A 350 ppm Emergency Pathway

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The first phase of the 350 campaign has been a wild success. "350″ is now an international symbol of emergency climate stabilization. More importantly, the 350 target reflects a scientifically-grounded assessment of what global climate protection really means. But what would it actually take to bring the atmospheric carbon-dioxide (CO_2) concentration back to 350 parts per million? This memo provides a quick, up-to-date overview of the issues here - issues significant to any plausible emergency emissions reduction target. To that end, it focuses on the extremely limited size of the remaining global CO_2 budget, and on the emissions pathways that would enable us to keep within it. And, by way of context, it compares 350 to the 2°C temperature target, and offers a very brief glimpse of the challenges that such emergency targets raise on this North / South divided world.

The scale of the 350 challenge

The atmospheric CO_2 concentration is now about 389 ppm. Average out seasonal variations, look just a bit ahead, and call it 390 ppm and rising fast. With current concentrations already so high above the 350 target, some observers are inevitably proclaiming 350 impossible [1], especially given the political context of fraught and faltering global negotiations. Given these realities, "350″ is a call to a new politics - a scientifically well-grounded politics that can draw upon a coherent understanding of what it would it actually take to bring concentrations back to 350 ppm.

Jim Hansen and his colleagues have taken important steps toward establishing this understanding, by way of a number of studies [2] designed to motivate a 350 target and explore its emission implications. Here, we've built on their principal 350 emissions pathway, updating it to capture the modest 2007-2009 downturn in global emissions caused by the recent financial crisis, and adapting it to yield essentially the same outcome in terms of atmospheric CO_2 concentrations. The result, in Figure 1 below, shows a representative 350 emission pathway - one expected to return concentrations to 350 ppm by approximately 2100. For comparison, we also show the International Energy Agency's business-as-usual projection, which sees 2030 emissions rise to be eight times higher than they would be in the 350 pathway.[3]

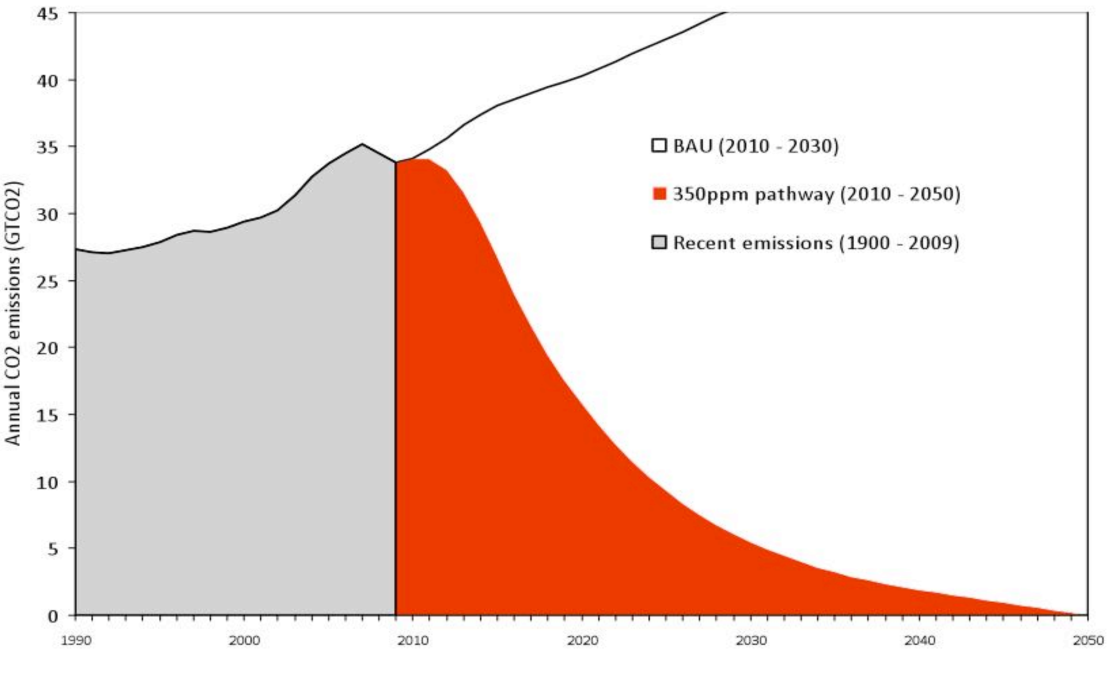

Figure 1 shows recent emissions (1990 - 2009), our "representative 350 ppm pathway " (2010 - 2050) and, for comparison, business-as-usual pathway that's consistent with the International Energy Agency's standard "no climate policy" projections.

Separately, a team led by Malte Meinshausen published an extremely relevant milestone analysis on the emissions budgets corresponding to various targets in Nature earlier this year.[4] This analysis focused on the relationship between cumulative CO_2 emissions and the odds of staying below 2°C of warming, but it also had the important side effect of establishing cumulative emissions budgets (in this case over the 2000-2050 period) as the best predictors of success for any given global emissions pathway. With it, we finally had an internationally recognized method for assessing the likelihood that a given pathway could meet a given target, whether it's a temperature target like 2°C, or (though this wasn't done in the Nature paper) a concentration target like 350 ppm.

The most salient conclusions of these analyses are that a 2°C target would be extremely difficult to meet, a 350 ppm target would be even more challenging, and that, despite all difficulty, neither is out of reach. More particularly, Meinshausen et al. conclude that we can preserve a reasonable probability (about 75%) of keeping warming below 2°C, as long as cumulative CO_2 emissions between 2000 and 2050 are kept below 1000 gigatonnes of CO_2 and comparable reductions are made in non-CO_2 greenhouse gases. In comparison, they report that Hansen's central case for a 350 ppm CO_2 budget provides a budget of about 750 gigatonnes between 2000 and 2050.

The difference between these two budgets - 250 gigatonnes CO_2 - might easily appear less important than it actually is. Obviously, it makes up a significant portion of the 1000 gigatonne, 2000 to 2050 2°C emissions budget. But even more to the point, it is a very significant fraction of the total remaining emissions budget, since approximately 330 gigatonnes of this 1000 gigatonne budget was already consumed between 2000 and 2009. In other words, over this past decade, we've consumed nearly one-third of the 2°C budget (330 out of 1000 gigatonnes CO_2) that was available at the beginning of the century, and nearly half of the 350 ppm budget (330 out of 750 gigatonnes CO_2).

Figure 2 shows the budget consumed between 2000-2009 (the grey area), the portion that remains to be emitted during the 2010-2050 period, relative to a 350 target (the red area), and the additional budget available during 2010-2050 if we accept the more risky goal of 2°C (the thin red line). And, for comparison, it also shows an emissions pathway based on the proposal put forward by the G8 governments, which is too often presented as being consistent with a 2°C target [5], though it is not. This "G8 pathway" is actually much less stringent than either the 350 ppm or 2°C pathways. It peaks after 2020, sees emissions halving (relative to 1990 levels) by mid-century, and consumes, during the 2010-2050 period, a total of 1170 gigatonnes CO_2 - nearly three times the emissions that are permissible under the 350 pathway..

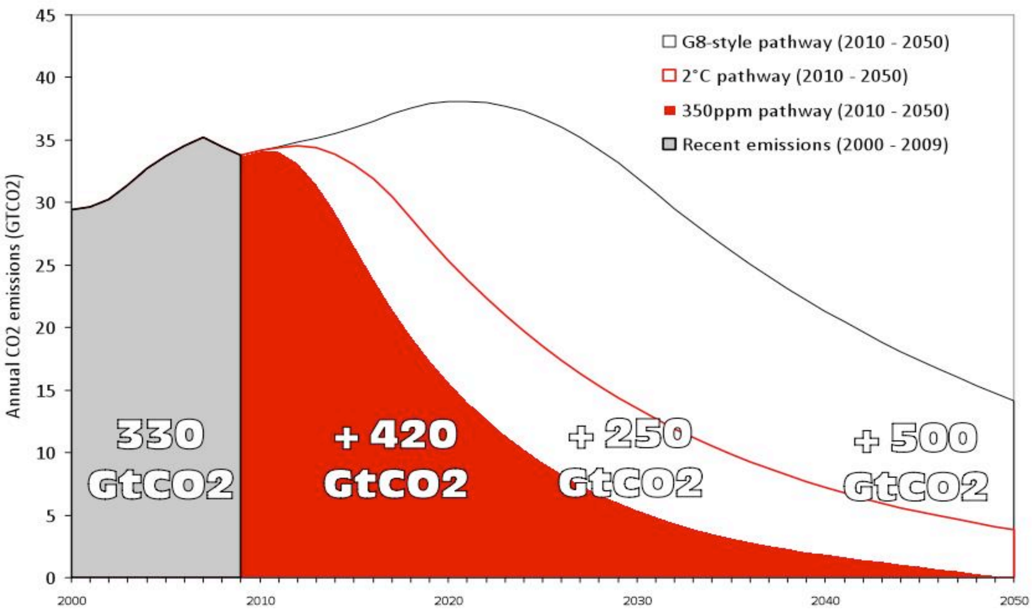

Figure 2 shows the century's emissions to date (the grey area), the 350 pathway (the top of the red area), a 2°C pathway consistent a 75% chance of keeping warming below 2°C (the thin red line), and a pathway consistent with the G8 proposal to halve emissions by 2050 (the thin black line). It also shows (the big numbers) the number of gigatonnes of CO_2 that each step in this sequence of ever less adequate targets would add to total cumulative emissions.

Also note that the recent recession, visible above as a minor dip around 2007-2009, is anticipated to have only a very minor impact on the rate at which the remaining budget is consumed .[6] This fact - that so serious a crisis could have so marginal an impact on global emissions - is an extremely important warning, for it very clearly implies that the deep emissions cuts we need will not come by way of any modest curtailment of economic activity. But neither can they come by way of a massive decline in economic activity, not while the world's poor majority is still counting on that activity to lift them out of poverty! Rather, the radical emission cuts we need can only come by way of a wholesale economic transformation - a global effort, fairly implemented - that, in particular, accommodates the aspirations of the poor and the disenfranchised, and can only correspond to a societal mobilization with few if any peacetime precedents.

Details of the 350 ppm and 2°C pathways

The single most important feature of these pathways is their overall cumulative emission budgets. Given budgets so constrained, there is not a lot of flexibility. For both the 350 ppm and 2°C pathways, keeping within budget means that a sustainable emissions peak has to come very soon. In the 350 case, if emissions peak by 2011, then keeping within budget means subsequent emissions have to drop extremely rapidly, soon reaching an annual rate of decline of 10% per year and remaining at this rate for several decades.

Does this sound unrealistic? Then consider that, if the global peak is delayed a mere four years - if emissions continue to rise until 2015 - the subsequent decline would have to reach a nearly unimaginable rate of 20% per year. If, that is, we're still to keep within the 350 budget. And that, if the peak is delayed beyond 2020, the entire remaining global carbon budget of 420 gigatonnes CO_2 will have been depleted. At that point, to hold the 350 budget, global emissions would need to immediately cease, which is obviously not going to happen.

Clearly, both of these paths reflect enormous transformations requiring unprecedented mobilization. In fact, at this late date, all adequately ambitious emissions pathways are outside the bounds of business-as-usual. The really key point is that the longer the climate transition is delayed, the more challenging it becomes. Accordingly, our representative 350 pathway peaks in 2011, and our representative 2°C pathway peaks only two years later, in 2013. Neither leaves space for a business-as-usual recovery from the recession. The new future is one that begins soon. A war mobilization is more like it, only this time without the war.

Here are the details of the two pathways:

	350 ppm pathway	***2°C pathway***
Cumulative CO2 budget (2000 to 2050)	750 GtCO2	1000 GtCO2
Remaining CO2 budget (2010 to 2050)	420 GtCO2	670 GtCO2
Year of peak emissions	2011	2013
Peak emissions (as % above 1990 levels)	25 %	27 %
Time from peak to max rate of decline	5 years	7 years
2020 emissions (as a % below 1990)	- 42 %	- 7 %
2050 emissions (as a % below 1990)	- 100 %	- 86 %
Max annual rate of emissions decline	- 10 % / yr	- 6 % / yr

Note that, in the 350 case, after a long, steady, more or less exponential "decline" (continuing at about 10% annually) emissions in 2040 will have dropped to be more than 90% below 1990 levels. The decline then continues on until emissions reach zero in 2050, though we do not mean to imply that emissions remain at zero forever thereafter. In fact, Hansen's pathway (which, again, we used as the basis of our own) assumes that enhanced sinks will draw more CO_2 out of the atmosphere than is emitted by fossil fuel combustion, yielding a net budget of about negative 150 gigatonnes of CO_2 over the second half of the 21st century.[7] It is important to note that, in making this assumption, Hansen is being relatively cautious, in that he avoids appeals to highly speculative technologies or geoengineering fixes. Rather, his discussion of negative emissions refers to reforestation, biochar, and sustainable biomass energy plus carbon capture with sequestration (CCS). Whether these will be available at the scale his scenario requires is uncertain. What is clear is that, given the small size of the total 21st century emissions budget, it's much easier to craft plausible 350 scenarios if they include negative emission options.[8]

Uncertainties

In the causal chain that stretches from human activities, to greenhouse-gas emissions, to greenhouse-gas concentrations, to temperature rise, to climate damages, there are all sorts of scientific uncertainties. These make it difficult to set targets definitively or project outcomes precisely. This uncertainty, moreover, has political consequences. For example, it has been welcomed by politicians who wish to pretend to the 2°C goal, even as they advocate emission targets that have very low chances of actually holding the 2°C line.

In all this, the fundamental choice is a global climate objective. What would really protect the climate? Hansen has made a compelling case that 350 ppm is a threshold that we don't want to exceed for long. But how long? The pathway we've adopted here is designed to return CO_2 back to 350 ppm by 2100. But it's quite conceivable that, as time goes by, we'll learn that the Earth's climate system is even less tolerant of elevated CO_2 concentrations than we currently fear, and conclude that we can't let concentrations remain above 350 ppm for the rest of the century. Or we may find that that the oceanic and terrestrial sinks that we're counting on to absorb our emissions are declining even faster than we currently fear, and conclude that we need even more mitigation. Acknowledging these uncertainties, Hansen presents a second, even more ambitious 350 ppm pathway. It is designed to return emissions to 350 ppm close to 2050, by limiting emissions to nearly half of the 420 gigatonnes of CO_2 budget available in his first pathway (as above) which returns CO_2 to 350 ppm by 2100. But also, things might turn out better than expected; thus, Hansen also presented a scenario that would see CO_2 return to 350 ppm well after 2100.

In the face of such fundamental uncertainties, two cardinal rules should govern any sane response to the climate crisis. First, stay informed. As the science evolves, keep reviewing and revising the climate target and the pathway it implies. Second, chose a path that is robust to bad news. That is, given the irreducible uncertainties of the moment, adopt a course that keeps more ambitious responses within reach should uncertainties resolve for the worse.

We thus stress that our 350 ppm trajectory is appropriate for the goal of returning CO_2 to 350 ppm by 2100, but that it should be reviewed and updated as new science emerges. We also claim that this pathway is probably as robust to bad news as it can be. It reflects an extraordinarily ambitious effort, implying economic, technical, and lifestyle changes that are rapid and far-reaching. It has a good chance of spurring many of the same near-term measures that would be needed to reach more ambitious long term targets. But whether it is robust to the worst possibilities is still uncertain.

A divided planet

So far, this discussion has been in terms of global emissions reduction pathways. But global pathways can only take us so far. The climate crisis, after all, does not merely arise from humanity's confrontation with basic biogeochemical limits. It arises as well from the terrible fact that we confront these limits within a profoundly divided civilization. The international North / South impasse, and more fundamentally the rich / poor divide that marks all nations - these are not incidental matters.

Think of the urgency of the situation, well expressed by the 350 movement, and of the emergency mobilization that's needed to stabilize the climate system. Then consider the deadlock that has settled over the negotiations, a deadlock that foreshadows anything but cooperation and solidarity on the global scale. Consider again that all serious low-emissions pathways entail momentous transformations, to the point where they can only be imagined by way of a process that William James, the great pragmatist philosopher, once called the "moral equivalent of war." Then ask yourself if such a transition can ever be sustained, if it impedes the ability of the poor to find economic justice.

In this context, here is one last figure, which we call "the South's dilemma."

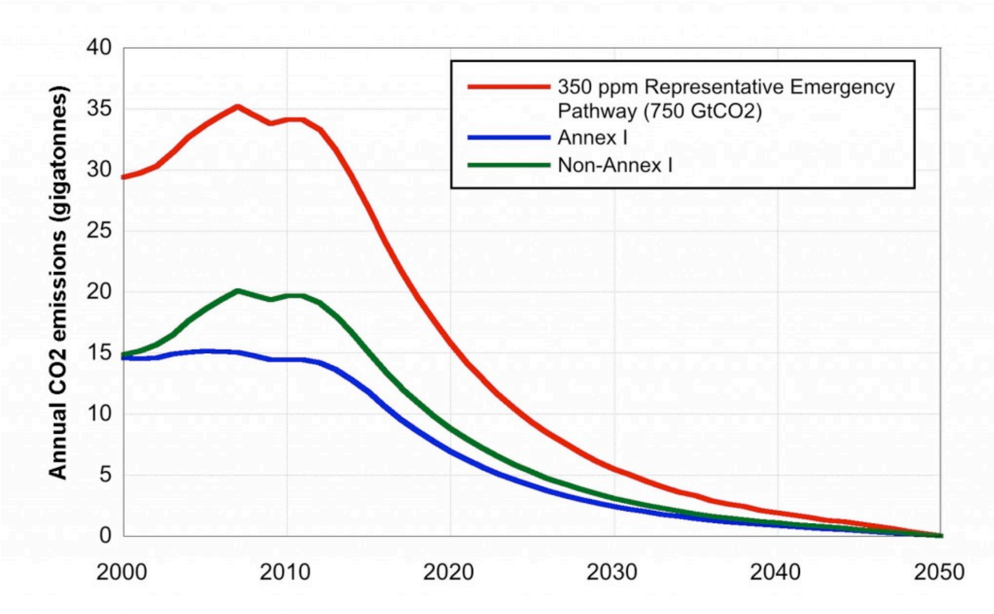

Figure 3. The red line shows a global 350 pathway, the blue line shows wealthy world (Annex 1) emissions declining more than 50% below 1990 levels by 2020, and to zero by 2050. The green line shows, by subtraction, the severely limited emissions space that would remain for the developing countries.

Figure 3 shows the 350 ppm pathway (the red solid line). We also show (the blue line) the portion of that budget that developed countries would consume - assuming they undertake fairly strenuous mitigation efforts, sufficient to reduce emissions 50% between now and 2020, and then continue on to wholly eliminate emissions by 2050. Doing so reveals, by simple subtraction, the alarmingly small size of the carbon budget (the green line) that would remain for the rest of the world (i.e. the developing world). Which to say that, by consuming 180 gigatonnes CO_2 between now and 2050 (out of a total available 420 gigatonne budget) the Annex 1 countries would leave only 240 gigatonnes CO_2 for the South.

Meeting such a tight budget demands extraordinarily ambitious reductions in the South. By 2020, its emissions, as shown here, have already fallen 50% from today's levels. They then continue to drop at least 10% each year for the following three decades and are eventually eliminated. And this must take place while, at the same time, most of the South's citizens are still struggling out of poverty and desperately seeking a meaningful improvement in their living standards. Since the only proven routes to development involve expanding access to energy services, and, consequently, a seemingly inevitable increase in fossil fuel use and thus carbon emissions, the South has been deeply concerned that an inequitable climate regime would force a choice between development and climate protection.

Two points must be underscored. First, the North's pathway is quite ambitious - well beyond the Annex 1 reduction pledges currently on the negotiating table [9] and beyond even the "at least 40% below 1990″ demand being made by many NGOs - but at the same time these pathways, taken as a set, assign far too little of the total mitigation burden to the North. After all, they show emissions in the North and the South declining at comparable annual rates, even though southern emissions would otherwise rise much more rapidly than the North's! And why not? The South's citizens are finally gaining access to the energy services, and building the infrastructure, that they have so long needed, and unsurprisingly they are hoping to keep moving toward some sort of parity with the citizens of the North. But by assuming comparable rate of reduction from today extremely unequal rates of consumption, we imagine a 2030 world in which the typical Northerner still consumes four times the carbon pace of the typical Southerner.

Second, Figure 3 is an illustration of conceivable emission paths in the North and South; it is not, by any means, an illustration of a fair allocation between North and South. It would for example allow the wealthy countries, with their one-fifth of the world's population, to consume nearly one-half of the remaining, quickly vanishing global emissions budget, and this despite the fact that they control three-quarters of the world's income and thus have a far greater ability to manage rapid climate transition.

Costs and conclusions

An obvious question is "how much would 350 cost?"

Much of the debate about climate targets has focused on allegedly high costs of targets in the range of 450-550 ppm CO_2-equivalent. Most assessments put the costs of 450 CO_2-e pathways (which are less stringent than 350 CO_2) in the range of 1-3% of Gross World Product, a figure that is taken to be high by the opponents of climate policy, but which is effectively noise in the context of a global growth rate of 2-3% annually over the coming decades. Very few studies of the economics of 350 ppm CO_2 pathways have been done, but (for example) one such study puts the costs of 350 stabilization at between about 3-5% of GWP, depending on the availability of carbon capture and sequestration from fossil fuels and biomass.[10]

Arguably, however, all such estimates miss the point. Under the kind of "war mobilization" effort required to get a greater than 50% reduction in CO_2 emissions in 10 years, standard models just don't yield much useful information. After all, depending on how the necessary investments are funded, the GWP might actually grow. (World War II saw the fastest US GNP growth in history!) The really key point is that an appropriate emergency climate stabilization program will require - in addition to a huge effort to reprioritize investment into low-carbon technologies - a substantial redirection of economic flows, between sectors, between countries, and especially between North and South. In this context, the fundamental obstacles are not economic but political.

The bottom line? The 350 movement has it right! Our focus must be on the demands of the science, and as that science becomes incontestable, it must shift to the political mobilization that is necessary to meet these demands. This is the realism of the greenhouse age.

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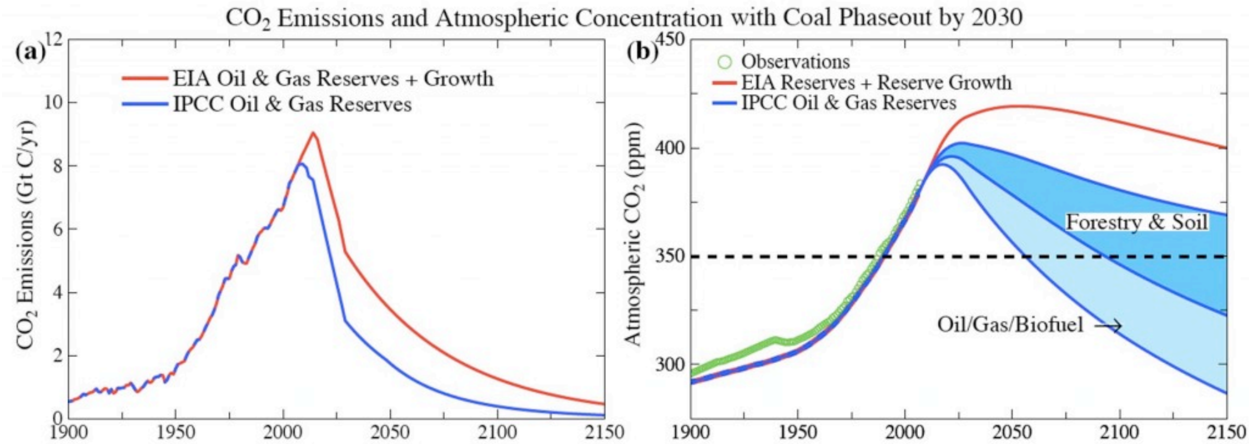
[1] See for example Andrew Revkin, "Campaign Against Emissions Picks Number," *New York Times*, October 24, 2009. http://www.nytimes.com/2009/10/25/science/earth/25threefifty.html?scp=1&sq=350&st=cse

[2] Hansen, J., M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D. L. Royerm and J. C. Zachos (2008). "Target Atmospheric CO2: Where Should Humanity Aim?" *The Open Atmospheric Science Journal* **2**: 217-231. www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf

Hansen and colleagues put the design of pathways targeting 350 ppm in the context of a detailed analysis of likely long-term climate sensitivity. The core of their policy scenario is shown in their Figure 6, reproduced below. In the accompanying text, they document the assumptions (particularly about carbon capture, land-use emissions and sink enhancement) that lead to the alternative emissions and concentration pathways shown. Cumulative emissions are not reported, and the chart (left panel) in fact shows only fossil emissions, rather than the net CO_2 emissions (from all sources) which enter into the atmosphere. As shown on the right panel, however, returning to 350 by 2100 under this scenario requires the dark blue "wedge" of forestry and soil sequestration, yielding about 6.5 gigatonnes of negative CO_2 emissions annually. (Note that the Y axis in the left panel is GtC; multiply by 44/12 to convert to CO_2)



g. (6). (a) Fossil fuel CO_2 emissions with coal phase-out by 2030 based on IPCC [2] and EIA [80] estimated fossil fuel reserves. (b) Re-lting atmospheric CO_2 based on use of a dynamic-sink pulse response function representation of the Bern carbon cycle model [78, 79].

Reproduced from Hansen et al. 2008.

[3] The IEA's BAU pathway projects fossil-fuel CO_2 emissions rising to about 40 gigatonnes in 2030 (see note 6 below). We adjust by including about 6 gigatonnes annually from land use emissions, comparable to the best estimate of current land use emissions from the Global Carbon Project (http://www.globalcarbonproject.org/carbonbudget/07/index.htm).

[4] 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**: 1158-1163. (http://www.nature.com/nature/journal/v458/n7242/full/nature08017.html). Meinshausen et al do a sophisticated statistical analysis to ground the calibration of their model (version 6.0 of MAGICC, an intermediate-complexity climate model that has often been used in the IPCC's scenario analyses due to its capacity to mimic the response of various general circulation models). The key results are shown in their Table 1, reproduced below. Although they also show graphically the spread of CO_2 concentrations associated with their model runs, they don't report them in a way that allows easy analysis in cumulative emissions terms. For example, their figures only report out to 2100.

Table 1 | Probabilities of exceeding 2 °C

Indicator	Emissions	Probability of exceeding 2 °C*	
		Range	Illustrative default case‡
Cumulative total CO_2 emission 2000–49	886 Gt CO_2	8–37%	20%
	1,000 Gt CO_2	10–42%	25%
	1,158 Gt CO_2	16–51%	33%
	1,437 Gt CO_2	29–70%	50%
Cumulative Kyoto-gas emissions 2000–49	1,356 Gt CO_2 equiv.	8–37%	20%
	1,500 Gt CO_2 equiv.	10–43%	26%
	1,678 Gt CO_2 equiv.	15–51%	33%
	2,000 Gt CO_2 equiv.	29–70%	50%
2050 Kyoto-gas emissions	10 Gt CO_2 equiv. yr^{-1}	6–32%	16%
	(Halved 1990) 18 Gt CO_2 equiv. yr^{-1}	12–45%	29%
	(Halved 2000) 20 Gt CO_2 equiv. yr^{-1}	15–49%	32%
	36 Gt CO_2 equiv. yr^{-1}	39–82%	64%
2020 Kyoto-gas emissions	30 Gt CO_2 equiv. yr^{-1}	(8–38%)†	(21%)†
	35 Gt CO_2 equiv. yr^{-1}	(13–46%)†	(29%)†
	40 Gt CO_2 equiv. yr^{-1}	(19–56%)†	(37%)†
	50 Gt CO_2 equiv. yr^{-1}	(53–87%)†	(74%)†

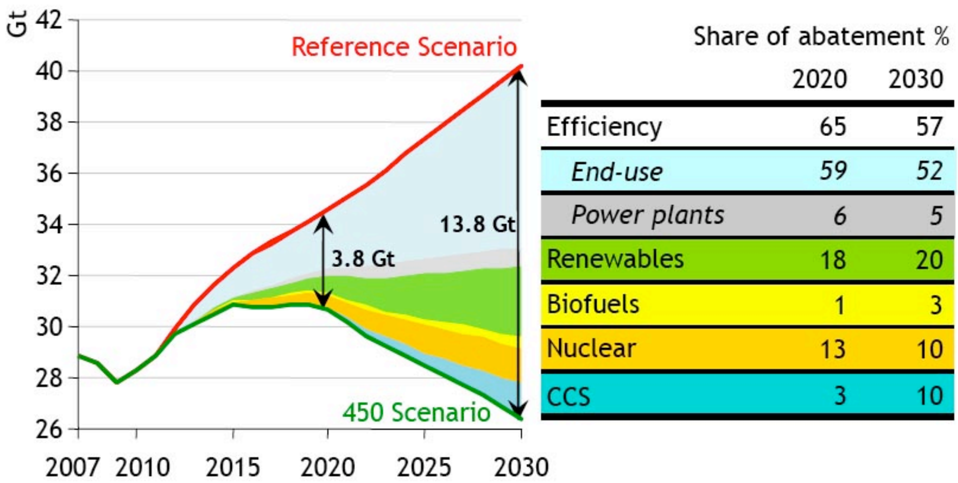
* Range across all priors reflecting the various climate sensitivity distributions with the exception of line 12 in Fig. 3a.
† Note that 2020 Kyoto-gas emissions are, from a physical perspective, a less robust indicator for maximal twenty-first century warming with a wide scenario-to-scenario spread (Supplementary Fig. 1c).
‡ Prior chosen to match posterior of ref. 19 with uniform priors on the TCR.

Reproduced from Meinshausen et al. (2009)

Meinshausen et al. do not report on model runs that match the 750 gigatonnes cumulative that are the net emissions in Hansen et al.'s central scenario. But they do note (see http://sites.google.com/a/primap.org/www/nature) that such a pathway would be expected to have a higher chance of staying below 2ºC. Linear extrapolation based on their table suggests that that risk would be on the order of 5-30%, with a central estimate ("Illustrative Default") of about 15%.

[5] In July, the G8 leaders meet in the Italian town of L'Aquila and announced the goal of reducing global emissions by 50% by 2050, with the wealthy countries making 2050 cuts of 80%. This pathway, which we estimate produces CO_2 emissions of about 1500 gigatonnes for the 200-2050 period, would (based on the Meinshausen et al. calculations shown in the table above) give only about a 50% chance of staying below 2ºC.

[6] While it's hard to estimate near-past global CO_2 emissions precisely, several estimates of the recession-induced emissions decline have already been published. We take our model of the drop here from the International Energy Agency, whose forthcoming *World Energy Outlook 2009* projects a roughly 4% drop between 2007 and 2009, and a subsequent return to 2007 levels by 2011 followed by a further 15% rise to 2015. Also note (see the figure below reproduced from IEA's public pre-release at the Bangkok UNFCCC meeting in October 2009) that the IEA is still using, as its low-emissions reference pathway, a "450″ policy scenario which peaks in 2015, is flat to 2020, and declines to 2030 by about 1.5% annually (at which point emissions still exceed 1990 levels by close to 20%).



Reproduced from IEA (2009), available at http://www.worldenergyoutlook.org/2009_excerpt.asp

[7] According to Hansen et al. (2008, note 2 above), "It is assumed that uptake of carbon via reforestation will increase linearly until 2030, by which time reforestation will achieve a maximum potential sequestration rate of 1.6 GtC per year (S28). Waste-derived biochar application will be phased in linearly over the period 2010-2020, by which time it will reach a maximum uptake rate of 0.16 GtC/yr (77). Thus after 2030 there will be an annual uptake of 1.6 + 0.16 = 1.76 GtC per year, based on the two processes described." Converting from GtC to $GtCO_2$ (multiply by 44/12) gives about 6.5 $GtCO_2$ per year, or about 325 $GtCO_2$ from 2050-2100. This more than compensates for fossil emissions, which total about 175 $GtCO_2$ over the same period. This yields a net budget of about negative 150 $GtCO_2$.

[8] It's important to realize that net negative emissions requires not only some kind of sequestration, as through land use, but the near total elimination of fossil fuel emissions. Negative land use emissions are consistent with positive net emissions. The practicality and cost of massive sequestration through agriculture and forestry remains uncertain and controversial, and economic free-air capture is even more speculative. Ackerman et al. (2009) cite these as reasons to *not* rely on negative net emissions in the creation of a 350 pathway, and indeed the scenarios they model all have emissions drop to zero (at different years) but not below. Ackerman, F., E. A. Stanton, S. J. DeCanio, E. Goodstein, R. B. Howarth, R. B. Norgaard, C. S. Norman, K. A. Sheeran (2009). "The Economics of 350: The Benefits and Costs of Climate Stabilization." Economics for Equity and Environment, www.e3network.org.

[9] For example, the UNFCCC Secretariat (2009) has estimated that reduction pledges by Annex 1 countries sum to a patently inadequate 17-24% reduction below 1990 levels by 2020. This is the estimate as of August 2009, three months before the milestone Copenhagen Conference of Parties to the UNFCCC. A second technical analysis (AOSIS, 2009) estimates the combined Annex 1 pledge to be 10-16%.

[10] 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: 47-79. In their literature review of cost studies, Ackerman et al. (2009, see note 9 above) also cite a recent paper from the Postdam Institute for Climate Impact Research (Knopf, B., O. Edenhofer, H. Turton, T. Barker, S. Scrieciu, M. Leimbach, L. Baumstark and A. Kitous (2008), "Report on First Assessment of low stabilization scenarios") which reports modeled costs for stabilization at 400 ppm CO_2 equivalent as being under 1.7% of GDP through 2100. While these and other studies give grounds to believe that very low emissions pathways are not economically prohibitive, it's not clear whether any of them in fact model a short-term (e.g., 2010-2020) decline of CO_2 emissions that is as rapid as that postulated here or in the Ackerman et al. scenarios, all of which have emissions falling by more than 50% between now and 2020.