Institution: University of Reading

Unit of Assessment: 7 Earth Systems & Environmental Sciences

Title of case study: Climate Emission Metrics for Policymakers

1. Summary of the impact:

Human activity leads to the emission of many greenhouse gases that differ from carbon dioxide (CO_2) in their ability to cause climate change. International climate policy requires the use of an "exchange rate" to place emissions of such gases on a "CO_2-equivalent" scale. These exchange rates are calculated using "climate emission metrics" (hereafter "metrics") which enable the comparison of the climate effect of the emission of a given gas with emissions of CO_2. Research in the Unit has contributed directly to (i) the calculation of inputs required for such metrics, (ii) the compilation of listings of the effects for a large number of gases and (iii) the consideration of alternative metric formulations. During the assessment period this work has been used in the implementation of the first commitment period of the Kyoto Protocol (2008-2012) to the United Nations Framework Convention on Climate Change (UNFCCC), and in decisions and discussions (which began in 2005) on the implementation of the Kyoto Protocol's second commitment period (2013-2020), as well to intergovernmental debate on aspects of the use of metrics in climate agreements.

2. Underpinning research

Prof. K.P. Shine, and co-workers within and outside the unit, have contributed underpinning research that has contributed heavily to impact. Shine was a member of academic staff in the Unit throughout both the impact period and the REF assessment period.

First, Shine was a convening lead-author in successive assessment reports of the WMO/UNEP (World Meteorological Organization / United Nations Environment Programme) Intergovernmental Panel on Climate Change (IPCC) and the WMO/UNEP Scientific Assessments of Stratospheric Ozone Depletion during the 1990s[7-9]. These assessments reported the values of the Global Warming Potential (GWP) which is the metric adopted by the Kyoto Protocol to the United Nations' Framework Convention on Climate Change (UNFCCC) to allow signatories to report the emissions of different greenhouse gases on a CO_2-equivalent scale. The GWP is one of a range of possible methods for comparing the climate impact of emissions of different greenhouse gases (technically it is the time-integrated (100-year) radiative forcing following a pulse emission of a gas, relative to the same quantity for an emission of CO_2). Shine's work in these assessments included the compilation of an essential input to GWP calculations (the so-called "radiative efficiency" or RE) for a large range of gases[7,8,9], the critical assessment of available RE values and the recommendation of the most appropriate values [7,8,9], and finally the calculation of GWPs themselves[9], which are tabulated within the assessments.

Second, Shine, with contributions from current Unit member, Prof. E.J. Highwood (initially as a post-doc and as a member of academic staff since 2001), calculated RE values for a large number of gases, in collaboration with several PDRAs and PhD students based within the Unit, and with laboratory and computational spectroscopists from outside the Unit. The spectroscopist collaborators were principally from the Department of Chemistry at the University of Reading (UoR), the Ford Motor Company Physical and Environmental Sciences Department (Dearborn, MI, USA) and the Molecular Spectroscopy Facility, at the Rutherford Appleton Laboratory, UK.

Since 1995, the Unit's ongoing work has developed and refined methodologies for calculating the RE, which included the use of numerical models which incorporated the laboratory observations made by our collaborators at high spectral resolution. It has updated and improved RE values for many known industrial greenhouse gases, and helped resolve instances where results presented in the literature had been in substantive disagreement. It has produced the first detailed assessments of the RE for several newly-detected gases including trifluoromethyl sulphur pentafluoride (SF_5CF_3) and nitrogen trifluoride (NF_3) which are emitted as a result of industrial activity. The work is reported in many papers, examples of which are given in section 3 [1,2,3,4].

Finally, research from 2005 onwards within the Unit led by Shine resulted in the proposal of novel alternative metrics. This research originated from debate within academic and policymaking circles as to whether the GWP was the most suitable metric for comparing the climate effect of emissions of different gases. This debate had been long-running (since the early 1990s), but prior to the Unit's work, no alternative had been proposed that had gained traction at the policymaker level.

The Unit's research led to the development of the Global Temperature-change Potential (GTP)[5] and its computation for a wide variety of greenhouse gases[6], as a viable alternative to the GWP; this has led to a renewed debate at the policymaker level, about the most suitable metric to be used within international protocols. The GTP characterises the effect of the emission of a gas on surface temperature at some point in the future, and may be better suited than the GWP to one of the aims of the 2009 Copenhagen Accord of the UNFCCC, which is to restrict temperature increases due to human activity to below 2°C. This work has involved collaboration within EC FP7 projects, most notably with the Center for International Climate and Environmental Research – Oslo (an independent research centre, associated with the University of Oslo).

3. References to the research:

The three outputs indicated by an asterisk are selected to indicate the quality of the research. The ISI Web of Science total number of citations is given (as of 22 Oct 2013) for these.

Journal Papers

1. *S. Pinnock, M.D. Hurley, K.P. Shine, T.J. Wallington, and T.J. Smyth (1995) Radiative forcing of climate by hydrochlorofluorocarbons and hydrofluorocarbons. *J Geophys Res*., 100, 23227-23238 doi:10.1029/95JD02323 (135 cites)
2. E. Highwood and K.P. Shine (2000) Radiative forcing and global warming potentials of 11 halogenated compounds. *J Quant Spectrosc Radiat Transf*, 66,169-183, doi: 10.1016/S0022-4073(99)00215-0 (29 cites)
3. *K. Sihra, M.D. Hurley, K.P. Shine, and T.J. Wallington (2001) Updated radiative forcing estimates of sixty-five halocarbons and non-methane hydrocarbons. *J Geophys Res*.,106, 20493-20506. doi: 10.1029/2000JD900716 (41 cites)
4. J.I. Robson, L.K. Gohar, M.D. Hurley, K.P. Shine KP, and T.J. Wallington (2006) Revised IR spectrum, radiative efficiency and global warming potential of nitrogen trifluoride. *Geophys. Res. Lett.* 33, L10817. doi: 10.1029/2006GL026210 (11 cites)
5. *K.P. Shine, J. Fuglestvedt, K. Hailemariam, ans N. Stuber (2005) Alternatives to the global warming potential for comparing climatic impacts of emissions of greenhouse gases. *Climatic Change*, 68, 281-30 doi: 10.1007/s10584-005-1146-9 (133 cites)
6. J.S. Fuglestvedt, K.P. Shine, J. Cook, T. Berntsen, D.S. Lee, A. Stenke, R.B Skeie, G.J.M. Velders, and I.A. Waitz (2010) Assessment of transport impacts on climate and ozone: metrics. Atmospheric Environment 44, 4648-4677, doi: 10.1016/j.atmosenv.2009.04.044 (76 cites)

Assessments

7. Shine KP, Fouquart Y, Ramaswamy V, Solomon S, Srinivasan J 1996: Radiative Forcing. Section 2.4 of "Climate Change 1995: The Science of Climate Change" Intergovernmental Panel on Climate Change Scientific Assessment Cambridge University Press. ISBN 0 521 56433 6
8. Shine KP, Fouquart Y, Ramaswamy V, Solomon S, Srinivasan J 1995: Radiative Forcing. Chapter 4 of "Radiative Forcing of Climate Change", Intergovernmental Panel on Climate Change Scientific Assessment Working Group, Cambridge University Press. ISBN 0 521 55962 6
9. Granier C, Shine KP, Daniel JS, Hansen JE, Lal S, Stordal F. 1998: Climate effects of ozone and halocarbon changes. Chapter 10 of "Scientific Assessment of Ozone Depletion:1998".Global Ozone Research and Monitoring Project Report No 44, World Meteorological Organization, Geneva. ISBN 92 807 1722 7

4. Details of the impact:

The GWP tables produced in the 1996 IPCC Second Assessment Report (for which Shine played a major role in compiling the REs[7,8] and which also included calculations performed in the Unit[1]) are now enshrined in international law, in the Kyoto Protocol to the UNFCCC. During the first commitment period of the protocol (2008-2012), signatories were required to convert their non-CO_2 greenhouse gas emissions to CO_2-equivalent emissions using these tables, and then report these emissions to the UNFCCC, as part of the monitoring of the extent to which individual country commitments were being met. In addition, the GWP values are used within the Clean Development Mechanism of the Kyoto Protocol that enables industrialized countries to fund emission-reduction

projects in developing countries, and to claim credit for these reductions in meeting their own targets. Where these projects involve reductions in emissions of gases other than CO_2 (historically this constitutes about 20% of the total number of projects), the GWP is used to calculate CO_2-equivalence. The same GWP tables are also used within the UK Climate Change Act (2008) to calculate CO_2-equivalent emissions to assess the extent to which the UK is meeting its own commitments under this Act.

The UNFCCC negotiations, starting in 2005 and continuing through the REF2014 assessment period, which led to the agreement on the second commitment period of the Kyoto Protocol (2013-2020), have recommended the adoption of the GWP tables listed in (the errata to) the IPCC Fourth Assessment Report. Of the 69 gases in this table that are covered by the Kyoto Protocol, inputs to about one-quarter can be traced directly to research in the Unit (including those publications given in Section 3[1,2,3,4]), and about half originate from previous IPCC or WMO Ozone assessments where Shine was the lead author of relevant sections of the assessment and played a major role in the compilation of the lists of REs [7,8,9]. Reading's work includes the first detailed RE value for nitrogen trifluoride[4], a compound widely used in the electronics industry and also for trifluoromethyl sulphur pentafluoride; emissions of these gases were not included in the first commitment period of the Kyoto Protocol, but are now part of the second commitment period. Hence the Unit's research helped enable the UNFCCC negotiations during the REF2014 assessment period; specifically its work helped enable the production of the updated GWP tables in the IPCC Fourth Assessment Report and the inclusion of additional gases in those tables.

The Unit's work on alternatives to the GWP has impacted public policy by enabling a policy debate on the most appropriate metrics for use in climate conventions. The work has led to debate within the IPCC and UNFCCC, with requests from parties to the Convention to assess the appropriateness of metrics to calculate CO_2-equivalence. As a specific example, because of the scale of its agricultural activity, Brazil has relatively high methane emissions. Using the standard GWP metric to place emissions on a CO_2-equivalent scale, Brazil's methane emissions account for about 17% of their total CO_2-equivalent emissions. By contrast, using the 100-year GTP metric, developed at the Unit[5], the methane emissions would account for only 5%. Brazil have stated (in their 2010 National Contribution to the UNFCCC) that "they object to the use of the GWP ... [and the] .. option for aggregating the reported emissions into carbon dioxide equivalent units using the GWP ... was not adopted". The same report states that "the use of GTP allows for more appropriate mitigation policies". The UNFCCC's Subsidiary Body for Scientific and Technical Advice (SBSTA) continues to discuss and debate the issue; for example, in 2012 it organised, a workshop on the issue, bringing together policymakers and scientists, at which Shine was a speaker.

5. Sources to corroborate the impact

The main evidence for the impact can be seen through UNFCCC, IPCC and other documentation of methodologies for reporting CO_2-equivalent greenhouse gas emissions.

(i) The Kyoto Protocol to the United Nations Framework Convention on Climate Change http://unfccc.int/essential_background/kyoto_protocol/items/1678.php.

Article 5 (paragraph 3) of the Kyoto Protocol refers to the use of the GWPs to calculate the CO_2-equivalence of the greenhouse gases listed in its Annex A. The tables of GWPs (for which work in the Unit contributed to their compilation and provided important input data[1,7,8]) used in the first commitment period are given at http://unfccc.int/ghg_data/items/3825.php

(ii) UNFCCC, GHG Inventories, Annex I, Compilation of technical information on the new greenhouse gases and groups of gases included in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change http://unfccc.int/national_reports/annex_i_ghg_inventories/items/4624txt.php. (updated 20 July 2010)

This page lists the source of GWPs values for "new" gases that are included in the second commitment period of the Kyoto Protocol but were not included in the first commitment period. The work of the Unit is explicitly mentioned on several occasions (search "Shine")

(iii) UNFCCC, Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its seventh session, held in Durban from 28 November to 11 December 2011, Addendum, FCCC/KP/CMP/2011/10/Add.1

http://unfccc.int/resource/docs/2011/cmp7/eng/10a01.pdf

This document confirms the adoption of the GWP table presented in the IPCC's Fourth Assessment Report in the second commitment period of the Kyoto Protocol. As detailed in Section 4, the Unit's research contributed heavily to producing the RE values that are used for the GWP calculation presented in the Fourth Assessment Report.

(iv) The role of GWPs in the Kyoto Protocol's Clean Development Mechanism can be seen in, for example,

http://cdm.unfccc.int/Reference/Standards/meth/reg_stan02.pdf

where the decision to adopt the GWP tables in the IPCC Fourth Assessment Report for the second commitment period of the Kyoto Protocol is stated. The numbers of projects that involve non-CO_2 emissions can be seen, for example, in this 2010 report from the UNFCCC (see for example, Table V-6):

http://cdm.unfccc.int/Reference/Reports/TTreport/TT_2010.pdf

(v) The UK Government's Climate Change Act 2008, paragraph 93(2) refers to the calculation of the CO_2-equivalent emissions following the international carbon reporting practice, which at the time was the GWPs adopted during the first commitment period of the Kyoto Protocol for which the Unit made an important contribution[1,7,8].

http://www.legislation.gov.uk/ukpga/2008/27/contents

(vi) Report of the IPCC Expert Meeting on the Science of Alternative Metrics, Oslo, 18-20 March 2009. Published by the IPCC Working Group I Technical Support Unit, University of Bern, Switzerland. ISBN 978-92-9169-126-5
http://www.ipcc.ch/pdf/supporting-material/expert-meeting-metrics-oslo.pdf.

This document confirms the request by the UNFCCC for the IPCC to consider a technical assessment of alternative metrics to the GWP as part of the policy debate taking place amongst parties to the UNFCCC. Frequent mention of the GTP metric developed by the Unit[5] can be seen in the motivation and conclusions of the document.

(vii) UNFCCC Ad-hoc working group on further commitments for Annex I parties under the Kyoto protocol, Eighth session, Bonn, 1–12 June 2009, FCCC/KP/AWG/2009/MISC.10
http://unfccc.int/resource/docs/2009/awg8/eng/misc10.pdf.

This document presents further evidence of the role of the GTP[5] in policy debate, and in particular the strongly expressed view of Brazil which is presented in more detail in the Second National Communication of Brazil to the UNFCCC (dated 26 October 2010)
http://www.mct.gov.br/index.php/content/view/326984.html

(viii) UNFCCC Subsidiary Body for Scientific and Technological Advice, Thirty-sixth session Bonn, 14–25 May 2012, FCCC/SBSTA/2012/INF.2
http://unfccc.int/resource/docs/2012/sbsta/eng/inf02.pdf.

This document is evidence of the policy debate surrounding the use of different metrics within the UNFCCC and contains frequent mention of the GTP metric developed by the Unit[5]. It is a report of a workshop held by the UNFCCC Subsidiary Body for Scientific and Technological Advice, for which further information (including confirmation of Shine's involvement) which is given at
http://unfccc.int/methods/other_methodological_issues/items/6737.php