Institution: University of Edinburgh / Scotland's Rural College		
Unit of Assessment: 6		
Title of case study: F: Refined greenhouse gas reporting informs policy and mitigation measures to reduce emissions from agriculture		
Period when the underpinning research was undertaken: 2010 – 2015		
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:**
Bob Rees	Head of Carbon Management	1987 – present
Vera Eory	Climate Change Researcher	2011 – present
Kairsty Topp	Agricultural Systems Modeller	1991 – present
Madeleine Bell	Lecturer in Environmental Management	2012 – present
Stephanie Jones	Soil Researcher	2007 – present
Bruce Ball	Soil Researcher/Reader	1978 – 2018
Joanna Cloy	Soil Researcher/Lecturer	2011 – present
Dominic Moran	Chair of Agricultural and Resource Economics	1999 – present
Period when the claimed impact occurred: 2017 – 2020		
Is this case study continued from a case study submitted in 2014? N.		

1. Summary of the impact

Underpinning Research: Research underpinning greenhouse gas (GHG) emission calculations has improved the accuracy of estimates from UK agricultural systems and showed soil-derived emissions of nitrous oxide (N_2O) are lower than previously estimated.

Significance and Reach of Impact: Improved understanding of the sources of agricultural GHGs allows targeted control measures aimed at reducing overall emissions. Our research made an important contribution to the UK and Scottish Government's development of GHG mitigation support policies (Committee on Climate Change report 2019; the Scottish Climate Change Plan 2018). As a result, the developed policies focus more on mitigating methane (CH_4) emissions from livestock production rather than N_2O soil-derived emissions. Internationally, our research has informed the United Nations' Intergovernmental Panel on Climate Change GHG reporting guidelines and been adopted by the United Nations Framework Convention on Climate Change .

2. Underpinning research

The Challenge: Develop understanding of the sources of agricultural GHG emissions and improve emission inventory reporting.

The UK Climate Change Act (2008, amended 2019) sets legally binding restrictions on total greenhouse gas (GHG) emissions. Progress towards these targets is assessed against the annual UK-GHG inventory. The United Nations' Intergovernmental Panel on Climate Change (IPCC) guidelines allow the UK-GHG inventory to be updated with improved data, analysis and estimates of Emission Factors (EFs) since 2017. High accuracy reporting is important to enable effective mitigation measures and policies.

Considerable uncertainty has surrounded the portion of agricultural GHGs attributed to nitrous oxide (N_2O) in the UK-GHG inventory. We have developed a unique, integrated, and interdisciplinary research programme to improve the accuracy of GHG-UK reporting and influence policy priorities to deliver future "low-carbon" farming systems. By accounting for UK-specific climatic, geographical, and farming practices we have refined GHG reporting at national and devolved levels. Most notably, this work has shown that soil-derived emissions of N_2O are lower than previously calculated (prior to 2016) but estimates for CH_4 emissions remain unchanged. Consequently, we showed CH_4 accounts for a greater proportion of overall agricultural GHG emissions in the UK than previously thought.

A UK-specific method for increasing the precision of GHG emissions factors.
Our research played a leading role, managing 7 of 37 national experiments (resulting in 12 peer reviewed publications) in the multi-disciplinary, collaborative GHG Platform Research Programme which involved 15 UK research groups. We received more than GBP5,000,000 between 2011 and 2015 from funders including the UK Government's Department for Environment, Food and Rural Affairs (Defra), the Biotechnology and Biological Sciences Research Council, the Natural Environment Research Council, the European Union, and the Scottish Government to support research on GHG reporting. By leading the national programme of field experimentation, we provided evidence for a UK-specific method of calculating emissions of N_2O. Unlike previously used methods, our new emissions model takes account of soil type, fertiliser, and rainfall, and has now been incorporated into the most recent inventory reporting on N_2O emissions from 2016 onwards first reported in 2018 [3.1-3.4].

To allow national comparison and validation of results collected using our new UK-specific method for calculating N_2O emissions, we developed new measurement approaches using chamber measurements [3.1] and harmonised approaches to experimentation and data analysis to improve estimates of GHG emissions [3.1]. This is important because of the high global warming potential of N_2O (298 times that of CO_2). Research on N_2O emissions has been developed in a series of papers published between 2016 and 2019 [3.2-3.4] and demonstrates that newly calculated emissions fall well below previously published estimates. For example, the EF for urine of grazing livestock was reduced from the previous inaccurate estimate of 2% to our improved estimate of 0.44% [5.1c]. N_2O emissions from soils are now 40% lower across the time series from 1990 than were reported prior to our research.

Integration of emission estimates with economic and social impacts of interventions to support policy interventions.
Using our estimates in national level GHG Marginal Abatement Cost Calculations (MACCs) has supported development of UK Carbon Budgets and the Net Zero goals. Our developments in GHG MACCs include a method to account for other pollutants such as ammonia, phosphorus, and sedimentation [3.5] and for uncertainty of the calculations [3.6].

3. References to the research

[3.1] D.R. Chadwick, L. Cardenas, T.H. Misselbrook, K.A. Smith, R.M. Rees, C.J. Watson, K.L. McGeough, J.R. Williams, J.M. Cloy, R.E. Thorman, M.S. Dhanoa, 2014. Optimizing chamber methods for measuring nitrous oxide emissions from plot-based agricultural experiments Eur. J. Soil Sci., 65 (2014), 295-307 doi:10.1111/ejss.12117

[3.2] Bell, M. J., Cloy, J. M., Topp, C. F. E., Ball, B. C., Bagnall, A., Rees, R. M., & Chadwick, D. R. (2016). Quantifying N_2O emissions from intensive grassland production: the role of synthetic fertilizer type, application rate, timing, and nitrification inhibitors. J. Ag. Sci., 154(5), 812-827. doi:10.1017/S0021859615000945

[3.3] 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. Sci. Tot. Env., 635, 607-617. doi:10.1016/j.scitotenv.2018.04.152

[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. Sci. Tot. Env, 661, 696-710. doi:10.1016/j.scitotenv.2019.01.082

[3.5] V Eory, CFE Topp, D Moran, 2013. Multiple-pollutant cost-effectiveness of greenhouse gas mitigation measures in the UK agriculture Env. Sci. & Pol., 27, 55-67 doi:10.1016/j.envsci.2012.11.003

[3.6] V Eory, CFE Topp, A Butler, D Moran 2018 Addressing uncertainty in efficient mitigation of agricultural greenhouse gas emissions. J. Ag. Econ., 182, 705-716. doi:10.1111/1477-9552.12269

4. Details of the impact

Pathways to impact

Our work to improve Emission Factor (EF) accuracy estimates has directly informed UK and Scottish Governments, through providing evidence for developing GHG mitigation support policies. As a result of our work, CH_4 contribution to agricultural emissions is recognised as higher than previously calculated (54% versus previously estimated 48%), so policies have been developed to increase focus on mitigating emissions from livestock production rather than from soil [5.1a]. Internationally, our research has fed into the IPCC GHG reporting guidelines [5.2] and been adopted by international reporting of GHG emissions to the United Nations Framework Convention on Climate Change (UNFCCC) [5.1c]. The improved EF accuracy has directly impacted the farming industry through advisory support and policies developed in the Scottish Government's Climate Change Plan [5.3]. In addition, providing a mechanism by which our above described research can directly impact farming practice, we developed a tool, AgRECalc©, that determines on-farm resource efficiency and emissions to help the farming industry lower its carbon footprint [5.4a, b].

Impact on UK GHG reporting and carbon budgets

Our experimental, modelling and synthesis research formed a pivotal role in GHG emissions reporting and was commended by the UK national emissions inventory team [5.3b]. As a result of our lead research on the GHG Platform programme and EF calculations, estimates of UK agricultural emission have become more accurate, and these more accurate estimates are now incorporated into annual reporting in the National Inventory [5.1]. Our more detailed methodology better reflects environmental conditions and management practices and has allowed the UK to adopt more detailed reporting, moving from IPCC defined Tier 1 to Tier 2 reporting [5.1].

Owing to this higher reporting Tier, the UK's reports of agricultural GHG emissions were reduced by 5.7MtCO_2e/year (via lowered N_2O emissions), compared with the previous IPCC default methodology. This reduction equates to a 11.6% reduction in agricultural emissions in the 2016 inventory report compared to the 2015 inventory figures. The implications for policy and industry of our improved method and the reduced emission estimates places greater emphasis on reducing other GHG sources such as ruminant CH_4 emissions [5.5d].

Our GHG research has provided information on the potential mitigation in UK agriculture and the cost-effectiveness of mitigation methods to the Committee on Climate Change (CCC) [5.5 a, b]. The CCC used our results in their carbon budget recommendations, which in turn form the basis of UK Carbon Budgets including those published at the end of 2020 [5.5 c, d] and set the target date earlier for the net zero target in the Climate Change (Scotland) Act 2009 [5.3a]. At a UK level, our analysis has identified that there is the potential for cost-effective mitigation of 7.1MtCO_2e/year by 2035, in work that has been referenced by the CCC Sixth Carbon Budget [5.5d]. Research results also informed Scotland's Climate Change Plan, which sets out the planned policies to achieve the climate targets [5.3a & b], and influenced policies on nutrient management, soil testing, livestock management and precision farming [5.3].

Impact on economy through footprint calculator

Our research has driven the development and improved design of an on-farm GHG calculator tool (AgRECalc©) [5.4], that calculates resource use and GHG emissions for the whole farm, per enterprise and per unit of saleable product. AgRECalc© has been used to footprint more than 4,000 farms with clients including major retailers Morrisons and Waitrose, providing farm

enterprises with detailed information on emission sources and approaches to mitigation as well as benchmarking against similar enterprises. The calculators allowed farms to reduce costs by an average of GBP10,000 per year while achieving approximately 10% reductions in farm carbon footprint and has generated GBP52,000 of commercial income to SRUC in 2019/20 [5.6].

Impact on agri-environmental policies

Our GHG mitigation work contributed to the UK and Scottish Governments' development of new carbon budgets and agri-environmental policies [5.7]. AgRECalc© is freely available on the internet and was deployed by SAC Consulting together with the wider farming community, through the Farming For a Better Climate (FFBC) policy programme, established by Scottish Government (2010). A 2018 evaluation of FFBC by the Scottish Government showed that a mixed farm in Perthshire was able to achieve a financial saving of around GBP11,000 per annum and a 10% decrease in the farm's carbon footprint by using the footprint calculator [5.8]. The programme is running in its third phase (2010-2013, 2014-2017, 2018-2021), with a cumulative investment of approximately GBP2,000,000 [5.3a]. AgRECalc© has also influenced Scottish Government climate change policy by supporting the Beef Efficiency Scheme (BES, 2018), which aims to support beef breeders to improve their efficiency, sustainability, and quality of their livestock [5.6].

5. Sources to corroborate the impact.

[5.1] Contribution to the United Nations Framework Convention on Climate Change (UNFCCC).
a. Published report documenting the United Kingdom's National Inventory Report (NIR) submitted in 2016.
b. Published report documenting United Kingdom's National Inventory Report (NIR) submitted in 2020.
c. Progress Report to Parliament for the Committee on Climate Change documenting improvements to method and the research underpinning new emissions estimates in The Smart Agriculture Inventory implemented in 2018.

[5.2] Published report: 2019 Refinement to IPCC Guidelines for National Greenhouse Gas Inventories.

[5.3] Impact on Scottish Government Climate Change Plan.
a. Published Report: Scottish Government Climate Change Plan.
b. A letter from the Economic Advisor at the Scottish Government endorsing SRUC's role informing the Scottish Government Climate Change Plan.

[5.4] AgRECalc©
a. Published scientific paper comparing greenhouse gas calculators including AgRECalc©: Sykes, A.J., Topp, C.F.E., Wilson, R.M., Reid, G. and Rees, R.M. 2017 A comparison of farm-level greenhouse gas calculators in their application on beef production systems. J. Clean. Prod. 164, 398-409. doi: 10.1016/j.jclepro.2017.06.197.
b. AgreCalc website

[5.5] Impact on UK carbon budget policy through the Climate Change Committee (CCC).
a. Published report on developing a low-carbon economy.
b. Published report describing the UK's contribution to stopping global warming.
c. A letter from the Senior Analyst at the Climate Change Committee (CCC) describing how SRUC's research informed the carbon budget development work in the CCC.
d. Published report summarising the CCC's Sixth Carbon Budget Advice, Methodology and Policy reports.

[5.6] A letter from the Principal Consultant at SAC Consulting endorsing the application of SRUC's research on industry, informing farms and their associated retailors of emission sources and approaches to mitigation.

[5.7] Published paper reviewing Marginal abatement cost curves for agricultural climate policy engineering agricultural MACCs developed in European countries:
Eory, V., Pellerin, S., Carmona Garcia, G., Lehtonen, H., Licite, I., Mattila, H., Lund-Sørensen, T., Muldowney, J., Popluga, D., Strandmark, L. & Schulte, R. (2018) Marginal abatement cost curves for agricultural climate policy: State-of-the art, lessons learnt and future potential. Journal of Cleaner Production, 182, 705-716. doi: 10.1016/j.jclepro.2018.01.252

[5.8] A webpage showing a Farming for a Better Climate (FFBC) case study on Glenilrie Farm in Perthshire. Archived24/11/2020