Institution: University of East Anglia

Unit of Assessment: 7 – Earth Systems and Environmental Science

Title of case study:

Informing Climate Policy with Global Carbon Budgets

1. Summary of the impact

International and national political negotiations and public debates about climate change mitigation policies can only progress with accurate and timely updates about the global carbon budget. Annual carbon updates have been supplied over many years, as a result of our work. The "Global Carbon Project" (GCP) has become the definitive source on carbon budgets for political and policy processes dealing with climate change mitigation and the GCP draws heavily on the School's work on the ocean carbon cycle, including ocean iron fertilisation, and its relevance to the contemporary global carbon budget. This is evidenced by its citation and influence on national (e.g. UK, Germany, Australia, USA, Sweden and Canada) and international (e.g. UN Framework Convention on Climate Change) deliberations.

2. Underpinning research

Global carbon budgets: Over many years, School of Environmental Sciences' researchers have played prominent roles in establishing global carbon budgets (e.g. [1]). Only about 45% of the global emissions of carbon dioxide (CO_2) remain in the atmosphere every year; the remainder is absorbed by the ocean and land "carbon sinks". As CO_2 is the most important anthropogenic greenhouse gas responsible for global warming, knowledge on the trends in global emissions and sinks of carbon is crucial for at least three reasons: (a) to maintain an accurate understanding of the evolution of world's climate; (b) to determine meaningful targets for reductions in CO_2 emissions; and (c) to provide early warning of any weakening in the efficiency of the carbon sinks.

In 2005**, Le Quéré** (at UEA since 2004) proposed the release of annual carbon budgets via the Global Carbon Project, which she now co-chairs. The first annual budget identified that global CO_2 emissions had increased beyond expectations, with a growth in emissions of 1% per year in the 1990s and 3% per year during 2000-2006 [2]. It also showed that the carbon sinks were probably responding to recent climate change and variability. These analyses were deepened in 2009 [3] and updated in three peer-reviewed correspondence items in *Nature Geoscience* (2010) and *Nature Climate Change* (2012, 2013). They are supported by an extensive database and methods that were published in the journal *Earth System Science Data* in 2013.

Ocean carbon sink and ocean acidification: The School has led the monitoring of the oceans' carbon sinks. The oceans are expected to be the main sink for anthropogenic carbon on century time scales. We have led high-profile studies showing the sensitivity of the ocean carbon sink to climate (e.g. [4]), demonstrating that it is possible to accurately observe the carbon flux into an ocean basin using instrumented commercial vessels. These results are used in the aforementioned global carbon budgets [3].

Iron fertilization: The School has led the scientific understanding of *how* iron affects uptake of CO_2 in the world's oceans, i.e. partly addressing how the ocean carbon sink functions. We have also been actively informing debates over ocean fertilization as a geoengineering technique. We have quantified geoengineering methods in general [5] and iron fertilization in particular. The puzzle of what limits plankton growth in "high nitrate low chlorophyll" regions– especially the Southern Ocean and Equatorial Pacific – has a long history. The hypothesis that iron deficiency might be critical was mooted in the 1930s and gathered momentum in the 1980s. The "iron hypothesis" was finally proved in several iron release experiments in the open ocean by international teams, in the Equatorial Pacific (in 1993) and in the Southern Ocean (in 2000). These experiments were made possible by a water-tracking technique developed in the School, and School scientists including **Watson, A.** (at UEA1996-2013) and **Bakker, D** (since 1998) were essential to most of these experiments, through leading the studies that quantified the uptake of

atmospheric CO_2 by iron fertilization [6].

3. References to the research

(UEA authors in bold) {citations from Scopus}

[1] **Manning, A. C.** and R. F. Keeling (2006) Global oceanic and land biotic carbon sinks from the Scripps atmospheric oxygen flask sampling network *Tellus Series B-Chemical and Physical Meteorology* **58** 95-116 doi: 10.1111/j.1600-0889.2006.00175.x {79}

[2] Canadell, J. G., **C. Le Quéré**, M. R. Raupach, C. B. Field, **E. T. Buitenhuis**, P. Ciais, T. J. Conway, **N. P. Gillett**, R. A. Houghton and G. Marland, (2007) Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks *Proceedings of the National Academy of Sciences of the United States of America* **104** 18866-18870 doi: 10.1073/pnas.0702737104 {531}

[3] **Le Quéré, C**., M. R. Raupach, J. G. Canadell, G. Marland, L. Bopp, P. Ciais, T. J. Conway, S. C. Doney, R. A. Feely, P. Foster, P. Friedlingstein, K. Gurney, R. A. Houghton, J. I. House, C. Huntingford, P. E. Levy, M. R. Lomas, J. Majkut, N. Metzl, J. P. Ometto, G. P. Peters, I. C. Prentice, J. T. Randerson, S. W. Running, J. L. Sarmiento, **U. Schuster**, S. Sitch, T. Takahashi, N. Viovy, G. R. van der Werf and F. I. Woodward (2009) Trends in the sources and sinks of carbon dioxide *Nature Geoscience* **2** 831-836 doi: 10.1038/ngeo689 {451}

[4] **Le Quéré, C.,** C. Rödenbeck, **E. T. Buitenhuis**, T. J. Conway, R. Langenfelds, A. Gomez, C. Labuschagne, M. Ramonet, T. Nakazawa, N. Metzl, **N. Gillett** and M. Heimann (2007) Saturation of the Southern Ocean CO_2 sink due to recent climate change *Science* **316** 1735-1738 doi: 10.1126/science.1136188 {269}

[5] **Lenton, T.M.** and **Vaughan, N.E**. (2009) The radiative forcing potential of different climate geoengineering options *Atmospheric Chemistry and Physics* **9** 5539-5561 doi:10.5194/acp-9-5539-2009 {94}

[6] **Watson, A. J., D. C. E. Bakker, A. J. Ridgwell**, P. W. Boyd and C. S. Law (2000) Effect of iron supply on Southern Ocean CO_2 uptake and implications for glacial atmospheric CO_2 *Nature* **407** 730-733 doi: 10.1038/35037561 {248}

4. Details of the impact

Global carbon budgets: The School's work on the world's carbon budget is published annually in the autumn prior to the annual meeting of the Conference of the Parties to the UNFCCC and is also widely disseminated via the media and social media. This effort has achieved impact in three ways:

(1) it has informed the wider public of the recent high growth in CO_2 emissions and the sensitivity of the carbon sinks,
(2) it has played a key role in strengthening the UK emissions target from 60 to 80% by 2050,
(3) it has provided incentive and information to support international climate negotiations.

The public has been informed widely of the recent trends in CO_2 emissions and sinks from the widespread diffusion of our carbon updates. For example, 1459 media stories were recorded worldwide between 2007 and 2012 [7] and since 2011 the news coverage is also diffused through new social media (Facebook and Twitter), e.g. *The Guardian* news item on this was re-tweeted 264 times in 2012. The true coverage will substantially exceed these numbers because of the difficulty of recording foreign-language news articles. The carbon budget is also re-disseminated through the independent organisations CO2now.org and www.rtcc.org. Highlights of our work were presented widely by other influential opinion formers, including Al Gore, HRH Prince of Wales and even Hollywood [8].

The UK emissions reductions target for 2050 was strengthened from 60 to 80% in 2008 a target that is now part of the UK Climate Change Act and at the core of the 5-year UK carbon budgets. Our work is cited in the report of the Committee on Climate change which underpinned this emissions target [9a]. Our work was also cited for two of the six reasons to strengthen the target in a letter written by **Lord Turner, Chair of the Committee on Climate Change to the UK**

Secretary of State [9b]. The first reason explained that:

> *'we know more about how rising temperatures will reduce the effectiveness of carbon sinks'*

and the second reason stated that:

> *'latest global emission trends are higher than those anticipated in most IPCC scenarios, largely because of higher economic growth and a shift towards more carbon intensive sources of energy'.*

Lord Turner's letter was published in advance of its planned publication date 11 days after (and possibly in response to) the publication of our 2008 carbon budget. Our work has also been cited in the Third Report of the Select Committee on Environmental Audit [9c].

In support of the International Negotiations, our carbon budget data have been requested by the European Commission, the Minister of the Environment in Germany, congressional advisers in the US, policy advisers in Sweden and the UK, and the Department of Climate Change in Australia [10]. We presented our work in briefings to the Leader of HM Government's Opposition (David Cameron, 2007), to the Prince of Wales's corporate leaders group on climate change (2008), to the Department of Energy and Climate Change (2010, 2012), to the Canadian Ambassador for Climate Change (2011), and to the UNFCCC Subsidiary Body for Scientific and Technological Advice on research and systematic observations (2011). Australian MP and Parliamentary Secretary for Climate Change and Energy Efficiency Mark Dreyfus testified in a radio interview on 3 December 2012 that our carbon budget released that day was being discussed at the UNFCCC Conference of the Party in Doha [11]. Further policy impact of this work will be delivered through the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013), co-authored by **Le Quéré**, where the climate impact on carbon sinks was adopted as one of the main key findings**.**

Ocean carbon sink and ocean acidification: In addition to its impact through the global carbon budget, the School's work in this area has helped efforts at international, European and national levels to construct an observing system for land and ocean carbon (e.g. [12]). **Liss** (since 1969) and **Watson, A.** were co-authors on the Royal Society report on ocean acidification [13], which is widely cited in connection with responses to this topic by the European Commission, NERC and other countries.

Iron fertilisation: The Royal Society's 2009 report on geoengineering [14] leaned heavily on the School's research which quantified geoengineering methods in general [5] and iron fertilisation in particular. **Watson** led the chapter on carbon removal methods. The House of Commons Science and Technology Committee in 2009 conducted a study on the regulation of geoengineering (**Liss** was Scientific Advisor). The US Congressional Science and Technology Committee were also simultaneously investigating this matter and drew upon our work. In recent years a few companies have developed plans to perform artificial iron fertilisation triggering reactions from national and international policymakers. UN bodies became involved in 2008 when the Scientific Group of the London Dumping Convention appointed an advisory group (including **Watson, A.**) and issued interim guidelines, and the 2010 Conference on Biological Diversity (CBD) issued a statement restricting iron fertilisation research [15]. IPCC 2013 highlighted the side effects of geoengineering methods citing [5], [6], and [14].

5. Sources to corroborate the impact

[7] In 2007 we monitored 78 written media articles worldwide following publication of the Global Carbon Project; 251 in 2008; 311 in 2009 (with the publication of [3]); 185 in 2010; 184 in 2011; and 450 in 2012.
Press releases and MediaClips for the on-going global carbon budget work can be accessed via: http://www.globalcarbonproject.org/carbonbudget and archived press material via: http://www.tyndall.ac.uk/carbon-budget/press-coverage

[8] Al Gore mentions numbers from the Global Carbon Project press release and publications in the first 30 seconds of his presentation delivered during the UN Conference of the Party in Copenhagen (15 December 2009):
http://www.youtube.com/watch?v=el1uHFch6bY&feature=related;

HRH Prince of Wales book *Harmony: a new way of looking at the world* (Blue Door Press, 2010, ISBN-10: 0007348037) mentions the carbon sinks in the 'Nature' chapter. **Le Quéré** provided input and comments on this book, as confirmed by her mention in the Acknowledgements

Trailer of 'The Island President', shows a figure of CO_2 emissions time series from the Global Carbon Project at 0:29: http://www.youtube.com/watch?v=OxufJ-vNqBc

[9] [a] The Committee on Climate Change report Building a low-carbon economy – the UK's contribution to tackling climate change (2008)
See: Chapter 1, page 11, which explains that the conclusion that CO_2 emissions have increased significantly is based on two papers from the Global Carbon Budget co-authored by **Le Quéré** (namely [2] and Raupach et al. (2007) *Proc. National Acad. Sciences* 104, 10,288-10,293).

[b] The letter by Lord Turner to Ed Milliband is available from: http://www.theccc.org.uk/publication/letter-interim-advice-from-the-committee-on-climate-change/

[c] Third report of the Select Committee on Environmental Audit (2008) reviewing the environmental content of the pre-Budget reports explains how the committee drew the conclusion that the carbon sinks could exacerbate climate change (point 61):
'Also, in October 2007 a study by the Global Carbon Project warned that rising emissions suggested "a carbon cycle that is generating stronger-than-expected climate forcing sooner than expected'

[10] For example, the European Commission Directorate-General for Climate Action (DG Clima) published guidelines on dealing with the impact of climate change, which includes an updated version of Fig. 1a from [3] on page 15, to set the context on future climate change. Available from: http://ec.europa.eu/environment/nature/climatechange/pdf/N2_CC_guidelines.pdf

[11] See page 1 of the transcript of an interview with Mark Dreyfus, Head of the Australian climate change negotiations in the UNFCCC. Available from: http://www.tyndall.ac.uk/sites/default/files/mark_dreyfus_transcript_interview_3_december_2012.pdf

[12] Integrated Carbon Observing System, available from: http://www.icos-infrastructure.eu/proj_doc

[13] Royal Society (2005) *Ocean acidification due to increasing atmospheric carbon dioxide* Royal Society Report, London. Available from: http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2005/9634.pdf

[14] Royal Society (2009) *Geoengineering the climate: science, governance and uncertainty*. Available from: http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/8693.pdf

[15] CBD Technical Series No. 66 (2013) '*Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters*'. Available at: http://www.cbd.int/climate/geoengineering/