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Can UK livestock production be configured to maintain production while meeting targets to reduce emissions of greenhouse gases and ammonia?

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ABSTRACT

We used a Life Cycle Assessment approach to determine whether the inherent differences in emissions to air among existing livestock production systems could be used to reconfigure the UK livestock sector in order to meet current greenhouse gas (GHG) and ammonia (NH_3) targets while maintaining production at current levels. Output, defined as financial value, was optimized across all sub-sectors. Using current management systems the greatest livestock output that could be maintained, while meeting emission reduction targets, was 84% of current. Adopting the most appropriate manure management practices and improved feed conversion ratio enables a further increase in outputs to 86% of current. Dairy production could be maintained at 84.1% of current if all production arises from high-yielding herds with autumn calving, all dairy cow manure is managed as slurry and diets to reduce rumen fermentation are adopted. Increasing the proportion of calves obtained from the dairy herd by 10% could maintain beef production at 85% of current. Raising finishing pigs on slurry systems, raising sows and weaners outdoors, finishing pigs at either 89 or 99 kg and improving dietary nitrogen use efficiency could maintain pig production at 87.5% of current. Manure drying within poultry buildings, immediate incorporation of poultry manures to tillage land and reduced protein feeds would allow 82.2% of current poultry meat production. Eliminating free-range egg systems and drying manure within the building could maintain egg production at 85.5% of current. Replacing lowland sheep herds (other than organic) with upland production could maintain sheep output at 86.4% of current.

1. Introduction

The 2008 Climate Change Act requires the UK to reduce greenhouse gas (GHG) emissions by 80% from 1990 levels by 2050. The agriculture sector will need to reduce annual emissions in England by 3 Mt of carbon dioxide equivalents (CO_2e) by the third carbon budget period (2018–2022) under the Government's 2009 Low Carbon Transition Plan. The EU Directive setting National Emissions Ceilings (Directive 2001/81/EC, NECD) set the UK national ammonia (NH_3) emission target as 297 t x 10^3 per year by 2010 (compared with 360 t $\times$ 10^3 in 1990). Agriculture accounts for *c.* 80% of the UK's national emissions of NH_3, with 86% of the agricultural total coming from livestock production (Choudrie et al., 2008).

Practical and effective techniques to reduce GHG emissions from UK agriculture and their cost-effectiveness were summarised by Anon. (2007a), while Webb et al. (2005, 2006) summarised UK approaches to reduce emissions of NH_3. Although the potential for increased costs and/or reduced production has been recognised in earlier work, the impacts on total national production from adopting abatement techniques have not been fully evaluated for the UK livestock industry. Moreover, the adoption of specific abatement techniques is not the only option for reducing emissions. Among existing production systems there are inherent differences in emissions, e.g. between:

- Manure managed as liquid slurry or litter-based farmyard manure (FYM).

Abbreviations: CO_2e, CO_2-equivalent; CP, crude protein; EAA, essential amino acids; EF, emission factor; FCR, feed conversion ratio; FYM, farmyard manure; GHG, greenhouse gas; GWP, global warming potential; IPCC, Intergovernmental Panel on Climate Change; LP, linear programming model; NAEI, National Atmospheric Emissions Inventory; NH_3, ammonia; NUE, N use efficiency; TAN, total ammoniacal-N.

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- Pigs raised outdoors or within buildings.
- Upland and lowland beef and sheep.

Since these systems are currently in commercial use, identifying and adopting those that produce the least emissions might be an effective means of reducing emissions while maintaining production.

In this study, we quantified systematic differences in gaseous emissions among production systems in use at the time of the study in order to assess the extent to which UK livestock production could be maintained, while reducing GHG and NH_3 emissions to meet emission reduction targets, by switching to those existing production methods that emit less GHG or NH_3. We then assessed the impact of adopting cost-effective abatement techniques on production.

The output from this exercise is an estimate of the greatest productivity, in terms of physical output and financial value of production, for each livestock sub-sector (Dairy, Beef, Pigmeat, Poultry meat, Eggs and Sheep) that can be achieved for the UK livestock sector as a whole, whilst reducing GHG and NH_3 emissions from the livestock sector. We also maximised outputs as the production of livestock protein and the total energy content of livestock produce. Since UK targets are applied at the agricultural sector level we considered an emission limit for the whole livestock industry and optimized sub-sectors accordingly and report the production implications for each individual livestock sub-sector.

2. Materials and methods

In order to evaluate fully the total GHG and NH_3 emissions arising from different modes of livestock production, including those arising beyond the farm boundary, we estimated those emissions using the Cranfield systems Life Cycle Assessment (LCA) models (Williams et al., 2006). These emission estimates will include some emissions arising both beyond the farm boundaries (hence not in the UK agricultural GHG or NH_3 inventories) and outside the UK, e.g. imported feeds and manufactured inputs. The analysis may superficially overestimate the reduction potential in the narrow sense of direct livestock emissions, but it avoids any illusions created by reducing UK emissions at the greater expense of increasing those overseas, e.g. if switching from extensive lamb to soy-based broiler meat. After all, the effects of GHG emissions are global. Ammonia emissions are much greater from livestock production facilities themselves than from feed crops, hence the changes proposed in the UK will be overwhelmingly quantified in the UK agricultural NH_3 inventory. We thus considered an LCA approach was the most appropriate methodology to enable a complete assessment to be made of emissions arising from different modes of production, e.g. upland and lowland beef and sheep.

The Cranfield systems LCA models (Williams et al., 2006) analyse individual production systems and evaluate national livestock production as the sum of the existing proportions of each production system. A production system is a combination of rearing methods, input timings, housing and manure handling systems, etc. Such discrete production systems include autumn-calving beef suckler herds; high-yielding, maize-fed dairy cows on slurry; spring or autumn calving; organic all-year calving; dairy-beef cross finishing on straw, a Most production systems require an amount of input from other production systems in the chain of production — for example dairy-beef cross finishing requires calves from dairy cattle.

The emissions and resource uses of the alternative livestock systems were analysed by constructing a system of constrained linear equations. We then explored feasible solutions to these equations (sizes of different combinations of livestock systems) to provide the optimal productivity, in terms of financial value, whilst meeting the emissions reduction targets and making use of the UK's resources. The outputs describe possible combinations of existing livestock systems that can lead to levels of financial value similar to those currently achieved by the livestock industry but producing fewer gaseous emissions than at present.

The first model section was to maximise the production of livestock products as the farm-gate price of the products. Though other metrics such as protein could be used, each sector produces a variety of other nutrients with different qualities. Price was used to encapsulate all these properties. Part of the farm-gate price includes consumer preference (e.g. organic) and in part the impact of shortage or abundance (autumn/spring), rather than simply the amount of production.

The second section expressed the logical constraints among the systems. Thus the need to produce replacements (day old broiler chicks of point of lay pullets in the case of poultry) and the different amounts of milk produced. For pigs, beef and sheep, this includes the movement of livestock from systems which raise young to other systems which produce the final commodity.

The third section was the use of resources, notably arable, grassland, hill-land. These can be limited, for example a maximum amount of hill land, or unlimited.

The fourth section set the emission constraints. 'Current' emissions were calculated using the matrix so that runs are self-consistent, by setting production to be the current, and the proportions of each system to be their current proportions. The limit is then set to 10% or 20% of these values and the resulting configurations observed.

The final section defined the current structure of the industry. For example, the proportion of cattle or pigs housed on liquid or solid manure management systems, the proportion of high-medium-low yielding dairy cows, indoor or outdoor raised pigs, housed, free range or organic laying hens.

2.1. Calculation of emissions data, productivity and resource use

Within each component livestock sub-system, the LCA model calculates the component's input requirements, outputs and emissions. For each commodity input, for example grass, the model calculates the inputs of fertilizer and machinery and emissions, and in turn calculates the inputs to fertilizer and machinery production. Emissions are calculated for the different production systems arising from management factors such as whether: livestock are raised within buildings or outdoors; excreta are managed as liquid (slurry) or FYM; livestock are raised on different planes of nutrition giving rise to different amounts of N excretion; livestock graze manufactured-N fertilized or clover-rich pasture.

To ensure that our calculations of GHG and NH_3 emissions were consistent with emissions reported by the UK's National Atmospheric Emissions Inventory (NAEI), the Cranfield LCA model was revised to incorporate activity data and EFs used in the NAEI.

When this work began (May 2007), UK emissions of GHG from agriculture were already 17% less than the 1990 baseline, while total UK ammonia (NH_3) emissions were expected to be less than the limit required by the NECD by 2010 due to the steady decrease in emissions from agriculture (262.7 kt in 2006). We therefore took the approach of estimating the impacts of further reducing emissions of GHG and NH_3 by 20% of the amounts estimated for 2006. The target of 20% was chosen to represent a significant, but potentially achievable target, which combined two real constraints on agriculture, especially the livestock sector. The initial scenario was that a reduction in GHG and NH_3 emissions could be achieved by reducing total livestock production by 20%. We then used the