Livestock production and greenhouse gas emissions: defining the problem and specifying solutions

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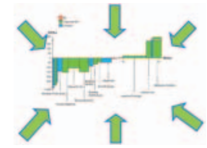

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Implications

- Global livestock production contributes an estimated 18% of anthropogenic greenhouse gas (GHG) emissions mainly in terms of methane and nitrous oxide. Enteric fermentation from livestock amounts to 6.2 Gt of CO_2 equivalents (4.4% of global emissions). These emissions are coming under scrutiny as countries improve emissions inventories and seek to include more sectors in binding emissions reductions.
- Global agreements on GHG place no obligations on countries to include agriculture (i.e., livestock) in national inventories or mitigation (emissions reduction) plans. But research suggests a range of cost-effective approaches to reduce emissions from animals including dietary changes and improved productivity through breeding and methods of waste management.
- Carbon footprinting has been used as a shorthand term to quantify emissions at a range of scales (e.g., the animal, farm, or, more commonly, the entire food chain). Life cycle analysis is a more technical approach to recording the environmental impact to be attributed to final products.
- Policy incentives can target the farm or actors in product life cycles. Governments typically focus on farms, whereas supermarkets and other retailers focus on product life cycles as a means of engaging with consumer demands for low impact (per product unit) or sustainable products.
- The growth of meat global consumption has highlighted the need to consider demand or consumption-side management, alongside production-side interventions. Emissions reductions from livestock production in the developing world offer significant synergies and a potential triple win, linking productivity gains, environmental conservation, and poverty alleviation.

Key words: livestock, global climate change, greenhouse gas emissions, life cycle analysis, production versus consumption accounting

Introduction

Although integral to many farming systems, livestock production is nevertheless associated with many impacts that are deemed socially undesirable. Whereas animal welfare concerns have been documented for centuries, damage attributed to and responsibility for greenhouse gas emissions are more recent concerns. Key questions relate to our understanding of emissions from alternative farming systems, different methods of counting these emissions, and policy options for their reduction. This paper considers these issues as a basis for informing a discussion about both the scientific and policy priorities in the area. Although there are significant uncertainties, we argue that the science is sufficiently clear for a coherent policy response focusing on both producers and consumers.

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Defining the Problem

Livestock products are an important source of global protein. With notable exceptions, meat is a component part of diets in many countries, with livestock groups being differently represented. Consumption preferences are influenced by religious and ethical differences, which in many countries are inextricably linked to the concern for animals as sentient beings with intrinsic and inalienable rights. Environmental impacts of livestock production have historically been confined to more localized problems of overgrazing, desertification, and pollution of water courses from poor waste handling. Such concerns were often offset by recognition of the cultural significance of livestock and more tangible benefits from the use of animal products and manures in farming systems (Moll, 2005). In developing countries, livestock production provides not only food, but also a wide range of nonfood products including income, employment, and many other contributions to rural and social development.

The need to respond to global climate change has focused attention on the main sources of emissions with all significant sources coming under scrutiny (World Bank, 2010; Wreford et al., 2010). This is largely because developed (or Annex 1; as defined under the United Nations Framework for Climate Change, http://www.ipcc.ch/pdf/glossary/ar4-wg3.pdf) countries have committed themselves to externally defined emissions reductions (mitigation) targets that must somehow be shared amongst polluting industries within their jurisdictional control. Livestock production systems contribute an estimated 18% of global anthropogenic green house gas (**GHG**) emissions (FAO, 2006). These emissions represent a significant proportion for some countries, including New Zealand, Ireland, and the United Kingdom. The main sources and types of GHG from livestock systems are methane production from animals (25%), carbon dioxide (CO_2) from land use and its changes (32%), and nitrous oxide (N_2O) from manure and slurry management (31%). These gases are usually converted to units of CO_2 equivalent (**CO_2 eq.**) as a common metric for gases that have varying global warming potential.

Both animal welfare and GHG, and to a lesser extent other local pollution problems, have distinct properties that complicate their management. In economic jargon, they are public goods or negative externalities. The agent giving rise to the emission inflicts a cost on many others, and there is no penalty or mechanism for those affected to be compensated. Ultimately, the emission of GHG contributes to global warming scenarios and potentially compromises the welfare of billions of people. There is no obvious medium or market to redress or transact compensation, leading Stern (2007) to conclude that global warming represents the biggest market failure of all time.

A collective response to this market failure nevertheless exists under the auspices of the United Nations Framework Convention on Climate Change (**UNFCCC**) and successive global agreements on emissions reductions. Under these agreements, relatively developed Annex 1 countries have signed up to binding emissions caps that have then to be shared out over responsible industries in the respective countries. Developing countries are largely outside this deal, with obvious implications for the external impacts from livestock production in countries such as Brazil, India, and China.

Annex 1 countries have adopted different approaches to burden sharing among polluting industries, including direct regulation and the use of so-called market-based instruments (**MBI**). The most notable example of the latter is the use of cap and trade schemes, which allocate emissions allowance permits that can then be traded (Hood, 2010). The European Union emissions trading scheme is perhaps the most well-established and greatest volume trading regimen to date. Despite teething problems in terms of initial allocations and trading volumes, such a system has been relatively straightforward to implement with initial allocations to polluting industries, such as energy and transportation. In these sectors, the origin of the emissions or so-called point of obligation is more easily identified and monitored. A central feature of a trading scheme is that trades allow the market to reveal a carbon price. In simple terms, it is now possible to buy extra permits on the market, and this price provides new benchmark costs for emitting sectors. It also acts as a useful incentive for reducing emissions.

Many countries have initially excluded agriculture from either direct regulation or any form of MBI. In contrast to other industries, agriculture is more complex with many thousands of medium and small producers giving rise to emissions from multiple sources. Difficulties in monitoring emissions from complex systems have so far meant that the sector has passed under the policy radar. But this situation is becoming more conspicuous with some studies (e.g., NERA, 2007) suggesting the feasibility of large livestock producers being included in mandatory schemes. The threat of more direct regulation or MBI has accelerated the industry interest in confronting the emissions problem to head off more stringent government regulation. In addition to this production-side pressure, supermarkets are also realizing that consumer pressure is also a driver of profitability. Emissions reductions are seen as part of an environmental footprint and integral to reporting for corporate social responsibility purposes. This gives rise to pressure for products to demonstrate their low emissions credential, which focuses on whole product life cycles.

What Should We Be Measuring?

Quantifying the likely impact of policy instruments or farm actions or both on climate change mitigation requires accurate estimation of emissions and their attribution to the responsible source or point of obligation. Estimates of GHG emissions tend to be compiled within the conventions set out by UNFCCC for consistent national inventories. For livestock most countries have initially applied standard coefficients (emissions per animal) to derive aggregate emissions for the sector. But it is accepted that the standard coefficients mask regional biophysical variation in systems, and some countries are moving to more complex estimation models. These levels of analysis are often referred to as tier 1 (standard coefficients), 2, and 3, the latter involving more specific biophysical modeling. As the science improves, the more complex measurements are likely to become standard inventory procedure with validation within UNFCCC protocol.

Whereas the animal is an important biological unit for research, mitigation policy can focus on emissions reductions from a variety of measures implemented within the farm system or at other points of the product life cycle. At the farm level a range of interventions can be applied in different systems, including those that target emissions from the animal (e.g., nutrition management, genetic improvement, rumen manipulation) and the wider systems (e.g., manure management options, grazing system management). Assuming the application of these measures to their fullest extent (i.e., to all animals) allows an estimate of the full technical mitigation potential. But it is important to distinguish this from an economic potential, which is the extent of mitigation that is cost effective. In other words, some livestock mitigation measures may be costly to implement relative to the costs of reducing equivalent volumes of emissions in other sectors of the economy (e.g., in transportation, energy, or industry). This comparison defines the economic potential for livestock emissions reduction. Ideally, government is seeking to reduce overall emissions efficiently or at the lowest cost. Thus, there is some value in sequentially seeking the lowest cost emissions in any one sector up to the point where the marginal (i.e., extra unit) cost is equal between sectors, or where the marginal cost of mitigation equals the carbon price. This analysis tends to show economic potentials significantly below technical potentials.

Economic mitigation potential tends to be defined using marginal abatement cost curve (**MACC**) analysis (Moran et al., 2010). Marginal abatement cost curves are useful tools for identifying the most cost-effective mitigation measures. They also provide a way of quantifying the amount of mitigation that can be achieved at a given marginal cost (i.e., the cost, at a given level of abatement, of reducing GHG emissions by one more unit), and the total cost of achieving that abatement. Figure 1 shows an example developed for UK agriculture and indicates, for example, that improving land drainage could reduce emissions by 3 Mt of CO_2 eq. (width of the bar) at a cost of about £20/t of CO_2 eq. (height of the bar). In this example, cost effectiveness is the estimated average across the UK; in practice, the bars would have upward sloping tops to reflect variation in cost effectiveness between farms. Knowledge of the marginal cost of abatement allows us to compare the cost of reducing emissions by one more unit with the benefits that accrue from that reduction. In theory, the comparison of marginal costs with the carbon price allows the determination of the socially optimal level of abatement from the sector. For example, a notional carbon price of £50$\cdot$ton$^{-1}\cdot CO_2$ eq.$^{-1}$, represented by a horizontal line drawn at that price in Figure 1, shows that greater cost measures to the right of the diagram would not be efficient to implement.

The process of developing MACC is data intensive (Figure 2) with challenges in terms of defining measure implementation costs and emissions mitigation potential of measures used in different biophysical conditions. Despite these difficulties, MACC are valuable tools for setting GHG emission reduction targets for emissions within the farm gate. This

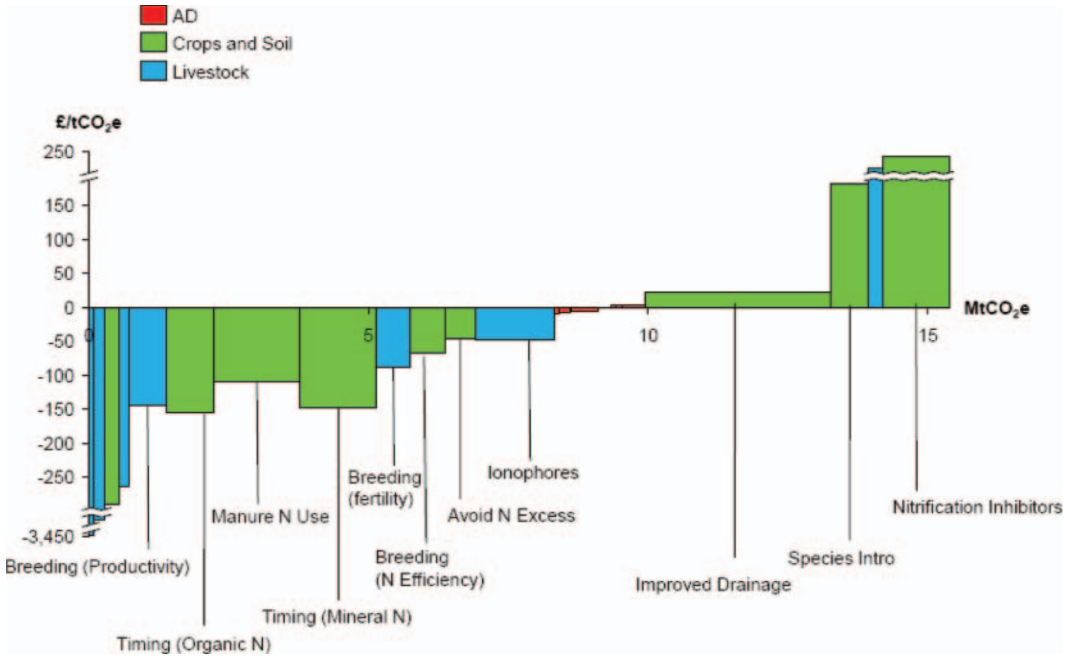

Figure 1. A marginal abatement cost curve for UK agriculture. The width of each bar shows the abatement potential of each measure, while the height shows the cost-effectiveness. Source: CCC modeling. AD = anaerobic digestion. Measures do not appear in exact cost-effectiveness order because of interactions between options. Source: Building a low-carbon economy–The UK's contribution to tackling climate change. 1st Report of the CCC, December 2008 (Committee on Climate Change, 2008).

information is useful for government aiming to regulate farms as business units on which they have good data.

But government objectives differ from those of retailers, who are more interested in the potential to label final products in terms of their overall impact on the environment. This essentially takes the analysis beyond the farm gate to include all upstream and downstream inputs and processes including distribution and retailing, which are likely to involve emissions of CO2. Ultimately an account of total emissions associated with products enables retailers and final consumers to discriminate between high and low emissions products. This alternative focus leads to interest in life cycle analysis (**LCA**).

Life cycle analysis is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). Life cycle analysis can be highly forensic in terms of data needs for the compilation of an inventory of relevant energy and material inputs, and environmental releases (de Vries and de Boer, 2010; FAO, 2010). Whereas LCA should ideally quantify all relevant external costs, in the food sector there has been specific interest in elements of carbon intensity of product life cycles. Varying quantities of CO_2 identified at key production stages can show how production processes can be modified. Emissions from each stage are typically aggregated and expressed per kilogram or liter of product. As such, LCA is the technical definition of a product carbon footprint.

In undertaking LCA for products, the definition of an analytical boundary is a crucial part of the calculation (Figure 3). More specifically, how far upstream should impacts be traced and attributed to a final product? For example, the attribution of the costs of animal feed production to the final livestock product can add a range of indirect impacts to the final emissions per unit of product. In this, we could include tropical deforestation as a precursor for soya cultivation that was used in feed production. The absence of a consistent boundary in the international literature has complicated the simple comparison of existing studies across different farming systems. Beyond this, LCA still presents further challenges in terms of impacts to include (e.g., biodiversity loss).

An increasing number of LCA studies show some consistency in terms of where key emissions hotspots lie, and the resulting prescriptions for production processes. Broadly these can be broken down into pre-farm gate activities, activities on farm, in the processing and retail stages. As per the MACC analysis, the farm prescriptions suggest a focus on breeding, manure management, fertilizer practices, and anaerobic digestion of manure with lesser reductions from energy efficiency. Reductions in GHG from processing of livestock products can be easily identified, including less energy-intensive packaging and more efficient use of energy in processing of livestock products. In retailing, options to improve freight efficiency and decarbonize chilling processes will benefit dairy products as well.

Policy and Industry Responses

As previously noted, there is increasing pressure for responsibility for emissions to be internalized, and this presents roles for both government (i.e., the public sector) and private sector stakeholders along the supply chain.

The public imperative comes from the fact that in Annex 1 countries there is a need to seek cost-effective ways to meet ambitious emissions reduction commitments set by external obligations (e.g., Kyoto). Although it is possible to argue about the validity of targets, they are binding on signatories. As previously noted, different countries have taken different approaches to the inclusion of agriculture within their plans to share the burden of reductions across domestic industry. In many countries the sector is perceived to be complex, and there are currently no binding obliga-

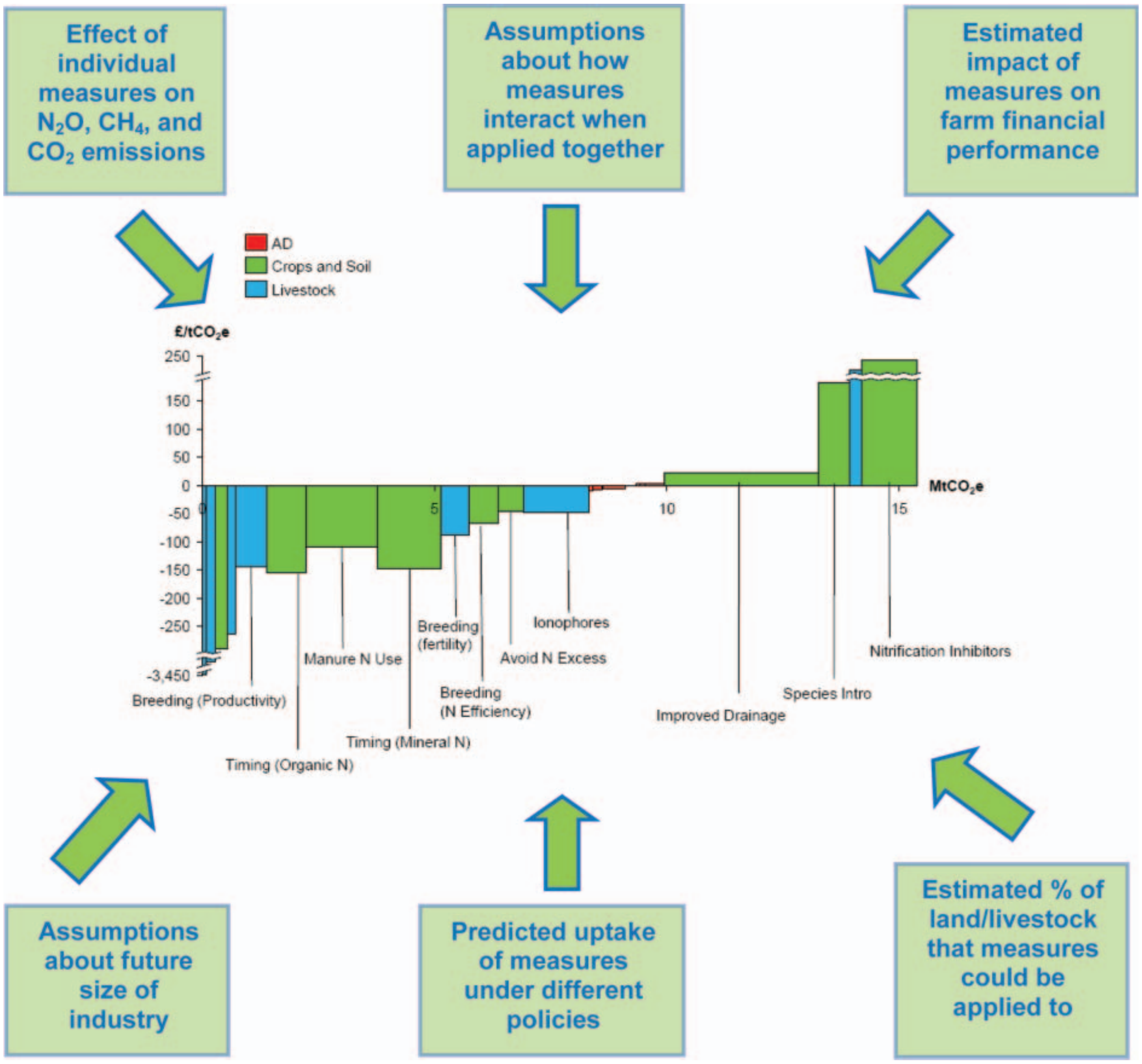

Figure 2. Examples of data and assumptions required to develop a marginal abatement cost curve for agriculture. Source: CCC modeling. AD = anaerobic digestion. Measures do not appear in exact cost-effectiveness order because of interactions between options.

tions on farmers to report or otherwise control GHG emissions from their activities.

But the presence of low-cost mitigation options has focused attention on the range of policy instruments available to affect reduction at the farm scale. In broad terms, approaches can be characterized in terms of sermons, carrots, and sticks. The sermon approach is the use of a farm advisory and overcoming informational barriers involving the adoption of win-win measures. It is currently uncertain how effective these messages are. In terms of carrots, existing agri-environmental policies in Organisation for Economic Co-operation and Development (**OECD**) countries are being scrutinized for their ability to accommodate emissions reduction activities in addition to or complimentary to existing cross-compliance requirements for support. Several governments are also seeing a role for new investment funds to promote renewable energy from anaerobic digestion of farm waste. The stick approach is unsurprisingly a more punitive use of penalties or the enactment of the polluter-pays principle applied to GHG. In theoretical terms, a carbon tax could be applied to livestock producers based on animal numbers multiplied by relevant emissions coefficients. A theoretically equivalent outcome could also be derived from the use of an emissions trading system, which would require producers to hold emissions permits (initially allocated for free or by auction) to account for all their emission sources. These permits allow some flexibility in that those producers who are more efficient in managing their emissions could choose to sell to less efficient producers. Several countries (e.g., United Kingdom, New Zealand, and Australia) have investigated the feasibility of such schemes in the livestock sector, and results suggest that only the largest producers could realistically be included in a scheme that would not be prohibitively expensive to administer.

In addition to formal trading arrangements, a growing voluntary carbon market has developed largely around forestry and renewable energy credits. There is nothing to stop enterprising livestock producers profiting from voluntary emissions reductions and selling credits for these to outside industries who find it more costly to comply with their obligations. The Canadian province of Alberta has been developing a carbon

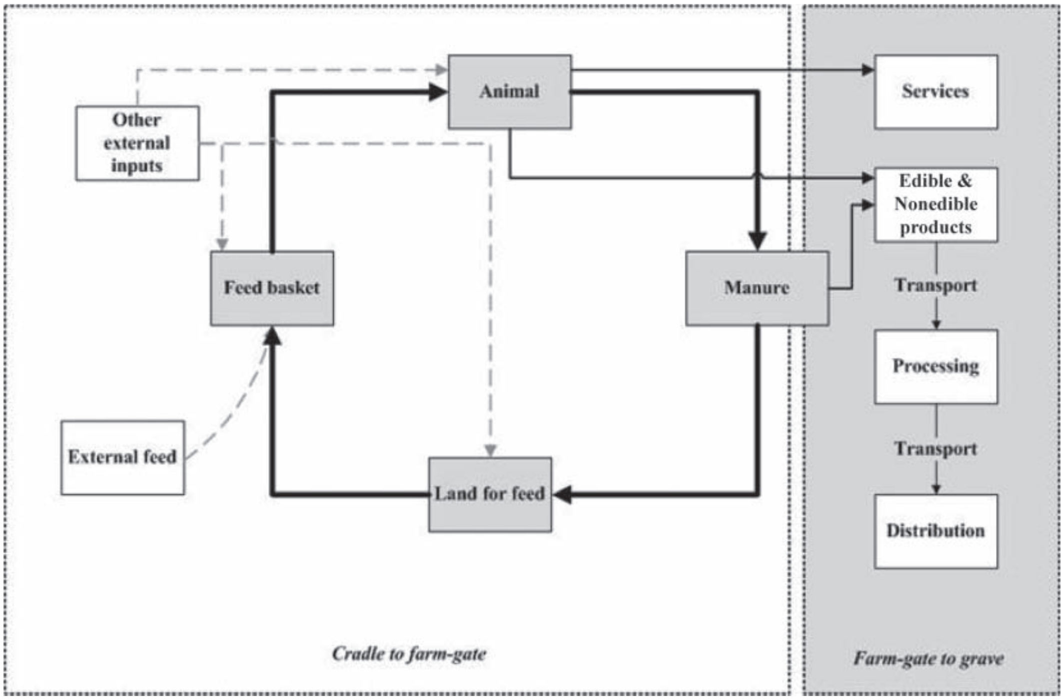

Figure 3. Life cycle analysis boundaries.

offset system based on a compliance carbon offset market with protocols developed for dairy system efficiencies (http://www.wcds.ca/proc/2010/Manuscripts/p139-150Haugen-Koyzra.pdf). Voluntary agricultural credits currently have no formal entry point to the European trading scheme. But outside the scheme there is a nascent voluntary credit and offset market, which in theory is open to anyone who can offer valid emissions reductions to anyone who wants to buy them. But the question of what constitutes a valid reduction is a crucial sticking point. Indeed, there is much uncertainty about how to verify the variety of agricultural emissions reductions as the basis of valid credits. This is reflected in a variety of farm-based calculators, none of which can claim to be an industry protocol or standard. Even if a standard tool could be agreed upon, further concerns relate to the permanence of reductions and whether they are additional to what would have happened anyway. Other commentators suggest that emissions reductions will simply lead to displacement abroad if they are associated with reduced domestic output as a result. Ultimately, this means that voluntary contracts in agriculture are more complex and viewed as less reliable than, for example, woodland credits, which are technically more verifiable. This in turn means that such credits are likely to be valued much less than more definite emissions reductions from, for example, forestry. Indeed, forestry offsets constitute the majority of early voluntary trades worldwide.

It would be hasty to assume that these problems cannot be overcome with better science and monitoring. International experience, particularly with soil carbon credits, has shown that a market for credits can be based on more pragmatic measurements applied on a regional scale. In a number of Canadian provinces and US states, as well as several developing countries, uncertainty has simply been side-stepped with regional voluntary credit markets emerging based on default soil carbon values. No such credits currently exist for livestock management. Moreover, validation issues are still conspiring to depress the price of soil carbon credits, and serious questions are also being posed about the validity of stand-alone institutions that are brokering these trades. For example, the Chicago Climate Exchange, which was the main independent market for Midwest soil carbon credits, has apparently been mothballed in the wake of a depressed US credit market, which in turn reflects the failure to instigate an economy-wide cap-and-trade scheme in the United States. If there is no country-wide cap-and-trade scheme, then there is simply less pressure for high-polluting industries to seek out all available credits. This inevitably dampens demand for the more hard-to-get-at reductions offered by agriculture.

Private Sector

Government regulation is mainly focused on producers, but it is not the only driver of change. Retailers also have a role in terms of other crucial interface with consumers. Consumer awareness turns out to be a key driver of change, and product labeling is a key instrument for promoting consumer awareness. As previously noted, footprinting or LCA is the key approach, and retailers have been instrumental in seeking emissions reductions that are coincidentally delivering production efficiency. In pursuing this agenda, however, retailers have to be strategic in determining what information consumers want (and respond to) and ways to present the information. For livestock products, this decision is one in which retailers are undecided on how close they want to locate their products to a consumer lifestyle choice that paradoxically prizes lower meat consumption.

Reducing Uncertainty

Agricultural mitigation measures are more complex than those in other industries characterized by homogenous production and mitigation technologies. As noted, there is an urgent scientific agenda in terms of driving down uncertainty in both biophysical effectiveness of measures and their cost. There is also a need to recognize the synergies between mitigation and inevitable autonomous and planned adaptations that will take place in response to climate change. Possible system synergies between mitigating and adaptation are identifiable in terms of breed selection, feed regimens, and livestock housing, but there is currently little research mapping these out for different farm systems.

Improvements in emissions measurement contribute to more accurate national inventories. There is also a requirement for institutional arrangements to monitor, report, and verify that emissions reductions are additional and permanent.

At the scale of the farm, the need for certifiable mitigation has led to interest in accounting tools that can be easily deployed by farmers. Such tools serve the purpose of signaling compliance with relevant good practice. Whereas policy on agricultural emissions is still evolving, voluntary compliance allows some producers to identify themselves in low carbon niche markets.

As previously noted, there are several potential directions for emissions policy. But the effectiveness of any policy instruments depends partly on behavioral responses. Without binding policy, farmers are unlikely to see any urgency to change management, even when there are alleged win-win situations. Further research is needed to identify key messages that work and methods of delivery. A further research need is to understand consumer responses and reactions to labeling and perception of where responsibility lies. This highlights an interesting divergence between production and consumption responsibilities.

Production Versus Consumption

Implicating consumers in the management of emissions raises wider questions that the livestock industry must confront. Advocates of plant-based diets have been quick to point out the relative emissions intensity of livestock products and how other ancillary health costs essentially outweigh the social benefits of meat production (Stehfest et al., 2009).

Consumption management is thus an alternative policy lever that may appeal to policy makers. As well as meat consumption, messages on how to transport, store, and cook meat products can all contribute to true life cycle emissions reductions.

A wider perspective on production and consumption reveals other problems and counterintuitive outcomes. The same dietary advocates inevitably trace their arguments back to the elimination of production or reduced animal populations. However, without corresponding intervention on the consumption side, this is only likely to displace production from one part of the world to another with no net overall reduction in the global external cost.

The wider perspective also suggests that the benefits of domestic abstention are likely to be offset by consumption in emerging economies, and China in particular. The implications of this are somewhat worrying even if animal science can maintain pace.

These observations echo a wider political debate that suggests that national inventories should be pinning life-cycle emissions onto the countries where final consumption takes place. This is in contrast to current production based inventories and negotiations. Under a consumption accounting protocol exporting countries are likely to see emissions liabilities reduced relative to countries with high imports of carbon-intensive products (Helm et al., 2007). Such a switch would be politically divisive, although clearly beneficial to some producing countries.

Developed Versus Developing Countries

The systems for producing different kinds of livestock are highly diverse, which results in large differences in the associated GHG emissions per kilogram produced in different regions. The impacts of livestock production on GHG emissions have been widely discussed, particularly those associated with rapidly expanding industrial livestock operations in Asia and those linked to deforestation in Latin America (Lambin and Meyfroidt, 2011). Nevertheless, in smallholder crop-livestock, agro-pastoral, and pastoral-livestock systems, livestock are one of a limited number of broad-based options to increase incomes. It is also important to recognize that livelihoods in developing countries are also often dependent on these systems, and although there is no mechanism for regulating related emissions in these countries, this represents an ecosystem service that is a potential vehicle for development aid.

Conclusions

Carbon footprinting for livestock products appears intuitive and in keeping with the advent of emissions accounting or sustainable production agendas in other industries. As this paper suggests, there are alternative accounting methods for emissions measurement and GHG represent one dimension of the greater ecological footprint of global animal production. Expanding livestock sectors play a role in the expansion of agricultural land and associated deforestation, the emissions of GHG, eutrophication of surface waters, and nutrient imbalances. While this has led to creeping demonization of the sector, it is important to offset the negatives with some positives: livestock products are a preferred protein source for millions of people; they contribute to sustainable livelihoods in developing countries; and they are an integral part of many socio-ecological systems that make up the agricultural mosaics we see in many OECD countries. Emissions are a new challenge, but more research can lead to better benchmarking activities that help reduce externalities from production. Farm-based studies indicate that there are huge differences between farms in terms of animal productivity and environmental performance. Comparisons at regional and country level have not been made yet, and it is possible for efficiencies to be gained. Overall, to deal with GHG the animal-production sector needs to challenge itself to identify mitigation measures that are effective, efficient, and equitable to implement.

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