INFORMATION NOTE

How Close Are We to the Two Degree Limit?

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By Chief Scientists Office, UNEP, in conjunction with representatives from nine scientific groups.

Copenhagen and the two degree limit

An important outcome of the Copenhagen Accord, noted at the end of the UN climate convention meeting in December 2009, was the declaration that "deep cuts in global emissions are required … with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius."[1] Based on current understanding of climate change science, scientists believe that the two degree limit will provide a measure of assurance that we can avoid many climate impacts.[2] Furthermore, this aim provides a scientific underpinning to the Accord and establishes a benchmark for comparing emission commitments and mitigation actions submitted to the UN Framework Convention on Climate Change (UNFCCC).

Now that this limit is enshrined in the Accord, the key question is, will emission reduction commitments/mitigation actions for 2020 be consistent with the two degree limit? Or put another way, will the world be on an emissions pathway compatible with a limit of two degrees temperature increase?

The aim of this paper is to sum up recent insights into these questions. To do so we divide the larger issue into three parts:

- Which emission pathways are consistent with the two degree limit? (A "pathway" is a curve depicting the temporal trend of global emissions into the future.) A related question is, what do these pathways imply for emission limits in 2020?
- What are the expected global emissions in 2020 if commitments/mitigation actions to the Copenhagen Accord are fulfilled?
- How do expected emissions compare to emission limits in 2020?

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[1] This excerpt is from Paragraph 2. Paragraph 12 also mentions temperature in connection with an assessment of the implementation of the Accord that should include "consideration of strengthening the long-term goal … in relation to temperature rises of 1.5 degrees Celsius."

[2] Based on a review of the scientific literature, the IPCC has summarized the benefits of limiting the increase of global average surface temperature to around 1.6-2.6 ^{0}C relative to pre-industrial conditions and, conversely, the risks of allowing temperature to rise above this level. Summaries may be found in various Fourth Assessment reports including the Synthesis Report; in Table 19.1 of the Working Group II report; and in Table 3.11 of the Working Group III Report.

Question 1: Which emission pathways are consistent with the two degree limit?

This first question has been addressed in a recent series of modeling studies (Table 1). As with all investigations of phenomena as complex as the global climate system, the uncertainties involved are high. In this paper we account for this uncertainty by compiling results from a number of studies and by identifying robust conclusions across these analyses.[3] We note that most of these studies are so new that they have not yet appeared in the scientific literature, although similar analyses have been published earlier indicating that the general approach is considered scientifically-sound.[4]

The model experiments carried out in these studies follow a similar procedure. First, the future temporal trends in global temperature are computed for a range of assumed pathways of emissions. Researchers then examine this collection of model runs to identify which emission pathways stay within the limit of two degrees increase.[5] The following results stand out from these studies:

1. The level of cumulative emissions has an important influence on complying with the temperature limit.
Although climate policy focuses on specific annual emission targets for specific years, it is actually the cumulative emissions that have a more profound influence on the maximum increase of temperature in the atmosphere.[6] This is because carbon dioxide and some other greenhouse substances have long residence times in the atmosphere which means that their concentration at any particular time relies on their accumulation over many previous years.

2. The cumulative emissions play a decisive role in determining which emission pathways are compatible with the two degree limit.
The fact that cumulative emissions are important in determining the maximum temperature increase means that emissions must follow a pathway over time that ensures that they do not accumulate too quickly. However, several different emission pathways can result in the same cumulative emissions over a period of time. For example, an emission pathway that has a high peak followed by a sharp decline could have the same cumulative emissions as one with a lower peak followed by a slower decline in emissions. At the same time, this flexibility is bounded by the maximum rate of emission reductions that can be achieved.

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[3] The studies are listed in the footnotes of Table 1.
[4] An example of an earlier published article using a similar methodology is: den Elzen, M. van Vuuren, D. 2007. Peaking profiles for achieving long-term temperature targets with more likelihood at lower costs. *Proceedings of the US National Academy of Sciences.* 2007. 104 (36): 17931-17936.
[5] Most modeling groups interpret the two degree limit to mean that global average surface temperature does not increase more than two degrees over the course of the 21st century relative to the pre-industrial era.
[6] It is important to note that a number of other factors, such as the level of sulfate aerosols, also have a significant influence on the maximum temperature increase.

3. Recent analyses suggest that there is medium likelihood [7] that global temperature will stay within the two degree limit if global emissions peak within the next few years and then moderately or sharply decrease afterwards [8].

Many recent modeling studies have assumed that it will be unrealistic that global emissions will immediately start decreasing (because of political and economic inertia) and therefore have focused on scenarios in which global emissions continue to increase for a few years and then decrease sharply afterwards.[9] Studies show that there is a tradeoff between the timing of the peak and the rate of decrease in emissions afterwards – the sooner and lower the peak, the slower the rate of decrease can be afterwards. Conversely, the more the peak is delayed and the higher it is, the faster emissions must decline afterwards in order to stay within the temperature limit. (See Figure 1.) Some scenarios aim to benefit from the slow temperature response by temporarily allowing higher greenhouse gas concentrations than would be consistent with a two degree limit in equilibrium (so-called "peaking" or "overshoot" scenarios).

4. According to various recent studies, there is a medium likelihood [10] to stay within the two degree limit if the following conditions are met:

- **Global emissions peak sometime between 2015 and 2021. [11]**
- **Global emissions in 2020 are approximately 40.0 to 48.3 Gt CO_2 eq/yr.[12]**
- **By 2050 global emissions decrease by 48 to 72% relative to 2000 [13].**

5. To increase the likelihood that that the two degree limit is met, more stringent emission limits must be observed and maintained.

The figures in Point Four refer to emission pathways that have about a 50% chance of staying within the two degree limit. To have a higher chance of not exceeding the temperature limit, emission targets must be still lower.

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[7] Here "medium likelihood" is used to mean "more likely than not" which is IPCC terminology corresponding to a 50% or greater likelihood. This is consistent with the explicit assumptions of the four studies reviewed in Table 1. Two of the four explicitly focus on the 50% chance of not exceeding the temperature limit, one focuses on the "29% to 56% risk of exceeding 2 ^{o} C", and the fourth study presents two results that correspond to "about 20 to 70% probability of remaining below 2^{o} C", and "40 to 90% probability of remaining below 2^{o} C", respectively.

[8] "Moderately to sharply" is used here to mean reduction rates of around 1.5 to 4 % per year, or greater.

[9] This assumption is reflected in some modeling analyses, for example, by forcing emissions to follow a baseline up to a particular point in time and then imposing emission reductions after this point.

[10] See note 7

[11] This is the span of mid-range values from Table 1. The full range is 2013 to 2027. The authors believe it is more policy relevant here to compare mid-range values from various studies rather than the full range of estimates because each of the estimates in Table 1 only has about a 50% chance of meeting the temperature limit. (See Footnote 7). The upper extreme values have the highest risk of not staying within the temperature limit and the lower extremes require very rapid policy action. Hence we focus on mid-range estimates rather than extreme values. At least one contributor to this paper does not consider the upper value of the full range (2027) to be robust because some modeling results show that it is very unlikely that temperature will stay within the two degree limit if emissions peak beyond 2020.

[12] "Gt CO_2 eq/yr" stands for the units of total annual emissions of greenhouse gases and particles in equivalent carbon dioxide units (including the "Kyoto gases": CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6). This is the span of mid-range values from Table 1. The full range is 40.0 to 54.0 Gt CO_2 eq/yr. See Footnote 11 for justification for using span of mid-range values rather than full range of estimates.

[13] Span of mid-range values from Table 1. Full range is 40 to 84%. See Footnote 11 for justification for using span of mid-range values rather than full range of estimates.

6. A delay in emission reductions lowers the feasibility of achieving the two degree limit from both the climate science and socio-economics point of view. From the climate science perspective, a delay in the reduction of global emissions adds to cumulative emissions, and moves the world further away from achieving the two degree limit.[14] From the socio-economic point of view, postponing action to reduce emissions will require faster emission reductions later[15] which could be very costly in both economic and social terms.[16]

7. A recent study suggests that the two degree limit could still be met with emission pathways in which emissions are higher in 2050 than usually assumed.
Results from a recent study imply that the two degree limit can be met if emissions are higher in 2050 than indicated in Point 4. [17] (See Table 2.) But it is important to note that this would require pursuing all technologically feasible emission reductions after 2050, including achieving substantial negative emissions by the end of the century. The other studies quoted in this paper do not assume as large a magnitude of negative emissions. Key questions here are whether negative emissions of this magnitude can be technically accomplished by geoengineering, or by combining the production of biomass for energy with carbon-capture-and-storage, or by other means, and whether these measures are feasible and desirable from the social, environmental and political standpoints.

8. There are many sources of uncertainty in estimating emission pathways that comply with the two degree limit. Nevertheless science has convincingly shown that feasible emission pathways do exist that make it possible to hold the global temperature increase below two degrees.
As noted above and in Table 1, various studies give different answers for the peaking year, the magnitude of the peak and the percentage decrease between 2000 and 2050. The differences are not surprising because different assumptions are used for baseline emissions, carbon cycle changes beyond 2050, and other important variables. Moreover, each calculation itself is uncertain because of the simplicity of the models used for the analyses as compared to the complexity of the climate system they simulate. Although these uncertainties explain the range of estimates, they do not take away from the robust conclusions above regarding feasible emission pathways.

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[14] Some authors argue that under some assumptions it is difficult to identify feasible emission reduction pathways that stay within the two degree limit. For example, O'Neill et al. (2010) examined different reduction pathways and found that if development paths, including demand for energy and land, proceed as in the IPCC A2 scenario before reductions begin, it may not be feasible to stay within the two degree limit up to 2100 with 50% likelihood. O'Neill, B., Riahi, K., and I. Keppo. 2010. Mitigation implications of mid-century targets that preserve long-term climate policy options. *Proceedings of the US National Academy of Sciences*. 107 (3): 1011-1016.
[15] For example, Meinshausen (2010) found that a medium emissions scenario up to 2020, with linearly decreasing emissions from 2021 onwards, requires annual reduction rates of greater than 5% in order to have a 50% chance of staying within the two degree limit. Meinshausen, M., N. Meinshausen, W. Hare, S. C. B. Raper, K. Frieler, R. Knutti, D. J. Frame and M. R. Allen 2009. Greenhouse-gas emission targets for limiting global warming to 2°C. *Nature* 458(7242): 1158.
[16] This point is made in den Elzen, M. G. J., van Vuuren, D. P. and van Vliet, J. 2010. Postponing emission reductions from 2020 to 2030 increases climate risks and long-term costs. *Climatic Change.* doi 10.1007/s10584.
[17] O'Neill, B., Riahi, K., and I. Keppo. 2010. Mitigation implications of mid-century targets that preserve long-term climate policy options. *Proceedings of the US National Academy of Sciences*. 107 (3): 1011-1016.

Question 2: What are the expected global emissions in 2020 if commitments/mitigation actions in the Copenhagen Accord are fulfilled?

9. Taking into account commitments/mitigation actions associated with the Copenhagen Accord, global emissions in 2020 are expected to range from about 48.8 to 51.2 Gt CO_2 eq/yr. The range of estimates reflects the difference between high and low pledges. The low value assumes high pledges are fulfilled, and the high value the opposite. These are the averages, respectively, of the low and high estimates from three groups. [18]

10. There are many sources of uncertainty in estimating global emissions expected from the Copenhagen Accord.
Estimates differ between studies because they make different assumptions, for example, about the business as usual scenario, about national actions, about the use of offsets included in other countries' targets, about particular emission categories, and about the role of land use change. Moreover, each estimate itself has an uncertainty range of at least ± 2 Gt CO_2 eq/yr due to uncertainty about base year emissions, future baseline emissions, future energy intensity and other reference points for emission reductions. [19]

Question 3: How do expected emissions compare to emission limits in 2020?

11. On one hand, the expected emissions for 2020 range between 48.8 to 51.2 Gt CO_2 eq/yr based on whether high or low pledges will be fulfilled.[20] **On the other hand, the emission targets in 2020 in line with the two degree limit are about 40.0 to 48.3 Gt CO_2 eq/yr.** [21] **Hence, if high emission pledges are fulfilled, the gap is between 0.5 and 8.8 Gt CO_2 eq/yr, with an intermediate value of 4.7; if low emission pledges are fulfilled the gap is between 2.9 and 11.2 Gt CO_2 eq/yr, with an intermediate value of 7.1. (See Figure 2.)**
Here we compare averages of expected emissions with mid-range estimates of emission limits rather than the full span of values from the studies quoted in this paper.[22] The wide range of estimates might narrow somewhat after the research community conducts more analyses. Also, it is important to recall that the emission targets presented here have only medium likelihood to meet the two degree limit. For greater assurance in meeting the limit, emission reduction targets would have to be stronger.

12. Even if the emissions gap is closed in 2020, further emission reductions after 2020 are necessary if the aim is to stay within the two degree limit. (Most studies indicate that the reduction rate after the peak in emissions should be at least 3% per year.) It is therefore advisable to set international emission targets not only for 2020 but also for 2050 to be

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[18] These are arithmetic averages of three different estimates in Table 3. We note that arithmetic averages are used here, whereas mid-range values are used in Point 4. The reason that averages are used here is that it is appropriate to average the data in Table 3 because three discrete estimates are available. By comparison, discrete estimates are not available for all the emission limits reported in Table 1 and, therefore, mid-range values are used instead to describe central tendency.
[19] Furthermore, Meinshausen suggests that taking into account special accounting provisions, like the banking of surplus emission allowances from the 2008-2012 period, can increase emissions in 2020 by about 3Gt CO_2 eq/yr.
[20] These numbers are from Point 9 and are arithmetic averages, respectively, of the low and high estimate from three groups.
[21] These numbers are from Point 4 and are the span of mid-range values from Table 1.
[22] See footnote 11 for discussion about using mid-range values rather than full range of estimates for emission limits.

confident that cumulative emissions over the long run do not cause a greater than two degree increase in global temperature. (See Figure 1.)
Because meeting the two degree limit depends on emissions beyond 2020, it is useful to set long-term targets to stimulate the necessary research and development of the mitigation technologies needed beyond 2020. These technologies may include carbon-capture-and-storage, second-generation bio-energy, wind power and new resource-efficient technologies.

13. To sum up, there is low confidence[23] that the two degree limit will be met under current commitments/mitigation actions to reduce emissions listed in the Copenhagen Accord. Conversely, stronger emission reductions and enhanced carbon sinks would increase confidence that the limit is met.
More creative thinking is needed about policy options for strongly reducing greenhouse gas emissions and enhancing carbon sinks. The range of possibilities is enormous, spanning from the enhancement of carbon uptake in coastal ecosystems to the development of highly resource-efficient and clean technologies. The full range of policy measures needs to be explored, and not only for controlling carbon dioxide but for all greenhouse substances.

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[23] "Low confidence" in IPCC terminology means roughly a "2 in 10 chance".

Table 1. Mid-range values of results of four studies of emission pathways consistent with two degree limit. **Full ranges are indicated in parentheses.**

Study	**1990 global emissions (Gt CO_2-eq / yr)**	**2000 global emissions (Gt CO_2-eq / yr)**	**2020 global emissions (Gt CO_2-eq / yr)**	**Peak year of emissions**	**Global emissions in 2050 (Gt CO_2-eq / yr)**	**Global emissions in 2050 (% rel to 1990)**	**Global emissions in 2050 (% rel to 2000)**
van Vuuren et al. [24]	37.7	40.4	45.4 (44.3 [25] - 46.5 [26])	2018 (2015 – 2020)	21.0 (17.7-24.2)	56 (47-64)	52 (44-60)
Bowen and Ranger [27]	37.0	41.0	44.0 ("Feasible" range: 40.0-48.0 [28]) 47.0 (Full range: 40.0-54.0 [29])	2015 2020 (2015-2025)	15.5 (14.0-17.0) 11.5 (6.0-17.0)	42 (38-46) 31 (16-46)	38 (34-41) 28 (16-41)
Meinshausen et al. [30]	38.0	40.0	40.0 [31]	2015 (2013-2017)	<20	<55	<50
Lowe et al. (AVOID Programme) [32]	36.0	39.8	42.6 (40.0 – 45.1 [33]) 48.3 (44.0 – 52.5 [34])	2021 (2014-2027) 2018 (2014-2021)	16.5 (12.2-20.8) 16.8 (13.0-20.5)	46 (34-58) 47 (36-57)	41 (31-52) 42 (33-52)

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[24] van Vuuren DP, Den Elzen MG, Lucas PL, Eickhout B, Strengers BJ, Van Ruijven B, Wonink S, Van Houdt R. 2007. Stabilizing greenhouse gas concentrations at low levels: An assessment of reduction strategies and costs. *Climatic Change*. 81; 119-159. van Vuuren, D., Stehfest, E., den Elzen, M. 2009. Exploring scenarios that keep greenhouse gas radiative forcing below 3 W/m^2 in 2100 in the IMAGE model. *Energy Economics*. Submitted

[25] Corresponding to a pathway that does not exceed 400 ppm CO_2 eq. In van Vuuren et al. (2009) the authors state that this pathway corresponds to "about 40 to 90% probability of remaining below 2^o C." van Vuuren, D., Hof, A. and M. den Elzen. 2009. Meeting the 2^o C target. Netherlands Environmental Assessment Agency. Office Bilthoven. PO Box 303. 3720 AH Bilthoven. The Netherlands. 98 pp.

[26] Corresponding to a pathway that does not exceed 450 ppm CO_2 eq. In van Vuuren et al. (2009) the authors state that this pathway corresponds to "about 20 to 70% probability of remaining below 2^o C." van Vuuren, D., Hof, A. and M. den Elzen. 2009. Meeting the 2^o C target. Netherlands Environmental Assessment Agency. Office Bilthoven. PO Box 303. 3720 AH Bilthoven. The Netherlands. 98 pp.

[27] Bowen, A., Ranger, N. 2009. Mitigating climate change through reductions in greenhouse gas emissions: the science and economics of future paths for global annual emissions. Policy Brief from Grantham Research Institute on Climate Change and the Environment at London School of Economics, and Centre for Climate Change Economics and Policy of University of Leeds and London School of Economics. 44 pp. http://www.ise.ac.uk/grantham.

[28] 50% chance of not exceeding two degree temperature limit up to 2100. Range of pathways constrained by requirement that maximum decrease in emissions between 2020 and 2050 does not exceed 4% per annum. These model runs include relatively