How feasible is changing track?

Scenario analysis on the implications of changing emission tracks after 2020, from an insufficient global deal on 2020 reductions, to 2°C and 1.5°C pathways

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Contents

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Summary

The IPCC indicated in its Fourth Assessment Report that Annex I (industrializes) countries need to reduce their industrial greenhouse gas (GHG) emissions 25-40% below 1990 levels by 2020 to be on track to limit global warming to near 2°C (above pre-industrial). However reduction proposals currently on the table approaching the Copenhagen Climate Conference in December 2009 fall short of that range. The minimum of current pledges suggest around a 13% reduction in aggregate, before consideration of the effects of land use, land use change and forestry (LULUCF) crediting. The high end of the present pledges, which are usually conditional on the level of ambition of an international agreement, suggests a maximum aggregate reduction of 20% below 1990 levels by 2020.[1]

This report analyses the potential for changing track after 2020, from an insufficient global reduction by 2020, to two emission pathways that imply a reasonable chance to stay below 2°C and 1.5°C respectively. The latter “base scenarios” were proposed by, respectively, Lord Nicholas Stern and the Alliance of Small Island States (AOSIS) and represent two of the more ambitious emission pathways discussed at high-level political meetings.

If one aims to reach temperature targets of 2°C or 1.5°C, an insufficient emission reduction by 2020 poses three basic problems. To reach these temperature targets, global emission reductions after 2020 need to be steeper, to compensate for the higher emissions until 2020:

- Current reduction targets result in a continuing rise of global emissions beyond 2020 and do not lead to a reversal of the emission trend that is required to reach low emission levels by 2050. This implies global emissions are unlikely to peak before the late 2020s at the earliest.
- Starting from an aggregate Annex I emission reduction level of 15% below 1990 by 2020, reduction rates from the late 2020s onwards have to be triple those in the base scenarios, against double for a somewhat more ambitious reduction to 25% below 1990 by 2020. For example, for a pathway that stabilises at 450 ppm CO_2-equivalent, global emissions between 2030 and 2050 are reduced by about -2% of 1990 emissions per year. Starting with the current pledges on the table to 2020, a reduction rate of -6% of 1990 emissions is required to reach an equal probability to stay below 2°C by 2100 as this 450 ppm scenario. This implies high economic costs and a more rapid transition than would have otherwise been necessary.
- The rapid rise in emissions until 2020 and the necessary rapid emission reduction after the 2020s results in a rate of temperature increase by the 2040s that is double to triple what is currently observed of about 0.15°C per decade and projected in the base scenarios. Since the currently observed rate of temperature increase already poses problems of adaptation for human society and ecosystems, a doubling or tripling of this rate will likely pose a serious threat to these systems, even if post-2020 emission cuts are ambitious enough to reach the same global warming peak level as the 1.5°C and 2°C base scenarios. This peak level will be reached decades earlier than in the base scenarios.

Although these problems arise for both the currently proposed emissions reductions by 2020 and a more ambitious 25% aggregate emission reduction, they are considerably less severe in the latter case.

[1] As of 21 November 2009. See http://www.climateactiontracker.org/ for more recent estimates. Once countries preferred LULUCF accounting options are included this range of industrial GHG reductions reduces to about 8-15% , far outside the IPCC range.

1 Introduction

Progress in the Copenhagen climate negotiations towards an ambitious agreement on emission reduction obligations for Annex I countries, and broad ranging action by the large emitters in the non-Annex I country group, is falling short of expectations.

A key question arising in this context is the feasibility of achieving global warming goals, such as limiting warming to 2°C – as put forward by the European Union, the G8 and the Major Economies Forum on Energy and Climate Change – and returning warming below 1.5°C and limiting CO_2 concentration below 350 ppm CO_2 – as put forward by the Alliance of Small Island States (AOSIS) and Least Developed Country Group (LDC) –, should greenhouse gas emission limits agreed in Copenhagen in December 2009 for 2020 fall short of those indicated by the IPCC in its Fourth Assessment Report as needed to stabilise at 450 ppm CO_2-equivalent or lower.

Stabilization at 450 ppm CO_2-eq implies a somewhat less than 50% chance of limiting warming to 2°C above preindustrial in the long-term. For both the 2°C and 1.5°C targets, the probability to achieve these in the long term increases rapidly if the stabilization level reduces in the range of 350 and 450 ppm CO_2-eq (Schaeffer et al. 2008). Recent work has indicated that if total global emissions exceed around 35% above 1990 levels in 2020 the chances of limiting warming to 2°C or below becomes quite small (Meinshausen et al. 2009). On the basis of current pledges from Annex I countries and policies put forward by non-Annex I countries, this level of greenhouse gases emissions could be exceeded in 2020, and the subsequent emissions would be likely to bring global warming over 3° by the 21st century's end.

2 Changing track: Scenario development

Given that currently proposed reductions for the period between 2020 and 2050 are insufficient to lead to concentration levels that would limit temperature increase to proposed levels with reasonable, or high confidence, the question arises if we can “change track” after 2020? What is required after 2020 in order to return to an emissions path that could limit warming to 2°C or below? In other words what is the additional effort in terms of increased reduction rates in emissions globally that could make up for insufficient action between now and 2020, and when will it be too late?

These questions are not easy to answer. It is clear that should emissions not peak by 2020 and be on a declining trajectory at that time, the present generation of energy economic models which are used to examine the technical and economic feasibility of low greenhouse gas concentration scenarios do not in general show feasible pathways. It is also well established that delaying deep emission reductions is more costly than acting sooner, which was most recently shown in the International Energy Agency World Energy Outlook 2009, where it was estimated that each year of delay would cost about US$500 billion (IEA 2009).

We have attempted to explore this problem by constructing several plausible scenarios which show the consequences of changing from one path to another after 2020 in terms of peak greenhouse gas concentration, risk of exceeding 2°C increase in global temperature, and rate of emission reduction after the change in track.

To look at this issue one needs to define the original goal which needs to be met. This is not as easy as it seems, given that there is no consensus about the probability with which a goal such as 2°C warming should be met by climate policy. If it is assumed that a 50% probability of achieving this goal is satisfactory, then the emission pathway is much more relaxed and less aggressive than if it is assumed that policymakers wish to achieve such a limit with a 75% or greater chance. For example, a 50% reduction in emissions globally by 2050 from 1990 levels would give an approximately 50% chance of exceeding 2° peak warming in the 21st century. A 75% or greater chance of limiting warming below 2°C would mean that emissions globally would need to be reduced by more than 80% compared to 1990 levels by 2050. In the longer term, emissions would need to be reduced substantially below these levels in order to ensure that warming stays below 2°C with any reasonable confidence in the longer term.

To answer the question we take two different analytical approaches. The first builds on recent work, which correlates the cumulative emissions to 2050 with the probability of exceeding a peak warming level. Cumulative greenhouse gas emissions of 2,000 Gigatonnes (Gt)[2] CO_2 equivalent between 2000 and 2050 would lead to about a 50% chance of staying below a peak warming of 2°C. In this approach, we explore the implications for the rate of emission reductions of changing track from higher to lower emission paths whilst maintaining the same cumulative level of greenhouse gas emissions between 2000 and 2050.

The second approach is more complicated, and examines what is needed using a time-dependent calculation of emission pathway through to the end of the 21st Century to bring global warming back towards the original goal (assumed above) with roughly the same probability of limiting warming below 2°C. This results in slightly lower probabilities of keeping peak warming limited to 2°C, but similar probabilities of limiting warming below 2° by 2100.

To address these questions, a set of emission scenarios was developed:

1) **350ppm/1.5°C**: AOSIS has proposed a 45% emission reduction below 1990 levels by 2020 for Annex I countries and a global emission reduction of 85% below 1990 levels by 2050 (AOSIS 2009). We have complemented these targets by defining a global emission level in 2020, as well as further emission reductions post-2050, reaching negative CO_2 emissions by the 2070s at a level somewhat below the medium of the negative-emissions range found in energy-economic models by the end of the 21st Century (Knopf et al. 2008; Rao et al. 2008; Van Vuuren et al. 2008). This emission pathway implies a probability of about 75% to limit peak warming to below 2°C, a roughly 95% chance of limiting warming below 2°C by 2100 and about a 75% chance of below 1.5°C by that time. CO_2 concentration would be brought back from peak levels of 425 ppm to around 360 ppm in 2100 and CO_2-eq from a peak of 510 ppm to 390 ppm by 2100. This is the most ambitious pathway being called for in the context of the Copenhagen climate negotiations.
2) **450ppm**: At the Greenland Ministerial Dialogue in New York on 20 September Lord Stern (Stern 2009a; Stern 2009b) outlined a scenario that is more ambitious than proposals presently on the table for Copenhagen, based on pledges from Annex I countries and policy proposals at the national level from non-Annex I countries. This pathway reaches emission levels of 44 GtCO2eq by 2020, 35 by 2030

[2] Billion tonnes

and 20 by 2050. We assumed a split in Annex I and non-Annex I industrial emissions, and global deforestation, that is roughly consistent with Stern's assumptions on emission intensity improvements in the major economies that make up these groups. It would peak greenhouse gas concentrations around 510 ppm CO_2-eq and, with continued emission reductions after 2050, reach 480 ppm CO_2-eq by 2100 and 450 ppm CO_2-eq in the long run, which, as noted above, would have a chance of staying below 2°C global mean warming of somewhat under 50%. Although the CO_2-eq peak is equal to the peak reached in the 350ppm/1.5°C scenario, the composition of emissions contributing to that peak is very different, with different consequences for the post-peak concentration pathway, as will be explained in the scenario analysis below.

3) **CPH25**: This scenario concerns a case in which the Annex I countries improve their pledges from the present best[3] of 20% below 1990 levels by 2020 by a further 5% in aggregate so that the Annex I emission reductions in 2020 equals the top of the IPCC range identified for this group of countries for the lowest scenarios reviewed in the AR4. By 2020, Annex I as a group would reduce emissions to 25% below 1990 levels and non-Annex I to 10% below business as usual emission levels projected for 2020.
4) **CPH15**: This is an illustration of Annex I reduction targets of 15% below 1990 by 2020 at the lower end of range of what is on the table from these countries at present, i.e. 13 to 20% reductions by 2020 from 1990 levels (as of 21 November 2009). Non-Annex I countries are assumed to reduce the growth in their emissions to about 5% below business as usual emission levels projected for 2020. The latter reduction range includes what non-Annex I countries have on the table at present in terms of domestic policies and measures proposed.
5) **Change Track**: Starting at the CPH15 and CPH25 scenarios, a set of "Change Track" scenarios was developed that reduce emissions further after reaching the 2020 targets, to bring the global concentration pathway back on track for the Stern and AOSIS scenarios by the second half of the 21st Century. In one set of these Change Track scenarios they will achieve approximately an equal probability to stay below 2°C peak warming. In the other set the Change Track scenarios will reach an equal probability to stay below 2°C, or 1.5°C by 2100 as the original scenarios (allowing for somewhat higher emissions after 2020 than the first set).

The table below summarizes the scenarios in terms of emissions globally and for Annex I and non-Annex I Parties (the latter two excl. land-use change).

[3] The “best” pledges are the maximum put forward by Annex I Parties and are usually conditional on the architecture, specific rules and/or overall level of ambition of the Copenhagen agreement.

TABLE 1. OVERVIEW OF SCENARIOS DEVELOPED HERE ON THE BASIS OF PROPOSALS AND CONCEPTS DISCUSSED AT HIGH-LEVEL POLITICAL MEETINGS LINKED TO UNFCCC NEGOTIATIONS. "CHANGE TRACK" SCENARIOS CPH15TO… AND CPH25TO… INDICATE SCENARIOS THAT REDUCE EMISSIONS FROM 2020 LEVELS OF THE CPH15, RESP. CPH25 PATHWAYS TO MUCH LOWER LEVELS FROM 2050 ONWARDS, TO REACH AN EQUAL PROBABILITY OF ACHIEVING TEMPERATURE TARGETS AS THE BASE PATHWAYS, EITHER AS PEAK VALUE, OR BY 2100. PERCENTAGES ARE ROUNDED TO NEAREST 5.

Scenario	2020 Annex I emissions relative to 1990	2020 non-Annex I emissions relative to BAU (SRES A1B)	Global emissions	Deforestation reduction relative to 1990		2050 total global emissions relative to	
			Above 1990	2020	2050	2005	1990
350ppm/1.5°C	-45%	-20%	15%	-50%	-100%	-85%	-85%
450ppm/2°C	-35%	-20%	20%	-35%	-75%	-55%	-45%
CPH25	-25%	-10%	35%	-25%	-50%	-	-
CPH25to350 peak	as CPH25	as CPH25	As CPH25	as CPH25	as 350/1.5°C	-	-
CPH25to350 2100	As CPH25	as CPH25	As CPH25	as CPH25	as 350/1.5°C	-110%	-110%
CPH25to450 peak	as CPH25	as CPH25	As CPH25	as CPH25	as 450	-80%	-75%
CPH25to450 2100	as CPH25	as CPH25	As CPH25	as CPH25	as 450	-55%	-50%
CPH15	-15%	-5%	50%	-20%	-40%	-	-
CPH15to450 peak	as CPH15	as CPH15	As CPH15	as CPH15	as 450	-90%	-90%
CPH15to450 2100	as CPH15	as CPH15	As CPH15	as CPH15	as 450	-65%	-60%

3 Implications of delayed reductions based on cumulative budget calculations

The likelihood that peak warming exceeds 2°C in the 21st Century correlates well with the total cumulative emissions in the period from 2000 to 2050 (Meinshausen et al. 2009). A total budget of 2,000 $GtCO_2$-eq over that time period corresponds roughly to a 50% probability that 2°C is exceeded (due to the time lags in the climate system this will happen around the 2070s, if at all). Between 2000 and 2009, global cumulative emissions were 400-450 GtCO2-eq, corresponding to roughly 20% of the budget to 2050. Figure 1 shows that if global emissions peak early around 2010, global emissions need to be reduced to about 35% below 1990 by 2050 to stay within this budget. If emissions peak later and higher, by following a business-as-usual pathway until the peak, reductions by 2050 need to be more ambitious and the implied emission reductions between 2020 and 2050 need to be more rapid. If emissions peak by 2015, global emissions need to be roughly 50% below 1990 by 2050, while for a peak around 2020, global emissions must approach zero by 2050.

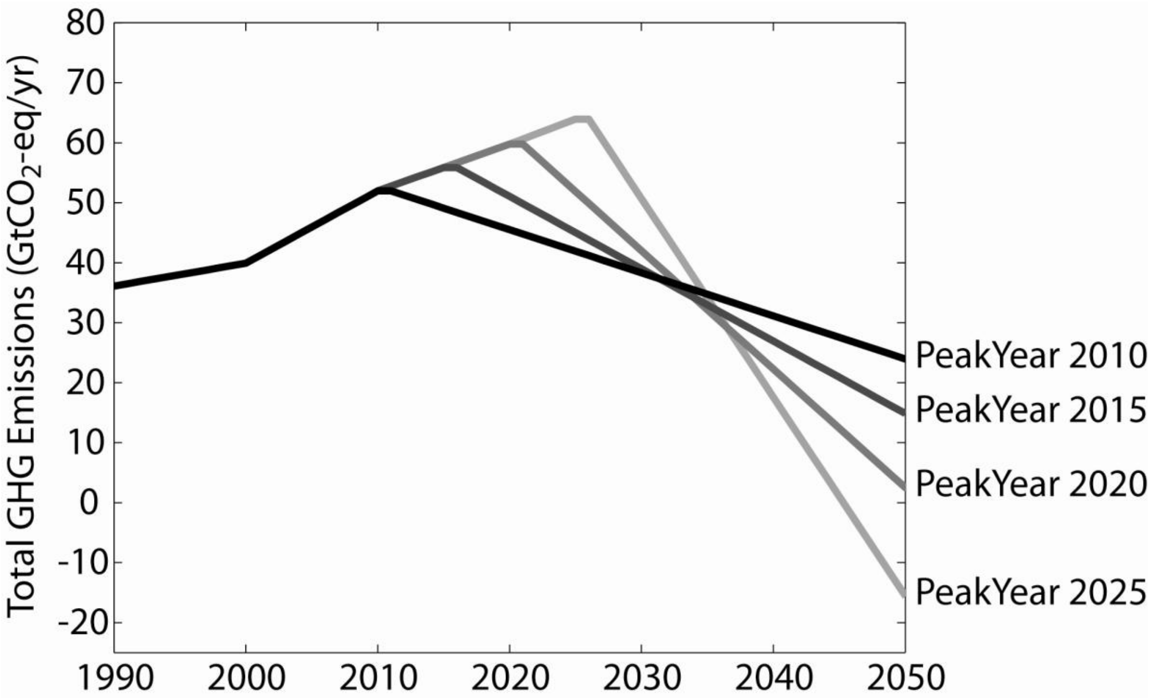

Figure 1 If total global emissions peak later, reductions around 2050 need to be more ambitious if the cumulative emission budget between 2000 and 2050 is to remain the same. Emissions follow SRES A1B baseline projections ('business-as-usual'; IPCC 2000) until the emission peak.

Since emissions in Figure 1 are assumed to follow baseline projections until the peaking year, the required reductions between 2020 and 2050 are sensitive to the baseline projection. In Figure 2, we show for various IPCC SRES baseline pathways (Nakicenovic and Swart 2000) the implied emission reduction rate after 2020, if the peaking year shifts from early (2010) to very late (2025). This illustrates the rapidly escalating problem posed by delayed action: the required emission reduction rate increases more rapidly as peaking occurs later. Ignoring the low and high outliers, a global peak around 2015 implies reduction rates of 1-3% of 1990 levels per year. Recently published low-emission scenarios (Knopf et al. 2008; Rao et al. 2008; Van Vuuren et al. 2008) generally show emissions peaking around 2015 and achieve a mean annual reduction rate of around 2% of 1990 emissions between 2020 and 2050. The reduction rates of 1-3% for peaking around 2015 roughly doubles to 3-5% for peaking around 2020. Note that this is only a rough indication of the required reduction effort and is an average over the 2020 to 2050 time period.

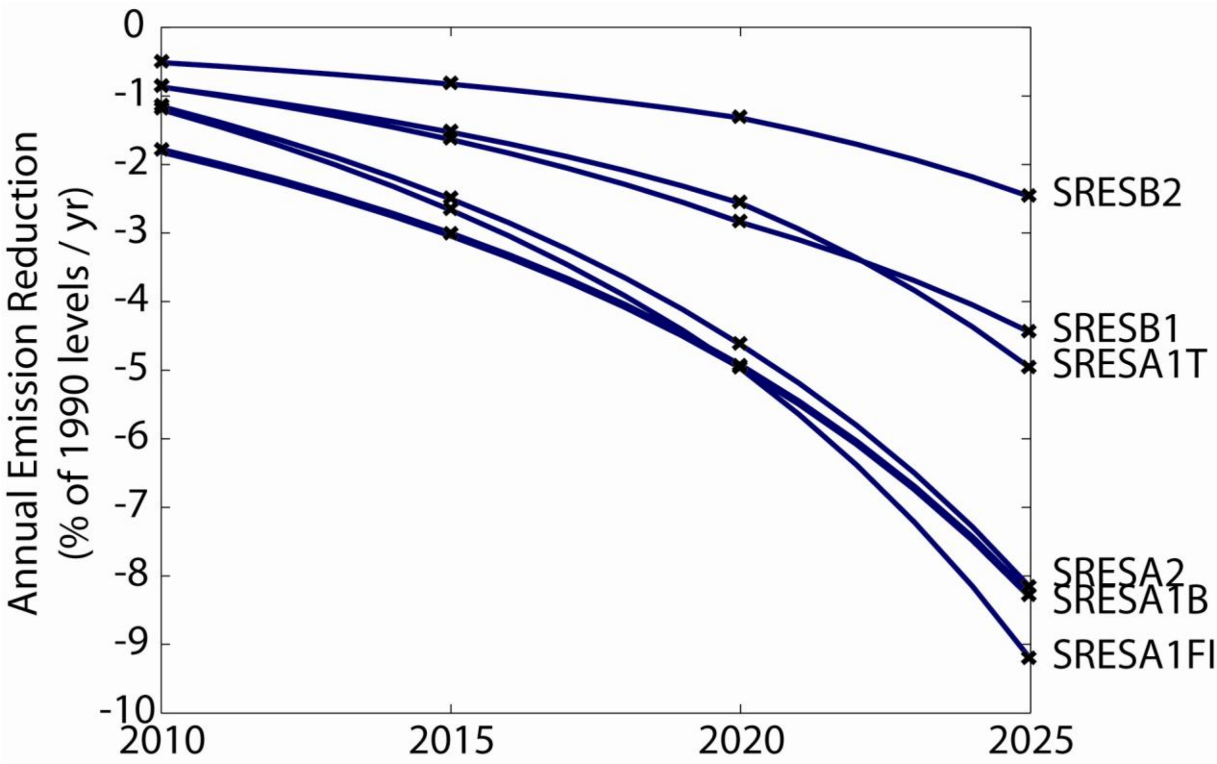

Figure 2. Under a fixed cumulative emission budget between 2020 and 2050, the required reduction rate between 2020 and 2050 increases if emissions peak later and higher, illustrated here by highlighting a peak in emissions in 2010, 2015, 2020 and 2025 (crosses). The implied reduction rates are shown here for various baseline pathways (business-as-usual pathways), because emissions are assumed to follow a baseline pathway up to the peaking year and hence more ambitious reductions up to 2050 -are required for baselines that project a higher emission peaking level.

4 Scenario analysis

Emission pathways resulting from proposals

The reduction targets summarized in Table 1 result in emission pathways shown in Figure 3. The scenarios based on current proposals (CPH15) and a somewhat increased ambition (CPH25) result in global emissions peaking after 2020. The reason is that the current proposals for 2020 do not constrain the future pathway enough and emissions are still strongly on a rise by 2020. The result is that in both pathways it is likely that global temperature will exceed 2°C and 1.5°C within the 21st Century, without strong constraints on global emissions post-2020. The 450ppm and 350ppm/1.5°C pathways peak emissions before 2015 and increase the chance of staying below 2°C peak warming considerably: to 60% in the 450ppm profile ("Stern") and 75% for the 350ppm/1.5°C pathway ("AOSIS").

With a chance of roughly 25% that peak warming stays below 1.5°C, it is the only the 350ppm/1.5°C scenario for which global temperatures are likely to drop below 1.5°C by the end of the 21st Century. (with a chance of about 75% - see further results in the Change Track section below). In the long term, stabilization of CO_2-eq concentrations at 450 ppm implies a chance of less than 50% to stay below 2°C, and stabilization at 350 ppm CO_2-eq a chance of 95%. These chances reduce for staying below 1.5C to 10% and 90% for stabilization at 450 ppm and 350 ppm, respectively (see Figure 4).

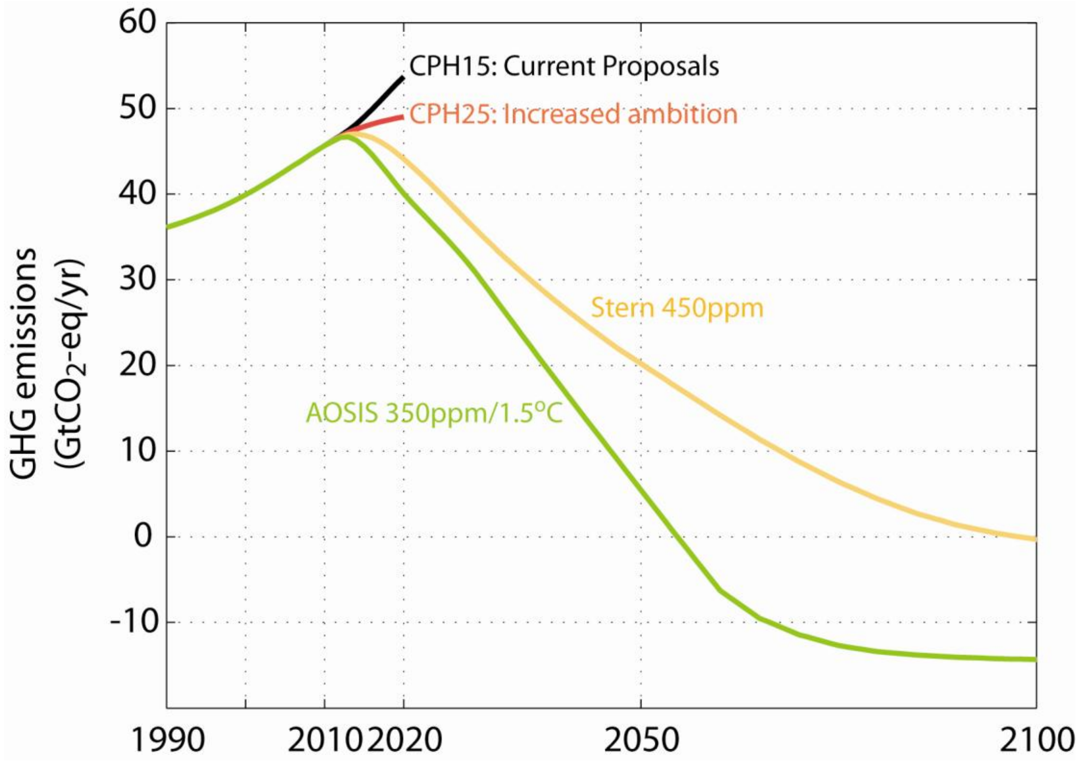

FIGURE 3. GLOBAL TOTAL EMISSIONS OF BASE SCENARIOS EVALUATED IN THIS REPORT.

For the projection of global warming resulting from the scenarios described above, the global CO_2-equivalent emission pathways were further developed into a pathway with emissions for all Kyoto greenhouse gases, as well as aerosols, using the Equal-Quantile-Walk approach (Meinshausen et al. 2006). This is a necessary step, since different greenhouse gases have a very different lifetime in the atmosphere and a different impact on the radiation balance for the same unit of volume, or mass, so a pathway defined in terms of CO_2-equivalent emissions only does not contain sufficient information.

The resulting pathway was then used to drive a reduced-complexity climate model (Meinshausen et al. 2008) to obtain probabilistic estimates of future atmospheric greenhouse gas concentrations and global temperature, given uncertainties in our understanding of how the climate system responds to changing concentrations of these gases (Monte-Carlo set-up, see Meinshausen et al. 2009). Unless stated otherwise, all values and graph curves for concentration and temperature increase below are 'median' values, meaning that under our current understanding we estimate that the uncertain 'real' value has a 50% (1 in 2) probability to lie *above* this median and an equal probability to lie *below* this median.

In Figure 4, we show the CO_2 concentration for the 450ppm and 350ppm/1.5°C pathways. For comparison, we have included a scenario without climate policy ('business as usual', SRES A1B, IPCC 2000), as well as a pathway that we developed in June 2009 (Rogelj et al. 2009), which reflects the proposals of both Annex I and non-Annex I for 2020 reduction targets, as well as targets for 2050 (to the extend these exist in the individual proposals). It would be roughly comparable to the CPH15 scenario extended beyond 2020. By the 2nd half of the 21st Century, both these scenarios are likely to exceed the level of CO_2 concentration that is estimated to lead to extinction of coral reefs. Enhanced atmospheric CO_2 concentrations lead to acidification of ocean surface waters, which makes it harder for calcifying organisms to sequester calcium (Silverman et al. 2009). By contrast, both the 450 and 350 scenarios stay below these levels, although for a long time the 450 scenario will stay close to the level that is estimated to inhibit growth of coral reefs, which weakens the resilience of these ecosystems to other external forces (e.g. extreme temperature events and water pollution, see e.g. Fischlin et al (2007)). This level of 450 ppm CO_2 cannot be considered 'safe' for coral reefs.

Although the 350ppm/1.5°C scenario peaks at a lower CO_2 concentration than the 450ppm pathway, the peak in CO_2-eq concentration is comparable at about 510 ppm (not shown). The reason is that the faster reductions in fossil CO_2 emissions in the 350ppm/1.5°C scenario are accompanied by faster reductions in sulphur oxides emissions. A rapid cessation of emissions of the latter will result in a fast removal of short-lived cooling sulphate aerosols, causing a temporary peak in CO_2-eq concentrations that now include a smaller amount of cooling aerosols than the 450 ppm pathway. However, the relatively higher contribution in the latter pathway to the peak of long-lived greenhouse gases, and slower decrease in these after the peak, results in the much higher CO_2-eq concentration in this path by the end of the Century of 480 ppm, against 390 ppm in the 350ppm/1.5°C scenario. The unfortunate side-effect of a temporary warming by a quick reduction in emissions of sulphur oxides also plays a role in the Change Track scenarios, as will be shown below.

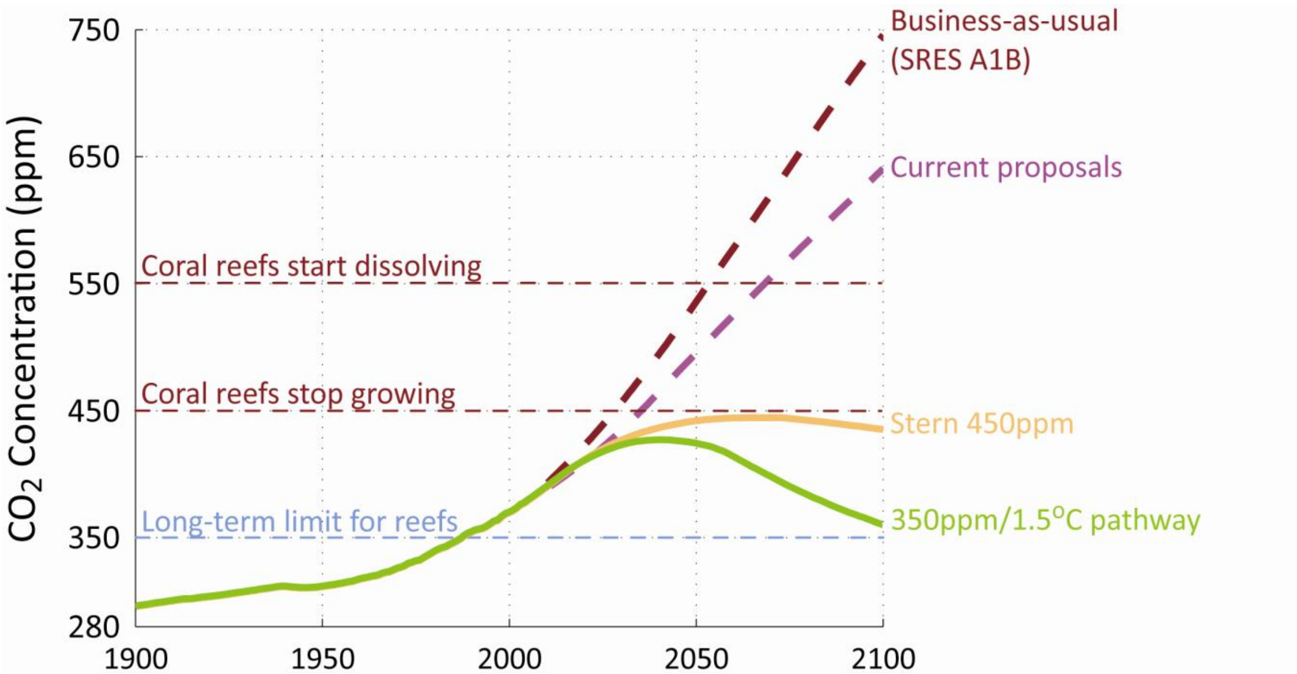

FIGURE 4. CO_2 CONCENTRATION PATHWAYS OF 450 AND 350 BASE SCENARIOS. FOR COMPARISON, A SCENARIO WITHOUT CLIMATE POLICY (BUSINESS-AS-USUAL) AND AN INTERPRETATION OF CURRENT PROPOSALS PUBLISHED IN JUNE 2009, WHICH INCLUDES 2050 TARGETS FOR THOSE COUNTRIES THAT HAVE INCLUDED THESE IN THEIR REDUCTION PROPOSALS. A LONG TERM CO_2 CONCENTRATION VIABILITY LIMIT FOR CORAL REEFS OF BELOW 350 PPM WAS RECENTLY IDENTIFIED BY VERON ET AL (2009). CAO AND CALDEIRA (2008) IDENTIFIED 450 PPM AS A LEVEL WHERE CORAL REEF GROWTH MAY STOP AND SILVERMAN ET AL (2009) ESTIMATE THAT CORAL REEFS WOULD START DISSOLVING AT 550 PPMV,

Change Track scenarios

The emission budget analysis roughly illustrated that if emission reductions for 2020 are delayed, steeper reductions between 2020 and 2050 are required to compensate and keep an equal chance to reach temperature goals. In this section, we will analyze which reductions post-2020 are required to compensate for a global deal in Copenhagen that does not achieve reductions by 2020 at the level required for the 350ppm/1.5°C or 450ppm scenarios.

In Figure 5, we show two Change Track scenarios that include steeper reductions after 2020, to switch from a CPH15 pathway to the 450ppm. If reductions by 2020 are at the level of what is currently on the table, global emissions between 2020 and 2050 need to reduce much faster than in the 450ppm pathway that includes earlier reductions and peaks emissions just before 2015. In the latter pathway, global emissions between 2030 and 2050 reduce by about -2% of 1990 emissions per year. Starting from the CPH15 level in 2020, a reduction rate of -6% of 1990 emissions is required to reach an equal probability to stay below 2°C by 2100. The same reduction rate is required to achieve an equal probability that peak warming in the 21^{st} Century will be limited to 2°C, but this rate needs to be achieved sooner, i.e. emissions must peak and decline earlier.

Figure 6 shows that starting from the CPH25 level in 2020, the required emission reductions to change track to a 450ppm pathway are somewhat less daunting: a mean reduction up to 2050 of -4% of 1990 emissions is required to reach an equal probability to stay below 2°C by 2100 and -5% of 1990 emissions to achieve an equal probability of peak warming below 2°C.

The 350ppm/1.5°C pathway in itself requires steeper reductions than the 450ppm pathway, in exchange for the lower peak temperatures and associated climate change impacts. This implies that to change track to this pathway from emission levels in 2020 that are too high will be more difficult (Figure 7) than changing track to the 450ppm pathway. The reduction rate between 2020 and 2050 to change track from a CPH25 level by 2020 to the 350ppm/1.5°C pathway is about 6% of 1990 emissions to reach an equal probability to stay below 1.5°C by 2100. This reduction rate is comparable to the rates found in the Change Track scenario that switches from the CPH15 level in 2020 to the 450ppm pathway, but to change track to the 350ppm/1.5°C pathway requires negative CO_2 emissions to be reached by the 2050s that are found in the latter pathway only by the 2070s.

A pathway that compensates 2020 emissions enough to lead to an equal probability of staying below 1.5°C peak warming as the 350ppm/1.5°C pathway implies yet higher reduction rates and deeper cuts by 2050. The very rapid greenhouse gas reductions that would have to follow the peak in emissions shortly after 2020 will lead, in our methodology, to an equally rapid reduction in the emissions of sulphur oxides. These emissions lead to cooling sulphate aerosols that have a short residence time in the atmosphere. Removing these will cause a modest spike in temperature that may be large enough to virtually eliminate the option of achieving an equal probability of staying below 1.5°C peak warming, compared to the more gradual reduction in emissions in the 350ppm/1.5°C pathway which peaks by 2010.

The results from this more detailed scenario analysis confirm the general observation on reduction rates from the simpler emission budget calculations. However, the temperature pathways in Figures 5 to 7 point to an additional large problem of delayed mitigation. The sharp reductions in sulphur oxides emissions adds a modest additional temperature increase to the effect of the continuously very high emissions of greenhouse gases up to 2020 in the Change Track scenarios. The total effect is a much more rapid increase in global-mean temperature, until peak values are reached around 2050, compared to the gradual increase in the base scenarios. This is especially apparent in Figure 5 for the CPH15 cases. The rate of temperature increase in the Change Track cases may reach best-estimate values as high as 0.4°C per decade in the 2030s. This doubles or triples the currently observed rate of temperature increase of 0.15°C per decade and would pose a very serious challenge to the adaptation capacity of human society and ecosystems.

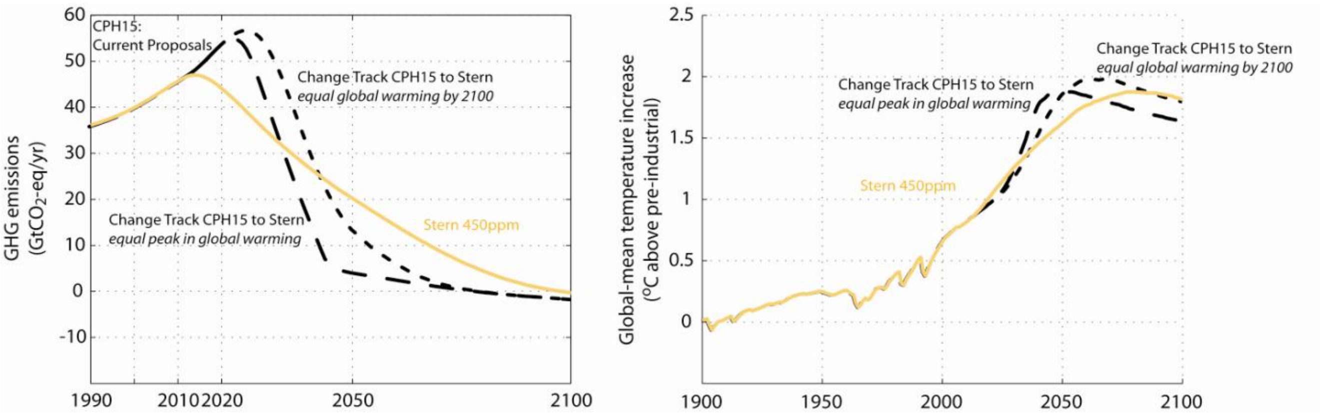

FIGURE 5. EMISSIONS (LEFT PANEL) AND GLOBAL WARMING (RIGHT PANEL) IN THE CHANGE TRACK SCENARIOS THAT SWITCH AFTER 2020 FROM THE CPH15 PATHWAY TO THE 450PPM PATHWAY. THE DOTTED LINE SHOWS THE PATHWAY LEADING TO AN EQUAL PROBABILITY TO STAY BELOW 2°C BY 2100 AS THE 450PPM SCENARIO, WHILE THE DOTTED PATHWAY ACHIEVES AN EQUAL PROBABILITY THAT *PEAK* WARMING STAYS BELOW 2°C.

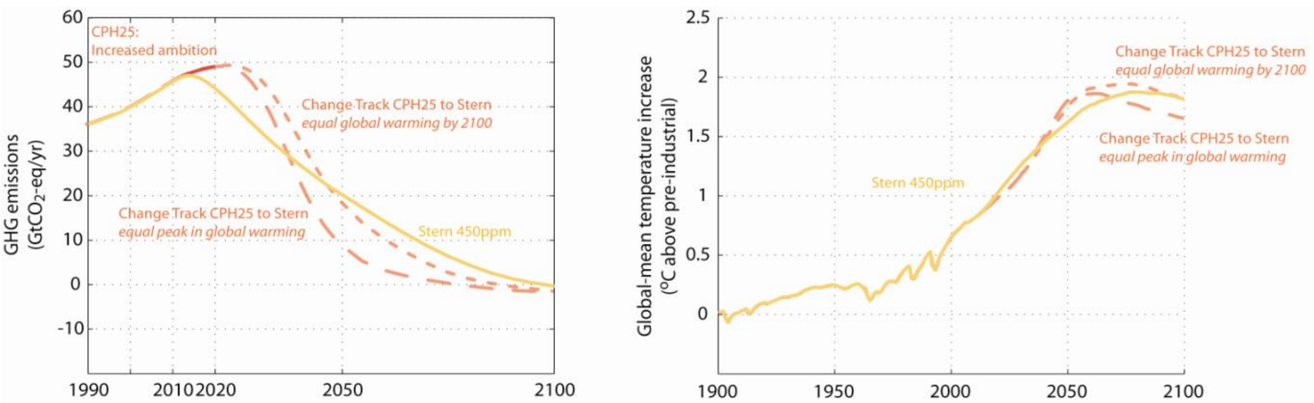

FIGURE 6. EMISSIONS (LEFT PANEL) AND GLOBAL WARMING (RIGHT PANEL) IN THE CHANGE TRACK SCENARIOS THAT SWITCH AFTER 2020 FROM THE CPH25 PATHWAY TO THE 450PPM PATHWAY. THE DOTTED LINE SHOWS THE PATHWAY LEADING TO AN EQUAL PROBABILITY TO STAY BELOW 2°C BY 2100 AS THE 450PPM SCENARIO, WHILE THE DOTTED PATHWAY ACHIEVES AN EQUAL PROBABILITY THAT *PEAK* WARMING STAYS BELOW 2°C.

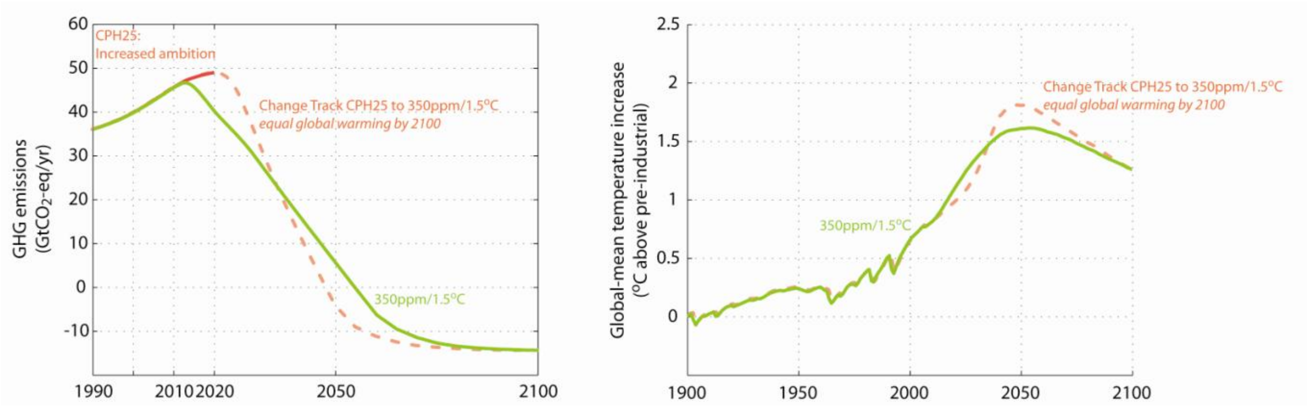

FIGURE 7. EMISSIONS (LEFT PANEL) AND GLOBAL WARMING (RIGHT PANEL) IN THE CHANGE TRACK SCENARIOS THAT SWITCHES AFTER 2020 FROM THE CPH25 PATHWAY TO THE 350PPM/1.5°C PATHWAY LEADING TO AN EQUAL PROBABILITY TO STAY BELOW 2°C BY 2100.

5 Conclusions

We have developed two base scenarios that reflect ambitious reduction targets put forward at high political level and have a reasonable chance to achieve peak warming below 2°C (Stern 450ppm pathway) and return to 1.5°C by 2100 (AOSIS 350ppm/1.5°C pathway) respectively. Current policy proposals by individual developed and developing countries will in aggregate result in emissions by 2020 much higher than in these scenarios.

We have shown that is will be very hard to change track after 2020 and switch to these lower emission pathways, while achieving a comparable probability of staying below dangerous levels of global warming. The global emission reduction rates required between 2030 and 2050 would have to double for the 2°C target and triple for the 1.5°C target, compared to the base scenarios, to make up for the additional decades of growing emissions implied by the currently proposed reduction targets for 2020.

In addition, the "Change Track" scenarios, even if peaking at the same temperature level, would result in a much higher rate of temperature increase before the peaking value is reached, which poses a serious threat to the parts of human society and ecosystems with limited adaptation potential.

Both problems of high reduction rates required after 2020 and an unavoidable high rate of temperature increase are less apparent in the Change Track scenarios that start from a somewhat more ambitious reduction target by 2020 than is currently on the table: of 25% below 1990 for Annex I countries and 10% below business-as-usual for non-Annex I countries.

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