

Institution. Oniversity of Oxford		
Title of case study: Carbon budgets and the need for net zero emissions		
Period when the underpinning research was undertaken: 2004-2017		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed:
Myles Allen	Professor of Geosystem Science	1997 – present
David Frame	Project Coordinator, climateprediction.net James Martin Fellow Hugh Price Fellow in Physics & Geography	29 July 2002 – 28 Feb 2006 01 Mar 2006 – 30 Sept 2008 01 Oct 2008 – 30 Sept 2011
Period when the claimed impact occurred: 1 August 2013 – 31 December 2020		
Is this case study continued from a case study submitted in 2014? N		
Research from Oxford Physics established the concept of a 'global carbon budget', a limited cumulative amount of CO ₂ that can be emitted before global average temperatures rise above a target threshold such as 2°C relative to pre-industrial temperatures, by demonstrating that the relationship between temperature and cumulative CO ₂ emissions is better constrained by observable quantities than earlier policy targets such as stabilisation of CO ₂ concentrations. Budgets to limit warming to 2°C and 1.5°C, developed and refined by Oxford Physics research, were very influential in key reports such as the IPCC 5 th Assessment Report, and IPCC Special Report on 1.5°C. These documents have gone on to inspire huge and wide-reaching change in climate policy, including Article 4 of the 2015 Paris Agreement which recognises the need for net zero CO ₂ emissions by 2050, and China's commitment to carbon neutrality by 2060. 2. Underpinning research (indicative maximum 500 words) For 20 years prior to the late 2000s, the stated goal of global climate policy was "stabilisation of greenhouse-gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference in the climate system". Establishing what that level was proved challenging because, as Oxford Physics research demonstrated, it was possible to generate plausible climate models that displayed 2 to 3 times the best-estimate equilibrium warming for any given stabilisation CO ₂ concentration [1] (high levels of equilibrium warming continue to be displayed by the latest generation of coupled models in 2020). An additional challenge was that these high-response models could not straightforwardly be ruled out by observations, because of the non-linear relationship between long-term equilibrium warming and quantities that can be observed [2].		
In 2005, Oxford Physicists proposed an alternative framing to this ubiquitous "stabilisation scenario", focussing on non-equilibrium peak warming under a scenario in which atmospheric concentrations peak and decline, noting that this is much more directly constrained by observations than the equilibrium warming [3]. The hypothesis that this implied a finite carbon budget for CO ₂ emissions over all time, provisionally estimated at one trillion tonnes of carbon to limit warming to 2°C, was presented using an idealized carbon cycle model at the international workshop "Stabilisation 2005" (the significance of this finding was immediately recognised by the then Government Chief Scientist, Sir David King, in his keynote address) and confirmed using a range of models and approaches in a series of papers published in 2009, including [4], several initiated by the 2005 workshop. Ref. [4], led by Oxford Physics, introduced the now-famous 'trillionth tonne' concept: they 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, implying a need for net zero carbon dioxide emissions to stop global warming.		

Impact case study (REF3)



An accurate determination of the carbon budget for various levels of warming was a crucial part of the 2014 IPCC 5th Assessment Report (AR5). Oxford Physics was involved in work led by the Canadian Centre for Climate Modelling and Analysis, with collaborators from Concordia University, that provided quantitative estimates [5]. The AR5's all-time budget for 2°C of CO₂-induced warming ended up very close to that in [4], confirming the robustness of the approach.

A strength of the AR5 carbon budgets for CO₂-induced warming was that they were scenarioindependent and supported by both observations and models. In 2015, the Paris Agreement called upon the scientific community to assess scenarios limiting global warming to 1.5°C above pre-industrial levels. AR5 had provided a carbon budget for 1.5°C that attempted to account for other climate warming agents, but it was based solely on models. Research led from Oxford demonstrated that the current level and rate of human-induced warming determined outstanding carbon budgets under such ambitious climate goals [6]. This research included an analysis and figure that directly anticipated the key opening figure (SPM.1) of the Summary for Policymakers of the IPCC Special Report on 1.5°C which demonstrated transparently that achieving net zero carbon dioxide emissions around 2050 would be necessary to limit warming to 1.5°C, a finding repeatedly cited in national legislation and corporate decisions since then in support of net zero 2050 goals.

3. References to the research (articles in peer-refereed international journals; named authors underlined)

[1] Stainforth DA, Áina T, Christensen C, Collins M, Faull N<u>, Frame DJ</u>, Kettleborough JA, Knight S, Martin A, Murphy JM, <u>Piani C</u>, Sexton D, Smith LA, Spicer RA, Thorpe AJ, <u>Allen MR</u>. "Uncertainty in predictions of the climate response to rising levels of greenhouse gases", *Nature* 2005; 433(7024):403-6; doi:10.1038/nature03301

[2] <u>D. J. Frame, B. B. B. Booth, J. A. Kettleborough</u>, D. A. Stainforth, J. M. Gregory, M. Collins, <u>M. R. Allen</u>, "Constraining climate forecasts: The role of prior assumptions",

Geophys. Res. Lett, 2005, 32, L09702; doi:10.1029/2004GL022241

[3] "Alternatives to stabilization scenarios" <u>D. J. Frame</u>, D. A. Stone, P. A. Stott, <u>M. R. Allen</u>, *Geophys. Res. Lett*, 2006, 33, L14707; doi:10.1029/2006GL025801

[4] "Warming caused by cumulative carbon emissions towards the trillionth tonne" <u>Allen MR</u>, <u>Frame DJ</u>, Huntingford C, Jones CD, Lowe JA, Meinshausen M, Meinshausen N, *Nature* 2009, 458, 1163-1166, doi:10.1038/nature08019

[5] "Constraining the Ratio of Global Warming to Cumulative CO2 Emissions Using CMIP5 Simulations" Gillett NP, Arora VK, Matthews D, <u>Allen MR</u>, *Journal of Climate* 2013, 26, 6844–6858, doi:10.1175/JCLI-D-12-00476.1

[6] "Current level and rate of warming determine emissions budgets under ambitious mitigation" N. J. Leach, R. J. Millar, K. Haustein, S. Jenkins, E. Graham & <u>M. R. Allen</u>, *Nature Geoscience* 2017, 11, 574-579; doi:10.1038/s41561-018-0156-y

4. Details of the impact (indicative maximum 750 words)

Pathway to impact: the IPCC Fifth Assessment Report, Paris Agreement and IPCC Special Report on 1.5°C. Myles Allen was a lead author on Chapter 10 "Detection and Attribution of Climate Change: from Global to Regional" and contributing author on Chapter 12 "Long-Term Climate Change: Projections, commitments and Irreversibility" of the IPCC Working Group 1 Fifth Assessment Report (AR5). The report contains more than 130 citations to his work (27 citations where he is lead author), citing 31 of his publications (7 as lead author), including [1]-[5]. He was also part of the core writing team of the IPCC AR5 Synthesis Report, which distils and integrates the findings of the three working group reports. One of the key reported findings (E.8) of the IPCC WG1 AR5 arises directly from the research described here. The findings of this and the other two Working Group reports are summarised in the 2014 Synthesis Report, which notes that "Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond. Limiting risks across [reasons for concern] would imply a limit for cumulative emissions of CO2. Such a limit would require that global net emissions of CO2 eventually decrease to zero and would constrain annual emissions over the next few decades (Figure SPM.10) (high confidence)" [A].



The IPCC AR5 was a critical scientific input to the United Nations Framework Convention on Climate Change (UNFCCC) <u>2015 Paris Agreement</u>, which put in place an agreement on how the 194 signatory nations would deal with the mitigation of global warming, with a pledge to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C" by "[achieving] a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" **[B].** In associated decisions, the UNFCCC also invited the IPCC to produce a special report "on the impacts of global warming of 1.5°C above pre-industrial levels and related greenhouse gas emission pathways".

Myles Allen had a key role in the resulting IPCC Special Report on 1.5°C (SR1.5): he was coordinating lead author on Chapter 1 "Framing and Context", a contributing author on Chapter 3 "Impacts of 1.5°C Global Warming on Natural and Human Systems", and a drafting author on the Summary for Policymakers. The report includes 54 references to his work (11 where he is lead author), citing 13 of his papers (4 as lead author), including [4], [5] and [6]. The first key figure in the Summary for Policymakers [C] (page 6) derived directly from [6] (figure 1). The report was released in 2018, with the key finding that limiting global temperature rise to 1.5°C is possible but would require "deep emissions reductions" and "rapid, far-reaching and unprecedented changes in all aspects of society." Notably, the SR1.5 also concluded (A.2.2 on Page 5) that "Reaching and sustaining net zero global anthropogenic CO₂ emissions and declining net non-CO₂ radiative forcing would halt anthropogenic global warming on multidecadal time scales (high confidence). The maximum temperature reached is then determined by cumulative net global anthropogenic CO_2 emissions up to the time of net zero CO_2 emissions (high confidence) and the level of non-CO₂ radiative forcing in the decades prior to the time that maximum temperatures are reached (medium confidence)." This conclusion can be traced directly to those 2009 papers, including [4], and subsequent research.

Changes to climate policies and laws across the world

London-based think-tank the Energy and Climate Intelligence Unit supports journalists, parliamentarians and other communicators with accurate and accessible briefings on key climate issues, and provides up-to-date tracking of global net zero ambitions under the supervision of an Advisory Board comprising MPs, other public figures and leading academics (all independent of Oxford Physics). Their annual "Countdown to Net Zero" report from June 2019 directly credits Oxford Physics research **[2,3,4]** as the initiator of scientific advocacy for climate targets based on carbon budgets and net zero emissions, rather than stabilising atmospheric concentrations and emission rates at a certain non-zero level. As of June 2020, they estimate that the nations, states and cities that have set, or intend to set, net zero targets by 2050 account for: 53% of the global economy; 23% of global CO₂ emissions; 2,600,000,000 people **[D].** At the time of writing 6 countries have passed legislation to commit to net zero by 2050, with a further 5 (and the EU) proposing legislation. The link between the research presented above and these changes is explored for three countries below; it is noted that it is very likely that the others were also influenced in similar ways.

Sweden: In June 2017, Sweden's Parliament decided by a large political majority to introduce a climate policy framework with a climate act for Sweden – "*the most important climate reform in Sweden's history [that] sets out implementation of the Paris Agreement in Sweden. By 2045, Sweden is to have zero net emissions of greenhouse gases into the atmosphere."* [E] This was based on the commissioned (directive 2014:165) recommendations of the Cross-Party Committee on Environmental Objectives, whose reports extensively cite IPCC AR5, and specifically the trillion tonne carbon budget for limiting warming to 2°C, which arises from [2], [3] and [4] [E]. The previous "Integrated Climate and Energy Policy" (passed 2009) targeted a 40% reduction in greenhouse gas emissions relative to 1990 levels by 2020 but did not commit to net zero emissions (although this was mentioned as a "vision for Sweden" by 2050).

UK: In October 2018, in response to publication of the IPCC SR1.5, the UK government asked the independent advisory group the Committee on Climate Change (CCC) to produce a report on whether further action was needed to meet the ambitious goals of the Paris Agreement. In



May 2019 the CCC produced "Net Zero – The UK's contribution to stopping global warming" **[F]** which "recommends a new emissions target for the UK: net-zero greenhouse gases by 2050... [this] emerges clearly from the extensive evidence presented here... including last year's IPCC Special Report on Global Warming of 1.5° C" (the report also cites further work by Myles Allen). These recommendations were accepted in June 2019, and the "Government response to the CCC" states "the overall 2050 target in the Climate Change Act was raised from an 80% reduction from 1990 levels to a net zero emissions target following advice from the CCC" **[F]**.

New Zealand: In May 2019 the New Zealand Government introduced the Zero Carbon Bill as an amendment to the Climate Change Response Act 2002 (which did not set specific emissions targets), which was signed into law on 13/11/19, and states that all greenhouse gases (except biogenic methane) must fall to net zero emissions by 2050. The Summary **[G]** cites **[C]** as follows "*The 2018 report of the Intergovernmental Panel on Climate Change (IPCC) concluded that in scenarios consistent with limiting warming to 1.5 degrees Celsius, as set out in the Paris Agreement, with limited or no overshoot: global emissions of carbon dioxide (CO2) reduce to net zero around 2050…*", a claim supported directly in **[C]** by **[6]** and building on all other cited work.

Changes to climate policies of commercial organisations

In February 2020, BP announced ambitious plans to reach net zero levels of greenhouse gas emissions from both its operations worldwide and the carbon in the oil and gas it produces, a total of around 415 MteCO₂e per year at present. Their 2019 Annual Report details 10 aims "consistent with the Paris goals" to help achieve net zero for BP and the world, reached after "the board and executive team consider[ed] risks and opportunities associated with climate change and the energy transition informed by a range of external inputs, including the IPCC". **[H]**

The UNFCCC's Race to Zero campaign comprises 454 cities, 23 regions, 1,397 businesses, 74 major investors, and 569 universities committed to achieving net zero carbon emissions by 2050 at the latest, explicitly building on the goals of the Paris Agreement. Criteria for joining and monitoring progress on this "Race to Zero" were developed by the UN Climate Ambition Alliance with the University of Oxford in recognition of the University's track record in establishing the science and policies underlying the net zero goal. **[I]**

Further examples of corporations setting 2050 net zero targets include Repsol (the first oil & gas company to set a net zero target including products sold), Amazon (mentioning the Paris Agreement explicitly in their decision), Ikea, Delta Airlines, Google, Microsoft, International Airlines Group (IAG), EasyJet, AstraZeneca, Sky and John Lewis Partnership. All mention the United Nations (Paris Agreement) and/or the IPCC (many specifically citing SR1.5) in announcements or justification of these targets to investors and customers. In recognition of the cumulative impact of carbon dioxide emissions on climate, Google and Microsoft have both committed to include their historical emissions in their net zero targets.

Consequences of updated climate policies and laws in the UK

Court challenges to the expansion of Heathrow: in February, 2020, the UK Court of Appeal found that the government had failed to take climate targets adequately into account in the decision to allow the building of a 3rd runway at Heathrow, stating "The Paris Agreement ought to have been taken into account by the Secretary of State in the preparation of the ANPS [Airports National Policy Statement], but was not," and the Government declined to appeal the ruling **[J].** In December, 2020, the UK Supreme Court ruled explicitly that the ANPS was consistent with UK climate policy in response to the Paris Agreement at the time it was approved (2018) which was prior to the publication of SR1.5 and the UK's subsequent adoption of a binding net zero 2050 goal in 2019, stating "It was not irrational to decide not to attempt to assess post-2050 emissions by reference to future policies which had yet to be formulated", referring to the Government's 2019 Net Zero legislation. Hence the decision in



2019 to enhance the ambition of UK climate policy from an 80% reduction of emissions relative to 1990 by 2050 to 100% was explicitly recognised by the Supreme Court to be of direct relevance to the decision on whether to approve the Heathrow 3rd runway, a finding that is likely to be cited in subsequent appeals to the European Court of Human Rights.

The UK Government's 10-point Plan for a Green Industrial Revolution **[K]** published in December 2020 brings forward the date of banning internal combustion engines in private cars to 2030 and commits to a target of 10,000,000t per year of CO_2 capture and storage by 2030, both targets directly motivated by the goal of net zero emissions by 2050.

Informing public debate

The IPCC AR5 received extensive coverage in the media, with many major news sources making explicit references to the trillionth tonne concept **[L]**. A key consequence of the existence of a limited global carbon budget is the possibility that a significant fraction of proven reserves of oil, gas and coal may be "unburnable carbon" in the absence of unprecedented development of carbon capture and sequestration.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] IPCC Fifth Assessment Report; <u>https://www.ipcc.ch/report/ar5/wg1/</u>. Myles Allen's work is cited as follows in Chapter X (Y times): 1 (3), 5 (3), 6 (1), 7 (3), 8 (1), 9 (7), 10 (88), 11 (8), 12 (16), 13 (2), 14 (2). In-text quote from IPCC Synthesis Report on page 19; <u>https://www.ipcc.ch/report/ar5/syr/</u>

[B] Paris Agreement, informed by the IPCC Fifth Assessment Report

[C] IPCC Special Report on a Global Warming of 1.5°C: <u>https://www.ipcc.ch/sr15/</u>. Myles Allen's work is cited as follows in Chapter X (Y times): 1 (25), 2(14), 3 (8), 4 (2), 5 (5). The quotation on page 5 directly refers back to his research and summary figure on page 6 is derived from **[B]**.

[D] Energy & Climate Intelligence Unit "Net Zero Ambition Globally" Infographic: <u>https://eciu.net/analysis/infographics/global-net-zero-ambition</u>; "Countdown to Zero" report, 25/06/2019, crediting Oxford research for the 'Net Zero' concept

https://eciu.net/analysis/reports/2019/countdown-to-zero

[E] The Swedish Climate Policy Framework summary, https://www.government.se/information-material/2018/03/the-swedish-climate-policy-

framework/ and SOU 2016:21 "Ett klimatpolitiskt ramverk för Sverige - Delbetänkande av Miljömålsberedningen" (A climate policy framework for Sweden - Interim report by the Environmental Goals Committee) where the cumulative carbon budget is mentioned (pg 22). [F] CCC report "Net Zero – The UK's contribution to stopping global warming" (May 2019) referencing SR1.5 and the Oxford research and Government Response to CCC (Oct 2019) accepting the 'Net Zero' recommendations

[G] New Zealand "Climate Change Response (Zero Carbon) Amendment Bill: Summary" citing the IPCC Special Report on a Global Warming of 1.5°C for the need for net zero CO₂ emissions by mid-century.

[H] BP Annual Report and Form 20-F 'Energy with Purpose' 2019, outlining their Net Zero aims; quote taken from page 45. <u>https://www.bp.com/en/global/corporate/investors/results-and-reporting/annual-report.html</u>

[I] UNFCCC Race to Zero Campaign, <u>https://unfccc.int/climate-action/race-to-zero-campaign</u> including link to "<u>Mapping of current practices around net zero targets</u>", University of Oxford Net Zero Network (now Oxford Net Zero), 2020.

[J] <u>Appeal Court ruling</u> paragraph 283 and <u>Supreme Court ruling</u> paragraph 155.

[K] <u>The Ten Point Plan for a Green Industrial Revolution</u>, December, 2020, referencing the Net Zero target.

[L] Media coverage on 27 Sept 2013 of IPCC Fifth Assessment noting the need for net zero emissions: <u>The Guardian</u>; <u>The Independent</u>; <u>BBC News</u>; <u>NY Times</u>