**Institution:**
Bangor University, 10007857

**Unit of Assessment:**
UoA 7 - Earth Systems and Environmental Sciences

**Title of case study:**
Improving the UK agricultural greenhouse gas emissions inventory

**Period when the underpinning research was undertaken:**
2010 - 2020

**Details of staff conducting the underpinning research from the submitting unit:**

| Name(s): | Role(s) (e.g. job title): | Period(s) employed by submitting HEI: |
|---|---|---|
| Professor Dave Chadwick | Professor of Sustainable Land Use Systems | October 2012 - present |
| Dr Prysor Williams | Senior Lecturer in Environmental Management | October 2006 - present |
| Dr David Styles | Lecturer in Carbon Footprinting & Life Cycle | July 2012 - March 2020 |

**Period when the claimed impact occurred:**
2017 - 31 July 2020

**Is this case study continued from a case study submitted in 2014?** N

## 1. Summary of the impact

Bangor University's greenhouse gas (GHG) research has impacted policy and industry through generation of new country-specific nitrous oxide ($N_2O$) emission factors. **Policy**: Bangor's evidence has significantly lowered calculated $N_2O$ contributions in the UK's Agriculture GHG Inventory (since submission year 2016), and informed changes to GHG guidelines at the international level (via inclusion in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories). **Industry**: Bangor research highlighted that enteric methane represents a greater proportion of the UK's total Agriculture GHG Inventory than previously thought and worked with red meat / dairy sectors in Wales to enable co-identification of practical GHG emission mitigation practices.

## 2. Underpinning research

Professor Dave Chadwick co-ordinated the Defra and Devolved Administrations-funded consortium research project **[3.a]** (GBP6,689,724) to more accurately quantify the nitrous oxide ($N_2O$) component of the UK agriculture greenhouse gas (GHG) inventory. Collaborators included Aberdeen University, Agricultural Development and Advisory Service (ADAS), Rothamsted Research, Scotland's Rural College (SRUC), Centre for Ecology and Hydrology (CEH) and the University of East Anglia. This *Inve$N_2$Ory* project (Defra code AC0116) took place during 2010 to 2016 (led from Bangor since 2012). It produced data to underpin the generation of new country-specific $N_2O$ emission factors (EFs) for nitrogen fertilisers, manures, urine and faeces deposited by grazing livestock, for use in the revised inventory. Aberystwyth University co-ordinated a sister project to improve the ruminant methane ($CH_4$) emission factors, whilst ADAS (UK's largest independent agricultural and environmental consultancy) led a project to synthesise the data and generate the new agriculture inventory model. Together, these three projects made up the UK GHGPlatform.

The *Inve$N_2$Ory* research project comprised 37 field experiments throughout the UK, using replicated plots to determine $N_2O$ EFs from nitrogen fertiliser (including different fertiliser types,

specifically urea and ammonium nitrate), different manure types, plus dung and urine deposited by grazing livestock, that better reflect the soils, climates and nitrogen management of the UK. The effects of season of application/deposition and methods of manure application on $N_2O$ EFs were assessed. Chadwick et al. also tested several $N_2O$ mitigation methods, e.g. use of the nitrification inhibitor, dicyandiamide (DCD), and splitting fertiliser doses into more frequent smaller amounts (to improve N use by the crop) **[3.1]**. In partnership with the five research groups involved in the field measurements, Chadwick developed a common sampling protocol for the chamber methods for measuring $N_2O$ fluxes **[3.2]**, thereby contributing to the *Nitrous Oxide Chamber Methodology Guidelines*, which are the internationally agreed reference guidelines for measuring $N_2O$ emissions using chamber methodologies. Chadwick recently contributed to a revision of this guideline document, specifically the Chapter on '*Sources of variability of $N_2O$ fluxes'*, subsequently published in a series of research papers in *Journal of Environmental Quality* in 2020 **[3.3]**.These guidelines are key to producing improved quality of $N_2O$ flux measurement data worldwide and better inter-comparability amongst international studies that are vital to improved understanding of the key factors controlling $N_2O$ EFs from different nitrogen sources.

Many of the individual site experiments have been published, but importantly several papers have synthesised the $N_2O$ EFs from the different N sources **[3.1, 3.4, 3.5]**. The revised $N_2O$ EFs from the project were combined with several additional datasets, and the new $N_2O$ EFs for fertiliser to arable soil ($EF_1$), urine to grassland ($EF_{3PRP}$), manure to arable and grassland ($EF_1$), and 'Pasture, Range and Paddock' ($EF_{3PRP}$) for excreta deposited by grazing livestock, were all significantly less than the IPCC default values for N applications ($EF_1$).

Bangor researchers (Dr Prysor Williams, Dr David Styles and Chadwick) have coordinated collaborative research activities and knowledge exchange with the livestock industry in Wales. The research co-identified suitable Carbon-Footprinting tools for benchmarking individual farms, and ranking the practicalities and costs of bundles of mitigation options to reduce net GHG emissions. These are critical to enable Welsh Government and the livestock sector to better track and reach GHG emission reduction targets (via the Welsh Government-funded Climate Smart Agriculture Wales project, led by Aberystwyth University in partnership with Bangor) **[3.b, 3.6]**. Styles is an expert in Carbon Footprinting and Life Cycle Assessment for land use.

## 3. References to the research

### Research outputs

3.1 Bell, M. J., Winning, N., Rees, R. M., Cloy, J. M., Topp, K., Cardenas, L., Donovan, N., Scott, T., Webster, C., Whitmore, A., Williams, J., Balshaw, H., Paine, F., and **Chadwick, D.** (2015) Nitrous oxide emissions from fertilised UK arable soils: Fluxes, emission factors and mitigation. *Agriculture, Ecosystems & Environment* **212**, 134–147. DOI (Peer-reviewed journal article)

3.2 **Chadwick, D. R.**, Cardenas, L., Misselbrook, T. H., Smith, K. A., Rees, R. M., Watson, C. J., McGeough, K. L., Williams, J. R., Cloy, J. M., Thorman, R. E., and Dhanoa, M. S. (2014) Optimizing chamber methods for measuring nitrous oxide emissions from plot-based agricultural experiments. *European Journal of Soil Science* **65**, 295–307. DOI (Peer-reviewed journal article)

3.3 Charteris, A. F., **Chadwick, D. R.**, Thorman, R. E., Vallejo, A., de Klein, C. A., Rochette, P. and Cárdenas, L. M. (2020) Global Research Alliance $N_2O$ chamber methodology guidelines: Recommendations for deployment and accounting for sources of variability. *Journal of Environmental Quality*, **49**(5), 1092–1109. DOI (Peer-reviewed journal article)

3.4 Cardenas, L. M., Bhogal, A., **Chadwick, D. R.**, McGeough, K., Misselbrook, T., Rees, R. M., Thorman, R. E., Watson, C. J., Williams, J. R., Smith, K. A., and Calvet, S. (2019) Nitrogen use efficiency and nitrous oxide emissions from five UK fertilised grasslands. *Science of the Total Environment,* **661**, 696–710. DOI (Peer-reviewed journal article)

3.5 **Chadwick, D. R.**, Cardenas, L. M., Dhanoa, M. S., Donovan, N., Misselbrook, T., Williams, J. R, Thorman, R. E., McGeough, K. L., Watson, C. J., Bell, M., Anthony, S. G., and Rees, R. M. (2018) The contribution of cattle urine and dung to nitrous oxide emissions: quantification of country specific emission factors and implications for national inventories. *Science of the Total Environment,* **635**, 607–617. DOI (Peer-reviewed journal article) Submitted to REF2021 (REF identifier UoA7_102)

3.6 Kipling, R. P, Taft, H. E., **Chadwick, D. R.**, **Styles, D.**, and Moorby, J. (2019) Implementation solutions for greenhouse gas mitigation measures in livestock agriculture: A framework for coherent strategy. *Environmental Science and Policy* **101**, 232–244. DOI (Peer-reviewed journal article)

**Grants**

3.a **Chadwick, D. R.** (2010–2016) *InveN$_2$Ory project*. Defra and Devolved Administrations (DAs) AC0116, GBP6,689,724 (Bangor University: R37C02)

3.b Newbold, J., **Chadwick, D. R.**, and **Styles, D.** (2017–2019) *Climate Smart Agriculture Wales*. Welsh Government c80970, GBP68,543 (Bangor University: R37G26)

## 4. Details of the impact

### Overview

Bangor's greenhouse gas (GHG) research has generated substantial impact on UK / international GHG **policy** and UK **industry**. The underpinning evidence provided by Bangor-led research has been synthesised with additional datasets to generate UK country-specific $N_2O$ emission factors (EFs) for different fertilisers, manures, and urine and dung deposited by grazing livestock (cattle and sheep), resulting in many of these new EFs being much lower than the Intergovernmental Panel on Climate Change (IPCC) default $N_2O$ EFs that the UK had previously been using **[5.1]**. This research led to key changes in the EF calculation informing the UK GHG inventory and IPCC policy guidelines.

### UK agriculture greenhouse gas inventory

The impact of these new Bangor-generated EFs on the reported UK agriculture greenhouse gas inventory emission for the 2016 submission (activity data year 2013) under the Framework Convention on Climate Change **[5.2]**, was a reduction by approximately 11.6% (i.e. from 49.2Mt$CO_2$e to 43.5Mt$CO_2$e). Since then, these new EFs have been used to generate a more sophisticated $N_2O$ emissions estimate that accounts for the influence of factors such as rainfall. This has resulted in a greater reduction in the inventory estimate, by approximately 18.5% (9.1Mt$CO_2$e) compared with default EF methodology. The largest contribution to this reduction has been the reduction in $N_2O$ emission estimates from soils, by approximately 30% (for 2013) **[5.2]**. Since the calculated methane ($CH_4$) emissions from enteric and manure management sources have only been decreased by approximately 4.5%, Bangor-led research has further highlighted the high relative contribution of GHG emissions from ruminant $CH_4$ **[5.2]** with implications for policy and industry to prioritise strategies to reduce this challenging source of emissions. Another significant impact of the research is that a lower total agriculture GHG emission means that a greater proportion of emissions can be offset by increases in carbon sequestration, improving the UK's ability to reach the 2050 target of net zero carbon.

Through Bangor's research, the introduction of the UK country-specific EF (for grazing livestock) has had the most impactful effect, with the *InveN$_2$Ory* project data resulting in a 75% reduction in the IPCC default $N_2O$ EF for cattle, from 2% of applied/deposited N (lost as $N_2O$-N) to 0.44% **[5.2]**. The result was a reduction in estimated total $N_2O$ emission from the excreta of grazing livestock from 15.62kt$N_2O$/year to 4.21kt$N_2O$/year, for the year 2013. These new data also contributed significantly to the 2019 Refinement of the 2006 IPCC Guidelines (see below).

### International greenhouse gas inventories

Bangor's research has influenced policy in many countries. Specifically, the *InveN$_2$Ory* project team have been requested by international groups to advise on improving estimates in their National Agriculture Greenhouse Gas Emissions. The countries specifically requesting Bangor's assistance in improving the $N_2O$ component of their inventories were:

- Chile (2016): Chadwick and the team trained 4 Chilean technicians and researchers, and 1 policy advisor in appropriate experimentation, inventory calculations, emission factors derivation, and greenhouse gas modelling, via the Newton Picarte, Institutional Skills Development project, *Improving the Greenhouse Gas Inventory for Agriculture in Chile*,

between INIA (Instituto de Investigaciones Agropecuarias, Chile), Bangor University (Chadwick) and Rothamsted Research **[5.3]**.
- Denmark: Chadwick is an invited expert advisor on a 3-year Danish Administration-for-Agriculture funded project (2019 to 2022) *Developing national emission factors for nitrous oxide from nitrogen fertilisers and crop rotations (NATEF)*.

***2019 IPCC Guidelines***

International impact of the Bangor-led research was achieved via the 2019 Refinement of the 2006 IPCC Guidelines **[5.4]**, which cites this research in its method modification for accounting for $N_2O$ emissions from urine and dung deposited by grazing livestock. The 2019 IPCC Guidelines used Bangor-led research evidence to support the case for disaggregating the combined grazing excretal $N_2O$ EF by separating $N_2O$ EFs for urine and dung. This resulted in a much-reduced EF (comprising 0.77% for urine and 0.13% for dung, which are close to the average reported by Bangor of 0.69% for urine and 0.19% for dung), compared with the combined $N_2O$ EF of 2% (for cattle) in the previous 2006 IPCC Guidelines. Moreover, data from the Bangor-led experimental research with real and artificial urine treatments were used by IPCC to confirm the use of artificial urine studies within the analysed dataset enabling an additional 63 observations (out of a total 326) to be included in the statistical analysis to derive the urine $N_2O$ EF **[5.4]**.

Bangor's research will impact on the annual Agriculture GHG inventories of all countries using the Tier 1 $EF_{3PRP}$ when submitting to the United Nations Framework Convention on Climate Change (via their compliance with the updated 2019 IPCC guidelines). Ultimately, all Carbon-Footprinting tools will also be modified to take account of the improved $N_2O$ EF resulting from Bangor-led research.

**UK Livestock Industry**

Impact on the Welsh Government (WG) and Welsh livestock industry has been via parallel engagement through knowledge exchange by the Bangor staff in this research group (Williams, Styles and Chadwick). Working with WG, *Hybu Cig Cymru* (Meat Promotion Wales) and the Agriculture and Horticulture Development Board, Bangor research co-identified and costed practical strategies for reducing GHG emissions from, and carbon sequestration within, Welsh farms via the Climate Smart Agriculture-Wales project **[5.5]**. Resulting impact was achieved by raising awareness of the potential levels of greenhouse gas mitigation across the meat and dairy sectors, and by co-producing a Welsh Government report reviewing the most appropriate Carbon-Footprinting tool to roll out across Welsh livestock farms **[5.6]** for future bench-marking.

Bangor's research **[3.b, 3.6]** informed the WG's multidisciplinary approach to the agriculture sector's contribution to the challenge of meeting Wales' national Carbon Budgets. Reflecting the close integration with this policy process, Williams was asked by WG to present this approach to the UK Climate Change Commission (the independent statutory advisory body for UK and devolved governments), which received positive feedback from the Commission. This culminated in Bangor's invitation to contribute to Hybu Cig Cymru's "Sustainability roadmap" for the red meat sector in Wales, outlining which strategies need to be implemented so that GHG emission-reduction targets are met by the Welsh livestock sector for the period 2020 to 2050.

**5. Sources to corroborate the impact**

5.1 **Testimony: Farming Science Programme Manager / Defra lead funder of UK GHG Platform** and hence *Inve$N_2$Ory* project (participant in the impact process) testifies how pivotal this Chadwick-led research project was in adjusting the UK Agriculture GHG Inventory.

5.2 **UK agriculture greenhouse gas National Inventory Report (NIR) 2016 submission** (activity data year 2013) Defra project AC0116 (led by Chadwick at Bangor from 2012) is credited as the source of the new $N_2O$ EFs in this report on p67, 334, 340 and 341 (Citation: Brown, P., Broomfield, M., Buys, G., Cardenas, L., Kilroy, E., MacCarthy, J., Murrells, T., Pang, Y., Passant, N., Ramirez Garcia, J., Thistlethwaite, G., and Webb, N. (2016) UK Greenhouse Gas Inventory, 1990 to 2014. Annual Report for Submission under the Framework Convention on Climate Change. Main report pp. 1-569. ISBN 978-0-9933975-1-6. Annexes pp. 569-889)

https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1605241007_ukghgi-90-14_Issue2.pdf

5.3 **Report of collaborative training sessions (2016) for Chilean** technicians/researchers in experimentation, inventory calculations, emission factors derivation, and greenhouse gas modelling, via the Newton Picarte, Institutional Skills Development project, *Improving the Greenhouse Gas Inventory for Agriculture in Chile*, with Chadwick (Bangor) providing the training. This source is in Spanish.
https://www.inia.cl/wp-content/uploads/2016/09/revista_infortambo_AGOSTO_2016.pdf

5.4 **2019 Refinement of the 2006 IPCC Guidelines (2019)** Annex report cited $N_2O$ EF data from the 15 Bangor-led urine/dung experiments **[3.5]**, used to modify the method for accounting for $N_2O$ emissions from urine and dung deposited by grazing livestock (in Chapter 11 (Volume 4): $N_2O$ emissions from managed soils, and $CO_2$ emissions from lime and urea application, page 11.11 (and Table 11.1) and page 11.41 (and Table A4.1))
CHAPTER 11 (iges.or.jp)

5.5 **Testimony: Industry Development and Relations Manager at Hybu Cig Cymru** (participant in the impact process) *Hybu Cig Cymru* corroborates the importance of Bangor University's wider links with industry to align the expectations of the effect of farmer-preferred (practical and affordable) GHG mitigation methods with the level of mitigation actually required, and hence the need to adopt less practical and more expensive mitigation strategies to make a greater impact on GHG mitigation.

5.6 **Welsh Government Project Report** (2018) (co-produced by the Institute of Biological, Environmental and Rural Sciences (IBERS), Aberystwyth University) reviewed the suitability of Carbon-Footprinting tools for adoption across Welsh livestock farms (Citation: Taft, H., Chadwick, D., Styles, D., Kipling, T., Newbold, J., and Moorby, J. (2018). A review of greenhouse gas calculators for use in the Welsh agricultural sector. Climate Smart Agriculture Wales Report. pp.79).