Institution: University of Southampton

Unit of Assessment: 07 Earth Systems and Environmental Sciences

Title of case study: 07-04 Geoengineering the Climate: Science, Governance and Uncertainty

1. Summary of the impact

University of Southampton research has been crucial in informing and stimulating worldwide debate on geoengineering - the possible large-scale intervention in the Earth's climate system in order to avoid dangerous climate change. Climate modellers at Southampton helped to reveal the potential extent of the fossil fuel "hangover" - the long-term damaging effects expected from anthropogenic CO_2 emissions centuries or even millennia after they end. This work led Professor John Shepherd FRS to initiate and chair a Royal Society study, whose 2009 report, *Geoengineering the Climate: Science, government and uncertainty*, is the global benchmark document on geoengineering strategies, influencing UK and foreign government policy.

2. Underpinning research

Atmospheric CO_2 concentrations are still rising by over 2% annually, not falling by the 3% needed to mitigate climate change. This threatens rapid and damaging global impacts, including floods, food shortages and extreme weather. It is one of society's greatest challenges. The 2006 Stern Review estimated its overall costs at equivalent to losing at least 5% of global GDP annually.

Predicting the Earth's response to rising CO_2 levels is essential to allow society to respond and adapt, but conventional climate models are too complex and expensive for very long-term investigations. During the late 1990s researchers at the National Oceanography Centre Southampton (NOCS) (which brought together two University of Southampton (UoS) departments and two NERC institutes) recognised the need for more efficient models, that would permit the large number of very long simulations required to undertake such long term modeling investigations and quantify uncertainty. Funded by Natural Environment Research Council (NERC), Bob Marsh (PhD student and then researcher, UoS 1991-present), Neil Edwards (Research Fellow, UoS, 1997-2000) and John Shepherd (Professor of Marine Science, UoS, 1994-present) developed a novel and efficient ocean-atmosphere model (C-Goldstein). This became the core of the coarse resolution Grid Enabled Integrated Earth system model (GENIE). Models of the land surface, the cryosphere and other parts of the Earth system were then developed and added, in collaboration with the Universities of Reading, Bristol, and East Anglia and others between 2002 and 2005. Its first results were published in late 2004 and 2005 **[3.1]**, **[3.2]**. GENIE-class models can run far faster than full climate models, permitting simulations over many thousands (up to a million) years, yet retaining sufficient complexity to give reasonably realistic quantitative and spatially-resolved results. Research at Southampton and elsewhere **[3.3]** quantified the extent of the fossil fuel "hangover", showing that the effects of CO_2 emissions may persist for many millennia after they end, and that reducing emissions may not suffice to avoid dangerous climate change.

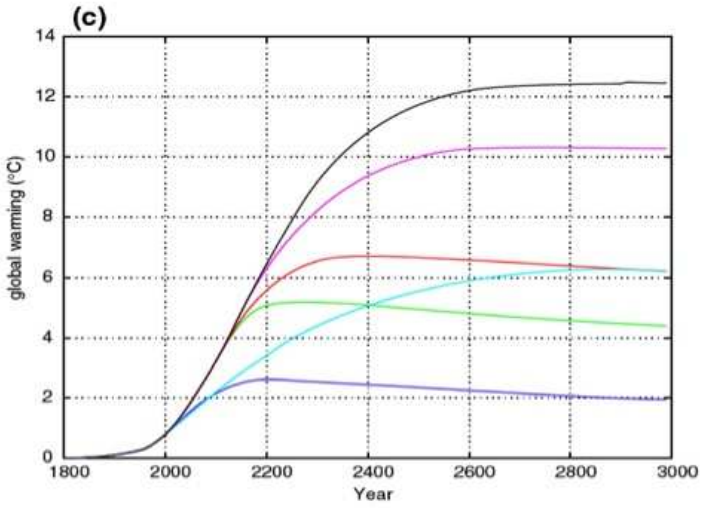

Figure 1: 1000 year simulations of global warming using the GENIE Earth System model, from [3.3], coloured lines represent a range of plausible CO_2 emission scenarios.

This led Professor Shepherd to initiate and co-chair a Tyndall Centre Cambridge-MIT workshop, *Macro-engineering Options for Climate Change Management & Mitigation* in 2004, which stimulated serious scientific consideration of geoengineering in the UK, and eventually led to the

Royal Society study of 2009 (see section 4).

An additional important aspect of GENIE was that for the first time it enabled innovative work using large ensembles (collections of thousands) of similar model runs to make formal statistical assessments of the uncertainty in long-term climate projections (e.g. **[3.1]**).

3. References to the research (the best 3 illustrating quality of work are starred)

[3.1] Marsh, R., Yool, A., Lenton, T.M., Gulamali, M.Y., Edwards, N.R., Shepherd, J.G. M. Krznaric, M., Newhouse, S. & Cox, S.J. (2004) **"**Bistability of the thermohaline circulation identified through comprehensive 2-parameter sweeps of an efficient climate model**",** *Climate Dynamics*, vol. 23, no. 7 - 8, pp. 761 – 777.

[3.2] Edwards, N.R., and Marsh, R. (2005). **"**Uncertainties due to transport-parameter sensitivity in an efficient 3-D ocean-climate model**"**, *Climate Dynamics*, vol. 24, no. 4, pp. 415 - 433

***[3.3]** Lenton T.M., Williamson, M.S., Edwards, N.R., Marsh, R., Price, A.R., Ridgwell, A.J., Shepherd, J.G., Cox S.J. & the GENIE team (2006) "Millennial timescale carbon cycle and climate change in an efficient Earth system model", *Climate Dynamics,* vol. 26, pp. 687 – 711, DOI 10.1007/s00382-006-0109-9

[3.4] Yool, A., Shepherd, J.G., Bryden, H.L., & Oschlies, A. (2009) "Low efficiency of nutrient translocation for enhancing oceanic uptake of carbon dioxide" *Journal of Geophysical Research*, vol. 114, no. C8, doi:10.1029/2008JC004792.

***[3.5]** Marsh, R., Müller, S., Yool , A., & Edwards, N.R. (2011) "Incorporation of the C-GOLDSTEIN efficient climate model into the GENIE framework: "eb_go_gs" configurations of GENIE (rel. 2.7.4)", *Geoscientific Model Development,* vol. 4, pp. 957-992.

***[3.6]** Williamson, M. S., Lenton, T.M., Shepherd, J.G. & Edwards, N.R. (2006) "An efficient numerical terrestrial scheme (ENTS) for Earth system modeling**",** *Ecological Modelling*, vol. 198, no. 3-4, pp. 362-374

Grants:

GENIE: Grid-Enabled Integrated Earth system. NERC e-Science NER/T/S/2002/00217-23. Awarded to Prof. P. J. Valdes (U Bristol, lead PI), Prof. J. G. Shepherd (Southampton, Co-I), and others. Period of Award: 2002-06. Total Value £1,378,496 split across multiple research centres.

GENIEfy: Creating a Grid ENabled Integrated Earth system modelling framework for the community. NERC e-Science NE/C515912/1, /C515904/1, /C515920/1, /C515939/1, /C515955/1. Awarded to Prof. T. M. Lenton (UEA, lead PI), Prof. J. G. Shepherd (Southampton, Co-I), and others. Period of Award: 2005 - 2010. Total Value: £1,130,290 split across multiple research centres.

4. Details of the impact

GENIE projections of long-term global warming contributed to the Stern Review (2006) on the economics of climate change, and GENIE users contributed large ensembles of climate simulations to the Intergovernmental Panel on Climate Change (IPCC) Fourth and Fifth Assessment Reports (2007 and 2013). These reports are important reference documents for policy makers. The Environment Agency also commissioned and has subsequently used the GENIE team's projections of millennial timescale sea level rise **[3.3]** to inform planning for future coastal flood risk and long-term waste management.

The stark implications of this research, that cutting emissions may not be enough to avoid dangerous climate change, led to the initiation and chairing by Shepherd of the Royal Society working group on geoengineering. According to Richard Heap, former RS Senior Policy Adviser **[5.1]** "*A number of geoengineering strategies were beginning to emerge, but there was a clear gap in knowledge about their viability and potential impacts. The proposal led by John Shepherd highlighted the need to address this gap and the significant risks this posed, particularly in the political arena*." The Royal Society (RS) report (2009) **[5.2]**, which objectively and authoritatively assesses geoengineering strategies and their associated effects, has become the global standard reference for policy-makers, opinion formers and potential investors. In the words of Professor

David MacKay, Chief Scientific Advisor for Department of Energy & Climate Change (DECC) "*It has influenced research, stimulated and informed discussion and influenced governments and policy-makers worldwide"* **[5.3]**. An example is the Scoping Report *Large-Scale Intentional Interventions into the Climate System? Assessing the Climate Engineering Debate* produced by the Kiel Earth Institute for the German Government which cites the RS Report heavily and credits it with "*attracting attention beyond academic circles*". The Royal Society report's publication prompted extensive media coverage (Independent, Times, Financial Times, Guardian, Economist, Observer, New Scientist, BBC, 2009, 2010, 2011 **[5.4]**), and briefings for DECC Secretaries of State Ed Miliband (20 July 2009) and Chris Huhne with Minister of State Greg Barker (29 November 2010).

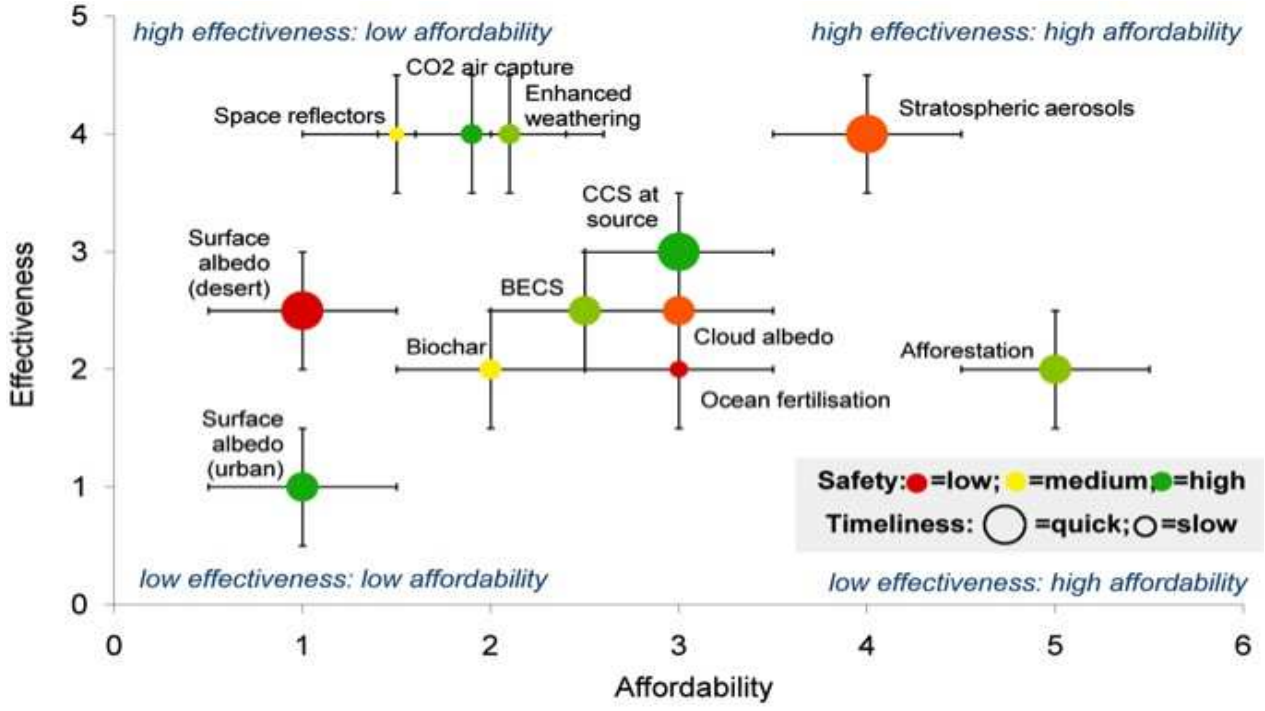

Figure 2: Geoengineering Strategies – Affordability and Effectiveness, from [5.2]

The report's emphasis on the need for international governance of geoengineering led to Shepherd being invited to testify to a hearing by the US House of Representatives' Committee on Science and Technology on 5 November 2009 to examine geoengineering **[5.5]**. In March 2010 the House of Commons Science and Technology Committee also published the report of an enquiry, *The Regulation of Geoengineering*, which repeatedly cites the Royal Society report as evidence **[5.6]**. On 3 October 2011 the US Bipartisan Policy Committee (an NGO serving both Houses of Congress and all political parties) published the report of a study (to which Shepherd had been the sole foreign contributor) building on the Royal Society report and recommending a major US research programme in the area **[5.7]**. The UK government now has an interdepartmental committee on geoengineering and an official position that follows the RS report closely **[5.8]**. In addition, the IPCC also subsequently held a special Joint Expert Meeting on Geoengineering in Peru in June 2011, and referred extensively to the Royal Society report **[5.9]**.

The Royal Society report asserted that public attitudes towards geoengineering should be a critical factor in considering the future of geoengineering - specifically whether (and if so how) the public think that these technologies should be taken forward. This led NERC to invest £155,000 in the Ipsos MORI geoengineering public dialogue exercise, *Experiment Earth*, in spring 2010 **[5.10]**. This gave 90 members of the public, recruited at three centres around the UK, the chance to inform future NERC decision-making on geoengineering. Each recruit attended 2 daylong workshops, with a subset attending a further event at Southampton where Professors Damon Teagle and Richard Lampitt (NERC-NOCS) gave presentations on potential geoengineering projects. The report of this study presents a number of recommendations; for NERC and other research funders and decision makers, for future public engagement on geoengineering research

and for communicating climate science.

Shepherd regularly engages with the public through popular science articles (for example the Guardian 2011 *Geoengineering: we need more evidence before we cast our vote*) or through frequently accepting invitations to speak to a wide range of audiences who want to be informed about geoengineering issues, in the UK and abroad. Venues include the Royal Society, Oxford University, National Theatre, village halls and Museum of Madrid (Fundacion Banco Santander public lecture), several of these lectures are freely available online **[5.10]**.

Since its publication the Royal Society report has been an important reference in numerous public information documents produced by Governments and International Organisations **[5.10]**, for example in Australia (*Geoengineering*, Occasional Paper Series, Issue 1. Office of the Chief Scientist, Canberra 2012) and UNESCO (Policy Briefs Series. *Engineering the climate: Research questions and policy implications*, November 2011). In addition the Solar Radiation Management Governance Initiative (SRMGI), an international NGO-driven project was launched in March 2010 in response to the 2009 Royal Society report. With John Shepherd on the steering group, SRMGI is especially focused on engaging with a wide range of stakeholders from the developing world and emerging economies and has held workshops in China, India, Pakistan, and Africa (Senegal, South Africa & Ethiopia) **[5.10]**.

5. Sources to corroborate the impact

[5.1] For verification of John Shepherd's instrumental role in the Royal Society Geoengineering Report, see Letter from former Senior Policy Adviser at Royal Society.

[5.2] Geoengineering the climate: science, governance and uncertainty, Royal Society Policy Document 10/09, September 2009. Chaired by Professor John Shepherd FRS. Provides a detailed assessment of the various methods of geoengineering, and considers the potential efficiency and unintended consequences they may pose.

[5.3] Chief Scientific Advisor, DECC and chair of interdepartmental committee on Geoengineering.

[5.4] For a list of, and links to press articles, see bottom of web page on Royal Society website: http://royalsociety.org/policy/publications/2009/geoengineering-climate/

[5.5] US House of Representatives Committee on Science and Technology, Hearing to examine Geoengineering, 5 November 2009 (see press release at: http://archives.democrats.science.house.gov/publications/hearings_markups_details.aspx?NewsID=2668 , see also http://archives.democrats.science.house.gov/press/PRArticle.aspx?NewsID=2676

[5.6] House of Commons Science and Technology Committee (2010). "The regulation of Geoengineering: fifth report of session 2009-10" (report, together with formal minutes, oral and written evidence). London: The Stationery Office (House of Commons papers 221, 2009-10). (Note - this is a joint inquiry with the Science and Technology committee of the U.S., House of Representatives. Page 54 clearly states that BOTH the UK and US S&T Committees draw upon the Royal Society Report and its contributing scientists and policy experts including Prof John Shepherd.)

http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/22102.htm

[5.7] "Geoengineering: A National Strategic Plan for Research on Climate Remediation" Bipartisan Policy Committee
http://www.bipartisanpolicy.org/library/report/task-force-climate-remediation-research
see also http://bipartisanpolicy.org/projects/task-force-geoengineering/about

[5.8] see "Government view on geo-engineering research" at
http://webarchive.nationalarchives.gov.uk/20121217150421/www.decc.gov.uk/en/content/cms/about/science/activities/climate_change/ger/ger.aspx

[5.9] http://www.ipcc-wg3.de/meetings/expert-meetings-and-workshops/em-geoengineering

[5.10] Links to this and other supporting documentation cited are available at
http://jgshepherd.com/science-topics/geoengineering/links-geoengineering/