Land Use Policy 49 (2015) 394–403

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Developing farm-specific marginal abatement cost curves: Cost-effective greenhouse gas mitigation opportunities in sheep farming systems

A.K. Jones*, D.L. Jones, P. Cross

School of Environment, Natural Resources and Geography, Bangor University, Gwynedd LL57 2UW, UK

ARTICLE INFO

Article history:
Received 24 October 2014
Received in revised form 3 August 2015
Accepted 6 August 2015

Keywords:
Agricultural emissions
Red meat
Climate change
Carbon footprint
Global warming
IPCC

ABSTRACT

Growing demand for agricultural produce, coupled with ambitious targets for greenhouse gas emissions reduction present the scientific, policy and agricultural sectors with a substantial mitigation challenge. Identification and implementation of suitable mitigation measures is driven by both the measures' effectiveness and cost of implementation. Marginal abatement cost curves (MACCs) provide a simple graphical representation of the abatement potential and cost-effectiveness of mitigation measures to aid policy decision-making. Accounting for heterogeneity in farm conditions and subsequent abatement potentials in mitigation policy is problematic, and may be aided by the development of tailored MACCs. Robust MACC development is currently lacking for mitigation measures appropriate to sheep systems. This study constructed farm-specific MACCs for a lowland, upland and hill sheep farm in the UK. The stand-alone mitigation potential of six measures was modelled, against real farm baselines, according to assumed impacts on emissions and productivity. The MACCs revealed the potential for negative cost emissions' abatement in the sheep industry. Improving ewe nutrition to increase lamb survival offered considerable abatement potential at a negative cost to the farmers across all farms while, lambing as yearlings offered negative cost abatement potential on lowland and upland farms. The results broadly advocate maximising lamb output from existing inputs on all farm categories, and highlight the importance of productivity and efficiency as influential drivers of emissions abatement in the sector. The abatement potentials and marginal costs of other measures (e.g. reducing mineral fertiliser use and selecting pasture plants bred to minimise dietary nitrogen losses) varied between farms, and this heterogeneity was more frequently attributable to differences in individual farm management than land classification. This has important implications for the high level policy sector as no two farms are likely to benefit from a generic one size fits all approach to mitigation. The construction of further case-study farm MACCs under varying farm conditions is required to define the biophysical and management conditions that each measure is most suited to, generating a more tailored set of sector-specific mitigation parameters.

1. Introduction

It is estimated that agriculture produces approximately 10–12% of global anthropogenic greenhouse gas (GHG) emissions (Smith et al., 2014). Corresponding figures for England and Wales are 7.6% and 12.9% of GHG emissions, respectively (Salisbury et al., 2013). As an important source of emissions, the agricultural sectors in England and Wales are required to contribute to the UK commitment of reducing total national GHG emissions by 80% by 2050 (from 1990 levels) under the Climate Change Act 2008 (DECC, 2011). Agricultural emissions are dominated by methane (CH_4) emitted largely as a by-product of feed fermentation in ruminant animals, and nitrous oxide (N_2O) primarily produced from soils in response to fertiliser application and excreta deposition (Edwards-Jones et al., 2009; Salisbury et al., 2013). The first and last of these can be primarily attributed to ruminant livestock production.

Mitigation measures (MMs) with potential to abate emissions from ruminant farm systems are well documented (e.g. Eckard et al., 2010; Gill et al., 2010; Jones et al., 2014a), and conceptually, the research and policy drivers needed to deliver emissions' abatement at the farm-level are well understood. Such drivers are founded upon an evidence-base that enables the selection of effective MMs based upon their lifecycle GHG impacts and costs, alone and in combination with other MMs, for a range of farm

* Corresponding author. Fax: +44 1248 354997.
E-mail address: a.k.jones@bangor.ac.uk (A.K. Jones).

http://dx.doi.org/10.1016/j.landusepol.2015.08.006
0264-8377/

baselines and conditions (Jones et al., 2013). Beyond the selection of effective MMs, policy must promote implementation through regulation, provision of information and financing (Stern et al., 2006). Despite this conceptual understanding, evidence on abatement potentials, costs and policy mechanisms for implementation remains fragmentary. The challenge of reducing emissions from this sector is compounded by its heterogeneous nature. Farm productivity, emissions and abatement potential vary spatially and temporally in relation to biophysical and management conditions (Beach et al., 2008). Furthermore, calculations of abatement potential must account for all carbon dioxide (CO_2), CH_4 and N_2O fluxes and the interactions between them (Schils et al., 2005; Stewart et al., 2009).

Whole-farm GHG models provide a representation of complex farm systems, their material and nutrient flows and related GHG emissions, which allow exploration of the abatement potential of farm-level MMs (Jones et al., 2014a; Schils et al., 2007). A number of studies have used whole-farm models to determine the abatement potential of single or multiple measures applied to case-study or modelled average farms (e.g. del Prado et al., 2010; Schils et al., 2005; Stewart et al., 2009). Consideration of the costs and benefits of MMs assessed in whole-farm models is necessary to facilitate final selection and implementation (e.g. del Prado et al., 2010; Gibbons et al., 2006). Such MMs can be cost-effective per tonne (t) of CO_2 abated in the context of both abatement from other sectors e.g. power and manufacturing (Norse, 2012), and when compared to the damage costs of carbon emissions (Moran et al., 2011).

In the UK, the evidence-base for cost-effective MMs is more developed than in many other countries (Norse, 2012). Moran et al. (2008) constructed marginal abatement cost curves (MACCs) for average sized cereal, mixed and dairy farms in the UK and scaled their results to the national level to inform the development of carbon budgets in climate mitigation policy. They estimated that approximately 17.3% of the UK's agricultural GHG emissions (in 2005) could be abated at a cost of less than £100/t CO_2 equivalents (CO_2e) in 2022, in their central feasible abatement scenario. Sheep farms were excluded from the analysis but several of the top performing MMs possess the potential to reduce GHGs when evaluated in a sheep farm setting. Using the results of this study, Jones et al. (2010) assessed the cost-effective mitigation potential for a range of farm types and sizes, taking into account current uptake levels. Mitigation measures possessing the greatest potential to reduce emissions on beef and sheep farms were: optimum diet formulation, livestock breeding and use of clover. All of which were found to be cost negative (money saving). Marginal abatement cost curves such as those constructed by Moran et al. (2008) are now a commonly used tool in the assessment of MMs for climate policy development (Kesicki and Strachan, 2011).

The first MAC curves, originally called supply curves, were developed by Meier (1982) to assess the cost-effectiveness of residential energy conservation measures. This approach was subsequently adopted to identify cost-effective abatement measures in the fields of air and water pollution (e.g. Braden et al., 1989; Silverman, 1985), and later GHGs (e.g. Nordhaus, 1991). The first agricultural GHG MACCs appeared in around 2000 (e.g. McCarl and Schneider, 2000). Many more have since been constructed; ranging from the farm-level nutrition focussed MACCs of the Institute of Biological, Environmental and Rural Studies (IBERS, 2010) to whole agricultural sector MACCs at a national, European and global level (Beach et al., 2008; De Cara et al., 2005; Wang et al., 2014). An array of methodological approaches exist in the MACC literature, variations include: the system boundary used for GHG modelling; the nature and extent of costs and benefits accounted for and associated choice of discount rate; the treatment of interactions between MMs; and the timescale over which MMs have been applied. Despite these differences in approach, providing assumptions are clear and limitations are communicated, MACCs enable simple interpretation of cost-effectiveness data for the multiple stakeholders involved in climate change policy (Kesicki and Ekins, 2012; Kesicki and Strachan, 2011).

Marginal abatement cost curves provide a graphical representation of the relationship between abatement potential and costs. They can be constructed using either, an "engineering" approach based on modelled abatement potentials and costs for individual MMs, or derived using energy models at the systems level where the introduction of a constraint such as a CO_2 tax leads to emissions' abatement (Kesicki and Strachan, 2011; Vermont and De Cara, 2010). In an engineered MACC, each bar on the graph represents an individual MM. The width of the bars on the *x* axis indicates abatement potential, whilst the height of the bar on the *y* axis indicates the marginal cost of emissions' abatement (e.g. in £/t CO_2e) (Kesicki and Strachan, 2011).

Following the construction of the national agricultural MACCs for the UK, Moran et al. (2011) stated that "*there is merit in deriving more regional and farm specific MACCs*", in order to reflect heterogeneity in abatement potential and costs. Developing tailored MACCs may enable MM recommendations to be refined by farm biophysical and/or management conditions. With this in mind, and given that no sheep farm-focussed MACCs have been constructed to date, this study was undertaken with the aim of constructing farm-specific MAC curves for a lowland, upland and hill sheep farm, indicating the most cost-effective MMs for farms within each land classification category. The sheep industry in England and Wales is characterised by interdependent lowland, upland and hill farm systems, differentiated by harsher climates, poorer quality grazing and lower productivity with increasing altitude (Croston and Pollott, 1985; Goodwin, 1979). This study builds on the previous sheep farm emissions abatement work of Jones et al. (2013, 2014b) which estimated the mean carbon footprint (CF) of finished lamb produced in England and Wales, and identified practical and effective MMs for lamb-producing farms based on expert and farmer opinions. The specific objectives of this study were to:

a use a whole-farm model to estimate the abatement potential of MMs pre-selected by farmers and GHG experts, on case-study lowland, upland and hill sheep farms in England and Wales.
b Calculate the private costs and benefits of the MMs to the farmers.
c Construct a lowland, upland and hill MAC curve that enabled the results to be scaled to other farms.
d Augment the evidence-base on cost-effective MMs applicable to sheep farms, exploring issues of farm heterogeneity and subsequent policy implications.

2. Methods

2.1. Mitigation measure selection

Modelled MMs were based on the selection criteria of Jones et al. (2013). The authors identified a subset of six, considered to be both practical to implement by farmers and effective in reducing emissions by agricultural GHG experts. The measures were aimed at reducing emissions per kg of sheep meat produced, reflecting the importance of expressing emissions per unit of output rather than at the whole-farm level (Franks and Hadingham, 2012). This approach allows consideration of MMs that increase farm productivity and possibly total farm emissions, but crucially reduce emissions per kg of product. The MMs, listed below, are numbered to facilitate referencing throughout:

- include legumes in pasture reseed mix (1).
- Increase lamb growth rates for earlier finishing (2).