Institution: University of Oxford

Unit of Assessment: 9 - Physics

Title of case study: [7] Cumulative carbon emissions targets for climate policy

1. Summary of the impact

Results from climate physics research at the University of Oxford have demonstrated that targets for cumulative carbon emissions, rather than greenhouse gas concentrations, are a more effective approach to limiting future climate change. This new approach and the resulting 'trillionth tonne' concept have had substantial political and economic implications. Impacts since 2009 include (a) stimulus to policy developments; (b) influence on the business decisions of Shell e.g. to invest in a $1.35bn carbon capture and storage facility; and (c) significant public and media debate with a global reach.

2. Underpinning research

Professor Myles Allen has led the Climate Dynamics group in the Physics Department at the University of Oxford since 2000. In April 2009, two papers, Allen et al (2009) [1] and Meinshausen et al (2009), were published as the cover story of *Nature,* the first led by Allen and the second with his input and co-authorship. Both demonstrated that the risk of dangerous anthropogenic interference in the climate system is primarily determined by the total carbon dioxide emissions accumulated over time, not by emissions in any given year or commitment period.

The research that prompted this work was also led by the University of Oxford and assessed the risks associated with different stabilisation concentrations of atmospheric greenhouse gases [2]. This concluded that the long-term equilibrium warming consequence of a doubling of carbon dioxide concentration (a common policy objective) could be substantially higher than the previously predicted likely range of 2–4.5^{o}C. It also called into question the conventional paradigm of framing climate policy in terms of targets for long-term stabilisation concentration [3], and prompted further research into alternative policy targets that could be more robustly constrained by the fundamental physics of the climate system and available climate observations.

Allen's *Nature* paper [1] presented ensemble simulations of simple climate-carbon-cycle models, constrained by observations and projections from more comprehensive models, to simulate the temperature response to 250 carbon dioxide emission pathways covering a broad range of scenarios. The key finding was that the peak warming resulting from a given cumulative injection of carbon dioxide into the atmosphere, and hence into the entire global system, is better constrained than the warming response to scenarios of stabilising greenhouse gas concentrations. Furthermore, the relationship between cumulative emissions and peak warming is remarkably insensitive to the emission pathway (such as timing of emissions or peak emission rate). Hence policy targets based on limiting cumulative emissions of carbon dioxide are likely to be more robust to scientific uncertainty than emission-rate or concentration targets.

In particular, it was shown that to limit the estimated most likely maximum global temperature rise caused by anthropogenic carbon dioxide emissions to 2^{o}C above pre-industrial temperatures, the cumulative injection over the entire industrial period needs to be limited to one trillion tonnes of carbon, of which approximately 500 billion tonnes has already been released. This gave rise to the concept of the 'trillionth tonne'. This was later confirmed to be robust for a broad range of scenarios up to the year 2200 [4]. Allen has also led more recent work to update the carbon budget using the latest observations and models [5].

Professor Myles Allen led the work described here. He joined Oxford as a NERC Advanced Fellow (2000-03), took up a Lectureship (2003-11) and is now Professor of Geosystem Science (2011-present). Other principal contributors at Oxford were Professor David Andrews (1989-2012), Dr Claudio Piani (PDRA, 2000-06); Dr David Stainforth (PDRA from 1998-2003 and NERC Research Fellow in Physics 2003-06), Dr David Frame (PDRA, 2000-06) and students Niel Bowerman (also research assistant 2009) and Ben Bronselaer (both CASE students sponsored by the Met Office).

In 2010, Allen was awarded the Appleton Medal and Prize by the Institute of Physics for *"his important contributions to the detection and attribution of human influence on climate and quantifying uncertainty in climate predictions".*

3. References to the research (Oxford authors, * denotes best indicators of quality)

*[1] Allen MR, Frame DJ, Huntingford C, Jones CD, Lowe JA, Meinshausen M, Meinshausen N, (2009), Warming caused by cumulative carbon emissions towards the trillionth tonne, *Nature*, 458, 1163-1166, doi:10.1038/nature08019, citations: 217 (Scopus). *This was one of the two key papers proposing cumulative carbon emissions as a more robust predictor of future warming. Allen and Frame (Oxford) designed, tested and ran the simple climate model for the ensemble. This paper was also discussed in Editor's View and News & Views*.

*[2] Stainforth DA, Aina T, Christensen C, Collins M, Faull N, Frame DJ, Kettleborough JA, Knight S, Martin A, Murphy JM, Piani C, Sexton D, Smith LA, Spicer RA, Thorpe AJ and Allen MR, (2005), Uncertainty in predictions of the climate response to rising levels of greenhouse gases, *Nature*, 433, 403-406, doi:10.1038/nature03301, citations: 475 (Scopus). *This paper presents results from 'climateprediction.net' simulations using a general circulation model with extreme climate sensitivities. The model is used to assess the risks associated with specific target stabilisation concentrations of atmospheric greenhouse gases.*

[3] Frame DJ, Stone DA, Stott PA, Allen MR. (2006), Alternatives to stabilization scenarios, *Geophysical Research Letters*, 33, L14707, doi:10.1029/2006GL025801, citations: 26 (Scopus). *This paper argued that, for policy-making purposes, scenarios that can exploit a consensus in the transient climate response may be preferable to stabilization scenarios, because of the difficulty of ruling out a high equilibrium warming response to elevated CO_2 levels.*

[4] Bowerman NHA, Frame DJ, Huntingford C, Lowe JA and Allen MR, (2011), Cumulative carbon emissions, emissions floors and short-term rates of warming: implications for policy, *Philosophical Transactions of the Royal Society A*, 369, 45-66, doi: 10.1098/rsta.2010.0288, citations: 10 (Scopus). *This paper showed the results in [1] are robust to a broader range of scenarios up to the year 2200.*

*[5] Gillett NP, Arora VK, Matthews D, Allen MR, (2013), Constraining the Ratio of Global Warming to Cumulative CO2 Emissions Using CMIP5 Simulations, *Journal of Climate*, 26, 6844–6858, doi: 10.1175/JCLI-D-12-00476.1, citations: 3 (Scopus). *This paper updates the carbon budget using the latest observations and model simulations.*

4. Details of the impact

Policy implications

The most important policy implication of this research was that the current focus of climate mitigation policy, limiting rates of greenhouse gas emissions in 2020 and 2050, is misplaced: effective mitigation policies need to limit the total cumulative release, not just the rate of emission in any given year. This matters, because not all measures to reduce the rate of emission in the short term will necessarily be effective in reducing the cumulative total.

Although the scientific case for limiting warming to 2^{o}C through emission reductions was noted in Copenhagen in 2009, specific measures indicating how this was to be achieved were not agreed. The need to limit cumulative emissions has substantial political implications, such as short- versus long-term effects, and industrialised versus developing world responsibilities.

The cumulative carbon emissions point was made by Allen i) in presentations to the United Nations Framework Convention on Climate Change delegates in Bonn and Copenhagen; ii) in separate briefings to senior civil servants in the Department of Energy and Climate Change (DECC) and the Department for International Development (DFID); iii) in evidence to the UK Climate Change Committee; iv) to the Royal Society (who have acknowledged the importance of cumulative emissions in public statements [A]); v) to the Parliamentary Environmental Audit Committee's 2009 enquiry into carbon budgets [B]. Allen also developed a visual demonstration of the cumulative carbon concept that he presented at the UN Climate Change Conference (COP18) in 2012. The DECC/Defra-funded AVOID programme, which provides advice to government on climate change, includes discussion of cumulative emissions in its analysis of whether the pledges in the Copenhagen Accord are consistent with the desired 2°C warming limit, and references [1] directly [C]. The campaign group Sandbag, founded by Baroness Worthington, has used the trillionth tonne concept in its analysis and subsequently in two of its 2010 viewpoint papers, which also cite [1] directly [D]. Sandbag uses these to lobby governments on emissions trading. It also advises the

public and organisations about personal carbon offsetting strategies, for example discouraging tree planting offsetting which, while it reduces carbon concentrations, does not affect the cumulative carbon emitted.

Allen's research in [5] directly influenced one of the key conclusions of the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment report. The report concludes that limiting the warming caused by anthropogenic CO2 emissions alone to less than 2°C (with a probability greater than 66%) will require cumulative CO2 emissions from all anthropogenic sources to stay between 0 and about 1000 gigatonnes of carbon. These estimates were based on the concept of Transient Response to Cumulative Carbon Emissions (TRCE) from [5], which was a variant of the cumulative warming commitment proposed in [1]. Allen was a draft-contributing author for the assessment of the literature on TRCE in the IPCC 5th Assessment. The final draft, highlighting the importance of the trillion tonne budget, was submitted to governments on 7th June, 2013. Paper [5] is cited in the full report and the summary for policy makers. Although these were published after the REF impact period, and so we are not claiming impacts that are a consequence of the final report, it is clear that Allen's research has heavily influenced the IPCC report.

Impacts on Carbon Capture and Storage

Petrochemical companies have been influenced by Allen's work and the trillionth tonne concept. In particular, Shell has used the cumulative carbon approach to climate change to inform their investments in carbon capture and storage (CCS) and also their long-term energy scenario planning. Shell said: *"Carbon capture and storage will be a critical technology for society over the course of this century […] more recently its importance has been cemented in our thinking by the 'trillion tonne' work that Professor Allen and his team have delivered since 2009"* [E].

Shell has directly used the research to influence their investment in carbon capture and storage. They said: *"The 'trillion tonne stock' approach has helped us build internal support for our CCS investments in Canada and Norway and more recently has been used by the team leading our potential UK CCS project."* The investments, informed by Allen's work, are significant. For example, the Quest CCS site in Canada is currently under construction at a total cost of $1.35bn. Shell is leading the commercial joint venture (60%) with two other companies and government funding. The final investment decision was taken by Shell in September 2012 and the facility is due to start operating in 2015.

Shell also identified impacts of the research on their Scenarios documents, which they have used for 40 years to challenge executives' perspectives on the future business environment using plausible assumptions and quantification. *"Our new Lens Scenarios makes extensive use of carbon stock thinking as we seek to show that the climate issue can be resolved over this century given the application of CCS"*, said Shell. In their current Scenarios document future emissions are described with respect to cumulative emissions. In one future scenario *"the cumulative emissions situation by the middle of the century means an overshoot of the 2°C goal, but the expanded use of CCS as a carbon sink later in the period provides a critical component to a potential pathway for managing net global emissions"* [E].

Press coverage

Allen has given numerous press interviews on the cumulative carbon results. The *Guardian* newspaper highlighted [1] on first publication, including quotes from Allen [F]. Later that year, at the start of the Copenhagen conference, a coordinated editorial was published in 56 newspapers [G], often as the front page, in 20 languages. This raised the issue, *"how we will share a newly precious resource: the trillion or so tonnes of carbon that we can emit before the mercury rises to dangerous levels",* with discussion of the required balance between industrialised and developing worlds. The text was drafted by a *Guardian* team during more than a month of consultations with editors from more than 20 of the papers involved, and raised 1072 on-line comments on the *Guardian* website in three days. The editorial also forms part of a wider sustainability campaign by the newspaper called '10:10'.

Stimulating public engagement and debate

In October 2009, alongside the final round of pre-Copenhagen talks, a heap of coal representing the 'trillionth tonne' was on display in the Science Museum in London as part of their exhibition,

'Prove It!' (Oct 2009 – Feb 2010). The coal is to be kept by the Museum of Oxford until its combustion is required. Professor Chris Rapley, then the Science Museum's Director, told a news conference, *"to avoid dangerous climate change...we must never release into the atmosphere the carbon dioxide from that trillionth tonne"* [H]. Professor Allen explained its purpose and significance in a 'Viewpoint' article for the BBC, which was commented on in detail by readers from a range of countries and linked to by campaign groups. In conjunction, a live, online countdown to emission of the trillionth tonne is maintained by Oxford at http://trillionthtonne.org.

George Monbiot, a vociferous campaigner on the need to reduce emissions, identified the 2009 pair of Nature papers along with one other as being key steps towards more meaningful emission targets and concluded that "*the targets and methodology being used by governments and the United Nations – which will form the basis for their negotiations at Copenhagen – are not even wrong; they are irrelevant"* [I]. Allen followed this with his own critical commentary on the 10:10 campaign in the *Guardian* in September 2009 [J].

Allen has also spoken on wider issues of climate policy arising from his work at the Sustainable Planet Forum in Lyon (Sept 2010), reportedly attended by 27,000 people, in a debate on climate politics with the former French Environment Minister and leader of the French Green Party, Dominique Voynet.

5. Sources to corroborate the impact

[A] 'Preventing dangerous climate change: The need for a global agreement', The Royal Society, December 2009, Document 12/09 DES1723, confirms the Royal Society's standpoint that cumulative emissions play a crucial role.
http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/4294969306.pdf
[B] House of Commons Environmental Audit Committee's 2009 enquiry into Carbon Budgets, Volume II. This confirms the policy debate was influenced by oral evidence given directly by Allen. Other contributors cite [1] including the Met Office.
http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenvaud/228/228ii.pdf
[C] 'Are the emission pledges in the Copenhagen Accord compatible with a global aspiration to avoid more than 2°C of global warming?', Technical Note by the AVOID consortium, 2010.
http://ensembles-eu.metoffice.com/avoid/meetings/AVOID_Copenhagen_Accord_260310.pdf
[D] Sandbag publications: 'A Closer Look at Voluntary Carbon Action' and 'To Offset or Not To Offset?' 2010. Both position papers cite [1] directly.
http://www.sandbag.org.uk/site_media/pdfs/reports/Closer_Look_At_Voluntary_Carbon_Action.pdf
and http://www.sandbag.org.uk/site_media/pdfs/reports/offset_or_not_offset.pdf
[E] Letter (held on file) from Chief Climate Change Advisor at Shell confirming the impacts on CCS investment decisions and on their Scenarios documents.
[F] 'Climate countdown: Half a trillion tonnes of carbon left to burn,' The *Guardian*, 29th April 2009. This communicates the trillionth tonne concept.
http://www.guardian.co.uk/environment/2009/apr/29/fossil-fuels-trillion-tonnes-burned
[G] Copenhagen climate change conference: 'Fourteen days to seal history's judgment on this generation', The *Guardian*, Editorial, 7th December 2009. This communicates the trillionth tonne concept and 1072 reader comments are significant evidence of public debate.
http://www.guardian.co.uk/commentisfree/2009/dec/06/copenhagen-editorial
[H] 'London museum confronts climate change sceptics', Reuters, 23rd October 2009. Press coverage of Trillionth Tonne exhibit. http://in.reuters.com/article/2009/10/23/idINIndia-43391420091023
[I] George Monbiot discusses the changes [1] has made to viewpoints in his blog, http://www.monbiot.com/2009/08/31/not-even-wrong/; and 'We're pumping CO2 to the point of no return. It's time to alter course', The *Guardian*, 1st September 2009.
http://www.guardian.co.uk/commentisfree/2009/sep/01/global-warming-emissions-fossil-fuels
[J] 'Make the CO2 cuts count', The *Guardian*, article by Myles Allen, 2nd September 2009,
http://www.guardian.co.uk/commentisfree/cif-green/2009/sep/02/10-10-carbon-cuts-climate