Agricultural Systems 123 (2014) 97–107

Contents lists available at ScienceDirect

Agricultural Systems

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

The carbon footprint of lamb: Sources of variation and opportunities for mitigation

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ARTICLE INFO

Article history:
Received 22 February 2013
Received in revised form 2 August 2013
Accepted 20 September 2013
Available online 29 October 2013

Keywords:
Agricultural emissions
Climate change
Global warming
IPCC
Partial lifecycle assessment
Red meat

ABSTRACT

Carbon footprinting can be used to characterise the greenhouse gas emissions profile of agricultural products, providing a baseline against which mitigation targets can be set and progress measured. Farm-level emissions vary in relation to local conditions and management choices. Carbon footprinting models can be used to assess the impact of farm characteristics on emissions; however, the benefits of such models have been underexploited thus far for sheep production. This study estimated the cradle to farm-gate carbon footprints of 64 sheep farms across England and Wales using empirical farm data. This large dataset enabled an assessment of the relationship between farm variables and carbon footprint at a multi-farm level. Mean carbon footprints of 10.85, 12.85 and 17.86 kg CO_2e/kg live weight finished lamb were recorded for lowland, upland and hill farms respectively, from samples with coefficients of variation of 33%, 23% and 34%. Multiple linear regression models indicated that four farm management variables had a significant impact on the size of the carbon footprint of finished lamb. Irrespective of farm category, these were the number of lambs reared per ewe (head/ewe), lamb growth rate (g/day), the percentage of ewe and replacement ewe lamb flock not mated (%), and concentrate use (kg/livestock unit). Dominance analysis indicated that, of these, the number of lambs reared per ewe mated and lamb growth rate were the most influential. Productivity improvements are arguably most problematic for extensive hill farms; however, the top performing hill farms in this study outperformed the mean lowland and upland farms. The results suggest that, at a national level, the emphasis for reducing the carbon footprint of lamb should be on closing the productivity gap between poor and top performing farms.

1. Introduction

Agriculture is responsible for approximately 10% of global anthropogenic greenhouse gas (GHG) emissions (excluding land use change) (Smith et al., 2007). Effective mitigation of such emissions is of increasing concern in research and policy (Garnett, 2009). In order to meet growing global food demands, agricultural intensification and expansion are needed (Foresight, 2011). The successful management of agricultural GHG emissions therefore presents a substantial challenge to the scientific, commercial and policy communities.

Robust and reliable methodologies for estimating and monitoring changes in emission levels are needed to inform the development and delivery of effective agricultural emissions' mitigation strategies (Norse, 2012; Smith et al., 2007). Life cycle assessment (LCA) is an internationally accepted, standardised methodology for quantifying the environmental impact of a product (ISO, 2006a, 2006b). The ISO 14040/44 standards provide a framework for assessing the global warming potential (GWP) of GHG emissions, forming the basis of the carbon footprinting approach. A carbon footprint (CF) provides an estimate of total GHGs emitted during part or all of the life of a good or service (BSI, 2011), expressed as carbon dioxide equivalents (CO_2e). Carbon footprinting is increasingly used in the food supply chain to determine the quantity of GHG emitted at each stage of the production process, and may extend to the distribution and use phases. Recent examples include estimates of the CF of American milk up to the farm gate (Rotz et al., 2010), Australian beef and sheep meat to the point of exiting the meat processing plant (Peters et al., 2010) and exported New Zealand lamb up to and including the consumer use phase (Ledgard et al., 2011).

Carbon footprinting enables carbon labelling of food products to inform sustainable consumer purchasing decisions, and provides an emissions' benchmark against which mitigation targets can be set and progress measured (Edwards-Jones et al., 2009; Plassmann et al., 2010). Such emissions data are reported per unit of produce. Conceptually, this should enable comparisons of the GWP of different food groups, producers and supply chains for the same product. Unfortunately, divergence in methodological approaches between studies often hinders meaningful comparison of calculated CFs (Flysjö et al., 2011). To tackle this issue and provide a consistent

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http://dx.doi.org/10.1016/j.agsy.2013.09.006

methodology for assessing the CF of products, the British Standards Institute (BSI) developed the Publically Available Specification 2050:2008 (PAS 2050) for assessment of the life cycle GHG emissions of goods and services, which was updated in 2011 (BSI, 2011). More recently, international product CF standards have been developed by both ISO (ISO 14067) and the Greenhouse Gas Protocol (Product Life Cycle Accounting and Reporting Standard) (ISO, 2013; World Resources Institute and World Business Council for Sustainable Development, 2011). Whether the development of multiple standards will improve methodological consistency remains to be seen.

Studies estimating the CFs of multiple food groups have shown that red meats are amongst the most emission intensive food products (Williams et al., 2006). Whilst beef and milk have received considerable research interest, the CF of sheep meat has been less well reported in the scientific literature. However, global sheep numbers are expected to increase 60% by 2050 (Foresight, 2011).

The largest sheep farm CF study undertaken in England and Wales estimated the mean CF of sheep production in England only to be 11.86 kg CO_2e/kg live weight (LW) lamb. Typically, the CF of an average or representative system is used to advise decision makers on the environmental impact of a product (Basset-Mens et al., 2009). However, there is increasing recognition that variation between and within farm types should be considered in the development of effective mitigation strategies (Jones et al., 2013).

Two sources of variation in estimates of farm-level CFs have been characterised. These are: (1) variation arising from uncertainties in the data and models employed to calculate the CFs, and (2) natural variation relating to differences in environmental conditions and management practices between farms (Basset-Mens et al., 2009; Henriksson et al., 2011). The former results from imprecise data and uncertainty when modelling the biological processes associated with nitrous oxide (N_2O) and methane (CH_4) emissions, and the latter from variability between farm characteristics and management practices. By refining input data and emission factors (EF), the precision of CF models can be improved both spatially and temporally and uncertainty in the CF estimate reduced (Basset-Mens et al., 2009; Karimi-Zindashty et al., 2012; Payraudeau et al., 2007). Variation between farm CFs may reveal opportunities to reduce emissions through improved management.

A small number of studies have explored how differences in farm variables (particularly in relation to management) can impact the CF of livestock products. One approach is to estimate the CF of a single farm based on empirical or modelled data, and to use sensitivity analyses to determine the impact of changing one or more farm variables (Cruickshank et al., 2008; Taylor et al., 2010). Variability in dairy and beef farm emissions is typically explored by calculating the CF of an average farm (constructed from national datasets) and using Monte Carlo (MC) simulations to vary farm parameters within known limits (Flysjö et al., 2011; Henriksson et al., 2011). For example, Basset-Mens et al. (2009) calculated the average CF per kg of New Zealand milk and used MC simulations to vary the values of key production variables, including milk output and fertiliser application rates, within the range specified in national industry databases. An alternative approach is to analyse the relationship between CF and farm variables across a large sample of farms, based on empirical farm data (Kristensen et al., 2011). This approach captures the true co-variation of farm parameters. No analysis of the relationship between farm variables and sheep farm CFs at a multi-farm or national level appears to have been reported in the scientific literature.

Given the diversity of systems within the English and Welsh sheep industry, a corresponding variation in footprint is to be expected. Farm holdings operate a range of production systems, often dictated by geography and climate. The industry 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). The main product of the industry is meat i.e. fat lamb and mutton (Goodwin, 1979). Output varies significantly between average and top producers (Brown and Meadowcroft, 1990). Wool is now a secondary product in the industry, with the income obtained from wool often insufficient to cover the cost of shearing.

Limited data on the CF of sheep production have been published in the scientific literature. Reported results typically lack depth in terms of the characteristics of the farms footprinted and analyses of the influence of farm variables on the CF. The aim of this study was to calculate the CF of lamb produced on a range of farm types, using empirical data collected from sheep farms across England and Wales. The calculated CFs were then analysed with the objectives of:

1. Providing an emissions breakdown, detailing the greatest sources of emissions.
2. Reporting variation in farm characteristics and analysing the impact of farm category on the CF.
3. Identifying key farm management variables as drivers of footprint size at a national level, and evaluating their potential for mitigation.

2. Methods

2.1. Footprint calculation

Empirical farm data were used to estimate the GHG emissions associated with sheep production on farms in England and Wales. The CFs were calculated using an updated version of the livestock model used by Edwards-Jones et al. (2009) and Taylor et al. (2010), as detailed below. The global warming potentials of emissions were reported relative to CO_2 over a 100 year time horizon where 1 kg CH_4 = 25 kg CO_2e and 1 kg N_2O = 298 kg CO_2e (IPCC, 2007). The functional unit used for reporting emissions was 1 kg of LW finished lamb.

2.1.1. Farm level production data

Sheep farmers were randomly sampled within the categories of lowland and less favoured area (LFA). LFA is a European Union designation for land disadvantaged by its natural characteristics (e.g. by altitude or climate), and is therefore often restricted to extensive livestock production (European Council, 1999). In the UK, LFA land is subdivided into disadvantaged and severely disadvantaged land (DEFRA, 2010), which is used synonymously in this study with upland and hill land, respectively. Lowland, non LFA farms typically have the best physical conditions for farming and are consequently the most productive. Respondents were drawn randomly from two lists, one of Welsh farmers held by Bangor University and one of English farmers held by EBLEX. Carbon footprints were calculated for 64 farms, based on data provided by farmers in face-to-face interviews. However, only 60 datasets were used in the final analyses, as explained in Section 2.2.1.

Farmers provided information on important aspects of their production system including inputs (for example feed, fertiliser and bedding use); stock movements (including purchases, births and housing); outputs (including number and weight of sheep sold) and farm characteristics (including area and soil types). Data were provided for a single year between 2010 and 2011, which the farmer considered representative of a typical production year. The quality of farm level data is sometimes questioned (e.g. Crosson et al., 2011) therefore written farm records such as stock movement books were used to verify important data elements.