Q&A

Twenty-six Questions and Answers in regard to the study "Greenhouse-gas emission targets for limiting global warming to 2°C" by Meinshausen et al. 2009, in 30th April issue of NATURE

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Q1: What is new about this study?

A: This study quantifies the emissions reduction requirements for staying below 2°C. This has not been done before in a similarly comprehensive manner.

Background: For the first time, we were able to consider the uncertainties in regard to the effect of multiple anthropogenic forcings, the climate and the carbon cycle response in a single computer model to quantify the exceedance probabilities of 2°C under a large set (approx. 1000) of emission pathways. Throughout the study, probability statements were used to summarize the current level of knowledge based on observational data. It also used a huge number of different simulation results from the latest assessment report of the Intergovernmental Panel on Climate Change. In taking this comprehensive approach the researchers went a step further than previous work.

Q2: Will we run out of fossil fuels before we can cause dangerous climate change?

A: No. If global warming shall be limited to below 2°C, less than a quarter of the available, and economically recoverable, fossil fuel reserves can still be burned between today (2009) and 2050. It is mainly the world's coal reserves which vastly exceed the allowable emission budget we have left.

Background:

We estimate the emissions that would arise from burning all proven fossil fuel reserves, that are economically recoverable at current prices and with current technologies, to be approximately 2,800 $GtCO_2$. Note that the unconventional fossil fuel resources (e.g. tar sands in Canada etc.) are still multiple times larger than the proven reserves based on current prices and technologies.

Q3: How many years at present levels of fossil fuel emissions can we still afford?

Having a good chance of staying below 2°C requires limiting our overall CO_2 emissions[1]. Our study indicates that we have an emission budget of a trillion tonnes CO_2 during the first 50 years of this century. Of that budget, we already used up a third in the first nine years (234 $GtCO_2$ up to 2006 and more than 36 $GtCO_2$/yr since then). At present rates of emissions, we will use up the remaining two-thirds in another 20 years, by around 2030[2]. We will consume this 2000 to 2050 budget even earlier, if emissions continue to increase according to the "business-as-usual" scenarios.

Q4: You specify emissions only until 2050. What happens after 2050?

A: As shown in Figure 2 of the manuscript, we consider a wide range of emission scenarios over the 21st century. Emissions after 2050 are assumed to follow a smooth trajectory. For the largest part of

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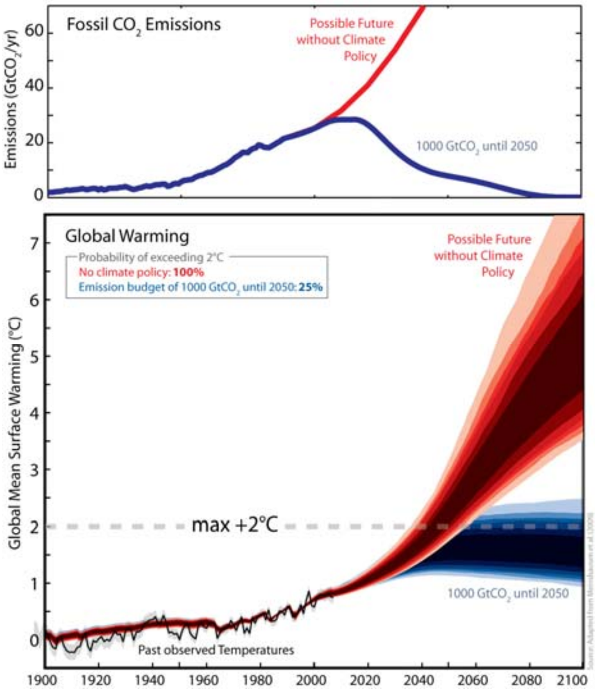
[1] Limiting the probability of exceeding 2°C to 25% in our illustrative default case.

[2] In Meinshausen et al., page 2, it says "Given that around 234 Gt CO_2 were emitted between 2000 and 2006 and assuming constant rates of 36.3 $GtCO_2$ / yr thereafter, we would exhaust the CO_2 emission budget by 2024, 2027 or 2039, depending on the probability accepted for exceeding 2°C (respectively 20%, 25% or 50%)"

the analyzed pathways (bright blue lines in Figure 2), trajectory are continuously decreasing once they started to decrease for the first time. Thus, in most cases, post-2050 emissions are declining and – for the lower set of analyzed pathways towards near-zero levels by 2100. For example, a pathway with a 1,000 $GtCO_2$ cumulative emission budget between 2000 and 2049 as pictured in the simple figure below, assumes another 153 $GtCO_2$ fossil carbon dioxide over 2050-2099. However, landuse related CO_2 emissions are largely negative so that the net CO_2 emission budget of the second half of the 21st century is close to zero, i.e. 14 $GtCO_2$.



Caption: Two possible futures. One in which no climate policies are implemented (red), and one with strong action to mitigate emissions (blue). Shown are fossil CO_2 emissions (top panel) and corresponding global warming (bottom panel). The shown mitigation pathway limits fossil and land-use related CO_2 emissions to 1,000 billion tonnes CO_2 over the first half of the 21st century with near-zero net emissions thereafter. Greenhouse gas emissions of this pathway in year 2050 are ~70% below 1990 levels. Without climate policies, global warming will cross 2°C by the middle of the century. Strong mitigation actions according to the blue route would limit the risk of exceeding 2°C to 25%. For more details, see Figure 2 in Meinshausen et al. (2009). Figure available at http://www.primap.org/SimpleFigureNature/Meinshausen2009Nature_SimpleFigure.zip

Q5: Does it matter, if we release emissions today or in 50 years?

A: A tonne is a tonne is a tonne. Thus, for the peak warming due to CO_2, it is largely irrelevant when the emissions occur, as shown by the companion study Allen et al.. However, in terms of the ability to adapt the energy-system towards a zero carbon future, in terms of the shorter lived non-CO_2 gases, and in terms of intergenerational equity, the timing of emissions is of high importance. A further delay in emission reductions might render the more pre-cautionary climate targets practically infeasible, as they would then imply sudden emission cuts in the future.

Q6: Are we bound to "overshoot" 2°C (Commentary by Parry et al.)?

A: No. Several lower mitigation scenarios show the technical challenges and economic moderate costs to achieve very low levels of emissions. It is not for us scientists to make the value judgement whether 1%, 2% or 5% GDP mitigation costs are too much to prevent sea level rise, droughts etc.. When scientists judge that politicians are likely not to act, fatalistic statements tend to become a self-fulfilling prophecy ("Scientist told us so"). **Background:** There is one technical point, which makes this analysis by Parry, Lowe and Hanson rather pessimistic, although we don't know, whether this is the cause for their provocative title. The chosen climate sensitivity distribution (Murphy et al.) is the second most pessimistic distribution within nearly twenty ones we analyze in our paper. Our Supplementary figure S1b is stating exceedance probabilities for 2050 Kyoto-GHG emissions and the Murphy line (No.17) implies around a 50% exceedance probability for halved emissions, roughly 20GtCO_2eq for baseyear 2000 (in line with the statement in the Commentary). The climate sensitivity distribution that is closest to the IPCC AR4 consensus estimate indicates a one-in-three risk of exceeding 2°C (see solid black line in Figure S1b).

Another technical point, which makes the notion of recovery even more doubtful, is that very few other climate runs, if any, show such a significant drop in temperatures besides positive CO2 and greenhouse gas emissions. Negative emissions seem needed for that (cf. Matthews and Caldeira, GRL, 2008, or Solomon et al. PNAS 2009). Anyway, once the Greenland ice sheet started its demise, a recovery within the next couple of hundred years seems doubtful to say the least.

Q7: How much can still be burned: "Less than a quarter" or "less than half" of the known economically recoverable fossil fuel reserves?

In our article's abstract, we wrote "less than half" of the economically recoverable fossil fuels can be burnt and in our press release, we mentioned "less than a quarter". Where does the difference come from? There are two reasons (1) the time horizon and (2) the whether a 25% or 50% exceedance probability is assumed.

a) In our press release, we refer to a *likely* probability of staying below 2°C, or *25%* probability of exceeding it; and we refer to the remaining carbon budget over the time horizon between *now (2009)* to 2050. Thus, it is smaller than the carbon budget over 2000 to 2050 as we already burned more than 300 billion tonnes CO_2 from 2000 to 2009. Thus, there are less than 700 billion tonnes CO_2 emissions remaining, which is **less than a quarter** of the 2,800 billion tonnes CO_2 expected in the economically recoverable fossil fuel reserves.

b) The original citation for the "Less than half" in the abstract of our paper is: "*Limiting cumulative CO_2 emissions over 2000–50 to 1,000 GtCO_2 yields a 25% probability of warming exceeding 2 °C—and a limit of 1,440 GtCO_2 yields a 50% probability—given a representative estimate of the distribution of climate system properties. As known 2000–06 CO_2 emissions were 234 GtCO_2, **less than half** the proven economically recoverable oil, gas and coal reserves can still be emitted up to 2050 to achieve such a goal.*" Thus, the 1,000 and 1,440 GtCO_2 budgets over 2000 to 2050, as stated in our abstract, are compared to the 2,800 GtCO_2, and characterized as "less than half".

The two statements "less than half" and "less than a quarter" are thus not contradicting each other, but they refer to a) a time horizon 2000 to 2050 and 50% exceedance probability and b) a time horizon between 2009 and 2050 and a 25% exceedance probability.

Q8: This paper is about a total emission budget to 2050 – what does it say about emission targets for 2020?

The small size of the emission budget remaining to 2050 (if 2°C shall be prevented with a reasonable probability) strongly reinforces the need for global CO_2 emissions to peak before 2020 so that emission pathways are likely to remain politically feasible, given the technological challenges and economic costs. We find that the higher emissions are in 2020 the higher the risk of exceeding 2°C (see Figure S1c in the Supplementary Material of Meinshausen et al.) or the harder it will be to achieve the required emission reduction rates after 2020.

Q9: Do we recommend the international negotiations to focus on a cap on cumulative emissions instead of a 2020 and 2050 target?

A: No. With these scientific papers, we are not advising any particular structure of the international climate change regime, as this is outside of the natural sciences realm.

Background: For effective climate policy, constraining cumulative emissions is necessary, but is not sufficient to create the signals that can bring emissions down fast enough. Climate policy has not only to take into account the inertia of the climate system and uncertainties in our understanding of it, but as well the inertia and dynamics of the energy-system, policies and social systems. Thus, emission milestones before 2050 have to be identified if we are to get onto a technologically and economically feasible path towards a low or zero-carbon future. Emission milestones are needed to send timely signals to investors and consumers, so that rates of technological change and economic adjustment are feasible. If emissions increase or do not go down fast enough in the belief that all that matters is the long-term cumulative carbon budget, then it is very likely that by the 2020s we will be confronted with the fact that the rates of emission reduction required to keep within the budgets will no longer be politically feasible given the involved economic costs and technological challenges. However, it is important for policy makers and the public to realize that there is only a limited amount of emissions we can still afford. Thus, it is important of short term targets are informed by the direction of the long-term journey.

→ See our commentary Allen et al. "The exit strategy: Emission targets must be placed in the context of a cumulative carbon budget if we are to avoid dangerous climate change." in Nature Reports climate change on www.nature.com/climate

Q10: Why do you start your analysis from a 2°C target?

A: For avoiding dangerous climate change, the ultimate objective of the United Nations Framework Convention on Climate Change, limiting warming to below 2°C is the most prominently discussed target in science and policy circles alike. The countries supporting a 2°C or lower temperature target comprise together a total of 110 countries and represent approximately 20% of the World's population in 2005. 2°C is not a safe level though, and significant impacts, like major long-term sea level rise is likely to occur even below 2°C warming. For a list of countries that stated a 2°C or lower temperature target, please see the Supplementary Material of Meinshausen et al. 2009.

Q11: Why did you not focus on the target by Small Island States and Least Developed Countries of 1.5°C?

A: The design of this study started more than 3 years ago, and the Small Island States and Least Developed countries offered the 1.5 °C target only as recently in December 2008 in Poznan[3]. The 1.5°C target will be a matter of future research.

Q12: Could we delay a peak of global emissions up to 2030 and then reduce emissions sufficiently quickly thereafter to make up for that?

A: From a purely physical point of view, that is correct. But the real world is different, and socio-economic and technological inertia has to be taken into account. The very rapid reductions which would be required after 2030 are very likely not feasible in practical terms. By peaking this late, we simply loose the option of staying below 2°C with a high likelihood.

Background: In the following, we provide a very simple illustration of how quickly the emission reduction rates become steeper with a delay in the peaking year. Assume that the world would want to stay within a GHG emission budget of 1,750 $GtCO_2eq$ (which implies a probability of exceeding 2°C of between 20% and 55%) and let's assume that the world follows a medium to high growth trajectory until the peak. If emissions were to peak by 2015, the annual emission reductions for subsequent years were equivalent to 3.6% of 1990 base year emissions. For 2025, these annual emission reductions were already beyond 10%, which is clearly outside of what we can currently imagine (see Fig. 1 below).

[3] For the announcement of the 1.5C target by the Alliance of Small Island states at COP14, Poznan, December 2008, see e.g. http://copportal1.man.poznan.pl/Doc.ashx?Id=46&Mime=application/pdf&Presentation=True

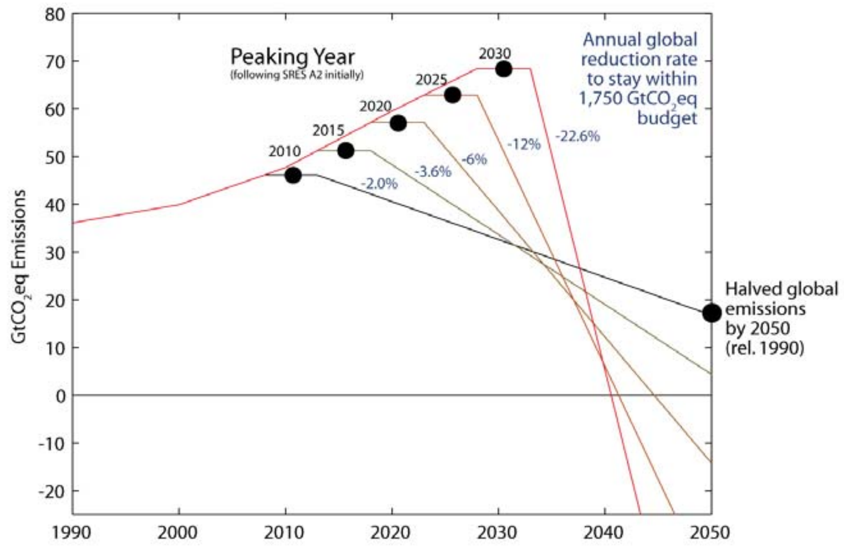


Figure 1 – Simplified illustration of the relation between the peaking year of global emissions and subsequent annual emission reduction rates (expressed as percentage of 1990 base year emissions) to stay within a 1,750 GtCO$_2$eq budget between 2000 and 2049. The full extent of the negative emissions is not shown here, as some of these negative emissions could as well be shifted beyond 2050.

Q13: What does the IPCC AR4 say on the global CO_2 emissions peaking date?

A: The IPCC AR4 Working Group on Mitigation (Working Group III) found that “For the lowest mitigation scenario category assessed, CO_2 emissions would need to peak by 2015... “[4]

Background: This lowest IPCC category of emission scenarios is closest to the ones of interest here, i.e. have a medium or likely probability of staying below 2°C[5]. The AR4 assessment confirms, that it might be very hard, if not impossible, for future generations to draw down emissions at very high rates. This in turn would very likely render a decision to delay a peak in global emissions into a decision to foreclose the option of limiting warming to 2°C. The below figure shows the lowest category of emission scenarios that has been analyzed by IPCC AR4.

[4] see IPCC Synthesis Report SPM, Footnote 20.

[5] Partially due to that fact that the IPCC Special Report on Emission Scenarios (Nakicenovic, Swart et al.) in 2000 was focussed on non-climate policy scenarios only, there are only a few lower mitigation scenarios in the literature, i.e. 6 for the lowest category at the time of IPCC AR4.

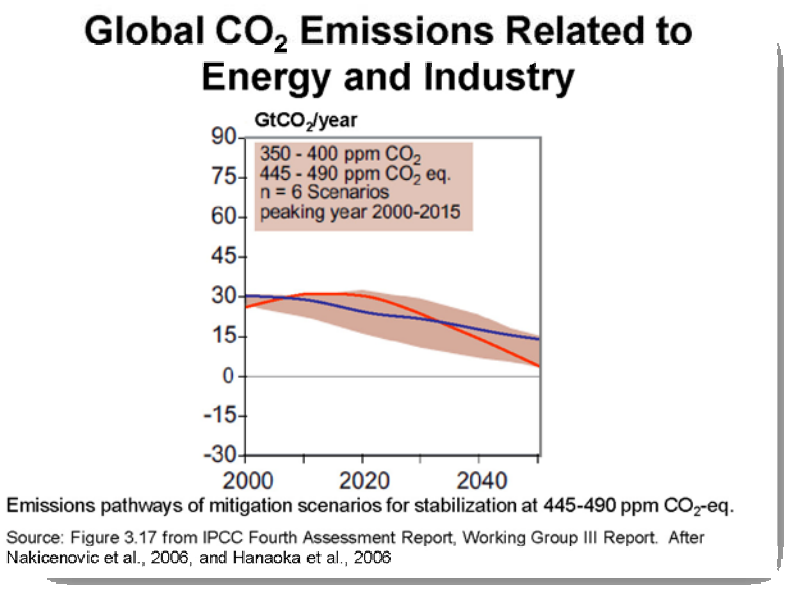


Figure 2 - Emission pathways for the lowest category assessed by IPCC AR4. Slide adapted from Figure 3.17 in IPCC AR4 WGIII, as presented by the US (Jonathan Pershing) at the AWG-LCA workshop, 1st April 2009, Bonn, Germany. The blue line implies modest reduction rates, but assumes a peaking date of global emissions already in the past. The red lines peaks global emissions before 2020, and implies higher reduction rates thereafter.

Q14: More than a decade ago, "The Carbon Logic" was already specifying a cumulative emission budget of 225GtC (=885GtCO$_2$) for returning back to 1°C. What has changed?

Admittedly, despite substantial more research over the last 10 years, the early estimates are largely confirmed by these studies Allen et al. and Meinshausen et al.. Bill Hare, co-author on the Meinshausen et al. study had already in 1997 published "The Carbon Logic"[6] indicating that total cumulative CO_2 emissions from 1995 onwards need to be constrained to 225GtC (=885 GtCO$_2$), if warming shall not exceed 1.5°C and return to 1°C. Accounting for roughly 30 GtCO$_2$ for the years 1995 to 2000, this leaves a carbon budget of ca. 715 GtCO$_2$. A sobering fact is that even the lowest pathways we consider do imply a 750 GtCO$_2$ budget between 2000 and 2050 and hence imply more emissions than considered in "The Carbon Logic" – due to the continued emission increase over the last decade. Our lower end of emission pathways corresponds to a 50% chance of exceeding 1.5°C warming, which hence confirms the study from 1997.

[6] An electronic copy is available here: www.climateanalytics.org/TheCarbonLogic/index.html

Q15: If you had included in your emission pathways substantially net negative emissions after 2050, the probabilities of exceeding 2°C were lower?

A: True, substantially negative emissions post-2050 would somewhat decrease the peak warming expected during the second half of the 21st century. However, temperature levels in year 2050 could obviously not be reversed. For very low mitigation pathways, 2050 temperature levels are already close to their maximum, so that negative emissions could only influence how quickly temperatures decrease after the peak, but not the temperature peak level itself.

Background: In most of the lower emission pathways analyzed in Meinshausen et al., global emissions are only turning to near-zero levels, with the exception of lower MESSAGE or IMAGE scenarios, that exhibit substantial negative emissions by 2100. On the one hand, it is comforting that large net negative emissions could somewhat reduce the probabilities of exceeding 2°C for the medium-low and high scenarios. On the other hand, large net negative emissions pose an enormous challenge for the involved technologies, and the safety, liability and permanence of stored underground carbon. Furthermore, one technology to achieve net negative emissions, the combination of biomass burning and carbon sequestration and storage, could have large implications to our land use patterns.

Q16: For the higher "business-as-usual" scenarios, is it correct that your Figure 3a indicates that there is still a 10% or 30% chance to stay below 2°C?

A: No. For the higher business-as-usual cases, Figure 3a in Meinshausen et al. actually shows the exceedance probabilities for the individual high scenarios (see red and orange dots) – and most of these have an exceedance probability of 100%. The solid lines in Figure 3a are best interpreted as "if you already emitted X tonnes over the years 2000 to 2050, there is very little chance to get a better probability of staying below 2°C. However, with high emissions after 2050, you can easily do worse." On the point that it will be hard to do better: see as well Figure S4 in Meinshausen et al. which indicates that even with sudden zero emissions after 2050, we would not be able to lower the exceedance probability substantially. Keep in mind that the study's focus lies on those emission scenarios that have a medium or likely chance of staying below 2°C, which is the lower part of Figure 3a. For these lower cases, once emissions are already sufficiently reduced until 2050, the remaining net emissions over second half of the 21st century are comparatively small.

Q17: 1 Trillion tonnes of carbon emissions – what temperature does that correspond to?

A: This depends on which trillion tonne you look at.

First option (Allen et al.): One trillion tonne of carbon.
In this case, the trillion tonne refers to carbon emissions (1TtC) over all times. According to their study, this would induce a most likely warming of 2°C just because of CO_2. Any warming from other

human influences on the climate (net effect of greenhouse gases, aerosols etc.) would be on top of that[7].

Second option (Meinshausen et al.): One trillion tonne of carbon dioxide.
Here, the trillion tonnes (in the paper indicated as 1000 $GtCO_2$) refers to carbon dioxide emissions (1$TtCO_2$ = 0.27 TtC) refers to emissions over the time horizon 2000 to 2050. According to Meinshausen et al. this leads in a likely achievement of the 2°C target (25% probability of exceeding 2°C), taking already the non-CO_2 effects into account.

Q18: Allen et al. indicate that a trillion tonnes of carbon (1TtC) in relation to 2°C, while Meinshausen et al. indicate emissions of 1000 billion tonnes of carbon dioxide (1000 $GtCO_2$ = 0.27 TtC). Why that difference?

A: First of all, the two studies largely agree, although they chose different underlying methods and a different presentation of results.

- The study by Myles Allen and colleagues, shows that total cumulative emissions of one trillion tonnes of carbon (1 Tt C, or 3,670 billion tonnes of CO_2) over the entire 'anthropocene' period 1750-2500 causes a most likely peak CO_2-induced warming of 2°C above pre-industrial temperatures. Of this budget, emissions to 2008 have already consumed approximately half of that (0.5 Tt C).

- The study by Malte Meinshausen and colleagues, finds that a total emission budget of about 0.9 Tt C gives a best-estimate peak warming by 2100 of 2°C, including the effects of other non-CO_2 greenhouse gases and human influences on climate. The emission budget drops to less than ¾ Tt C (equivalent to 1,000 billion tonnes, or one trillion tonne, of CO_2 between 2000 and 2050) if the risk of temperatures exceeding 2°C is limited to one-in-four.

Thus, the three main reasons for the apparent difference:

- Firstly, Allen et al. consider the warming induced by CO_2 alone, while in Meinshausen et al. the warming arising from all radiative forcing agents is considered. Thus, Allen et al. effectively looks at a higher temperature target than Meinshausen et al.

- Secondly, the time frames for these cumulative emissions are vastly different. Allen et al. integrate all CO_2 emissions over the entire anthropocene, from 1750 to 2500. Meinshausen et al. however look at emissions over the first half of the 21st century only (2000 to 2049).

- Thirdly, Allen et al. estimate a most likely peak warming of 2°C after a one trillion tonne carbon emission. Meinshausen et al. however relate 1,000 $GtCO_2$ (1TCO_2 = 0.27 TtC) to a "likely" achievement of the 2°C target, so that the probability of not reaching the 2°C target is diminished to 25% (illustrative default case).

[7] The extra radiative forcing by the non-CO2 anthropogenic influences are about 10% to 40% on top of the CO2 forcing in year 2100 (cf. Figure S6 in Meinshausen et al.). This would roughly translate into a 10% to 40% higher peak temperature, i.e. 2.2°C to 2.8°C warming.

Technical Background: When taking into account all the fine details, the results of the two studies Allen et al. and Meinshausen et al. are surprisingly difficult to compare, though. They use different statistical frameworks (Frequentist vs. Bayesian), different gas baskets (CO_2-only vs. all forcings), and different warming levels (CO_2-induced 2°C warming vs. total 2°C warming). Thus, in most cases, and certainly in terms of their headline results, apples are easily compared to oranges.

	Allen et al.	Meinshausen et al.
Radiative Forcings considered	CO_2	CO_2 + other anthropogenic forcings + natural forcings
Statistical approach	Frequentist	Bayesian
Confidence interval for climate sensitivity (Frequentist)	66%: 2.4-3.7K 90%: 2.0-4.8K	68%: 2.3 to 4.5 °C 90%: 2.1 to 7.1 °C
90% frequentist confidence interval of CO_2-induced warming for 1TtC CO_2 emissions over anthropocene.	1.3 to 3.9°C with most likely 2°C warming	Not applicable
For a most likely CO_2-induced warming of 2°C, what are the corresponding emissions.	1TtC over the whole anthropocene and 1,550 to 1,950 $GtCO_2$ over first half of 21st century.	Not applicable
90% Bayesian credible region of CO_2-induced warming for 1TtC CO_2 emissions over anthropocene.	Not applicable	1.1°C to 2.7 °C (Bayesian posterior for illustrative default priors)
For a median peak warming of 2°C, (50% probability of exceedance), what are the emissions for the first half of the 21st century?	Not applicable	2,000 $GtCO_2$eq Kyoto-gas emissions, of which roughly 1,440 Gt CO_2-only. (illustrative default)
For a likely achievement of a 2°C target (e.g. 25% probability of exceeding it), what are the corresponding emissions?	Not applicable	1,500 $GtCO_2$eq Kyoto-gas, of which 1,000 Gt are CO_2 emissions. (illustrative default)

Q19: Could we not just burn all available fossil fuel reserves, provided that we combine them with CCS ?

A: If the carbon is safely and permanently sequestered, then burning fossil fuels would not release carbon emissions. Thus, the early large scale deployment of carbon sequestration and storage (CSS) would increase the allowable fossil fuel extraction.

Word of caution: However, this technology is as yet unproven on a commercial scale, entails risks and has significant infrastructure requirements with multi-year lead times. Thus, further investment into fossil fuel exploration and extraction (rather than into renewable energies and energy efficiency) will either (i) be stranded (as retrofitting the plant with CCS turns out to be a less viable option than anticipated), or (ii) push cumulative emissions beyond the point where avoiding dangerous climate change could become impossible or (iii) lock in the need for future large scale deployment of technologies to extract CO_2 from the air.

Q20: What about geo-engineering?

A: Geo-engineering is not considered in this study. So far, the potential side-implications for ecosystems (i.e. changing of rainfall patterns), the legal implications, or the only partial effectiveness of geo-engineering (ocean acidification would still proceed despite sulphate cooling) strongly cautions against relying upon geo-engineering in expense of emission mitigation.

Q21: How do these results compare to a recent GRL study on "how much warming can be avoided by mitigation?" by Washington and others?

A: On 21st April 2009, Washington, Knutti and others[8] published an analysis of a mitigation scenario that in their model limits warming below 2°C. The results are in broad agreement with the study by Meinshausen et al. and confirm that the lower economically plausible emission scenarios with very strong emission reductions by the end of the century are likely to remain below the 2°C target. Washington et al. use a single comprehensive model that allows them to study regional changes, sea ice, permafrost and extreme events, but they can't quantify the uncertainties in their model and cannot offer a probabilistic interpretation. Their warming in 2100 of course depends on the model that is used, which has a relatively low effective climate sensitivity. Earlier results show that for global temperature, the simple model provides a good approximation to the more comprehensive model.

Background: More specifically, the cumulative fossil and industrial CO_2 emissions in the scenario used by Washington et al. in the 2000-2050 period are around 1,300-1,400 $GtCO_2$, which according to our results gives a 20-70% chance of exceeding 2°C, or with our best estimate around a 40-50% chance of exceeding 2°C. The reason why the results of Washington *et al.* appear to have a higher chance of limiting warming to 2°C , is that this work used one climate model with a relatively low climate sensitivity (2.7°C for a doubling of CO_2 in equilibrium, or around 2.1 for the effective climate sensitivity over the 21st century[9]).

Q22: How does this budget relate to the UK Climate Change Committee's proposed carbon budgets?

A: The UK Climate Change Committee aims only for a 50% chance of staying below 2°C, which is why their budget is higher than our 25% case. When comparing like with like, the budgets agree relatively well with the results of our study.

Background: The UK Committee on Climate Change (CCC) is, to quote its web site, "an independent body established under the Climate Change Act to advise the UK Government on setting carbon budgets, and to report to Parliament on the progress made in reducing greenhouse gas emissions."

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[8] Washington, W. M., R. Knutti, et al. (2009). "How much climate change can be avoided by mitigation?" Geophys. Res. Lett., available here: http://www.agu.org/pubs/crossref/2009/2008GL037074.shtml

[9] See Table 4 in Meinshausen, Wigley & Raper (2008) ACPD, available online at http://www.atmos-chem-phys-discuss.net/8/6153/2008/acpd-8-6153-2008.html

In early December 2008, the committee released its first report [10] in which it proposed a global emission pathway designed to limit warming to about 2°C and to limit the probability of exceeding 4°C to less than 1%. As the report states: "Cumulative emissions between 1990 and 2050 for the trajectories recommended here are 2,420 $GtCO_2eq$ to 2,540 $GtCO_2eq$"[11]. Given the emissions between 1990 and 2000, the conclusion that around 2,000 $GtCO_2$-eq cumulative emissions imply a ~50% probability of exceeding 2°C is thus in broad agreement with our study. In Table 1 and the Supplementary material for the paper, Figure S1b shows the probability of exceeding 2°C for Kyoto-GHG emissions in 2050, for the scenarios used in this study. In order to have a higher than 50:50 chance of limiting warming to 2°C a larger reduction until 2050 would be needed than recommended in the CCC report.

Q23: How do these results relate to the 350 ppm CO_2 concentration goal proposed by James Hansen and others?

A: In the recent work by Hansen and co-authors "Target Atmospheric CO2: Where Should Humanity Aim?", cumulative net emissions to 2050 are approximately 750$GtCO_2$, and thus give according to our results a higher than 75% chance of staying below 2°C.

Background: James Hansen and co-authors have proposed an initial climate protection goal of returning atmospheric CO_2 to 350 ppm – back from its present levels of over 385 ppm. The fossil fuel reserves are quite consistent with our estimates. In the lower Hansen et al scenario (as shown in figure 6 of Hansen et al.[12]) about 900 $GtCO_2$ are emitted from fossil fuel use in the period 2000-2050, however the scenario also assumed that about 150 $GtCO_2$ are taken up by the increasing sink in the forests: thus the cumulative net emissions to 2050 are approximately 750$GtCO_2$, and thus give according to our results a higher than 75% chance of staying below 2°C.

Q24: What is special about 25% exceedance probabilities?

A: Frankly, not much, although respecting the 2°C target can then at least be termed "likely", according to the IPCC Terminology. Surprisingly, in many debates on climate policy, even a 50% risk of missing the target seems acceptable at times. Thus, we do not endorse certain probability levels in these papers, as this is in itself a value judgment. Whether 1%, 25% or 50% exceedance probability is the too much, is a policy decision. We simply note that for any other policy area, like nuclear safety, aviation transport or food safety, we naturally prefer rather generous safety margins, well below 1 promille. Nobody would board a car, if the chance of not making it to the destination would be one-in-four.

[10] http://www.theccc.org.uk/
[11] See page 26 of report available here http://www.theccc.org.uk/pdf/TSO-ClimateChange.pdf
[12] Hansen et al. "Target Atmospheric CO_2: Where should humanity aim?" http://www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf

Q25: The study by Allen et al. is following a frequentist approach, while Meinshausen et al. mainly use Bayesian inference. In simple terms, what is the difference ?

A: Both techniques have the estimation of the likelihood function at its core, which is used in the Bayesian setting to update a prior information. Bayesian approaches have the advantage that they can express subjective probabilities, like the probability of exceeding 2°C. Frequentist approaches are more objective and do not rely on prior information, which can be an advantage if no such prior information is available or if it is of doubtful quality.

Q26: Where can I access additional information, the figures and data of the manuscript?

A: Please see the Supplementary material posted on www.nature.com/nature,and additional material on www.primap.org. Furthermore, there is a lot of related material on www.nature.com/climatecrunch.

For additional question or clarifications, please contact:

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