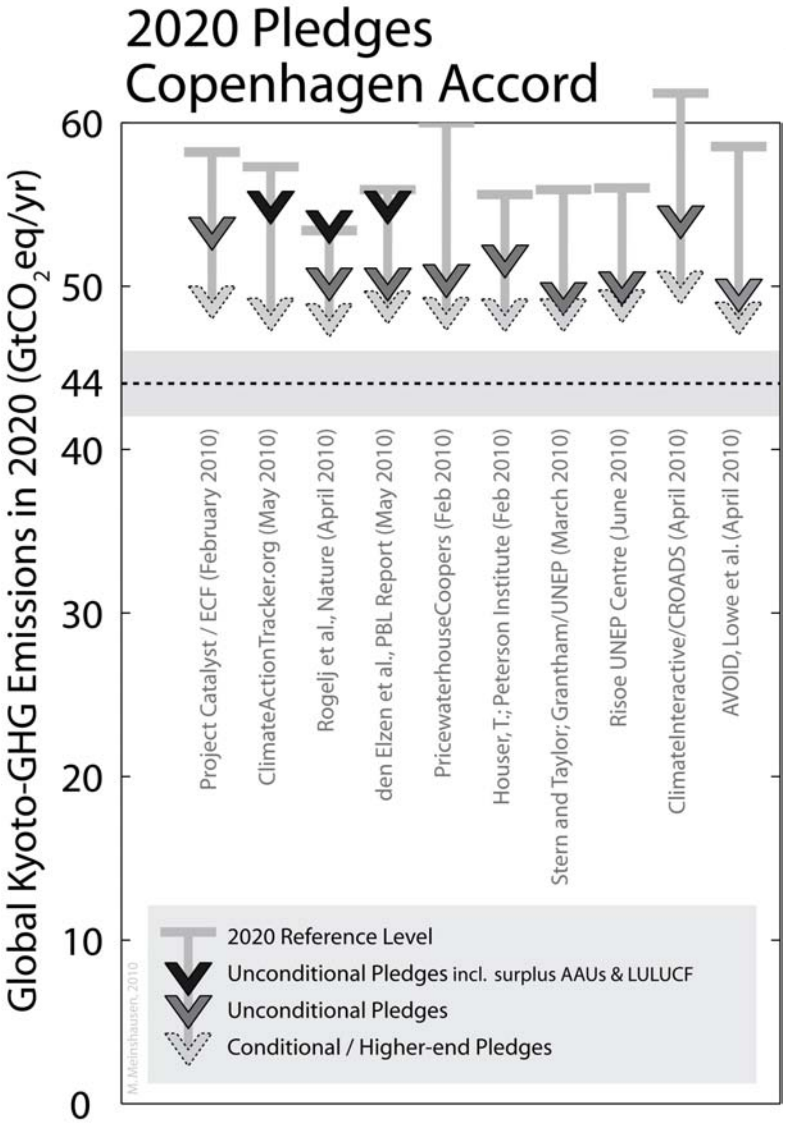
4. Analysis of the Copenhagen Accord pledges

The Copenhagen Accord invited parties to submit their pledges for 2020 emissions by 1 February 2010. Over 76 countries, accounting for approximately 80% of global emissions, provided their pledges as of 30 June 2010. Various studies have now quantified the potential implications for global emissions by 2020, ten of them being summarized in Figure 4.1. More recent pledges have little effect on these results (the sum of additional pledges amount to <0.1 $GtCO_2eq$).

Although these assessments start from various hypothetical 2020 reference levels – some even higher than any other scenario in the literature analyzed here, the studies agree relatively well with each other, in terms of the emission levels to be expected if all higher ambitious pledges were realized. Without the use of surplus emission allowances from the Kyoto Protocol's first commitment period (Rogelj et al. 2010), without any allowances resulting from accounting for non-additional LULUCF activities and without double counting of financed mitigation action in developing countries (Den Elzen et al. 2010), the projected emission level is 48 $GtCO_2eq$. This is around 4 $GtCO_2eq$ higher than the 44 $GtCO_2eq$ (±2 $GtCO_2eq$) quoted above. It is also higher than any of the scenarios (<47 $GtCO_2eq$) we have analysed in Figure 3.1 and that has a likely chance of remaining below the 2°C limit. ***Therefore, even under the most optimistic assumptions and interpretations, the Copenhagen Accord Pledges fall short of the 2020 reductions required for a likely chance of maintaining the 2°C limit.***

Furthermore, the most optimistic assumption of the Copenhagen Accord might not even be realized given that many of the higher ambition pledges are conditional on, for example, a binding regime. Some Parties therefore offered unconditional pledges, albeit less ambitious, with the quantifications ranging from 49 to 54 $GtCO_2eq$ in 2020. There is also the question of an extra provision (surplus allowances, LULUCF, and/or potential double counting etc.) that could further deteriorate effective emission allowances by an additional 3 to 4 $GtCO_2eq$. This has been taken into account in at least three studies and implies a 2020 emission level of 54 to 55 $GtCO_2eq/yr$ (Den Elzen et al. 2010; Rogelj et al. 2010; Climateactiontracker.org 2010) (cf. Black arrows in Figure 4.1). Taking these extra provisions into consideration, the gap between 44 $GtCO_2eq$ (±2 $GtCO_2eq$) and these upper-end Copenhagen Accord assessments could therefore widen to 10 $GtCO_2eq$.

__Figure 4.1__ Assessments of the Copenhagen Accord Pledges following the low unconditional (medium grey arrows) and high conditional pledges (bright grey arrows) inscribed in the Copenhagen Accord, with some taking into account extra accounting provisions allowing higher emissions due to surplus AAUs or LULUCF (black arrows).



Some of the assessment studies might generally underestimate effective 2020 emissions, since underlying officially reported country-by-country emission data tends to be lower than globally-aggregated top-down emission estimates. A correction for that discrepancy could increase some of the studies' 2020 emission level estimates by as much as 5% (Rogelj et al. 2010).

The emission levels of unconditional/lower pledges (54-55 $GtCO_2eq/yr$) far exceed any pathways which have at least a likely chance of limiting warming to below 2°C. Our analysis suggests that even a 50% chance or greater is only possible by embarking on potentially infeasible reduction rates of 4% or higher, see Figure 3.1. Even under the most optimistic interpretation of the Copenhagen Accord Pledges, and the assumption that all Parties would aim for their conditional higher-end pledges, very few, if any literature scenarios would suggest a likely (66%) chance of limiting warming to 2°C.

Net negative emissions in the second half of the century might be able to compensate for a reduced emission reduction rate between 2020 and 2050, but this carries the sizeable risk of relying on experimental technology that has not yet been tested on a large scale.

5. Prospects for effective action

The transition to a society with near-zero emissions of greenhouse gases before the end of the century is an enormous challenge. To facilitate this radical transformation of the global energy and food systems both public support and credible and effective policies stimulating the transition are necessary. This essentially includes a mix of different policy tools, including the use of a carbon price mechanism, stimulation of RD&D, and additional policies that ensure that new technologies are widely available and deployed.

Options to reduce CO_2 emissions

A massive investment in carbon-free energy technologies and supporting infrastructure is needed in order to achieve an emissions peak within the next 3 to 5 years and to be on a pathway consistent with a 2°C limit. Such transition would bring about important co-benefits in terms of reduced air pollution (Haines 2009) and increased energy security (IEA 2010). Recent studies suggest that more than 50%, and up to 90%, of the global primary energy supply must be provided by low carbon technologies by 2050 (compared to about 20% in 2005) if the CO_2eq concentration is to be below 400-450 ppm (which implies at least a 50% chance of a 2ºC limit) by 2100 (Edenhofer 2010; Clarke, et al. 2009). In addition, the global primary energy demand is expected to grow in the coming decades. How much it expands depends on the efforts to reduce emissions of greenhouse gases and the potential for energy efficiency and conservation measures (see below). However, in baseline scenarios the global primary energy demand is expected, in round numbers, to double by 2050 (Clarke et al. 2009; Edenhofer 2010; IEA 2010). The difficulty of reducing emissions also depends on development pathways, including such issues as equity, poverty, attention to sustainability and the environment as well as resource availability and extraction cost of fossil fuels. Taking this into account, there are three principle ways of reducing CO_2 emissions from the energy system.

1) *Reduction of energy use through efficiency and conservation measures*. Improving energy efficiency is considered to be one of the most important mitigation options for the first half of this century and has a great potential for being low cost, and to a limited extent have negative costs (e.g. van Vuuren et al. 2009, McKinsey 2009, IEA 2010, Kitous et al. 2010). Harnessing this potential will require, in addition to price-based policy instruments, directed policies such as building codes and efficiency standards as well as long-term planning of urban structures and transport infrastructure.

2) *Transition of fuels to less CO_2-emitting fossil fuels and to renewable and nuclear energy.* In the coming decades renewable energy technologies must expand profoundly if low emission limits are to be met (Edenhofer et al. 2010; IEA 2010). Biomass energy (or biofuels) is found to be especially important for making low concentration limits (400-450 ppm CO_2eq) feasible and for the costs of achieving such limits (Edenhofer et al. 2010). However, there may be risks of land use conflicts and increased N_2O emissions related to a biomass expansion. Nuclear is found to increase above its present level in many mitigation studies (Edenhofer et al. 2010; IEA 2010; Kitous et al. 2010).

However, nuclear is found to be less important than renewable energy or carbon capture and storage (CCS) for the feasibility and cost of reaching low stabilization targets (Edenhofer et al. 2010). Problems with nuclear weapons proliferation and safety as well as storage of spent fuel may put additional constraints for a large-scale expansion of the energy source (Socolow and Glaser 2009).

3) *Capture and storage of carbon dioxide from fossil fuels and biomass*. Though not yet commercially available, this technology is considered to be very important for meeting stringent stabilization limits (Azar et al. 2010; Edenhofer et al. 2010; van Vuuren et al. 2009; Calvin 2009). Capturing and storing CO_2 from biomass would imply negative emissions if the biomass is constantly re-cultivated, reaching, in some IAMs, as much as -10 $GtCO_2$ or less by the end of the century (Edenhofer et al. 2010; Azar et al. 2010; Calvin et al. 2009). A large-scale expansion of BECCS is believed to be necessary to achieve annual emission reduction rates of more than 3-4% (den Elzen et al. 2010). In addition, the geological CO_2 storage needs to be safe and permanent so as to achieve the full climate benefit of the technology and to avoid risks with leakage of CO_2.

Furthermore, management of soil and forest carbon can, to a limited extent, lessen the required pace of the transformation of the energy system.

Options to reduce non-CO_2 GHG emissions and other contributors

Although CO_2 is the most important anthropogenic greenhouse gas, reducing non-CO_2 greenhouse gas emissions can also contribute to lowering near-term temperature increases (Ramanathan and Xu 2010). Most importantly, there is a significant potential to decrease emissions of greenhouse substances such as methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), black carbon (BC) and tropospheric ozone (O_3) pre-cursors such as carbon monoxide (CO). Addressing aviation-induced cirrus clouds may also provide some contribution.

CH_4 emissions from waste and sewage treatment plants and the energy industry as well as N_2O emissions from industrial sources can be reduced to small levels at low costs (Delhotal et al. 2006, Lucas et al. 2007). Emissions of CH_4 and N_2O from the agricultural sector are inherent parts of the biological processes in food production, although some abatement options are available and more could become available given successful RD&D (Lucas et al. 2007; Smith et al. 2008).

The mitigation of BC and O_3 are required in addition to reductions in CO_2, to increase the chances of achieving the 2°C limit. Short-lived greenhouse gases (such as O_3) and some aerosols (such as BC), also tend to warm the climate (Forster et al. 2007; Ramanathan and Carmichael 2008). Given their short atmospheric lifetimes, temperatures in the longer term will be little affected by BC and O_3 mitigation action in this decade, although mitigation would slow the current rate of warming.

Mitigation cost and timing of emissions reductions

Recent studies, such as those undertaken within the ADAM project (Edenhofer et al. 2010) and EMF 22 (Clarke et al. 2009), provide evidence that the cost of stabilizing at 450 ppm CO_2eq in 2100 would be in the order of a few percent of Net Present Value Global GDP over the 21st century in a cost-effective climate regime, given global participation and the availability of the technologies described above.

A delay in the transition to a low emission society reduces the economic and technical feasibility of reducing emissions enough to maintain a 2°C limit (den Elzen et al. 2010). For a likely chance of maintaining a 2°C limit, the turnover time in the energy system and other sectors of society is expected to be too long to support the rapid transition that would be necessary after a postponement of emissions peaking beyond 2015. Earlier peaking allows for gradual replacement of old inefficient fossil-based technologies and earlier development and diffusion of new technologies.

Immediate participation by both developing and developed nations would provide the most cost-effective pathway to limit warming to below 2°C. Delayed participation of major emitters among developed and developing countries under a stringent emissions reduction target appears to be more costly for all parties. If emission reductions were initially undertaken only in Annex B countries that are party to the Kyoto Protocol, other countries' emissions would later need to be reduced from a higher level and more rapidly (Krey and Riahi 2009).

Implications of the current economic downturn

Recent analysis shows that 2009 was the first year since 1992 in which the global emissions of CO_2 did not increase (Olivier and Peters 2010). The economic downturn will most likely result in meeting Kyoto targets more easily, increasing the surplus emission allowances from the first commitment period, and that the reference emissions in the coming decades will be lower than what was believed prior to the crisis (den Elzen et al. 2009; IEA 2009). How much lower the reference emissions may be depends on how rapidly the world recovers from the crisis. Although, as economies start to grow again, emissions are expected to increase if stringent climate policies are not in place (e.g. Blanford et al. 2009, den Elzen et al. 2009).

6. Avoiding dangerous climate change

As has been found in the IPCC AR4 and reinforced in the EU 2°C Target Paper (EG Science 2008), if an increase in the global average temperature exceeds 2°C, it becomes less likely that the majority of human systems can adapt to climate change at globally-acceptable economic, social and environmental costs. In fact, by the time the global average temperature has reached 2°C, some regions are likely to have already experienced sizeable impacts on human activities and ecosystems.

A key area where advances have occurred since the IPCC AR4 and the EU 2°C Target Paper, is in the understanding of large-scale accelerated or irreversible changes in the climate if a certain threshold or tipping point is passed. These include disruptions in the El Niño Southern Oscillation phenomenon in the Pacific, dieback of the Amazon Rainforest and disappearance of summer Arctic sea-ice. Melting of the Greenland and West-Antarctica ice sheets could also occur, contributing to an eventual sea level rise of several metres within a few centuries. A number of studies (including Rahmstorf 2010, Lowe and Gregory 2010, Pfeffer et al. 2008) have indicated an accelerated sea level rise in the order of 1 to 2m within this century.

The outcome of several recent studies, which used expert interpretation of the literature and other available evidence, reinforces the AR4 conclusions – that the probability of triggering at least one major climate system change, such as those mentioned above, increases greatly as warming exceeds approximately 2°C (Zickfeld et al. 2010; Lenton et al. 2008; Kriegler et al. 2009; Smith et al. 2009).

The evidence base for site and sector specific impacts caused by future climate change has also grown rapidly since the IPCC AR4. A brief selection of evidence since the AR4 is provided in Table 6.1. In general, the recent literature reinforces observations and predictions reported in the IPCC AR4. A key aspect is that the impacts are likely to vary regionally, but with large-scale negative impacts outweighing any positive benefits of climate change. Some regions are likely to experience a disproportionate share of negative climate impacts, e.g. parts of Africa and the Small Island States.

Despite large uncertainty on the "tipping points" and impacts, it is a robust conclusion that temperature targets below 2°C further decrease the risks of causing accelerated or irreversible changes or unacceptable levels of impacts.

Table 6.1 Impacts of climate change in IPCC AR4 and more recent studies[1].

Impact	IPCC AR4	Examples of key studies since AR4 WG2
Coastal systems	Progressive; > 2-3°C: millions or tens of millions of additional people affected by flooding depending on adaptation and other factors	Agreement with IPCC AR4 that south-east Asia will be the most affected region. Global estimates of the number of impacted people remain at similar levels (e.g. [1]). It is increasingly recognised that adaptation, socio-economic and other non-climatic factors will likely play an important role [2], and the current uncertainty in the magnitude of sea-level rise adds further complexity to estimating impacts.
Ecosystems & Biodiversity	Ongoing: contribution to extinction of species such as some amphibians, increased coral bleaching, increasing risk of wildfire. 2°C: 20-30% of species at increased risk of extinction. > 2.5°C: terrestrial biosphere becomes a net carbon source. > 4°C: major extinctions (40-70% species)	Increasing evidence to support the IPCC AR4 statement that 20-30% of plant and animal species are at increasingly high risk of extinction as global mean temperature rise exceeds 2 – 3°C. Recent observations from the Amazon provide further understanding of forest susceptibility to drought [3]. Increasing recognition that effects other than greenhouse gas warming are critical for the forest [4, 5]. Further evidence that ocean acidification could result in a mass extinction of worldwide coral species [6, 7, 8] More research into the impact of ocean acidification on fish and shell fish, with the impacts generally being shown as detrimental [9, 10, 11].
Water resources	Progressive; 1 – 1.5°C: additional 0.4 to 1.7 billion people at increased water stress	Recent studies do not suggest a major change in the risk since AR4, but they do represent a move towards a better representation of uncertainty in water resources modelling [12, 13, 14]. Results show that that mitigation could lower, but not eliminate, the impact of climate change on water resources [15, 16].
Agriculture & food security	>1.5°C: negative impacts on some regions (low latitudes) and crops, positive in others >4 °C: low latitude yields decrease for all cereals	More research has examined the potentially positive effect of CO_2 enrichment on crop productivity [17, 18, 19, 20, 21, 22, 23]. Generally, the results of these studies suggest a less optimistic response of crops to CO_2 enrichment and highlight the reduced yield associated with increased temperature, ozone, and occurrence of pests and weeds.
Human health	Ongoing and progressive: mortality and morbidity from heat waves, flood and droughts; changed distribution of some disease vectors > 1°C: increased burden from malnutrition, diarrhoea > 3°C: substantial burden on health services	[13] shows that in a 4°C warmer world annual summertime heat-related mortality could increase by more than threefold from present-day levels for cities including Boston, Budapest, Dallas, Lisbon, London and Sydney without adaptation. Conversely, milder winters will contribute to reduce the number of temperature-related deaths [13, 24, 25], with important regional differences. Recent research confirms AR4 findings and elaborates upon the influence of climate on the distribution of vector-borne diseases; for dengue and malaria, non-climatic factors are expected to dominate [26, 27]. [1]

1 All temperature increases are relative to preindustrial. References: [1]Dasgupta et al. 2009; [2] Nicholls et al. 2008;[3] Philips et al. 2009; [4] Golding and Betts 2009; [5] Malhi et al. 2009; [6] Cao and Caldeira 2008; [7] Veron 2008; [8] Veron et al. 2009; [9] Checkley et al. 2009; [10] Munday et al. 2009; [11] Legge and Tyrell 2009; [12] Preston and Jones 2008; [13] Gosling et al. 2009; [14] Hayashi et al. 2010; [15] Fischer et al. 2007; [16] Arnell et al. 2010a,b; [17] Tubiello et al. 2007; [18] Lobell et al. 2008; [19] Ainsworth and McGrath 2010; [20] Aggarwal 2008; [21] Reilly et al. 2007; [22] Van Dingenen et al. 2009; [23] Booker et al. 2009; [24] Bosello et al. 2006; [25] Hayashi et al. 2010; [26] Jansen and Beebe 2010; [27] Wandiga et al. 2010.

Are lower limits feasible?

The Copenhagen Accord provides for a review of a potential 1.5°C limit in 2015. Greater insight on this is expected to be provided in the IPCC 5th Assessment Report. Currently, there are only a few studies that have examined emission pathways and scenarios that provide a reasonable chance of limiting warming to 1.5°C. These have provided preliminary evidence that to have a reasonable chance of limiting warming to below 1.5°C, GHG emissions reduction rates in excess of 3 or 4% per year would be required following an emissions peak within the next few years. There are currently insufficient mitigation measures available in many Integrated Assessment Models to achieve such reduction rates (Bosetti et al*.* 2009; Clarke et al*.* 2009). Even under a very stringent level of mitigation action, temperatures will probably exceed 1.5°C for some time, so that such a goal may only be achievable by aiming to return temperatures to 1.5°C by the end of the century or later which would require large-scale negative CO_2 emissions. Further research on this would be useful for the review in 2015.

Appendix

Abbreviations

AAUs	Assigned Amount Units
AOSIS	Alliance of Small Island States
BECCS	Biomass Energy and Carbon Capture and Storage
BC	Black Carbon
CA	Copenhagen Accord
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
$GtCO_2$	Gigatonnes of Carbon Dioxide
$GtCO_2$ eq	Gigatonnes of Carbon Dioxide equivalent
HFCs	Hydrofluorocarbons
IPCC AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
LDCs	Least Developed Countries
LULUCF	Land use, land use change and forestry
N_2O	Nitrous oxide
O_3	Ozone
RD&D	Research Development and Demonstration
UNFCCC	United Nations Framework convention on Climate Change

Endnotes

1. The likelihood assessment underlying Figure 3.1 is based on a climate sensitivity uncertainty in line with the IPCC AR4 estimate (see 'illustrative default' in Meinshausen et al., 2009). This is slightly different to Figure 2.1, in which the somewhat higher warming in part results from a climate sensitivity uncertainty distribution based on Murphy et al. (2004), as detailed in Lowe et al. (2009).
2. There is no particular reason why emissions should fall at a specific and constant rate beyond the peak. However, this has been assumed in the analysis underlying the graph so as to make it transparent and simple.
3. For providing the overview of the current mitigation literature we took into account the following emission scenarios and pathways: (1) We use 91 emission scenarios from various modelling groups that took part in EMF-22 (Clarke et al. 2009), namely ETSAP-TIAM (Loulou et al. 2009), FUND (Tol 2009), GTEM (Gurney et al. 2009) , IMAGE (van Vliet et al. 2009), MERGE (Blanford et al. 2009), MESSAGE (Krey and Riahi 2009), MiniCAM (Calvin et al. 2009), POLES (Russ and van Ierland 2009), SGM (Calvin et al. 2009), and WITCH (Bosetti et al. 2009). (2) We use 15 fossil CO2 scenarios from five modelling groups participating in the EU ADAM project (Edenhofer et al. 2010), namely E3MG (Barker and Scrieciu 2010), POLES(Kitous et al. 2010), MERGE (Magne et al. 2010), REMIND-R (Leimbach et al. 2010) and TIMER (van Vuuren et al. 2010). (3) We use six fossil CO2 scenarios from the RECIPE project, as described in Edenhofer et al. (2009) and Luderer et al. (2009). (4) We included new emission scenarios for climate model intercomparison (so-called RCPs) (Moss et al. 2010). (5) STERN / Bowen and Ranger (2009): Several multi-gas emission pathways (6) AVOID / Gohar and Lowe (2009): The AVOID programme designed various stylized multi-gas emission pathways, eleven of which are included here. (7) PRIMAP/Rogelj et al. (2010): We include four PRIMAP emission scenarios consistent with a quantification of the low or high pledges. (8) EQW / Meinshausen et al. (2009): Two strong EQW mitigation case scenarios building on SRES multi-gas characteristics are included. We complemented any missing gases of EMF-22, ADAM and RECIPE scenarios using the RCPs, in particular RCP3-PD, RCP4.5 and RCP8.5 and linear interpolations in between based on the cumulative fossil CO2 emissions over the 21st century and harmonized to ~40 GtCO2eq/yr emission levels in year 2000 and emission trends up to 2005 consistent with observations of atmospheric concentrations (Meinshausen et al., submitted).

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