Institution: University of Oxford

Unit of Assessment: 9 – Physics

Title of case study:
Accounting for the warming impact of methane emissions in climate policy

Period when the underpinning research was undertaken: January 2012 – December 2019

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
Ray Pierrehumbert	Halley Professor of Physics	2015 – present
John Lynch	Postdoctoral Research Associate	2018 – present

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

1. Summary of the impact (indicative maximum 100 words)

Climate policy since the early 1990s has depended heavily on the notion of "CO_2-equivalent emissions" that equate one tonne of methane with a certain number of tonnes of CO_2. This is problematic because CO_2-induced warming is proportional to cumulative (time-integrated) CO_2 emissions while methane-induced warming is not. While this has long been known to be a problem, research at Oxford Physics proposed a simple but accurate solution that equates a change in methane emission rate with an absolute number of tonnes of CO_2 using well-established constants. The simplicity of the solution and the fact that it relied on constants that were already familiar in policy circles resulted in much wider uptake than previous proposals based on bespoke modelling of methane impact. This Oxford-led work was a key influence on the Zero Carbon Act in New Zealand, is informing climate policy in the UK, Norway, European Union and Republic of Ireland, contributed to public understanding of the climate impact of agriculture and diet, has been incorporated in major international reports, and informed agricultural sector professionals.

2. Underpinning research (indicative maximum 500 words)

Methane is the second most important anthropogenic greenhouse gas after CO_2, contributing 25% of CO_2's contribution to warming to date, and 11% of the current CO_2-induced warming trend. A science-based treatment of methane emissions has long proved a challenge for climate policy. Research at Oxford Physics established in the 2000s that CO_2-induced warming is proportional to cumulative (time-integrated) CO_2 emissions, but it was immediately noted that this result could not apply to methane. In 2011, the UK Department of Energy and Climate Change commissioned a study, "Assessing the options for greenhouse gas metrics -- TRN 307/11/2011" led by Oxford Physics and the Oxford Environmental Change Institute involving CEH Wallingford, the Met Office, University of Reading and Tau Scientific, which resulted in a series of publications [1-5] that culminated in a scientifically robust unified treatment of methane and CO_2 that is, crucially, simple enough for use by government officials and agricultural professionals in climate policy.

Early work [1] (led by the Met Office and UK Climate Change Committee, with Oxford Physics contributing to study design and modelling implications for decadal temperature projections) showed that peak global temperatures were determined by *cumulative emissions* of long-lived climate pollutants (LLCPs) such as CO_2 and N_2O, and by *emission rates* of short-lived climate pollutants (SLCPs) such as methane. This was followed in 2013 by a report (led and implemented by Oxford Physics) that explored the implications of [1] for meeting the goal of limiting global warming to 2°C above pre-industrial levels [2].

In 2016, an Oxford-led team (involving collaborators from Reading, Leeds, the New Zealand Agricultural Greenhouse Gas Research Centre and CICERO in Norway: quantitative results were produced by Oxford, with collaborators contributing diverse views on interpretation and policy implications) proposed a way of relating the impact of LLCPs and SLCPs on global temperature, subsequently known as GWP*, by equating a permanent change in the emission rate of an SLCP with a one-off emission of a fixed quantity of CO_2 [3]. The key contribution of

this work was to point out that it was possible to equate the impacts of LLCPs and SLCPs using existing quantities (CO_2-equivalent emissions reported using 100-year Global Warming Potential) that were already widely reported. Application to a selection of real global emission scenarios and country-level emissions by the team in 2018 (with additional involvement of the Oxford Environmental Change Institute, Oxford Martin School and Victoria University of Wellington) gained wider appreciation of the implications and potential importance of this research [4].

The formula from the 2016 report [3] was further refined in 2019 to better represent the temperature impact of methane emissions, by a similar team (now led by the Oxford Environmental Change Institute/Oxford Martin School), where members of Oxford Physics were involved in initiating and developing the work [5]. The amended formula allows more accurate incorporation of SLCPs into carbon budgets. Oxford Physics has been heavily involved in exploring the policy implications, including a high-impact publication using climate modelling to compare the climate impacts of cattle production with 'lab-grown meat' [6], highlighting the contrasting dynamics of energy-sector and agricultural greenhouse gas emissions.

3. References to the research (all references are journal articles)

[1] "Equivalence of greenhouse-gas emissions for peak temperature limits" S. M. Smith, J. A. Lowe, N. H. A. Bowerman, L. K. Gohar, C. Huntingford, M. R. Allen, *Nature Climate Change* **2012**, *2*, 535-538, doi: 10.1038/nclimate1496.
[2] "The role of short-lived climate pollutants in meeting temperature goals" N. H. A. Bowerman, D. J. Frame, C. Huntingford, J. A. Lowe, S. M. Smith, M. R. Allen, *Nature Climate Change* **2013**, *3*, 1021-1024, doi: 10.1038/nclimate2034.
[3] "New use of global warming potentials to compare cumulative and short-lived climate pollutants" M. R. Allen, J. S. Fuglestvedt, K. P. Shine, A. Reisinger, R. T. Pierrehumbert, P. M. Forster, *Nature Climate Change* **2016**, *6*, 773-776, doi: 10.1038/nclimate2998.
[4] "A solution to the misrepresentations of CO_2-equivalent emissions of short-lived climate pollutants under ambitious mitigation" M. R. Allen, K. P. Shine, J. S. Fuglestvedt, R. J. Millar, M. Cain, D. J. Frame, A. H. Macey, *Climate and Atmospheric Science* **2018**, *1*, 16, doi: 10.1038/s41612-018-0026-8.
[5] "Improved calculation of warming-equivalent emissions for short-lived climate pollutants" M. Cain, J. Lynch, M. R. Allen, J. S. Fuglestvedt, D. J. Frame, A. H. Macey, *npj Climate and Atmospheric Science* **2019**, *2*, 29, doi: 10.1038/s41612-019-0086-4.
[6] "Climate Impacts of Cultured Meat and Beef Cattle" J. Lynch, R. T. Pierrehumbert, *Frontiers in Sustainable Food Systems* **2019**, *3*, 5, doi: 10.3389/fsufs.2019.00005.

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

Although apparently a simple update to accounting principles, the impact of the revised treatment of methane on climate policy, particularly for agriculture, is considerable. Under the traditional 100-year Global Warming Potential (GWP_{100}) used for greenhouse gas reporting by the United Nations Framework Convention on Climate Change (UNFCCC), in climate policy in the UK and EU, and ubiquitously in "carbon footprint" calculations, methane emissions are simply multiplied by 28 to give "CO_2-equivalent" emissions. Oxford Physics have shown that the actual rate of "CO_2-warming-equivalent" emissions, which generate approximately the same amount of warming whether emitted as CO_2 or methane, is given [5] by multiplying the current methane emissions rate by 112 and subtracting the methane emission rate of 20 years ago multiplied by 105. Hence the traditional metric overstates the impact of constant methane emissions by a factor of 4 (an issue for traditional livestock farmers and in quantifying the environmental impact of supermarket supply chains), while simultaneously understating the impact of changes in methane emission rates, also by a factor of 4 over the first 20 years after the change (an issue for regulation of new methane sources such as fracking).

This work bridges the gap between contemporary climate physics and the 'emission metrics' commonly used by policy-makers, industry, environmental scientists and the general public to quantify impact on climate. It provides a new conceptual framework to compare the impacts

of different activities on global temperatures, with especially important implications for the assessment of agricultural sustainability.

Improving policy targets for methane emissions

The 2015 Paris Agreement calls for signatories to take action on limiting global warming to no more than 2°C (and ideally no more than 1.5°C) above pre-industrial levels, while also recognising the fundamental priority of safeguarding food security. As energy-sector emissions decline, agricultural emissions will become increasingly prominent, yet the majority of countries have yet to incorporate them into climate policy. The research outlined in Section 2 has focussed attention on what must be done to achieve these aims, as highlighted by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C, which contained a specific Box (Cross Chapter Box 2, pg 66-68, [A]) on the role of cumulative and short-lived climate pollutants in meeting ambitious temperature goals, with the figure provided by Oxford based on their research [3] and [4].

New Zealand Zero Carbon Act

Methane emissions make up around half of New Zealand's greenhouse gas emissions under conventional accounting, and it has the highest per capita methane emission rate in the world (6 times the global average), as, unusually for a developed country, a large part of its economy is based on agriculture. Research produced by Oxford Physics has been heavily cited in the debate over the New Zealand Zero Carbon Act, and has influenced one of its key policies – to treat biogenic methane separately to other greenhouse gases, and to set reduction, not elimination, targets for methane emissions. The Zero Carbon Bill was developed from submissions by Generation Zero, a youth-led climate activist organisation who in July 2018 produced a Submission [B] on the Zero Carbon Bill citing [1]-[4] (plus two other Oxford-led publications, extensively) as key evidence for the need to recognise the difference between LLCPs and SLCPs with a 'two baskets' approach. In parallel, the New Zealand Agricultural Greenhouse Gas Research Centre released a report [C] in August 2018: "The contribution of methane emissions from New Zealand livestock to global warming" which cites [3] and [4], and was in turn cited in much of the documentation around the introduction of the Zero Carbon Act [D]. Myles Allen has given Climate Change Minister James Shaw two in-person briefings on the topic, while co-author of [2], [4] and [5] D. J. Frame (formerly of Oxford Physics, now Victoria University of Wellington) has been cited several times in person in Parliamentary debates [E]. In May 2019 the New Zealand Government decided to introduce the Zero Carbon Bill as an amendement to the Climate Change Response Act 2002, and produced the 'Climate Change Response (Zero Carbon) Amendment Bill: Summary' which included the key policy to "*distinguish between biogenic methane and all other greenhouse gases*", citing both the IPCC Special Report on 1.5 Degrees (which features this research prominently, as noted above), and directly citing reference [4] as an example of "*expert advice… that the world must reduce emissions of both long- and short-lived gases to achieve the Paris Agreement's temperature goal*". The summary also has an explanatory section "Why a different target for biogenic methane?", with the discussion on the separate treatment of biogenic methane occupying a full 2 pages of the 17-page document [D]. The 'Climate Change Response (Zero Carbon) Amendment Act 2019' was signed into law on 13 November 2019 and sets separate mitigation targets for biogenic methane and all other greenhouse gas emissions: while all other greenhouse gases must fall to net zero emissions by 2050, biogenic methane emissions must decrease by 10% by 2030, and 24% to 47% by 2050 (relative to 2017 rates).

Informing UK and European climate policy

The work described in section 2 continues to inform other nations as they develop policy to meet the Paris Agreement targets. The UK Committee on Climate Change cited [4] and [6] in their recent report 'Land use: Policies for a Net Zero UK' [F], and devoted a number of pages to the work and its implications for UK emission reduction policy. The GWP* metric has been explicitly used in the White Paper behind Norway's new Climate Plan for 2021-2030 to document the climate impact of Norwegian agriculture ([G] see pages 102-103, including plots of annual and cumulative agricultural emissions under the GWP* metric).

The research is also informing policy development in the European Union, as evidenced by the enclosed letter from the Chair of JPI-Climate [H]. John Lynch (Oxford Physics) was invited by the DG for Energy to present an intervention on methane emission abatement in agriculture for a European Commission event held on 9 June 2020. The topic is also under consideration in Ireland, with a working paper published by the Irish Climate Change Advisory Council on Climate Change Mitigation and the Irish Agriculture and Land Use Sector [I] citing [3] and considering the potential of the work for improved policy formulation.

Communicating Agriculture's Role in Climate Change Mitigation and Informing Agricultural Sector professionals

As methane emissions are such a large part of agricultural emissions, the issue of their misrepresentation in some climate metrics has generated much confusion and uncertainty in the agricultural industry and wider policy community, and is potentially hindering progress on climate change mitigation. The research presented here overcomes this challenge. Some of the limitations of treating agricultural emissions as directly analogous to fossil CO_2 were highlighted in [6], providing a case-study comparing beef production to potentially energy intensive manufactured alternatives. This study received significant international media attention, bringing an improved understanding of different greenhouse gases to the public debate. The paper has been highlighted in major international policy reports from the IPCC (Special Report on Climate Change and Land Use; Chapter 5: Food Security), and the Food and Agriculture Organization of the United Nations (Climate change: Unpacking the burden on food safety) [J].

The findings of [1]-[5] have also been welcomed by farming associations, evidenced by a recent supporting statement by 15 agricultural bodies from the UK and New Zealand [K]. The ambition is that through adoption of a new framework that treats the majority of their emissions (methane) more fairly and transparently, it can be shown that farming can have an active role in maintaining climate within safe limits, while continuing to produce food, maintain landscapes/ecosystems, and support tourism, cultural traditions, rural communities and employment.

~ in New Zealand

Myles Allen visited New Zealand in March 2019 to give a series of talks (public and specialist, relating to both policy and science) about climate change, with an emphasis on the correct 'accounting method' for methane, presenting this as an opportunity for New Zealand farmers to be world leaders in the global fight against global warming. The New Zealand Red Meat Industry have written to thank Myles "*for the assistance and knowledge you have willingly given to our sector over the last 18 months. NZ Meat Industry have been like many industries seeking to understand the impacts and mitigations for Climate Change and your team has always readily helped with our learning and understanding*" [L,M]. Myles' visit was well covered in the media, particularly in publications with an agricultural focus, including pieces in the New Zealand Herald (readership 447,000) and the Newsroom (readership 100,000) [N].

~ in the United Kingdom

The Oxford Physics authors of [1]-[5] have built strong relationships with the agricultural sector, and have been issued with around 30 invitations to speak in this community, initially via the UK NFU (National Farmers Union) and then through people in the audience inviting them back to further events – for example Oxford Farming Conference and the Global Roundtable on Sustainable Beef [N]. They have also been approached by many stakeholders within the farming community to aid in their understanding and application of the work. The NFU funded a summer research assistant in 2019 to produce a study and internal report on UK agriculture, and the think tank IDDRI funded a summer student researcher in 2019 to work on a report on European scenarios. Co-author on [4] and [5] Michelle Cain (of the Oxford Martin School) is working with Defra to apply GWP* in strategic scenario analysis and the algorithm is being incorporated into the Agricalc on-farm environmental footprint calculator developed by SRUC. This will be a test of how useful the method can be for allowing civil servants, local planning agencies and farmers themselves to analyse emissions data in terms

of the effect it will have on global warming, and therefore enable them to prioritise policies to achieve their goals. [F,G]

This research, and the concept of GWP* in particular, has been extensively covered in the international, UK, New Zealand and Irish agricultural media, including Country Life, Farmers Weekly and the Irish Farmers Journal. [N].

5. Sources to corroborate the impact

[A] Cross-chapter Box 2 in Chapter 1, Framing and Context, IPCC Special Report on 1.5°C, IPCC, 2018, pages 66-68, shows direct application of GWP* concept in figure.
[B] Generation Zero Zero Carbon Bill Consulation Submission cites Oxford Physics research in support of "two-basket" approach.
[C] Report from the New Zealand Agr. GHG Res. Ctr.: The contribution of methane emissions from New Zealand livestock to global warming, citing [3] and [4] in explaining methane science.
[D] New Zealand's Climate Change Response Zero Carbon Amendment Bill: Summary, available online: https://www.mfe.govt.nz/publications/climate-change/climate-change-response-zero-carbon-amendment-bill-summary, citing ref. [4] on page 9.
[E] Corroborator 1: James Shaw, Co-Leader of the New Zealand Green Party and Minister for Climate Change; Transcript of Hansard Record of Parliamentary Debate on first reading of the Climate Change Response (Zero Carbon) Amendment Bill with references to New Zealand co-author Professor David Frame highlighted, reflecting the impact of his work with Oxford Physics.
[F] UK Committee on Climate Change Report: Land use: Policies for a Net Zero UK, see discussion of "New usage of CO_2-equivalence metrics for biogenic methane", page 43 et seq
[G] Klimaplan for 2021-2030, Melding til Stortinget (Report to Parliament, equivalent to a UK White Paper) 13, Norwegian Ministry of Climate and Environment, see analysis of agricultural emissions in terms of GWP* on page 103.
[H] Letter from the Chair of the European Joint Programming Initiative on Climate research (JPI Climate) and Chief Climate Scientist at Ireland's Environmental Protection Agency (EPA)
[I] Irish Climate Change Advisory Council Working Paper: Climate Change Mitigation and the Irish Agriculture and Land Use Sector (2019): See section 2.4 Common Metrics for Emissions Accounting, page 29 onwards including figure 5 from ref. [3]
[J] Special Report on Climate Change and Land Use; Chapter 5: Food Security IPCC (2019) p 437-550, in pdf p 1-114: https://www.ipcc.ch/site/assets/uploads/sites/4/2021/02/08_Chapter-5_3.pdf and Climate change: Unpacking the burden on food safety FAO (2020), in pdf page 115-290: http://www.fao.org/3/ca8185en/CA8185EN.pdf
[K] Open letter from 15 farming organisations appealing to IPCC to consider GWP* metric, available online at https://www.nfuonline.com/news/latest-news/farming-organisations-ask-ipcc-to-consider-new-ghg-metric/
[L] Email on behalf of New Zealand Red Meat Industry, acknowledging value of Oxford Physics research and engagement.
[M] Letter from the Chairman of Beef+Lamb New Zealand, acknowledging value of Oxford Physics research and engagement.
[N] Media coverage: MA visit to NZ in the New Zealand Herald (readership 477k) Farm Carbon website, Scoop Political News; MA writes article for the Newsroom (readership 100k). UK (agricultural) coverage: Country Life; Resilience.org; Farmers Weekly; Irish Farmers Journal (subscription only, PDF provided); Bowerman 2013 had coverage in NBC News; Allen 2016 had coverage in the Washington Post, Scientific American; Allen 2018 had coverage in FactCheck.org (which checks the veracity of scientific claims made by politicians). A YouTube video independently produced by UC Davis explicitly citing Oxford research has had 109,840 views.