Emission reductions by the USA in 2020 and the risk of exceeding 2°C warming

Authors

Dr. (h.c) Bill Hare (PIK and Climate Analytics)
Dr. Michiel Schaeffer (Climate Analytics)
Dr. Malte Meinshausen (PIK)

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Quantitative assessment using PRIMAP Potsdam Real Time Integrated Model for the Probabilistic Assessment of Emission Paths, Potsdam Institute for Climate Impact Research (PIK) e.V. and analysis by CLIMATE ANALYTICS GmbH

Executive Summary

This report examines the relationship between the level of emission reductions to be undertaken by the United States by 2020 and the risk of exceeding a 2° Celsius (3.6° Fahrenheit) warming globally in the coming century, within the context of a new international agreement on climate change to be adopted at Copenhagen in 2009. International negotiations are focusing on a reduction range for Annex I countries as a group of 25-40% below 1990 levels by 2020 and for Non Annex I countries of a 15-30% reduction relative to business as usual growth by the same time.

The level of action by the United States is a very significant political variable in the Copenhagen climate negotiations and is likely to influence the level of ambition for the entire agreement. A stronger level of action by the USA would likely lead to more action from others, and vice versa. A delay in achieving emission reductions consistent with the 25-40% Annex I reductions would likely lead to delay by others. It is in this context that the Administration of President Obama faces difficult dilemmas. Under the previous Bush Administration very little was done to limit greenhouse gas (GHG) emissions, and by 2006 they were some 14% above 1990 levels, making a reduction to the 25-40% below 1990 levels within little more than a decade a very difficult task. President Obama has indicated that the United States should reduce its domestic emissions to 1990 levels by 2020, and to 80% below 1990 levels by 2050. Recently the US Special Climate Envoy Todd Stern argued that meeting the 25-40% reduction target range from 1990 levels by 2020 for the Annex I countries can be deferred, and faster reductions in the post 2020 period can make up for slower reductions to 2020.

We address the consequence of different levels of action by the USA by focusing on two questions:

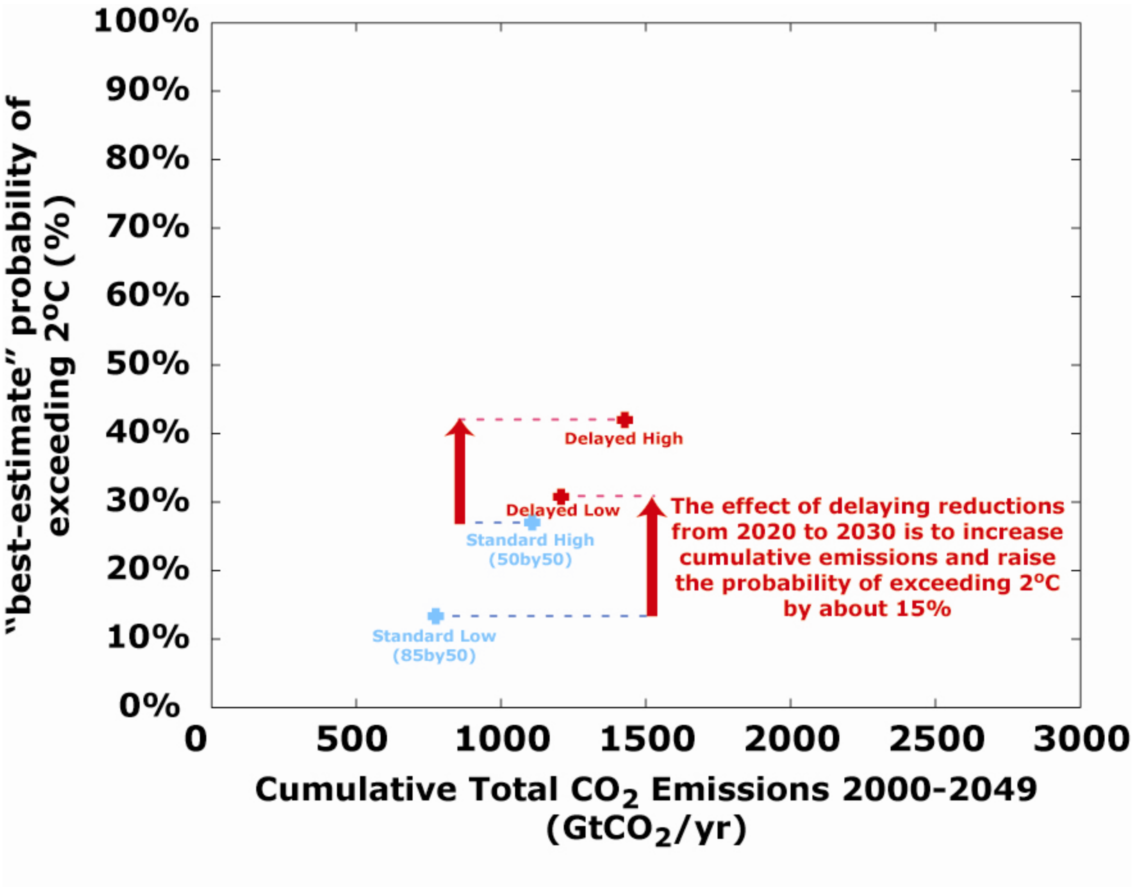
- The relationship between different global emission levels, Annex I reductions and reduced growth in non-Annex I emissions by 2020, and the risk (probability) of exceeding a global 2°C warming above pre-industrial.

- Whether a delay in reaching the 25-40% range of emission reductions from 1990 levels by 2020 for industrialized (Annex I) countries can be made up with steeper emission reductions to 2050. This is evaluated by examining the changes in the risk of exceeding a global 2°C warming.

On these questions we reached two broad conclusions:

- Higher emissions in 2020 resulting from delayed action by Annex I countries, degrades the ability to meet the 2°C warming limit. If global emissions were to return to the level of 1990 by the year 2020, the chance that 2°C warming is exceeded is estimated as roughly 1 in 6, which rises to 1 in 4, if global emissions are still 40% above 1990 in 2020.

- Delaying emission reductions by the Annex I group by 10 years, from 2020 to 2030, results in significantly higher cumulative greenhouse gas emissions and increases the rate of emission reduction in future decades. The probability of exceeding 2°C warming is increased by about 15% for such a delay, from a base probability for the two non-delay scenarios of 14% (6% to 32%) and 27% (14% to 48%), respectively. A delay thus results in an increased risk that is not compensated for by steeper reductions in later years.



Effects of a delay in Annex I countries limiting their emissions to 30% (High) or 45% (Low) below 1990 levels, from 2020 until 2030, on the probability of exceeding 2°C warming above preindustrial levels. Results of two cases are shown: one for a global reduction of 50% by 2050 (High) and the second for a global reduction of 85% in emissions from 1990 levels by 2050 (Low).

Given that it is likely that should the US take weaker action, others would follow suit, a delay in achieving significant reductions by the United States would likely result in an increased probability of exceeding a 2°C warming. The increased risk of exceeding 2°C, caused by a ten-year delay in reaching a 30% reduction from 1990 levels for the Annex I countries, is comparable to the increased risk caused by a 35% higher global level of emission in 2020. This analysis shows that a delay in reducing greenhouse gas emissions by ten years causes a higher overall level of emissions in 2020 and converts an emission pathway with about a 1 in 7 chance of exceeding 2°C to a 1 in 4 chance.

1 Introduction

This report addresses the question of the relationship between the level of emission reductions to be undertaken by the United States by 2020 and the risk of exceeding a global 2°C warming above pre-industrial. In the context of negotiations now underway towards a new international agreement on climate change to be adopted at Copenhagen in 2009 the question of what level of action will be undertaken by the United States is very significant. The level of ambition shown by the USA is likely to strongly influence the overall level of ambition for the entire agreement in Copenhagen.

The context for this assessment of the level of action to be taken by the USA is the international focus on a range for industrial greenhouse gas emission reductions by the Annex I countries as a group of 25-40% below 1990 levels by 2020. This is the range of reductions in **emission allocations**[1] for the Annex I countries as a group from the lowest category of emission scenarios reviewed by the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4). The choice of this range reflects an emphasis on the goal of many countries to limit warming to 2°C or below. For this category of scenarios, Non-Annex I countries as a group reduce emissions to 15-30% below **business as usual** levels by 2020 (den Elzen and Höhne 2008), and global CO_2 emissions peak before 2020 (IPCC 2007).

Hence, the first issue addressed in this paper is the relationship between different global emission levels, Annex I emissions reductions and reduced growth in non-Annex I emissions by 2020 and the risk (probability) of exceeding a global 2°C warming above pre-industrial.

The Administration of President Obama faces difficult dilemmas in relation to the level of ambition for the Annex I countries as a whole. Under the previous Bush Administration very little was done to limit greenhouse gas emissions, and by 2006 they were some 14% above 1990 levels, making a reduction to the 25-40% below 1990 levels within little more than a decade a difficult task. President Obama has indicated that the United States should reduce its domestic emissions to 1990 levels by 2020, and to 80% below 1990 levels by 2050. There is as yet no indication of a national emission reduction obligation (quantitative emission reduction objective) which the Administration would consider in the context of an international agreement. As with the European Union, its domestic reductions would likely be significantly less than the overall national emission reduction obligation adopted as part of broad international agreement in Copenhagen.

It is natural in this context that questions will be asked as to whether or not the United States should make commitments that are in the 25-40% reduction range by 2020, or whether this can be delayed. Thus it has been argued by Special Climate Envoy Todd Stern that meeting the 25-40% reduction target range from 1990 levels by 2020 for the

[1] This refers to an emission allowance (a quantitative limit on national emissions), that can be met by a combination of domestic emissions reductions and acquisition of emission trading units from other Annex I countries, or from trading units acquired from activities in Non-Annex I countries.

Annex I countries can be deferred, and faster reductions in the post 2020 period can make up for slower reductions to 2020. This is the second issue that this paper addresses: whether a delay in reaching the 25 to 40% range of emission reductions from 1990 levels by 2020 for industrialized countries can be made up with steeper emission reductions to reach similarly deep levels of reductions in 2050.

2 Background and assumptions

2.1 IPCC AR4 mitigation scenarios

The IPCC Fourth Assessment Report (AR4) reviewed the range of mitigation scenarios in the published literature up to 2006, and categorised these into six ranges as shown in Figure 1 below. The lowest category stabilizes greenhouse gas concentrations in the range 445-490 ppm CO_2 equivalent, with the highest stabilizing in the range 855-1130 ppm CO_2 equivalent. The long-term equilibrium global mean warming that would result from these stabilisation levels is shown on the right-hand frame of Figure 1. The lowest category of the scenarios shows the range of warming that would result at equilibrium from a little over 1.5°C to close to 4°C, depending upon the actual sensitivity of the climate system to increases in greenhouse gas concentrations. The middle line on the right hand frame shows the global mean warming that would result from the greenhouse gas concentration stabilizations' levels if the IPCC AR4 best estimate of the climate sensitivity for a doubling of CO_2, 3°C, were the true sensitivity of the system. It can be seen however that there is a large uncertainty in this, with the figure showing the lower and upper bounds of the IPCC AR4 estimates of climate sensitivity for a doubling of CO_2 (2°C and 4.5°C respectively).

For the lowest category of emission scenarios it can be seen that a number of scenarios reduce emissions to negative levels after the mid-century, reflecting the introduction of biomass energy carbon capture and storage technologies (Vuuren, Elzen et al. 2007; Azar, Lindgren et al. 2006), which effectively extract carbon dioxide from the air. Such technologies appear to be necessary in the period beyond the mid-21st century to draw CO_2 concentrations down to low levels.

Table 1 summarises the results of the analysis of these low emission scenarios for global emissions in the top half of the table, as well as for Annex I emissions in the lower half of the table. The top of the table is drawn from the IPCC synthesis report. The lower half is drawn from Box 13.7 of chapter 13 of IPCC Working Group III AR4.

Equilibrium warming for different levels of greenhouse gas concentration stabilisation does not convey information about the dynamic and transient response of the climate system to greenhouse gas emissions and changes in concentrations over time. In order to show the effects of uncertainty in emissions, the effects of greenhouse gas emissions on climate forcing and ultimately on climate change globally a modelling approach is needed. The approach taken in this paper is to use a reduced complexity climate system model to characterise uncertainties in the climate system based on state of the art scientific understanding about the system (Meinshausen, Raper et al. 2008). With this approach we are able to provide probabilistic assessments of change, synthesising uncertainties in climate system science for any given emission pathways.

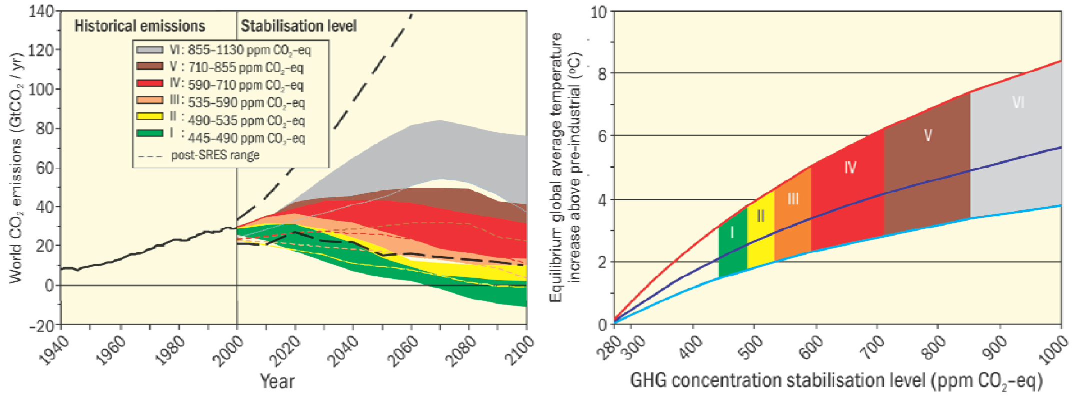


Figure 1 IPCC AR4 stabilization scenario assessment: global CO_2 emissions on the left hand side and equilibrium warming for these stabilization levels on the right hand side. The Category I stabilization levels provide the ranges for the Annex I countries reductions discussed in the text. From Figure SPM.11, IPCC AR4 Synthesis Report Summary for Policy Makers (IPCC 2007) where a full description of the figures can be found.[2]

Table 1 Emission ranges of lowest IPCC stabilization scenarios

CO_2-equivalent Stabilization level (2005 = 375 ppm CO_2-eq)	Global Mean temperature increase at equilibrium (ºC)	Global average sea level rise at equilibrium <u>from thermal expansion only</u>	Year global CO_2 emissions need 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
Scenario category	Region		2020	2050
A-450 ppm CO_2-eq	**Annex I**		**-25% to -40%**	**-80% to -95%**
	Non-Annex I		Substantial deviation from baseline in Latin America, Middle East, East Asia 15-30% below business as usual (den Elzen and Höhne 2008)	Substantial deviation from baseline in all regions

Source: Top half of table from Table SPM.6 of the IPCC AR4 Synthesis Report Summary for Policy Makers (IPCC 2007) and lower half from Box 13.7 of IPCC WGIII (Gupta, Tirpak et al. 2007).

[2] http://www.ipcc.ch/ipccreports/ar4-syr.htm

2.2 IPCC AR4 and Delay issue

The IPCC also reviewed the question of delayed action and found that this could lead to significantly increasing risks of climate damage. The particular findings of the Fourth Assessment that relate to this issue are as follows:

> "Decision-making about the appropriate level of global mitigation over time involves an iterative risk management process that includes mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity, and attitudes to risk. 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."
>
> "Delayed emission reductions lead to investments that lock in more emission-intensive infrastructure and development pathways. This significantly constrains the opportunities to achieve lower stabilization levels (as shown in Table SPM.5) and increases the risk of more severe climate change impacts [3.4, 3.1, 3.5, 3.6]." (IPCC 2007)

These findings give some general guidance on the question of delay, but do not specifically answer the questions raised by Special Envoy Stern. Based on the conclusions above, it would be reasonable to expect that a delay in emission reductions could have a consequential effect in terms of increased risks from climate change, and in terms of more rapid rates of emission reduction due to a build up of more intensive infrastructure and development pathways. This is a working hypothesis of this report, and it will be tested below, along with the significance of any increase in risk or increased rate of emission reduction implied by a delay in the achievement of Annex I emission reduction targets.

2.3 2°C warming limit and the Annex I 25-40% reduction range for 2020

In the international climate negotiations significant emphasis has been given to the lowest of the range of emission mitigation scenarios evaluated and assessed by the IPCC AR4. Stabilisation of greenhouse gas concentrations at the ranges set for these mitigation scenarios (around 450 ppm CO_2-equivalent greenhouse gas concentrations) could limit warming to around 2 to 2.4°C above preindustrial levels in the long term for the IPCC best estimate of the climate sensitivity. These scenarios would require industrial carbon dioxide emissions globally to peak before 2020, and to be reduced by 50 to 85% below 2000 levels by 2050. For the Annex I countries, these scenarios imply that the emissions of greenhouse gases from industrial sources would need to be reduced by 25 to 40% from 1990 levels by 2020, and to 80-95% below 1990 levels by 2050. By 2020, the emissions from the Non-Annex I countries would need be 15 to 30% below the projected business as usual (BAU) growth of 100-200% above 1990 by 2020. Such emissions relative to BAU translate to 35% to 150% above 1990 levels.

Many governments internationally have focused on the lowest GHG stabilization levels from the IPCC AR4 because of concerns about the consequences of high levels of greenhouse gas concentrations and consequently higher levels of warming. A sizeable group of countries, drawn principally from the small island developing states and the least developed countries, have argued that these lowest IPCC levels are not low enough to ensure the safety and security of their countries in the future. Over 100 countries accounting for more than one fifth of the world's population (UN 2007) have called for warming to be limited to an increase of 2°C above preindustrial, or lower. Since 1996 the European Union has called for global warming to be limited to a maximum increase of 2°C relative to preindustrial levels (Council of the European Union 2005). Other countries have joined this call since the IPCC AR4 was concluded: Norway (Stoltenberg 2007), South Africa (Marthinus van Schalkwyk 2008), Iceland, Costa Rica, El Salvador, Honduras, Nicaragua, and Panama. The Alliance of Small Island States and the Least Developed Country group have called for warming to be limited to 1.5°C (ENB 2008). With such a level of concern there has been a significant focus within the international political discussions on climate change on the need to peak emissions globally before 2020, as implied in the lowest mitigation scenarios from the AR4.

From a climate system perspective, the level and timing of peak emissions is quite important for the probability of limiting global warming to level such as 2°C above preindustrial levels. The lower the peak and the earlier in time, the greater is the chance of limiting warming to 2°C or below. Conversely, the higher the peak in emissions and the further away it is in time, the larger will be the cumulative emissions emitted to the atmosphere and the lower the ultimate chance of limiting warming to a future goal, and the faster emission reductions are required later in time to reach the ultimate goals.

In general, the mitigation scenarios reviewed by the IPCC AR4 used energy economic models to achieve GHG concentration stabilisation targets, which were specified in advance as targets for the models. These scenarios did not in general look specifically at the emission pathways to limit warming to specific levels, which entail significantly more uncertainties than for concentration stabilization. In this paper we approach the problem of analyzing emission pathways by accounting for a full range of uncertainties in climate system science. This enables a probabilistic approach to the question of achieving targets to limit warming. Emission pathways can be evaluated in terms of the risk of exceeding specific warming levels. This approach assists in interpreting the emission reduction ranges derived from the IPCC AR4 review of mitigation scenarios in the context of emission target setting for the Copenhagen climate negotiations and the achievement of the goal of limiting warming below 2°C.

2.4 International policy context

Under the Bush Administration the United States did not move forward at the same pace with climate policies as the European Union and some other countries. US emissions have risen substantially, so that in 2006 industrial greenhouse gas emissions were 14% above 1990 levels[3]. International commitments on the levels of action to be undertaken on greenhouse gas emissions are tightly linked to questions of fairness and equity. Slow action by a major emitter such as United States is likely to lead to slower action by others, both in the industrialised world and amongst the developing country (non-Annex I) group[4]. Slower action would thus likely lead to higher overall levels of emissions and to a higher and later peak in global emissions than would otherwise have been the case.

In the context of the Copenhagen negotiations, the relative level of action between Annex I and non-Annex I countries will be a key political issue. The developing countries expect that all of the Annex I countries will take on legally binding emission reductions similar to the obligations, currently to be found in the Kyoto protocol for the industrialised countries and which are inscribed in Annex B to that agreement.

President Obama has indicated that the United States should reduce its domestic emissions to 1990 levels by 2020, and to 80% below 1990 levels by 2050. The European Union has indicated its willingness to reduce its emissions by 30% reduction from 1990 levels by 2020, contingent upon action undertaken by other countries and the development of a new international agreement in Copenhagen in 2009. It is important to note that this commitment is to a legally binding commitment to cap the allowed emissions of the EU at 30% below 1990 levels. As such this commitment would not be met by purely domestic action, as this commitment would be met in part through the acquisition of emission trading units from countries outside the European Union. Emission units would be obtained from other Annex I countries covered under legally binding national emission limits, or from internationally recognised trading units generated by the clean development mechanism and new instruments that are anticipated to be developed under the new Copenhagen agreement, such as sectoral emission crediting mechanisms.

The U.S. like the European Union could make an international commitment where a significant level of the reduction is achieved through the acquisition of emission trading units from countries outside the United States. Emission units could be obtained under legally binding national emission limits, and from internationally recognized trading units generated by the Kyoto Protocol's Clean Development Mechanism and/or sectoral crediting instrument or mechanisms that may be developed under the new Copenhagen agreement for Non Annex I Parties.

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[3] http://unfccc.int/files/inc/graphics/image/gif/total_excluding_2008.gif

[4] For the purposes of this discussion we consider only two groups, the Annex I countries of the United Nations Framework Convention on Climate Change (UNFCCC), and the non-Annex I countries which are the countries not belonging to Annex I of the UNFCCC and who are classified as developing countries.

On the issue of the Annex I 25-40% reduction range for 2020 the US Special Climate Envoy Todd Stern has argued that meeting the 25-40% reduction range from 1990 levels by 2020 for the Annex I countries is "as a matter of substance, [...] not necessary" and "what counts is getting on a viable path between now and 2050". He argues that it is not necessary because "a somewhat steeper path in the latter period could make up for the slightly slower start" (Stern 2009)[5]. It is important to note that in his statement the Special Climate Envoy reinforced the commitment of President Obama to 80% or more reductions by 2050 from 1990 levels. Thus the steepened pathway of emission reductions referred to by Mr. Stern would still limit emissions of warming gases to these or lower levels by 2050.

3 Assumptions and methodology

In order to be able to evaluate the questions raised in this assessment, a number of assumptions are needed and these are described below. Two broad emission pathways are assumed to evaluate the consequences of peaking at different levels of greenhouse gases by 2020 and of delaying the Annex I achievement of reduction targets for limiting warming to 2°C. One is for a 50% reduction of global greenhouse gas emissions by 2050, and the other for an 80-85% reduction below 1990 emission levels. In each case, after 2050 it is assumed that carbon dioxide emissions are asymptotically be reduced to zero by 2100. For each of these two classes of scenarios, we have developed specific cases with interim reduction levels in the years 2020 to 2030 for the World, Annex I and non-Annex I regions. The 50% reduction by 2050 class approximates an emission pathway which limits warming to 2°C with about a 60-70% probability (the range is given by the span of interim reduction levels). The 85% reduction by 2050 class corresponds to about a 70-85% probability – or put another way the former has a about a 30-40% chance of exceeding 2°C and the latter about a 15-30% chance of exceeding 2°C[6].

Not delaying the achievement of the 50% and 85% reduction levels, enables an examination of the implications of a delay in achieving the 2020 Annex I targets whilst maintaining a commitment to achieve a 2050 reduction goal, in spite of the steeper emission reduction that would be required in the delay case. The choice of a different reduction level for 2050 could reflect a policy choice about the level of relative risk to be taken that the 2°C warming limit would be exceeded.

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[5] Full quote: "Reducing 25-40% below 1990 levels would be a good idea if it were doable, since it would allow a less steep reduction path in the 2020-2050 time period. But it is not independently necessary; a somewhat steeper path in the latter period could make up for the slightly slower start."

[6] Note that the probability ranges associated with any "ultimate" 2050 target can be widened by extending the range of interim levels, and also that the ranges widen yet further when more information is included concerning uncertainty in climate system response, as will be done in the analysis presented in the next sections.

For the division of global emissions in 2050 between Annex I and non-Annex I countries it is assumed that a common per capita level of emissions is achieved in that year. In other words by 2050 the per capita emissions in both the Annex I and non-Annex I regions will have converged to a common level. The population assumptions for 2050 are drawn from the IPCC SRES B2 scenario (Nakicenovic and Swart 2000), which reflects a mid range scenario for population projections in that year. This is a good working assumption as a convergence towards common per capita emissions is widely understood, at least in broad terms, as a useful first approximation to global equity.

An important source of emissions, apart from those caused by the burning of fossil fuel, industrial activities and agriculture (termed here industrial greenhouse gas emissions, or Kyoto gas emissions as these are all reported under the Kyoto protocol), derives from deforestation. We have separated out deforestation emissions from industrial greenhouse gas emissions in this analysis for several reasons. Firstly, it enables a comparison between the industrial greenhouse gas emission reductions undertaken by the Annex I countries and the relative level of effort from similar industrial, energy and agricultural sources from the non-Annex I countries. Secondly, there is a significant level of uncertainty in deforestation emissions that is far greater than that found in the estimated sources of industrial greenhouse gas emissions. Thirdly, the policy instruments required to affect deforestation emissions appear to be quite different from those required to change the course of industrial and energy greenhouse gas emissions. This is due to the complexity of forestry issues, involving multiple objectives, indigenous people, sovereignty and the scale of illegal logging activity that is not all linked to industrial greenhouse gas activities.

For each of the industrial greenhouse gas scenarios we have computed a deforestation reduction scenario using the Equal Quantile Walk model (Meinshausen, Hare et al. 2006). This model looks for the lowest deforestation emissions scenario which corresponds to the scenarios from emissions from industrial sources in Equal Quantile Walk database of mitigation scenarios. In other words, if it is assumed that the world will take action on industrial greenhouse gas emissions, then it is assumed that a similar level of effort will be placed on reducing deforestation emissions. This is a reasonable assumption given the effort underway now to establish an international mechanism to incentivise the reduction in deforestation and degradation emissions.

The Equal Quantile Walk model generates quite large emission reductions from deforestation, when forced to find deep emission reductions from industrial greenhouse gases (see Figure 2). Therefore, the emission pathways evaluated, and the consequent probability of exceeding 2°C limits already embed substantial deforestation emission reductions. For a scenario that delays emission reductions from industrial gases the Equal Quantile Walk model will compute a slower reduction in deforestation than would otherwise be the case.

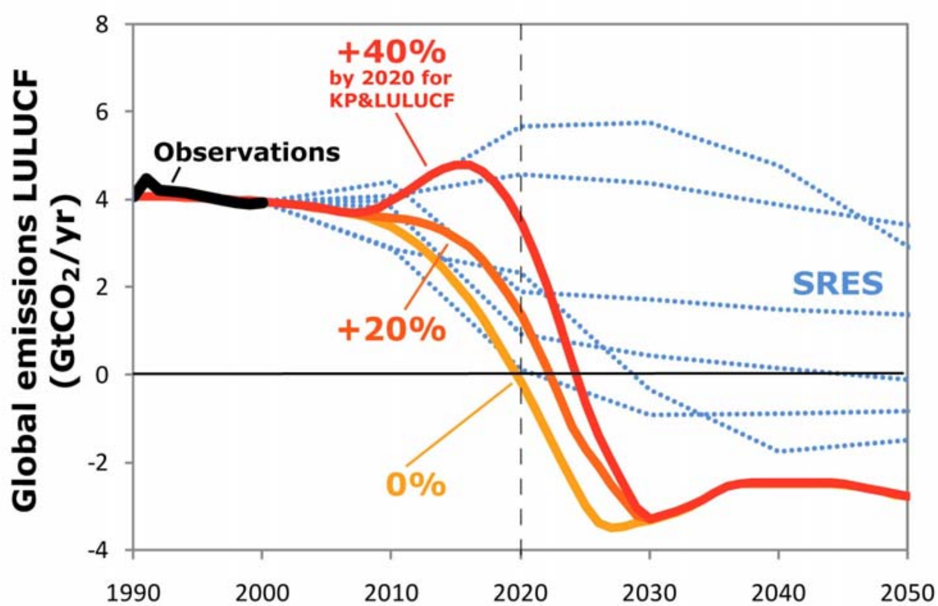

Figure 2 Emissions from land-use change. Observations from Houghton and Hackler (2002) - black line; IPCC SRES reference scenarios - blue dotted; Three land-use change emission scenarios from the Equal Quantile Walk model (Meinshausen, Hare et al. 2006) corresponding to the three global emission scenarios described in the text (see for details of these scenarios the next section in this report). These land-use change (deforestation) emission scenarios are generated by the Equal Quantile Walk model which draws upon a database of emissions scenarios and literature to find deforestation scenarios similarly low as the low fossil CO_2 scenarios. These scenarios are plotted against the range of IPCC SRES deforestation scenarios, which show that after the elimination of deforestation emissions there is an uptake of carbon. Regrowth of forests and other vegetation is expected once deforestation stops. Given advances in the assessment of land-use change in the context of climate change policies in the last few years a further set of sensitivity studies would be needed to examine fully the role of different deforestation scenarios in relation to the questions being addressed in this paper.

A further source of emissions to be accounted for in assessing the risk of exceeding 2°C is the emissions of ozone-depleting substances, which are also powerful greenhouse gases affecting both the lower atmosphere and the stratosphere. For this assessment we have assumed full compliance with the Montréal protocol and its successive amendments and adjustments. We have not assumed additional action in this area, although there is some potential for this in the form of earlier and more rapid phase-out of hydrochlorofluorocarbons (HFCs), recovery of ozone-depleting substances held in operating equipment prior to release. The benefits of this, however, are quite small compared to the level of reductions required from industrial greenhouse gas emissions and from deforestation reductions. Further work would be needed to examine this issue.

For evaluating the climatic consequences of emission pathways we have used the reduced complexity couple climate-carbon cycle model MAGICC 6, described by Meinshausen et al. (2008). This model has been set up to evaluate uncertainties in all aspects of the climate system including radiative forcing, climate sensitivity, and the carbon cycle. The climate model parameters are chosen so that a probabilistic estimate of future climate change can be made, taking into account the uncertainty in the climate system. The parameters are chosen for the model so that it is constrained by observations of climate change and ocean heat uptake over the last century.

4 Global emission levels in 2020

The timing and magnitude of the peak in global emissions has an important influence on the ability to limit warming to 2°C or below. The level of action undertaken by the USA would have influence on the timing of this peak and as well its quantitative magnitude, through the direct effect of US emissions and through the relative effect on the level of action that other countries were prepared to undertake. In this section we explore the consequences of three levels of global emissions of Kyoto-Protocol gases and from deforestation in 2020, after the peak: a return to 1990 levels emissions by 2020, 20% above 1990 levels and 40% above 1990 levels. The Kyoto-gas emissions in all of the emission pathways after 2020 go down towards an 80% reduction from 1990 levels by 2050.

These global scenarios are shown below in Figure 3. As would be expected, the higher the peak in global emissions, the faster is the decline required in the period between 2030 and 2050 for emissions to approach the 80% reduction level selected here. There are substantial uncertainties in future business as usual emissions, as shown in the range of the SRES scenarios in this figure. However, it can be seen that by 2020 in nearly all cases emissions are below, or well below, the lowest of the IPCC SRES scenarios. In Figure 4 the consequences of the total effect of deforestation emissions and emissions of ozone-depleting substances and the Kyoto gases are shown for the 20% increase by 2020 case. With large reductions by 2020 in deforestation emissions the total emission envelope begins to approach the Kyoto gas emission trajectory, and subsequently drops below it as deforestation ceases and there is substantial re-growth of vegetation on previously cleared land and forest. This is consistent with many of the fully process based scenarios for the 21st century.

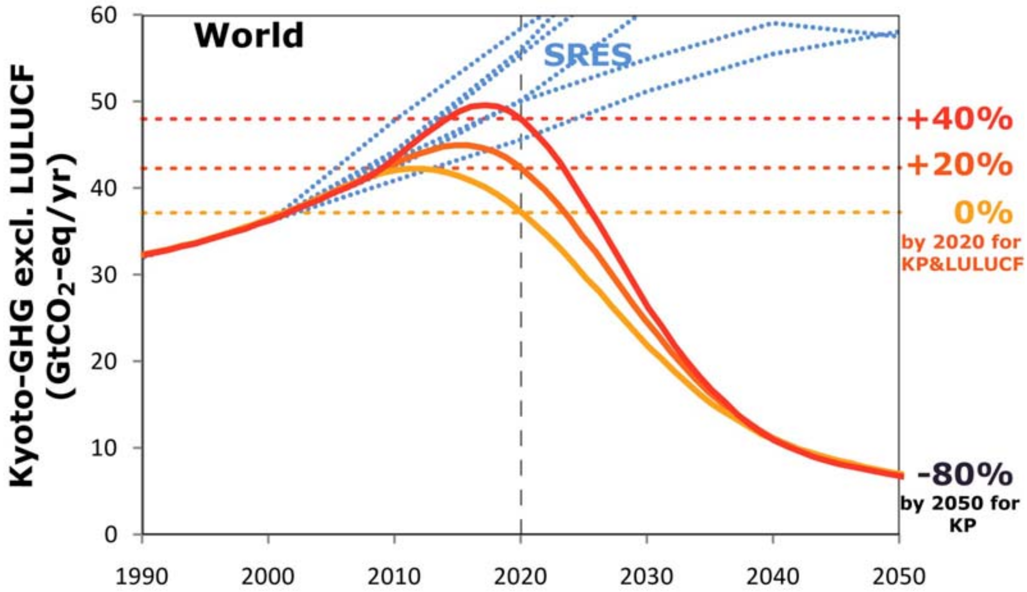

Figure 3 Global emission pathways for different levels of greenhouse gas emissions in 2020. The levels in 2020 are with respect to 1990 emissions of the industrial (Kyoto) gases (KP) and land-use change and forestry (LULUCF), while the 2050 target if defined for Kyoto gases only. All cases are compared with the IPCC SRES scenarios (blue dotted).

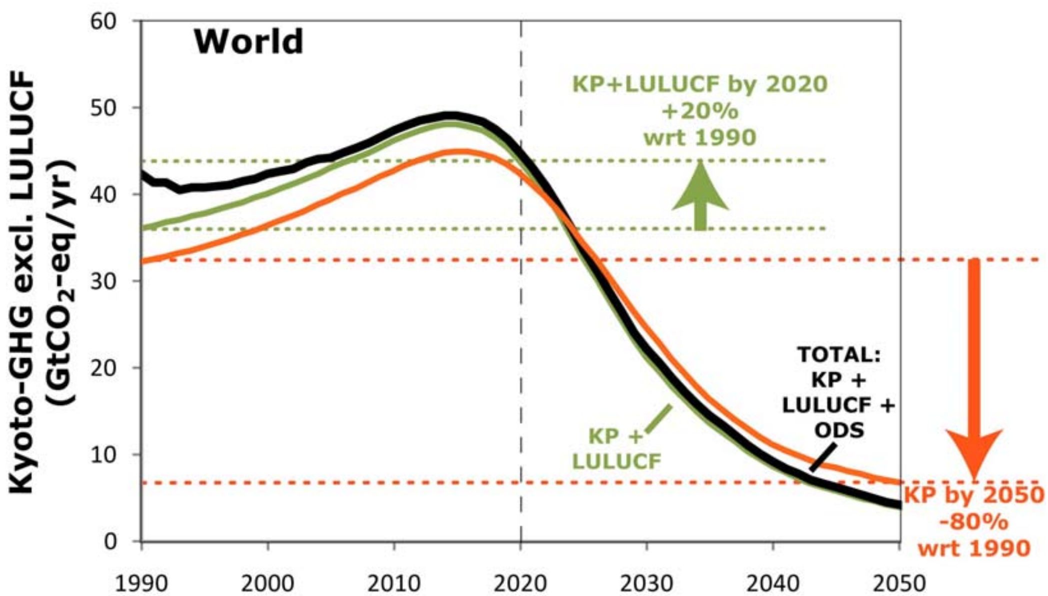

Figure 4 Global emission pathways for the case of a 20% increase in industrial (Kyoto) gases (KP) and emissions from land-use change and forestry (LULUCF) above 1990 levels by 2020, showing the total greenhouse gas emissions, including emissions from LULUCF as well as Montréal gases (ozone-depleting substances, ODS).

For each global level in 2020, we developed emission profiles for four reduction levels by the Annex I countries: 0%, 15%, 25% and 40% below 1990 levels (Figure 5). Each of these cases requires efforts by Non Annex I countries to keep emission levels well below business as usual (SRES scenarios). Of course, stronger action for the year 2020 implies more flexibility and smaller reduction rates in the years 2020 to 2050.

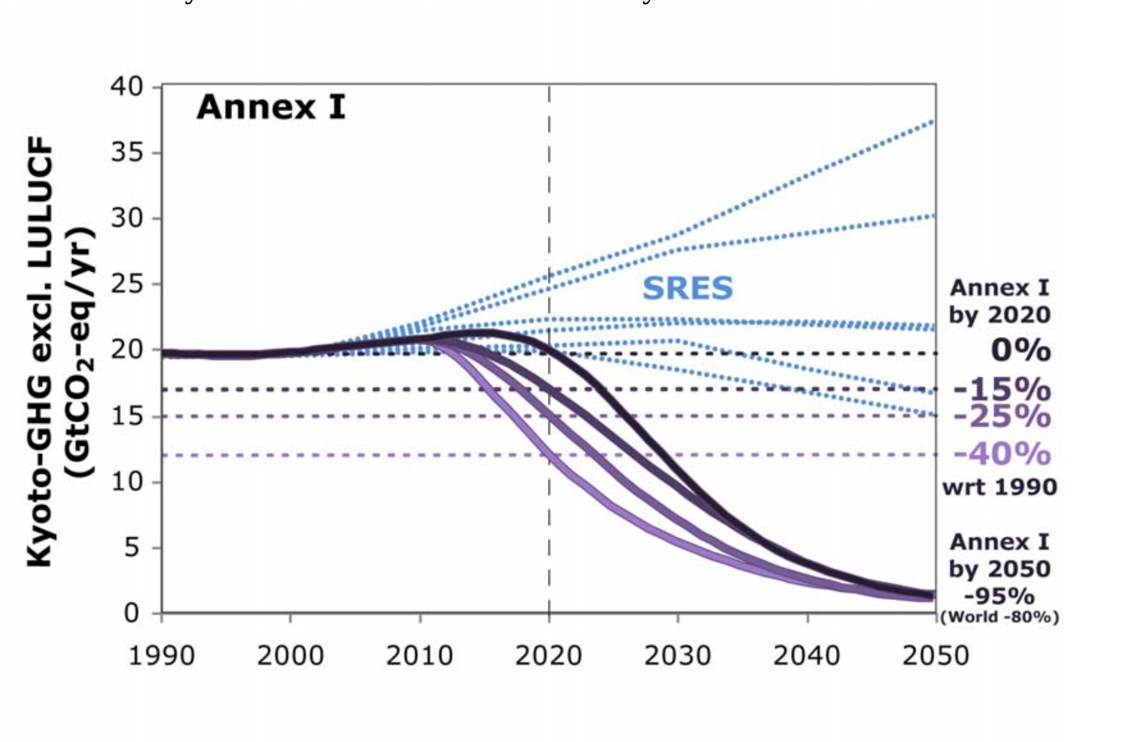

Figure 5 Emission trajectories for four cases for Annex I countries - a return to 1990 levels by 2020 (0%), a 15% reduction, 25% and 40% reductions. The overall level of reductions for Annex I by 2050 is awarded 95% in order to be equalized for KP emissions by that time with per capita emissions by non-Annex I countries.

Figure 6 shows the implications for the non-Annex I group if the four different Annex I reduction levels are applied to the global +0% by 2020 scenario. Assuming non-Annex I will take complete advantage of the emission space left by Annex I whilst still achieving global goals, strong action is required from non-Annex I as well. In the extreme case where Annex I ambition is the most lenient by returning to 1990 levels by 2020 (0%), non-Annex I emissions need to be reduced to 45% below business as usual, which in absolute terms would bring non-Annex I emissions below those of Annex I. Such a scenario is of course implausible.

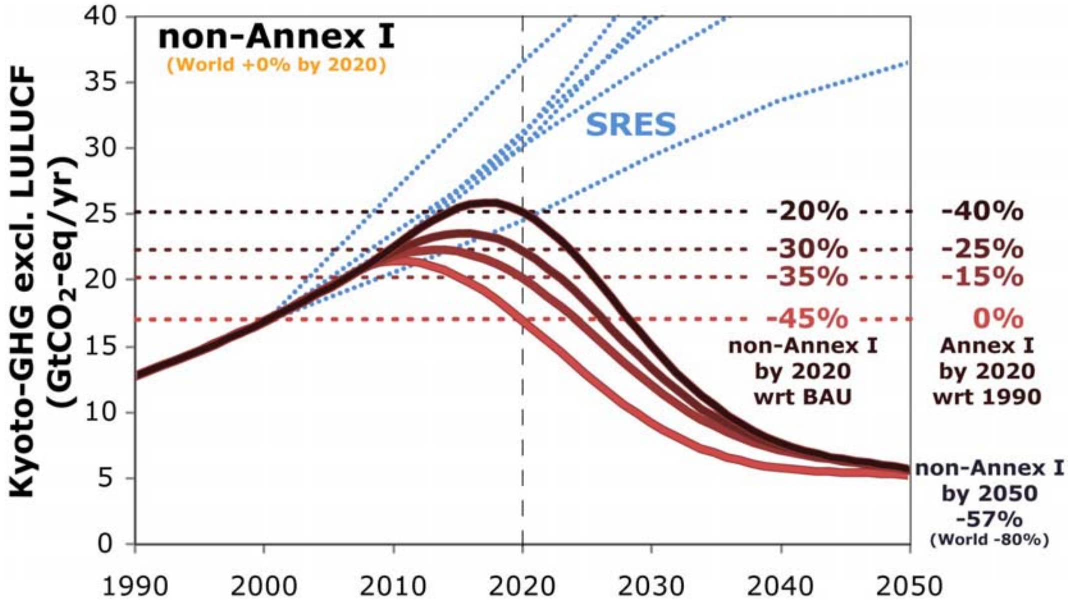

Figure 6 Non-Annex I greenhouse gas emissions for the global +0% increase by 2020 case. The four non-Annex I emission trajectories correspond to each of the cases from the Annex I reductions (see Figure 5). Included in the figure are reduction percentages in 2020, for Annex I compared to 1990 and for non-Annex I to the business as usual, or reference case SRES A1G, roughly the mean in the range of IPCC SRES Scenarios around 2020. The overall level of reductions for non-Annex I in 2050 is awarded 57% in order to be equalized for KP emissions by that time with per capita emissions by Annex I countries.

The next case shown is for a global increase in emissions of industrial gases by 20% and 2020, which is a reduction from the peak levels achieved before that time. Figure 7 shows the implications for the non-Annex I countries in this scenario. For the case where Annex I emissions abate to about 15% below 1990 levels by 2020, non-Annex I emissions need to be about 15% below business as usual by that time. If Annex I emission reductions are deeper, then the extent to which non-Annex I countries need to be reduced below business as usual is lower (a trivial result). It can also be seen that the higher the non-Annex I emissions peak, the more rapid must be the rate of reduction from peak levels before 2050. Were Annex I emissions to be in the range of 25 to 40% below 1990 levels by 2020 then the level of reductions below business as usual for the non-Annex I countries would range from not much to about 10%.

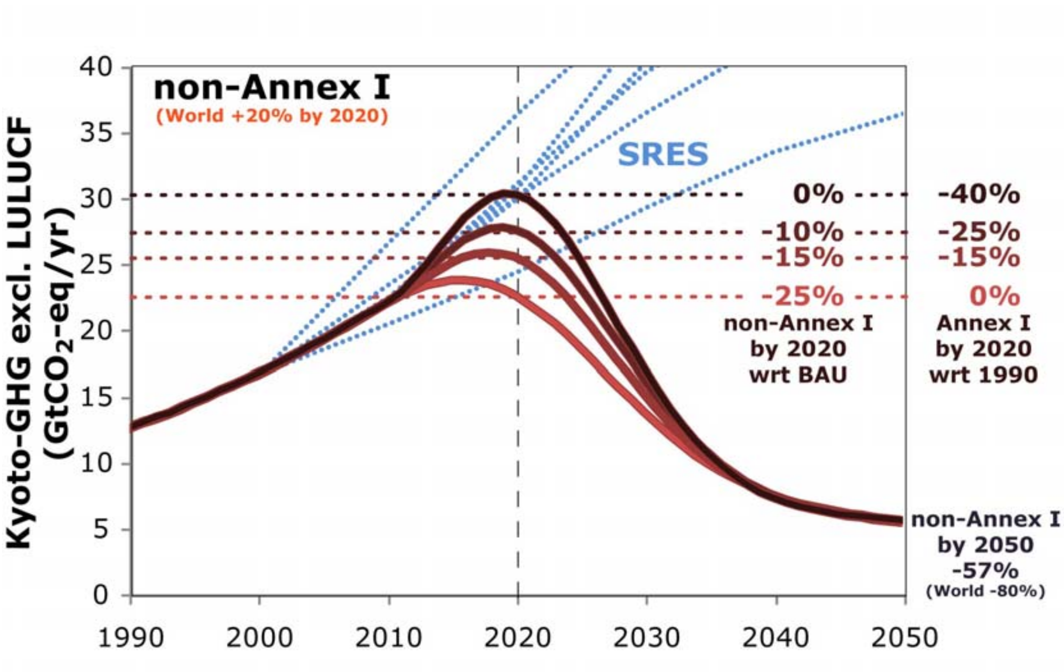

Figure 7 Non-Annex I greenhouse gas emissions for the global +20% increase by 2020 case. See also caption Figure 6.

In the case of a 15% reduction by the Annex I countries by 2020, the non-Annex I countries would need to reduce to around 15% below their business as usual levels. For an even lower level of achievement by the Annex I countries, a larger reduction from business as usual will be needed from the non-Annex I countries to remain within the total global emission limit by 2020. Such a reduction from business as usual in the absence of significant Annex I action is politically implausible.

Figure 8 shows the trajectory of per capita emissions for the two cases, where Annex I emissions are reduced by 40% and where they only return to 1990 levels by 2020. In the former case there is a more rapid convergence of the per capita emissions, whereas in the latter there remains a very wide disparity between the two groups regarding per capita emissions for much of the period to the 2040s.

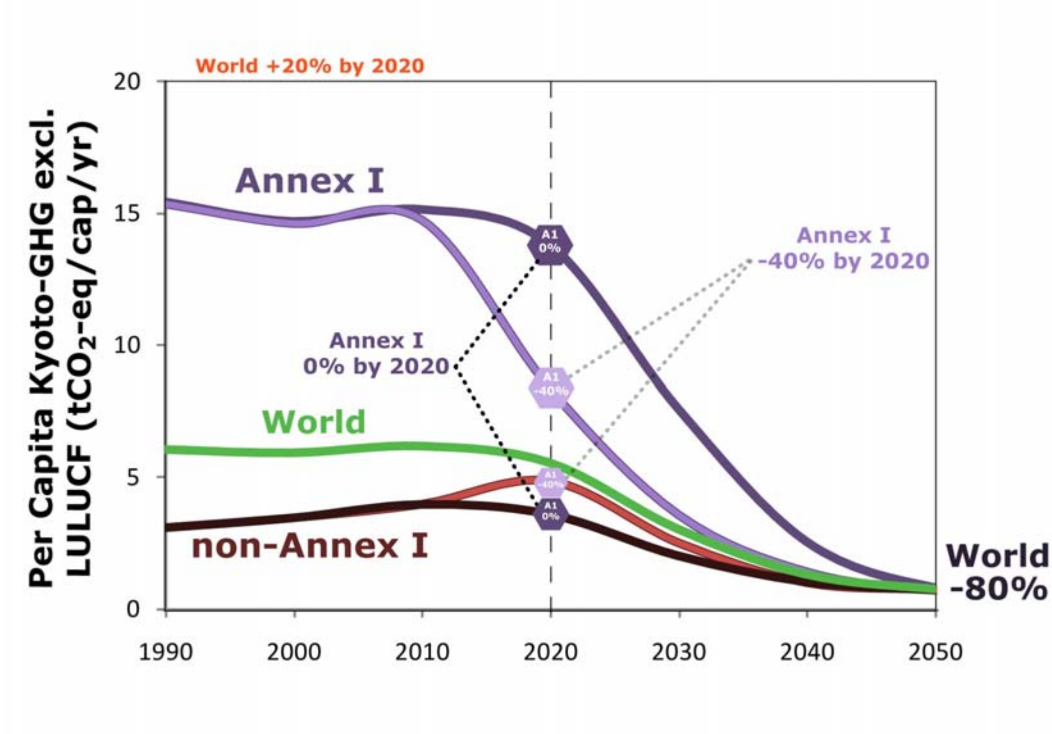

Figure 8 Per capita emissions trajectories for the Annex I cases of reducing to +0% and -40% of 1990 by 2020. Annex I and non-Annex I converge to equal per capita emissions in 2050.

The final case is shown in Figure 9 for a 40% increase in global emissions by 2020 above 1990 levels. In this scenario, a 40% reduction in Annex I emissions by 2020 produces extremely high non-Annex I emissions, above the IPCC SRES range, which is quite unlikely. At this high global limit in 2020, a 15% reduction by the Annex I countries implies very little change with respect to business as usual by non-Annex I countries. A 10 to 15% reduction by the Annex I countries as a group would not be inconsistent with the US position of a return to 1990 levels by 2020 when considering the comparability of efforts between different countries within the Annex I group. A lower level of achievement by the Annex I group by 2020 would effectively lead to little or no restrictions on the non-Annex I group compared to business as usual.

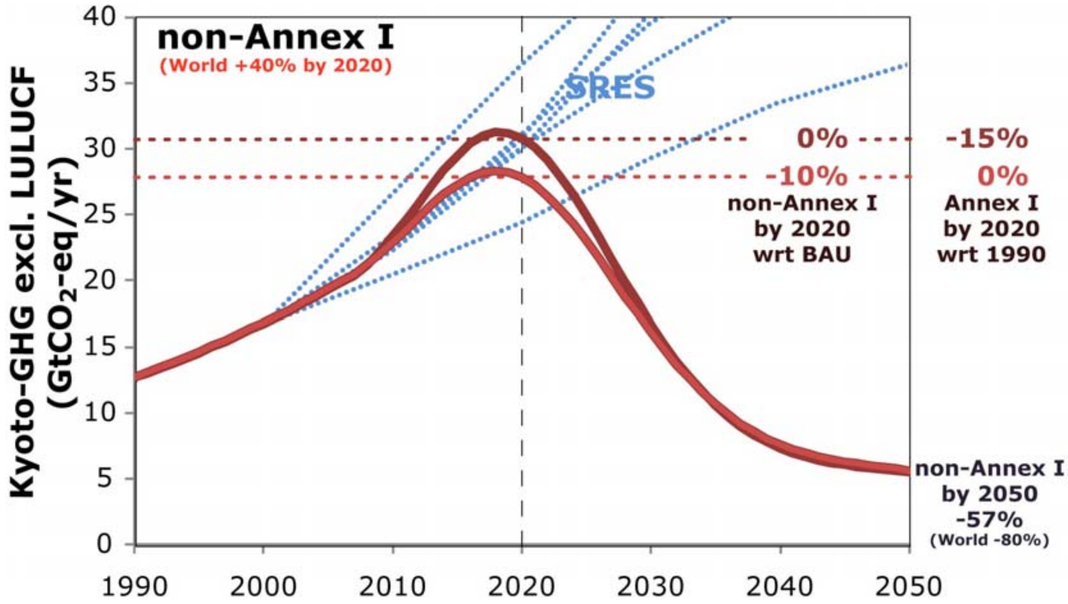

Figure 9 Non-Annex I greenhouse gas emissions for the global 40% increase by 2020 case. See also caption Figure 6.

The results of these scenarios are summarized in Table 2. Reducing emissions globally to 1990 levels by 2020 would likely yield a 17% (7% to 36%)[7] chance of exceeding 2°C warming for a global emission path reducing emissions by 2050 to 80% below 1990 levels. A global increase bringing emissions to 20% above 1990 levels by 2020, would increase the risk of exceeding 2°C by 4%, as does a further increase of emissions by 20%.

This table also shows that as one increases the level of global emissions, the required rate of emission reductions in the 2020 to 2050 period increases for the non-Annex I countries. Every increase of the global limit in 2020 by 20% implies an additional -0.5%/yr reduction rate for non-Annex I countries, sustained over the full 30-year period of 2020 to 2050, compared to a base rate of around 5%/yr. An Annex I target that is 10% more lenient by 2020 implies an additional -0.5%/yr sustained reduction rate for Annex I from 2020 to 2050. Complementary, this requires a more ambitious non-Annex I level in 2020, which in turn implies a decreased reduction rate for non-Annex I by +0.5%/yr for 2020-2050, for each 10% less strict 2020 level for Annex I.

[7] For all probabilities a "best-estimate" value is given, based on reproducing the probability distribution of climate sensitivity as in Frame et al (2006) by the model results, in which model parameters are constrained by observational sets of output variables, Along with this "best-guess" a range of probability estimates is provided that covers the scientific literature on climate-sensitivity estimates. The probabilities include uncertainty in carbon-cycle modeling as well.

Table 2 Implications of global emission levels in 2020 for 2°C target.

	Global	2°C	Annex I		non-Annex I			
	2020 Global Emissionsl: Percent of global total (KP+LUCF) GtCO2e emissions in 2020 above 1990	Probability of global warming exceeding 2°C wrt PI	Percent of KP gas emissions in 2020 above 1990 (%)	2020-2050 mean KP reduction rate (%/yr)	Emissions in 2020 as percentage of SRES A1G (A1FI)	Range of emissions in 2020 as percentage of BAU (SRES Markers)	2020-2050 mean KP reduction rate (%/yr)	
2020 Level Scenarios	+40%	25% (11% to 44%)	0%	-9.0%	-10%	25% below to 10% above BAU	-5.0%	KP Global 2050 80% below 1990
			-15%	-8.5%	0%	15% below to 30% above BAU	-5.5%	
			-25%	-8.0%	+5%	10% below to 30% above BAU	-5.5%	
			-40%	-7.0%	+15%	5% below to 40% above BAU	-6.0%	
	+20%	21% (9% to 40%)	0%	-9.0%	-25%	40% to 10% below BAU	-4.5%	
			-15%	-8.5%	-15%	30% to 0% below BAU	-5.0%	
			-25%	-8.0%	-10%	25% below to 10% above BAU	-5.0%	
			-40%	-7.5%	0%	15% below to 20% above BAU	-5.5%	
	+0%	17% (7% to 36%)	0%	-9.0%	-45%	55% to 30% below BAU	-4.0%	
			-15%	-8.5%	-35%	45% to 20% below BAU	-4.0%	
			-25%	-8.0%	-30%	40% to 10% below BAU	-4.5%	
			-40%	-7.5%	-20%	30% to 0% below BAU	-5.0%	

These scenarios looking at increasing levels of global greenhouse gas emissions in 2020 show that for higher levels of global emissions in 2020 there is a real degradation of the ability to constrain the risk of exceeding the 2°C limit.

5 Delays in Annex I reductions

To more directly grapple with the question of the implications of a weaker, rather than a stronger position by the United States, or other countries, we examined two paired delay scenarios, one for each of two global emission pathways: a 50% reduction globally by 2050 and an 85% reduction by 2050. In the delay scenarios, the action undertaken by Annex I and non-Annex I groups by 2020 is delayed by 10 years (to 2030), compared to the standard scenarios (see Table 3). The Annex I reduction levels are selected in such a way that in the delayed scenarios the level of action undertaken in 2020 by the Annex I group is comparable with the objective of reducing US emissions back to 1990 levels by 2020, i.e. a reduction of 10% for the Annex I group as a whole. To reach the -50% global target in 2050, Annex I needs to reduce its emissions by 30% in 2020. In the paired delay scenario, these reduction numbers change to 10% by 2020 and 30% by 2030. It is assumed that if the Annex I countries make a reduction of 30% by 2020 (2030) then the non-Annex I countries will reduce by 20% below baseline by 2020 (2030), where the baseline case is the SRES A2 scenario. For the global target of -85% by 2050, these emissions reductions need to be deeper as can be seen in Figure 14.

Table 3 Delay scenario for Annex I reductions.

	Default pathway '50by50'	Delayed pathway 'Delayed 50by50'	Default pathway '85by50'	Delayed pathway 'Delayed 85by50'
Annex I Interim Reductions	30% by 2020	10% by 2020 30% by 2030	45% by 2020	10% by 2020 45% by 2030
Non-Annex I Interim Reductions	20% below baseline by 2020 (BAU assumed here SRES A2)	20% below baseline by 2030 (BAU assumed here SRES A2)	30% below baseline by 2020 (BAU assumed here SRES A2)	30% below baseline by 2030 (BAU assumed here SRES A2)
2050 Emissions	Halved – with Annex I and Non-Annex I shares roughly according to equal per capita emissions		Reduced from 1990 by 85% – with Annex I and Non-Annex I shares roughly according to equal percapita emissions	
2100 Emissions	Asymptotic approach to zero fossil CO_2 emissions		Asymptotic approach to zero fossil CO_2 emissions	

Figure 10 shows a potential consequence for Annex I countries of relaxing Annex I reductions from a -30% average to -10%. Figure 11 and Figure 12 show the emission pathways of these scenarios for the 50% global reduction by 2050 case, respectively for the Annex I and non-Annex I countries as a group, and Figure 13 shows the global emission reductions resulting from these assumptions. Finally, Figure 14 shows the Annex I emissions for the standard and delayed case of the global -85% by 2050 scenario.

As discussed in the introduction, the current proposal of the EU is to reduce its emissions relative to 1990 by 30% by 2020, conditional on other Annex-I countries adopting comparable ambitions. Figure 10 shows the implication of a methodology for allocating reductions amongst Annex-I countries, recently proposed by the EU. We have interpreted this proposal for a methodology for the case where the EU makes a 30% reduction, and one plausible outcome is that reductions by the US would need to amount to 24% below 1990 levels by 2020 to be comparable to the EU commitment. For this case the total reductions for the Annex I group as a whole amount will be 30% below 1990 levels. The latter is consistent with the non-delayed scenarios discussed here. The consequences for other countries of the US adopting a reduction target of returning to 1990 emission levels by 2020 can be examined by following the same allocation rules, but changing the parameters to get a reasonably equitable result in terms of a comparably lenient change in reduction levels for all countries involved. Figure 10 (red bars) shows that this amounts to reductions of the EU emissions to 10% below 1990. The net result for the Annex-I group as a whole is -10% by 2020, consistent with the delayed scenarios presented here.

Other approaches are possible and as plausible. As an example one could adopt an allocation principle on the basis that all Annex I countries make the same reduction from 2005 levels that is implicit in President Obama's call to bring US emission back to 1990 levels by 2020. Since US emissions have grown by about 14% from 1990 to 2005 one could apply a 14% reduction level to all Annex I countries taking 2005 as a reference, rather than 1990. For the EU this would mean a reduction of 16% below 1990 levels, hence more lenient than the current EU position. Obviously, if applied to all Annex I countries, the net result would be a reduction of -14% for Annex I as a whole relative to 2005. Since total emissions of Annex I from 1990-2005 has been roughly constant, this is consistent with the Annex I reductions of around -15% relative to 1990, which were discussed in section 4 above, including implications for non-Annex I emissions at various global emission levels by 2020.

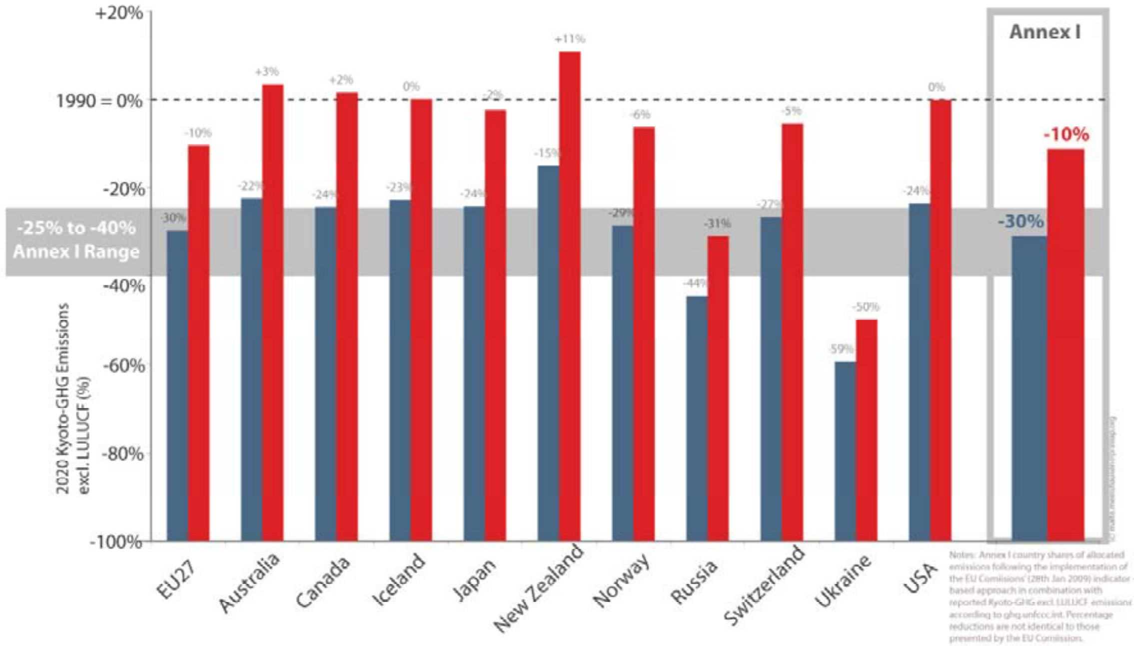

Figure 10 Comparable levels of emission reductions within the Annex I group for a 30% reduction scenario and for a scenario where the United States reduces emissions to 1990 levels by 2020. In the former case it is assumed that the EU does a 30% reduction and a comparable level of effort for the United States involves about 24% reduction from 1990 levels. For the case where the United States has a 0% target (brings its emissions back to 1990 levels by 2020) the EU emissions are 10% below 1990 levels by 2020.

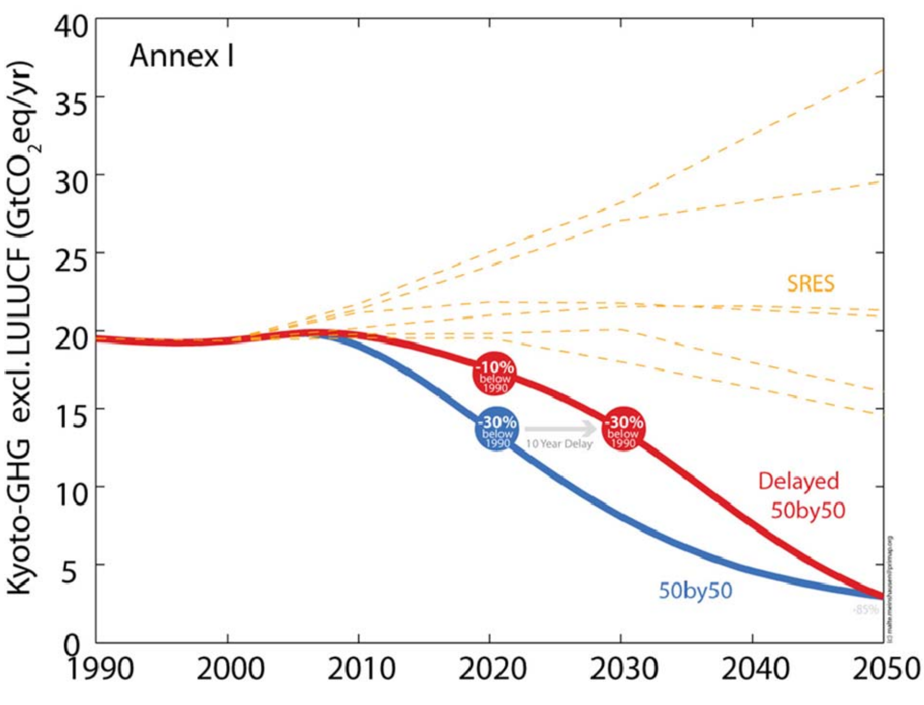

Figure 11 Effects of a delay in achievement of an Annex I reduction of 30% by 2020 by 10 years (from 2020 to 2030), for the 50% global emission reduction by 2050 case. All cases compared to the IPCC SRES reference scenarios (orange dashed).

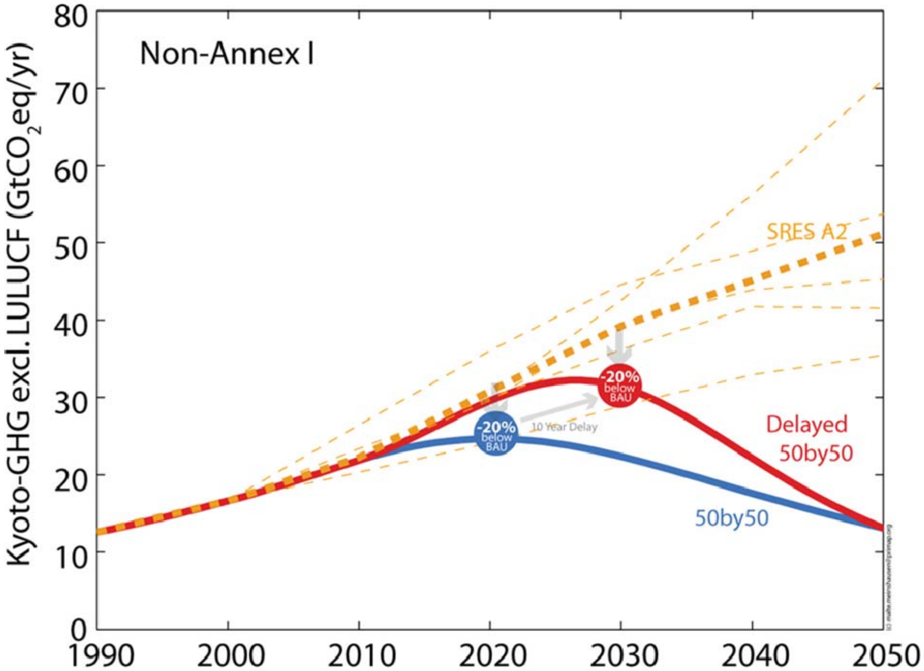

Figure 12 Effects of a delay in achievement of a non-Annex I reduction of 20% by 2020 relative to business as usual by 10 years (from 2020 to 2030), for the 50% global emission reduction by 2050 case. All cases compared to the IPCC SRES reference scenarios (orange dashed).

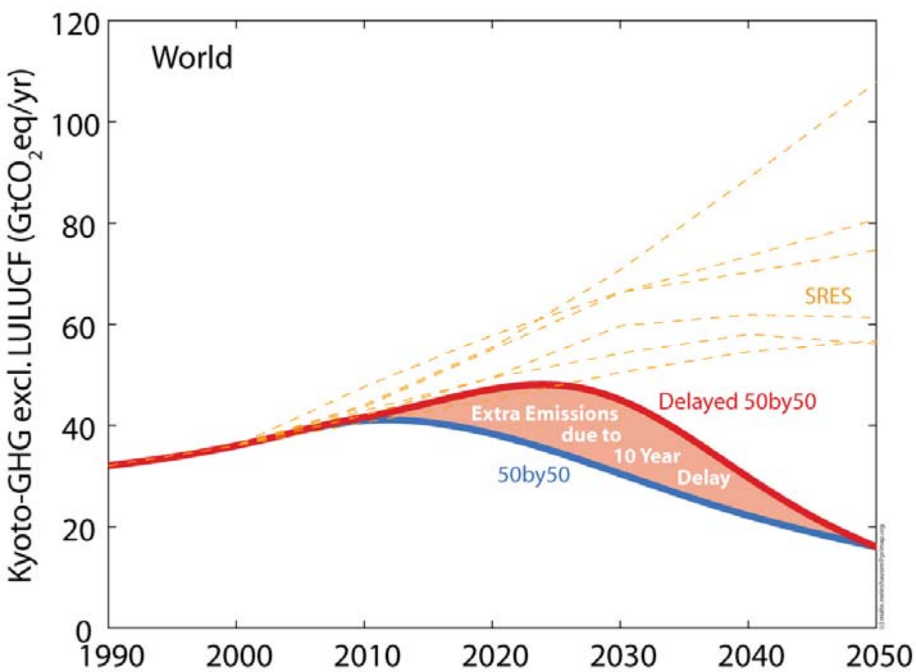

Figure 13 Global industrial greenhouse gas emissions compared to IPCC SRES reference scenarios for the 50% reduction by 2050 case (orange dashed).

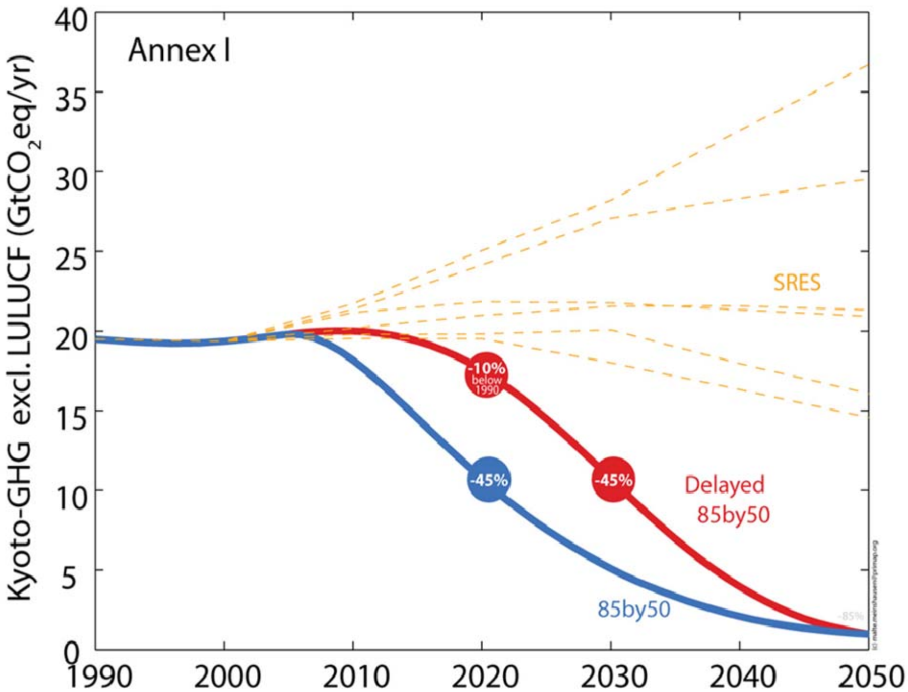

Figure 14 Effects of a delay in achievement of an Annex I reduction of 45% by 2020 by 10 years for the 85% global emission reduction by 2050 case. All cases compared to the IPCC SRES reference scenarios (orange dashed).

Table 4 shows the results of these scenarios in terms of the probability of exceeding 2°C warming, the total level of emissions and the rates of emission reductions associated with these scenarios. The probability of exceeding 2°C warming is shown in the second column for the emission scenarios specified in each row. Two scenarios for Annex I reductions are shown: a 30% and 45% reduction by 2020, with delays until 2030 in each case. A 30% reduction from the Annex I countries achieved by 2020 would limit total greenhouse gas emission increases to about 5% above 1990 levels, or taking account of deforestation emissions and ozone-depleting substances, a 20% increase in Kyoto gases with respect 1990 globally. Delaying this reduction until 2030 would result in an increase of 40% in total greenhouse gas emissions (50% in Kyoto protocol gases) by 2020, with the probabilities of exceeding 2°C increasing from about 27% (14% to 48%) to about 42% (29% to 70%). For the global 2050 target of 85% below 1990, and the case where Annex I emissions are reduced by 45% in 2020, delaying this reduction from 2020 until 2030 increases the probabilities exceeding 2°C from 14% (6% to 32%) to 31% (17% to 54%).

Table 4 consequences of delaying a 30% and 45% reduction for the Annex I countries from 2020 until 2030 for global emissions and for exceeding a 2°C warming above the pre-industrial level.

	Global	2°C	Annex I		non-Annex I			
	2020 Global Emissionsl: Percent of global total (KP+LUCF) GtCO2e emissions in 2020 above 1990	Probability of global warming exceeding 2°C wrt PI	Percent of KP gas emissions in 2020 above 1990 (%)	2020-2050 mean KP reduction rate (%/yr)	Emissions in 2020 as percentage of SRES A1G (A1FI)	Range of emissions in 2020 as percentage of BAU (SRES Markers)	2020-2050 mean KP reduction rate (%/yr)	
Illustrative Scenarios	85by50 **-15%** (+0%KP)	**14%** (6% to 32%)	-45%	-7.0%	-30%	40% below to 10% above BAU	-5.5%	KP Global 2050 85% below 1990
	Delayed 85by50 **+40%** (+50%KP)	**31%** (17% to 54%)	-10%	-8.5%	-5%	20% below to 30% above BAU	-6.0%	
	50by50 **+5%** (+20%KP)	**27%** (14% to 48%)	-30%	-5.0%	-20%	30% to 0% below BAU	-2.0%	KP Global 2050 50% below 1990
	Delayed 50by50 **+40%** (+50%KP)	**42%** (29% to 70%)	-10%	-5.5%	-5%	20% below to 20% above BAU	-2.5%	

The implications of these scenarios for the probabilities exceeding 2°C are summarised in Figure 15, showing that the consequences of a ten-year delay in the achievement of an Annex I target reduction of 30% (45%) is likely to be an increase in the probability of exceeding 2°C warming above the preindustrial level by about 15%.

6 Conclusions

A strong conclusion from this study is that higher emissions in 2020 resulting from lesser action by Annex I countries, degrades the ability to meet the 2°C warming limit. If global emissions return to the level of 1990 by the year 2020, the chance that 2°C warming is exceeded is estimated as roughly 1 in 6 for an emission path that reduces emissions by 80% in 2050. However, this risk rises to 1 in 5 if in 2020 global emissions are 20% above 1990, and rises further to 1 in 4 if 2020 emissions are 40% above 1990 levels.

For a case where the Annex I countries as a group limit emissions by 2020 to 15% below 1990 under global cap of 20% above 1990 in that year, then by 2020 the growth of emissions from non-Annex I countries as a group would need be reduced to about 15% below business as usual. If the associated 1 in 5 chance of exceeding 2°C warming were to be preserved for the case of weaker Annex I action where their emissions were returned only to 1990 levels (0%) by 2020, non-Annex I emissions would need to be further reduced to 25% below business as usual by that same year.

Delaying emission reductions by the Annex I group by 10 years, from 2020 to 2030, results in significantly higher cumulative greenhouse gas emissions and increases the rate of emission reduction in future decades. The probability of exceeding 2°C warming is increased by about 15% for such a delay, from a base probability for the two non-delay scenarios of 14% (6% to 32%) and 27% (14% to 48%), respectively. Given that it is likely that should the US take weaker action, others would follow suit, a delay in achieving significant reductions by United States would thus likely result in an increased probability of exceeding a 2°C warming. As a consequence, the assertion that a delay in reducing emissions can be made up by steeper reductions in later years is not supported by the analysis presented here.

The increased risk of exceeding 2°C caused by a ten year delay in reaching a 30% reduction levels for the Annex I countries is comparable to the increased exceeding risk caused by a 35% higher global level of emission in 2020. This analysis shows that a delay in reducing greenhouse gas emissions by ten years causes a higher overall level of emissions in 2020 and converts an emission pathway with about a 1 in 7 chance of exceeding 2°C to a 1 in 4 chance. Arguably this is a significant change in risk for a task that is already very difficult (Schellnhuber 2008) and it certainly does not support the argument that steeper reductions later can make up for a delay in reducing emissions.

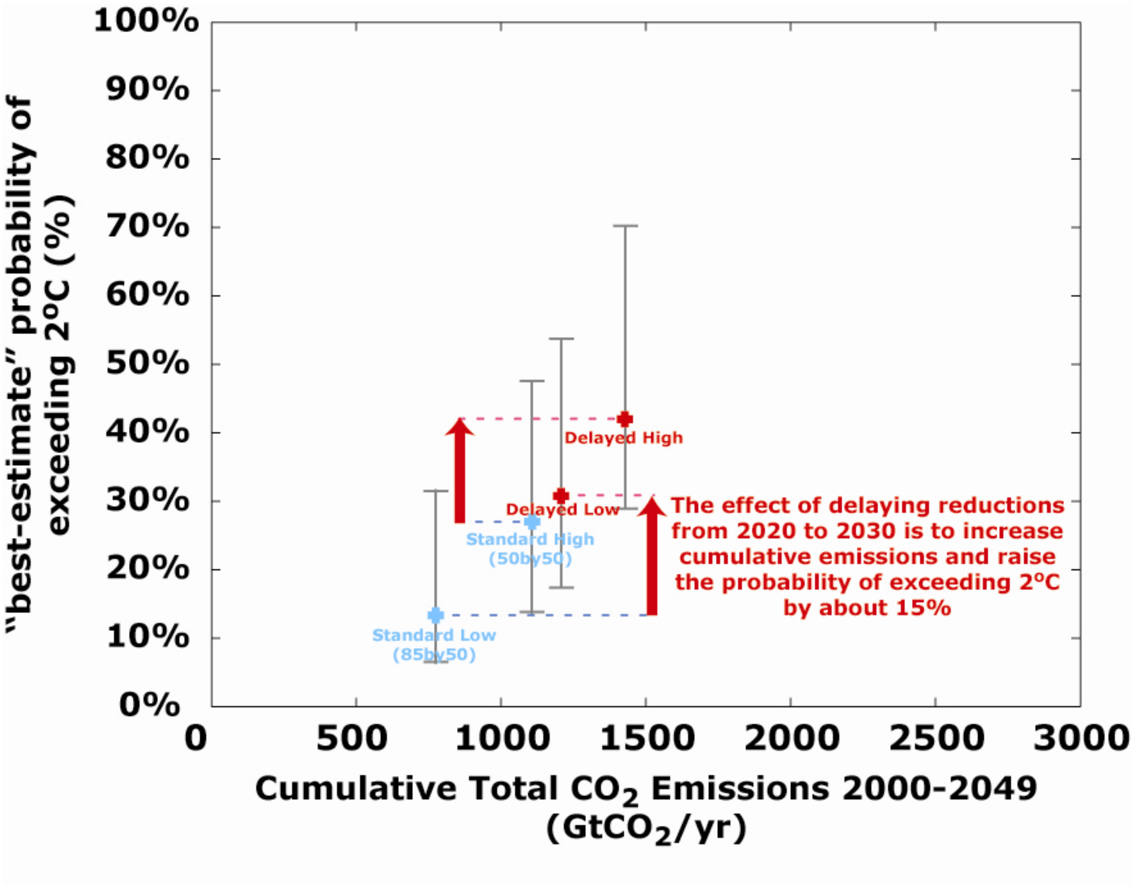

Figure 15 Effects of delay on the probability of exceeding 2°C warming about preindustrial levels. This figure shows the consequences using the assumptions outlined here of a delay in the Annex I countries limiting their emissions to 30% (50by50) and 45% (85by50) below 1990 levels, from the 2020 until 2030. Results of two cases are shown: one for a global reduction of 50% by 2050 and the second for a global reduction of 85% in emissions from 1990 levels by 2050. In both cases the effects of attending a delay is to significantly increase the cumulative greenhouse gas emissions and to give about a 15% higher probability of exceeding a warming of 2°C above pre-industrial levels. The grey error bars represent the ranges in probability estimates that results from covering the full scientific literature on climate-sensitivity estimates.

7 References

Azar, C., K. Lindgren, E. Larson and K. Möllersten (2006). "Carbon Capture and Storage From Fossil Fuels and Biomass – Costs and Potential Role in Stabilizing the Atmosphere." Climatic Change **74**(1): 47-79.

Council of the European Union (2005). Presidency conclusions - Brussels, 22/23 March 2005, European Commission**:** 39.

den Elzen, M. and N. Höhne (2008). "Reductions of greenhouse gas emissions in Annex I and non-Annex I countries for meeting concentration stabilisation targets." Climatic Change **91**(3): 249-274.

ENB (2008) "COP14 Highlights." Earth Negotiations Bulletin **Volume**, DOI:

Gupta, S., D. A. Tirpak, N. Burger, J. Gupta, N. Höhne, A. I. Boncheva, G. M. Kanoan, C. Kolstad, J. A. Kruger, A. Michaelowa, S. Murase, J. Pershing, T. Saijo and A. Sar (2007). Policies, Instruments and Co-operative Arrangements. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. B. Metz, O. R. Davidson, P. R. Bosch, R. Dave and L. A. Meyer. Cambridge, United Kingdom, Cambridge University Press and IPCC http://www.mnp.nl/ipcc/pages_media/AR4-chapters.html**:** 745-808.

Houghton, R. A. and J. L. Hackler (2002). Carbon Flux to the Atmosphere from Land-Use Changes. A Compendium of Data on Global Change., Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

IPCC (2007). Climate Change 2007: Synthesis Report. An Assessment of the Intergovernmental Panel on Climate Change. . Geneva, Intergovernmental Panel on Climate Change.

IPCC (2007). Summary for Policymakers IPCC Fourth Assessment Report, WorkingGroup III. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. B. Metz, O. R. Davidson, P. R. Bosch, R. Dave and L. A. Meyer. Cambridge, United Kingdom, Cambridge University Press and IPCC http://www.mnp.nl/ipcc/pages_media/AR4-chapters.html.

Marthinus van Schalkwyk, M. O. E. A. A. T. (2008). Climate Change: Extinction Threat Necessitates Definitive Action M. o. E. A. A. Tourism. Johannesburg, Government of South Africa. 21 July 2008.

Meinshausen, M., B. Hare, T. Wigley, D. Van Vuuren, M. Den Elzen and R. Swart (2006). "Multi-gas Emissions Pathways to Meet Climate Targets." Climatic Change: 1-44.

Meinshausen, M., S. C. B. Raper and T. M. L. Wigley (2008). "Emulating IPCC AR4 atmosphere-ocean and carbon cycle models for projecting global-mean, hemispheric and land/ocean temperatures: MAGICC 6.0." Atmos. Chem. Phys. Discuss. **8**(2): 6153-6272.

Nakicenovic, N. and R. Swart, Eds. (2000). IPCC Special Report on Emissions Scenarios. Cambridge, United Kingdom, Cambridge University Press.

Schellnhuber, H. J. (2008). "Global warming: Stop worrying, start panicking?" Proceedings of the National Academy of Sciences **105**(38): 14239-14240.

Stern, T. (2009). Keynote Remarks at U.S. Climate Action Symposium. US Special Envoy for Climate Change. U.S. Climate Action Symposium, Senate Hart Office Building, Washington, DC, March 3, 2009.

Stoltenberg, P. M. J. (2007). Speech at UN Climate Change Conference in Bali P. Minister. Oslo, Government of Norway.

UN. (2007). "World Population Prospects: The 2006 Revision Population Database." from http://esa.un.org/unpp.

Vuuren, D. P. v., M. G. J. d. Elzen, P. L. Lucas, B. Eickhout, J. S. Bart, B. v. Ruijven, S. Wonink and R. v. Houdt (2007). "Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs." Climatic Change **V81**(2): 119-159.