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Tyndall°Centre
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An institute of Imperial College London

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Emissions pathways to limit climate change

Global greenhouse gas emissions are rising, but they need to start to fall and reduce to a substantially lower level if we are to limit global temperature rise in this century. This note shows results of a scientific study into how soon emissions need to start falling, how quickly they must then fall, and the level of emissions that can be emitted each year in the long-term. We also consider how much future bio-energy, combined with carbon capture technology — that extracts carbon dioxide from the atmosphere — could help meet temperature targets to the end of the century.

KEY FINDINGS

- **Within the framework used in this study, limiting global warming to 1.5 °C above pre-industrial levels in this century is no longer feasible.** The greenhouse gas emissions pathways generated by the models used in this study could not find a feasible path to a 50% chance of global temperature rise of less than 1.6 °C. A 1.6 °C limit could only be adhered to by designing a pathway at the absolute extremes of what is presently considered feasible.

- **Keeping emissions on a pathway likely to limit global warming to 2 °C above pre-industrial levels is feasible but challenging, and reduces the chance of exceeding a 4 °C rise to less than about 1%.** For a 50% chance of not exceeding a 2 °C global temperature rise, greenhouse gas emissions must start falling by 2016, and decline at 3.5% per year thereafter if net negative emissions are not included. This is challenging because emissions are still rising and 3.5% is the maximum possible reduction rate thought feasible (Den Elzen et al., 2010). Getting emissions to start falling sooner, by 2014, allows a slower subsequent reduction rate of 2.7% to achieve the target.

- **Limiting global warming to a target that is higher than 2 °C increases the risk of more harmful impacts on key global policy areas such as food security, water scarcity and drought but delays the year that emissions must start to fall and the rate at which they must decline.** For example, a 50% chance of limiting global temperature rise to 2.2 °C could be achieved if emissions start to fall as late as 2020 and decline at 2% per year.

- **Bio-energy crops combined with carbon capture and storage have the potential to provide contingency, but would put additional pressure on food security.** It is a concept for negative emissions on a large scale that, if developed, could be used as a tool for managing delays in emissions reductions; managing a shortfall in the emissions reductions rate; or responding to new information about irreversible change to the climate system. However, using this tool adds to the challenge of ensuring sufficient land is available in appropriate locations for food security. Our calculations suggest that this technology could give us another 10 years to get emissions falling, and more than halve the rate of reduction required to achieve a 50% chance of staying below a 2 °C temperature rise. But this is at the expense of significant land-use change and habitat conversion.

DEPARTMENT OF ENERGY & CLIMATE CHANGE

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Living With Environmental Change

CAN WE ACHIEVE 2 °C?

What's different compared with previous AVOID reports?

Previous results from the AVOID programme also indicated that it is challenging but possible to reduce greenhouse gas emissions enough to limit global near-surface temperature rise to within 2 °C of pre-industrial levels. The earlier the annual emissions started to fall, the less dramatic a rate of reduction was required thereafter, and vice versa. In this study, we have filled in the gaps of some plausible emissions pathways that were not included in the previous work; and we have also included an indicative measure of the scope for carbon capture and storage from bio-energy after 2040.

Keeping global temperature below 2 °C requires emissions to start falling no later than 2016 and a subsequent reduction rate of 3.5% per year, or the successful application of unproven negative emissions technology. Either method could achieve a 50% chance of meeting the temperature target. This is a slight relaxation of our previous finding that a 4% reduction rate would be required (see 'Can we limit warming to 2 °C?', AVOID (2010)). Confidence in our ability to achieve high reduction rates has waned since the previous AVOID study, and 3.5% is now thought to be the maximum achievable (Den Elzen et al., 2010).

In this study, all the emissions pathways that have a 50% chance of limiting global temperature rise to 2 °C also have a very low chance – less than about 1% – of exceeding 4 °C. The UK's Committee on Climate Change (2008), for example, has made the judgement that a global temperature rise of 4 °C would be extremely dangerous for the world, and advises that the chance of exceeding a global temperature rise of 4 °C should be kept very low (1%).

HOW WERE EMISSIONS PATHWAYS CREATED?

Emissions pathways to 2100 were calculated relative to greenhouse gas emissions per year to 2100 in the Intergovernmental Panel on Climate Change 'business as usual' scenario (SRES A1B). Four variables defined each emissions pathway:

- the year mitigation begins, i.e. emissions deviate from business as usual (2009–2014);
- the year emissions peak (2014–2045);
- the rate of reduction after peaking (up to 3.5%);
- the lowest emissions per year achieved in the long-term (+11 to -11 $GtCO_2e$).

In addition, pathways included negative emissions variables:

- the year negative emissions from carbon capture and storage by bio-energy crops begins (never or between 2040 and 2070);
- the time taken to fully deploy the technology (20 to 50 years).

A dataset of many thousands of plausible emissions pathways was created. The Earth system will respond to different emissions pathways with different amounts of global temperature change. The simple climate model framework described in Lowe et al., 2009 (based on MAGICC 4.2) was used to calculate the probability of the corresponding global temperature rise.

Figure 1 illustrates emissions pathways (here, carbon dioxide only, but the other main greenhouse gases are included in this study) and the median value of corresponding temperature projections.

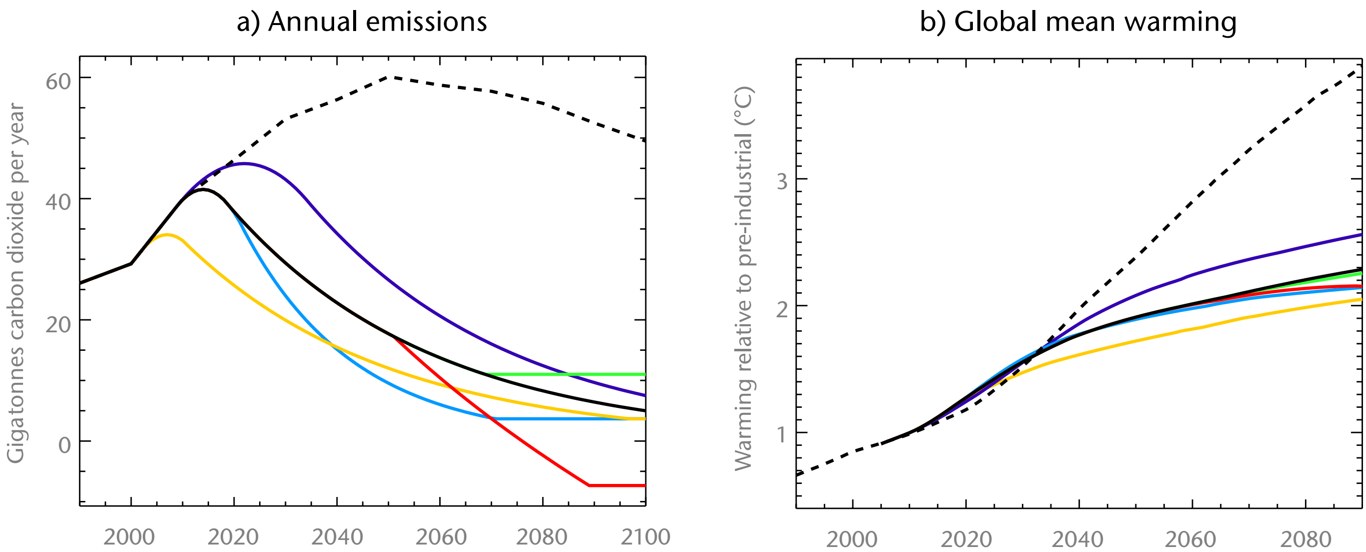

Figure 1 Illustrative emissions pathways used in this AVOID programme study, changing the variables defining each scenario: (a) annual emission of carbon dioxide; and (b) median values of global near-surface temperature projections by the MAGICC 4.2 simple climate model. Dashes — SRES A1B emissions pathway; solid lines — emissions reduction pathways.

WHAT DO THE RESULTS TELL US?

The results show that the earlier emissions start to fall the less steep the subsequent rate of emissions reductions will need to be. Several pathways lead to less than a 2 °C global temperature rise. None lead to 1.5 °C or less. The results also show that the lowest emissions rate achieved in the long-term has a significant impact on the value of the other variables needed to keep within 2 °C. Applying a maximum reduction rate of 3.5%, and without achieving net negative long-term emissions, emissions must peak by 2016 to retain a 50% chance of limiting temperature rise to 2 °C by 2100. If emissions peak by 2014 then the reduction rate can be relaxed, slightly, to 2.7%, and still have a 50% chance of limiting global temperature rise to 2 °C.

Figure 2 shows when emissions must start to fall and how fast in order to stay below the 2 °C temperature rise limit. Delaying the year emissions start to fall will require an increase in effort for subsequent reduction rates, and vice versa. At the bottom left of the figure are the early start, rapid-rate pathways that require the greatest technical effort, and therefore perhaps the most political and economic contribution. No new negative emissions technology is required to meet the 2 °C target in the green shaded area. Moving towards the top right of the diagram, this target can still be met with a later emissions peak year and slower annual rate, but negative emissions beginning 2040–2070 soon become increasingly necessary (yellow, amber and red areas).

To the right of the red area it was not possible, within our study framework, to stay below the 2 °C global temperature rise in 2100. None of the pathways whose emissions start to fall after 2020 comply with the Copenhagen Accord national emissions reduction pledges (UNFCCC 2011a,b) now being used in the Durban Platform, but many of those where large net negative emissions are possible later in century are still able to meet the 2100 target whilst missing the Copenhagen Accord pledges.

Applying a scenario where carbon dioxide is removed from the atmosphere by bio-energy crop growth, later in the century, implies additional stresses on regional land availability and so food security, especially in developing countries. This potential large-scale mitigation technology will have to meet other challenges: the implementation of carbon caption and storage; the consequences of land-use change, including water stress; and, the creation of a biomass production and transport system. However, it does allow the peak year to be relaxed – in our scenarios by 10 years to 2026 – or the reduction rate to be more than halved to 1.5%. It does not allow temperature to stay within 1.5 °C. The lowest global temperature rise this century was 1.6 °C, even with the most extreme land-use scenario for carbon capture from bio-energy and the earliest feasible values of other pathway variables (year emissions start to fall, reduction rate, and long-term maximum emissions).

Greenhouse gas emissions pathways to 2 °C (+/- 0.1 °C) to 2100

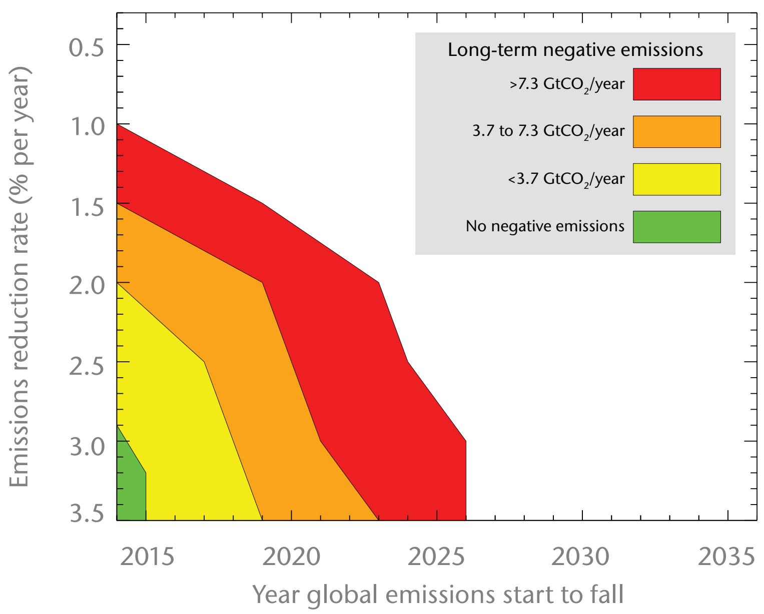

Figure 2 Greenhouse gas emissions pathways that this study's framework finds will limit global temperature rise in the 21st century to 2 °C (+/- 0.1 °C). Location on the diagram shows the year global emissions start to fall, and the rate at which they subsequently fall. Negative emissions technology from bio-energy combined with carbon capture (colours) allows later peaks in global emissions and lower reduction rates, but creates competition for land for agriculture, adding a food security risk. No emissions pathway peaking later than 2019 in this framework is consistent with the Copenhagen Accord pledges (UNEP, The Emissions Gap Report, 2010) assuming a maximum feasible emissions reduction rate of 3.5% per year after Den Elzen et al. (2010). Top right (white) 2 °C limit exceeded.

FURTHER RESULTS

UNEP's Emissions Gap Report (2010) found that pathways to a global temperature rise of 1.5 °C were at the edge of what might be feasible. Using an integrated assessment model methodology, it did not find any pathways with a greater than 66% chance of occurrence, and only one with a 50–66% chance.

If we dismiss negative emissions technology, the area of possible pathways in Figure 2 is small: a peak 2014–2016 and subsequent annual reduction rate in emissions of greater than 2.7%. Negative emissions technology could be needed for contingencies if new information about climate feedbacks increases the amount of temperature rise expected; mitigation policy was delayed; or the projected impacts of climate change became unacceptable.

Increasing the chance of reaching a temperature target from 50% to 66% is equivalent to reducing the temperature achievable by 10%. For example: a 66% chance of 2 °C by 2100 gives a 50% chance of 1.8 °C by 2100.

This study also looked at the impacts of global temperature rise in this century of greater than 2 °C on water stress, suitability of land for crops, drought frequency, productivity of soy bean and wheat, and heat-related mortality. It found that the impacts were increasingly detrimental for global temperature rise above 2 °C but below 3 °C. However, there was no clear evidence of a threshold for rapid increase in impacts below 3 °C. There is some indication in the results that impacts increase more rapidly for limits above 3 °C. These higher global temperature rises have pathways with later peak years and slower subsequent reduction rates.

For example, without negative emissions, there is a 50% chance of staying below a global temperature rise of 2.2 °C if the emissions peak by 2020 and reduce at 2% per year. Limiting global temperature rise to 2.4 °C, in this framework, has a 50% chance of success if negative emissions are used, even if the peak year is delayed to 2035.

To limit global warming to 2 °C without new technology to remove carbon from the atmosphere we must:

- peak emissions before 2020;
- reduce emissions year-on-year by around 3% per year if emissions peak immediately or;
- reduce emissions even faster with each year the emission peak is delayed;
- consider stepping up research on new technologies to extract additional carbon dioxide out of the air, for instance, by combining bio-energy with carbon capture and storage.

Contacts and further information

A more detailed description of this project is available from **www.avoid.uk.net** by downloading AVOID programme report 28: AVOID Workstream 2, Report 28, Bernie, Gohar and Lowe (2012) 'Development of emissions pathways meeting a range of long-term temperature targets.'

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