Policy challenges for livestock emissions abatement: lessons from New Zealand

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Under the current framework embodied in the Kyoto Protocol and envisaged for future multilateral agreements, Annex I parties are obliged to limit their economy-wide GHG emissions and accept responsibility for exceeding their targets through various flexible mechanisms. The predominant sources of agricultural GHGs, which represent about 8% of total Annex I emissions, are methane and nitrous oxide from livestock. Efforts to reduce livestock emissions have so far been limited due to disagreements over the abatement potential, technical feasibility, and cost-effectiveness of the policy instruments available, including market-based measures. Two key challenges facing the application of market-based measures to livestock emissions are evaluated: first, to design a policy framework that appropriately aligns the measurement of emissions, the abatement options, and the incentives facing livestock producers; second, to address the risk of leakage and economic regrets that arise from unilateral domestic policy action. Particular attention is given to the policy developments in New Zealand and the lessons learnt from its experience. The challenges of applying market-based measures to livestock emissions are surmountable, but require innovative policy responses.

Keywords: agricultural emissions; Annex I; emissions trading scheme; livestock; mitigation policy

Sous le cadre actuel incarné par le protocole de Kyoto et envisagé pour de futurs accords multilatéraux, les Parties de l’Annexe I sont tenues de limiter leurs émissions de GES sur l’ensemble de leur économie, et accepter la responsabilité d’avoir excédé leurs cibles à travers divers mécanismes de flexibilité. Les sources principales de GES d’origine agricole, représentant environ 8% de la totalité des émissions de l’Annexe I, sont le méthane et l’oxyde nitreux provenant de l’élevage de bétail. Les efforts visant à réduire les émissions de l’élevage ont jusqu’à présent été limités à cause des désaccords sur le potentiel d’abattement, la faisabilité technique, et l’efficacité de coût des instruments politiques disponibles, y compris les mesures fondées sur le marché. Deux défis clés à la mise en œuvre de mesures de marché pour les émissions de l’élevage sont évalués : en premier lieu, concevoir un cadre de politiques alignant de manière appropriée la mesure des émissions, les options d’abattement et les incitations aux éleveurs de bétail ; deuxièmement, aborder le risque de fuite et les regrets économiques émanant de l’action politique nationale unilatérale. Une attention particulière est donnée aux développements des politiques en Nouvelle-Zélande et les leçons tirées de cette expérience. Les défis liés à l’application de mesures de marché aux émissions de l’élevage sont surmontables, mais requièrent des réponses politiques innovantes.

Mots clés: émissions agricoles; Annexe I; système d’échange d’émissions; élevage; politique de mitigation

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1. Introduction

According to data from 2005, agriculture is directly responsible for an estimated 13.8%, or 6.1 GtCO$_2$e, of total global GHG emissions (WRI, 2010). These figures include direct emissions from enteric fermentation, manure management, rice cultivation, agricultural soils, prescribed burning of savannahs, and burning of agricultural residues. This contribution to total global GHG emissions would be considerably higher if emissions from land-use change that arise from agricultural extensification (i.e. deforestation), and energy for processing and distribution were attributed to agriculture (FAO, 2006) rather than to the energy and forestry sectors (IPCC, 2007). The contribution of livestock to agricultural emissions is difficult to estimate because global emissions databases do not distinguish nitrous oxide (N$_2$O) emissions from livestock pastures, or from emissions related to crops for human consumption or from exported feedstocks. The Food and Agriculture Organisation of the UN (FAO, 2006) estimates that the total global methane (CH$_4$) and N$_2$O emissions attributable to livestock systems in 2005 was about 4.4 GtCO$_2$e, or approximately three-quarters of total agricultural non-CO$_2$ emissions. In the absence of targeted mitigation measures, global direct agricultural emissions are projected to increase by about 40% from 2000 to 2030 (Smith et al., 2007a).

Developing cost-effective multi-gas mitigation strategies that limit the rate and magnitude of climate change requires appropriate treatment of non-CO$_2$ emissions (Meinshausen et al., 2006; Rao and Riahi, 2006; van Vuuren et al., 2006). The policy issues posed by efforts to mitigate direct livestock emissions in Annex I countries, with binding economy-wide emissions targets under the Kyoto Protocol and/or its successor agreements under the UNFCCC, are analysed in this article.¹

Although none of the arguments for excluding livestock emissions from mandatory market-based instruments in developed countries is compelling, it is acknowledged that such emissions generate distinctive policy challenges that require innovative and carefully tailored responses. In Section 2, the contribution of livestock emissions to total emissions in Annex I countries is outlined, and current climate policies directed at controlling livestock emissions are analysed; the case of the New Zealand Emissions Trading Scheme (NZ ETS) is also introduced. In Section 3, an overview of the technological and farm-management mitigation options and costs for livestock emissions is provided. In Section 4, the two main challenges to including livestock emissions in market-based mechanisms are discussed, and New Zealand’s experience of developing an emissions trading scheme is used to highlight some policy options that might overcome these challenges. In Section 5, it is concluded that despite concerns about leakage and economic regret, agricultural emissions should be included in economy-wide market-based mitigation measures. The recent policy experimentation by New Zealand provides a first and important step in identifying potential solutions to the policy challenges of livestock emissions abatement.

2. Livestock emissions and climate policies in Annex I countries

Annex I countries contribute 24% of total agricultural GHG emissions, a smaller share than the Annex I contribution to total global emissions (47%). Agriculture is also a smaller fraction of total GHG emissions in Annex I countries (8%) than in non-Annex I countries (15.8%) (WRI, 2010). The relative importance of GHGs attributable to livestock emissions in national emissions profiles is highly
differentiated across Annex I countries. Although the US is the largest Annex I agricultural emitter in absolute terms, livestock emissions constitute only about 6% of its total GHGs. The EU-15 countries\textsuperscript{2} have the second largest volume of GHG emissions from livestock, although livestock constitutes only 9% of their total emissions. By contrast, based on UNFCCC inventory data for 2007, livestock emissions in New Zealand and Ireland constitute a large fraction of their national totals (48% and 26%, respectively), excluding emissions or removals from land-use change and forestry. Other Annex I countries with higher than average livestock emissions include France, Denmark, Australia, and several economies in transition (Belarus, Latvia, and Lithuania) (see Figure 1). In addition, some subnational governments (e.g. Scotland) have relatively high livestock emissions (ACCSG, 2008; Moxey, 2008).\textsuperscript{3} Despite their relatively small share of total Annex I emissions, addressing CH\textsubscript{4} and N\textsubscript{2}O emissions, including those from agriculture, is important for the efficient functioning of a multi-gas mitigation strategy (Hyman et al., 2002). Were Annex I countries to focus exclusively on the largest emitting sectors, the potential for economy-wide emissions reductions could be substantially diminished. Accordingly, if economy-wide GHG emissions are to be addressed in non-Annex I countries, the development of

\textbf{FIGURE 1} Estimated direct livestock emissions for Annex I countries expressed as MtCO\textsubscript{2}e and as a percentage of total gross GHG emissions for Annex I countries

\textit{Source}: Data from WRI (2010).
policy programmes and technological and farm-management options for reducing livestock emissions in Annex I countries can assist and inform this process.

In principle, agricultural emissions can be addressed with the same policies and measures that have been developed for, and applied in, other sectors. These include market-based measures (such as taxes and/or tradable permits), standards and regulations, subsidies and tax credits, information instruments and management tools, R&D investment, promoting the deployment and diffusion of technological mitigation options, and voluntary compliance programmes (Gupta et al., 2007). Gerber et al. (2010) have reviewed the main policy instruments available for mitigating GHGs from livestock and the recent experience of subsidies and voluntary offset programmes. Several Annex I countries have begun to implement livestock emissions abatement programmes. Table 1 summarizes these policies.

As Table 1 demonstrates, the most common policy approaches for livestock emissions abatement to date have been subsidies, grants and tax incentives, and voluntary offset programmes. In the few cases where there are estimates of mitigation impacts, the volume of reductions is small. Offset programmes can encourage producers to abate agricultural GHGs, thus earning emissions credits. These credits are then sold to emitters that are subject to emissions caps. The principal requirements of offset programmes are the establishment of a register of abatement practices, fixing the amount of credits to be earned through such practices, and certification that abatement practices have been undertaken. Because offset programmes are voluntary, they require governments to implement these systems in the absence of any guarantee concerning the likely level of abatement. The ability of offset programmes to generate emissions abatement depends *inter alia* on the presence of abatement options for livestock producers that cost less than the value of earned emissions credits. In their meta-analysis of the cost of mitigating agricultural GHGs, Vermont and De Cara (2010) found that few studies identified significant abatement potential at low cost (less than EU€15/tCO₂e). The ability of offset programmes to reduce livestock emissions may therefore be limited. Furthermore, the higher profits that offset programmes offer to producers for reducing emissions could provide incentive for increased livestock production by making the farming system more profitable. Because this production occurs outside a cap on agricultural emissions and rewards improvements in emissions intensity rather than absolute reductions in emissions, offset programmes could conceivably function as subsidies for additional production and therefore increase net emissions (Gerber et al., 2010).

The potential for international coordination of offset programmes and project-based mechanisms has been described within a sectoral approach for emissions abatement (Schmidt et al., 2008). Key and Tallard (2012) describe this approach as employing sector-level, rather than producer-level, measurement, reporting, and verification (MRV) of emissions. Within this approach, livestock emissions would be reported as a national sector aggregate, and emissions reductions would be targeted against each country’s sectoral baseline. One benefit of this approach is that sector-level MRV would result in lower administrative and transaction costs than farm-level MRV. However, as Key and Tallard (2012) note, sectoral policies do not directly provide incentives for emissions mitigation but rely on governments to create them for agricultural producers. However, because countries would be able to opt out, there is significant uncertainty about the potential volume of emissions abatement achievable in a sectoral approach. Finally, the compatibility of a sectoral approach for agricultural GHGs within the framework of national emissions caps embodied in the Kyoto Protocol is problematic. Although national emissions caps provide a market for offset credits, leaving the agricultural sector...
### TABLE 1  Examples of existing policies for livestock emissions abatement in Annex I countries

<table>
<thead>
<tr>
<th>Type of policy instrument</th>
<th>Location</th>
<th>Programme name</th>
<th>Focus activity</th>
<th>Estimated mitigation impact per annum$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information provision</td>
<td>Australia</td>
<td>National Agriculture and Climate Change Action Plan</td>
<td>Efficiency improvements in livestock production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Finland</td>
<td>Long-term Climate and Energy Strategy</td>
<td>Biogas systems, emissions from urine and dung</td>
<td>0.02 Mt</td>
</tr>
<tr>
<td></td>
<td>Slovenia</td>
<td>Rural Development Programme</td>
<td>Nutrient management, efficiency improvements in livestock production</td>
<td>0.11 Mt</td>
</tr>
<tr>
<td></td>
<td>United Kingdom</td>
<td>Agricultural Industry GHG Action Plan</td>
<td>Efficiency improvements in livestock production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scotland (UK)</td>
<td>Farming for a Better Climate</td>
<td>Efficiency improvements in livestock production</td>
<td></td>
</tr>
<tr>
<td>Subsidies, grants, and tax incentives</td>
<td>Austria</td>
<td>Programme for Rural Development</td>
<td>Manure management, biogas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bulgaria</td>
<td>State Agricultural Fund</td>
<td>Manure management, nutrient management</td>
<td>0.07 Mt</td>
</tr>
<tr>
<td></td>
<td>Estonia</td>
<td>National Programme of Greenhouse Gas Emission Reduction</td>
<td>Efficiency improvements and breeding improvements in livestock production</td>
<td>0.11 Mt</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>Agricultural Investment Assistance Program</td>
<td>Biogas systems, manure storage and application</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greece</td>
<td>Rural Development Program</td>
<td>Manure management</td>
<td>0.19 Mt</td>
</tr>
<tr>
<td></td>
<td>Poland</td>
<td>Rural Development Programme</td>
<td>Manure management, biogas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>United States</td>
<td>Conservation Innovation Grants</td>
<td>Nutrient management, efficiency improvements in livestock production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>California (US)</td>
<td>Dairy Power Production Program</td>
<td>Anaerobic digestion and biogas energy generation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>California (US)</td>
<td>Self-Incentive Program</td>
<td>Manure methane capture and biogas energy generation</td>
<td></td>
</tr>
<tr>
<td>Offsets</td>
<td>Australia</td>
<td>Carbon Farming Initiative</td>
<td>Reduction of ruminant methane, emissions from urine and dung, other non-livestock-related activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Victoria (Australia)</td>
<td></td>
<td>Manure methane capture</td>
<td></td>
</tr>
</tbody>
</table>
outside such caps could increase the likelihood that other sectors will be exempted, thereby reducing the potential for net reductions in global GHG concentrations.

Compared with the relative proliferation of voluntary and programme-based approaches, the development of policy instruments that mandate participation of all agricultural producers in emissions abatement programmes has been limited. Several factors have hampered the development of such policies: uncertainty over the economic mitigation potential of direct emissions reductions of CH₄ and N₂O in different national contexts (Vermont and De Cara, 2010); large measurement uncertainties for livestock emissions and for soil carbon flows (Smith et al., 2007b), which make it difficult to reflect potential mitigation actions by individual farmers in national inventories; and the large international trade in agricultural commodities, which makes markets potentially sensitive to price distortions from bilateral climate or trade policies (Gupta et al., 2007; Smith et al., 2007b). Given the emergence of emissions trading as the preferred policy instrument for mitigation of GHGs within Annex I countries, the exclusion of agricultural GHGs from these market-based policy instruments is notable.

New Zealand is so far the only Annex I country to have legislated mandatory inclusion of livestock emissions in a market-based instrument to reduce emissions. In countries where carbon pricing policies have been implemented, agricultural producers may be exposed to increasing energy costs, but livestock-generated emissions remain outside the scope of these instruments. Nevertheless, consideration has been given to extending such schemes to include agriculture, and various discussion documents have been prepared in several European countries and Australia (Radov et al., 2007; ACCSG, 2008).

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**TABLE 1 Continued**

<table>
<thead>
<tr>
<th>Type of policy instrument</th>
<th>Location</th>
<th>Programme name</th>
<th>Focus activity</th>
<th>Estimated mitigation impact per annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alberta (Canada)</td>
<td></td>
<td>Greenhouse Gas Reduction Program</td>
<td>Ten types of offsets for agricultural producers (e.g. edible oils and reduced feed days for beef cattle, biogas)</td>
<td></td>
</tr>
<tr>
<td>Ten-state agreement (US)</td>
<td></td>
<td>Regional Greenhouse Gas Initiative</td>
<td>Manure methane and anaerobic digestion</td>
<td></td>
</tr>
<tr>
<td>California (US)</td>
<td></td>
<td>Livestock Projects Compliance Offset Protocol</td>
<td>Manure methane capture</td>
<td></td>
</tr>
<tr>
<td>Carbon taxes</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions trading</td>
<td>New Zealand</td>
<td>New Zealand Emissions Trading Scheme</td>
<td>All GHGs, includes agricultural gases from 2015</td>
<td></td>
</tr>
<tr>
<td>Mandatory standards</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figures taken from Fifth National Communication on Climate Change for respective countries.*
The New Zealand ETS, established in 2008 and revised in 2009, mandates the reporting of agricultural GHGs by participants from 2012 and the full inclusion of the agricultural sector from January 2015 (New Zealand Parliament, 2009). The inclusion of agriculture in the New Zealand ETS was seen as necessary, given New Zealand’s emissions profile (Moyes, 2008) and a desire to avoid distortionary and inefficient exemptions (Ward, 2006). New Zealand is distinctive among Annex I countries in that nearly half of its emissions arise from agriculture (mainly from its extensive livestock) in the form of CH$_4$ and N$_2$O. Nevertheless, including agriculture in the New Zealand ETS has remained controversial, so the decision was revisited in 2011 as part of a planned independent review (Ministry for the Environment, 2011). The review panel recommended that the current implementation timetable be retained but that additional transitional measures be introduced. Whether the government will accept these recommendations remains uncertain. The development of the New Zealand ETS and continuing debate over alternative or complementary measures to address New Zealand’s agricultural emissions within the Kyoto Protocol framework has highlighted several issues that may inform livestock emissions abatement policies in other countries. Thus, although not wholly representative, the New Zealand case is instructive.

### 3. Mitigation options for livestock emissions

Controlling livestock emissions presents a more complex problem than controlling emissions from other sectors due to the relation to, and reliance on, biological systems (Commission of the European Communities, 2009). Nonetheless, identifying abatement strategies for livestock emissions relies on the same MRV principles as controlling other GHGs. Abatement strategies at various points in livestock production have been identified, such as improving pasture quality, more efficient or reduced applications of nitrogenous fertilizers, improving animal breeding, using feed supplements, and the application of anti-methanogenic vaccines (ECCP, 2001; Moorby et al., 2007). These abatement options for livestock emissions fall into two categories: technological options and farm-management options. Currently, the technological options available to reduce livestock emissions are limited. Some technologies may offer low-cost mitigation under certain conditions, but various other technologies are only at an early stage in their development and their potential to reduce emissions remains uncertain (Clark, 2006; Smith et al., 2008).

#### 3.1. Technological options for mitigating livestock emissions

Methane emissions from enteric fermentation – a digestive process specific to ruminant animals – constitute the majority of GHGs arising from livestock production (O’Hara et al., 2003). Additional sources of CH$_4$ associated with livestock production include effluent ponds and manure, both of which are significant sources of emissions from dairy livestock and are also associated with non-ruminant livestock production including pigs and poultry. As methane production is affected by the composition of ruminant diets, decreasing the relative proportion of fibre to starches or carbohydrates consumed by animals would reduce CH$_4$ emissions (Monteny et al., 2006). However, there are practical impediments to changing livestock feed regimes, especially in extensive pastoral systems. Other options, such as the manipulation of the rumen microbial ecosystem and vaccinations to stem methanogenesis, continue to be researched (Iqbal et al., 2008; Buddle et al., 2010), but their potential to reduce agricultural GHGs
remains uncertain. There are various strategies for dealing with emissions that arise from manure and effluent ponds (USDA, 2009). These management options, which include using captured CH₄ for energy production (Siikamäki, 2008), may be of use in intensive livestock operations where the movement of animals is closely managed or housed, but are less useful in extensive grazing systems for beef cattle and sheep or in open dairy production.

The N₂O attributable to agricultural production arises primarily from animal waste and the use of fertilizers. Various technological options to reduce N₂O emissions through animal, feed, and soil interventions have been identified (de Klein and Eckard, 2008). Animal interventions could include dietary amendments (e.g. salt supplementation) and breeding techniques that foster the development of stock with improved production efficiency in terms of both N₂O and CH₄ per unit of product (de Klein and Eckard, 2008; de Klein et al., 2010). Nitrification inhibitors, such as dicyandiamide, have been shown to be effective in reducing N₂O emissions from pasture under particular conditions (Eckard et al., 2010), but their ability to deliver large-scale and sustainable reductions across a wide range of climate and soil conditions remains uncertain.

3.2. Farm-management options for mitigating livestock emissions

Changes to farm-management practices currently appear to hold greater potential than purely technological interventions for the abatement of CH₄ and N₂O emissions from livestock production. Garnett (2007, p. 152) has suggested that the reduction of livestock numbers would be ‘the most straightforward way to reduce GHG emissions from livestock’ and notes that, in Britain, stock numbers have reduced by almost a third over a 25-year period without reducing meat or milk production. O’Hara et al. (2003) has confirmed a similar long-term improvement in production efficiency for the New Zealand sheep industry. However, reducing animal numbers does not cut CH₄ emissions in proportion to the decline in overall livestock population. Indeed, an increase in production of meat or milk production per animal can partially counteract the reduced emissions from a smaller livestock population. The potential for a further increase in production per animal unit will vary between countries and regions depending on the existing baseline from which improvements are made and the rate of improvements in pasture grasses and animal breeding. Such changes would rely on various complementary activities including information sharing between farmers, the livestock sectors, and scientists, and additional incentives that allow farmers to internalize benefits from reduced GHG emissions. Furthermore, given that the global demand for dairy and meat products continues to grow, gains in agricultural productivity would need to be achieved globally, and even then may only limit, rather than reduce, further increases in livestock emissions.

Strategies such as improving the utilization of nitrogen, better irrigation or drainage to lower nitrate leaching, use of nitrification inhibitors, and reduced animal grazing during wet seasons could reduce N₂O emissions by 15% in grazing-based systems and by up to 50% in animal housing systems (de Klein and Eckard, 2008). Velthof et al. (1998) have claimed that up to 70% of N₂O emissions could be eliminated by better management of nitrogen flows, particularly through improved efficiency in applying fertilizers, restricted grazing, and use of maize silage. When several strategies are combined, overall emissions may fall significantly, although the level of abatement could vary depending on regional differences (Luo et al., 2010). In addition, most current national inventories would not be able to capture the effect of farm-management changes such as the increased use of winter stand-off pads,
improved fertilizer application regimes, or grazing restrictions to reduce excess nitrogen deposition and associated N$_2$O emissions.

### 3.3. Abatement costs

The abatement of livestock GHGs depends on feasible technological or farm-management options and the cost-effectiveness of implementing such changes within farm operations (which in turn may depend on the presence of price or quantity restrictions on GHG emissions). A number of studies have estimated the cost of agricultural and livestock emissions abatement (e.g. Hyman et al., 2002; US EPA, 2006; McKinsey & Co., 2009), several of which have identified some potential for cost-effective abatement of livestock emissions. Given the diversity of livestock production systems in developed countries and the heterogeneity of emissions levels and abatement potential regionally and nationally, abatement cost models at highly aggregated scales have limited utility for policy development. To this end, some studies have provided regionally disaggregated estimates (Beach et al., 2008).

Several farm-level abatement options have been modelled that show low-cost or even positive financial returns for farmers (Neufeldt and Schafer, 2008; Beukes et al., 2010). Moran et al. (2011a, 2011b) developed marginal abatement cost curves showing that 14% of Britain’s agricultural emissions could be abated at zero cost or even at profit. In New Zealand, modelling studies suggest that more intensive dairy systems could generate greater profits and reduce GHG emissions per unit of output, even in the absence of a carbon charge (de Klein et al., 2009; Kerr and Zhang, 2009). The failure of livestock producers to carry out farm-management changes that would generate emissions reductions at a net profit may indicate attitudinal and social barriers to changing farming practices. Hence, measures such as information programmes and agricultural extension activities may be necessary, in addition to a price signal, to achieve large-scale behavioural change. Further analyses that consider capital constraints, risk scenarios, and the specific characteristics of various farm enterprises may be useful for understanding the potential for farm-level emissions abatement (Kerr and Zhang, 2009).

Scaling up abatement costs from individual farms to a national aggregate also involves a range of assumptions that can undermine the accuracy of abatement cost modelling. The limited capacity of aggregate models to preserve contextual differences between farming systems and the small number of farm-level abatement studies is responsible for the large divergence in views regarding overall abatement potential and costs at national scales. Such uncertainties regarding the effects of implementing emissions abatement policies represent a critical challenge for policy makers. The difficulties in quantifying abatement potential and its costs are not, however, insurmountable. Vermont and De Cara (2010) found that differences in abatement cost between studies were primarily attributable to differences in modelling approaches and the definitions and assumptions used in abatement cost models. The influence of different approaches and assumptions is notable in models of livestock emissions abatement potential and costs associated with the New Zealand ETS (Sustainability Council of New Zealand, 2007; ICF, 2008; Stroombergen et al., 2009a). Given the significant barriers to the adoption of farm-management-based mitigation options, and the challenges of scaling up in-principle mitigation options to annual and national scales, investigations of the economy-wide effect of market-based measures in New Zealand have assumed the complete absence of mitigation options other than reducing production (Stroombergen et al., 2009a, 2009b). In the absence of reliable and transparent cost abatement comparisons between agricultural and non-agricultural GHGs, the economic
impact of abating livestock emissions has remained politically contentious and has encouraged claims that mitigating agricultural emissions is not feasible.

Finally, the complexity of processes involved in agricultural GHG production requires that policies to promote abatement options recognize the relations among emissions-generating activities and farm-management practices (Weiske and Petersen, 2006). Although some technological options and farm-management changes that rely on improved feed quality have the potential to reduce direct CH$_4$ and N$_2$O emissions from livestock, such changes could increase emissions elsewhere in the product chain outside Annex I countries, thereby increasing net GHG emissions across the life cycle of production (Garnett, 2009; Gavrilova et al., 2010).

4. Applying market-based instruments to livestock emissions: the policy issues

Efforts to design and implement market-based policies in the livestock sector have generated two key challenges. The first is to design a policy framework that appropriately aligns the measurement of emissions, the abatement options, and the incentives facing livestock producers. The second addresses the risk of leakage and economic regrets that arises from unilateral domestic action.

The logic for including the livestock sector in an ETS is two-fold: first, voluntary measures appear unlikely to generate significant emissions reductions and, second, economic theory suggests that exposing all economic activities to a price on emissions can be expected to deliver reductions at optimal long-run efficiency. A possible objection is that beyond some initial low-cost options, the evidence indicates that the potential to mitigate livestock emissions is low and the abatement costs are high (DeAngelo et al., 2006; Lucas et al., 2007; Beach et al., 2008). For example, studies in New Zealand have suggested that including livestock emissions in the New Zealand ETS would, at least in the short term, result primarily in reduced agricultural production and land-use change from high-quality sheep and beef lands to dairy, and marginal sheep and beef lands to forestry (MAF, 2008; Kerr and Zhang, 2009). This is likely, at current carbon prices, to reduce net economic returns from primary production. Against this, from a theoretical perspective, the limited range of mitigation options and/or their relatively high cost is not a problem *per se*, as applying a market-based approach will still lead to the most cost-effective response across the economy as a whole.

In New Zealand the design of climate policies for the livestock sector has been influenced by a number of considerations: ensuring a flexible policy framework that can respond appropriately to changes in technology and the global climate policy environment; maximizing certainty for livestock producers by clearly signalling medium-to-long-term policy intentions; minimizing transaction and compliance costs; expanding the range of potential mitigation options through targeted investments in R&D; and taking into account the specific concerns of powerful agricultural lobby groups.

4.1. Aligning measurement and verification and selecting the point-of-obligation

Setting the point-of-obligation is a critical decision in the design of any ETS in order to promote effective mitigation responses (ATAG, 2009). Within any sector there are several points along the product chain where environmental monitoring, standards, or charges can be applied. Emissions from livestock production occur at the farm, which is characterized by numerous producers, each of whom contributes a small proportion of sectoral emissions. Processing firms are the first step down the product
chain and, in most contexts, are significantly more concentrated than farms in both the number of operators and scale of operations. Selecting either farms or processing firms as the point-of-obligation for a market-based policy instrument requires the consideration of several issues.

If it is assumed that no cost-effective mitigation options exist other than destocking, the point-of-obligation might be placed downstream with agricultural processors and fertilizer supply companies to minimize transaction costs (ATAG, 2009). However, this approach risks creating a self-fulfilling prophecy, because any incentive to reduce emissions intensity at the farm level is weakened unless specific incentives and monitoring tools are provided that enable farmers to respond to a processor-level price signal through the production chain. Moreover, were the cost-effectiveness of mitigation options to change either as a result of technological innovation or a significant shift in the price of emissions units, a processor-level point-of-obligation would be less capable of responding to these changes, as it requires passing incentives up the production chain. By contrast, if cost-effective abatement options for livestock emissions are available, then placing the point-of-obligation at the farm level could provide direct incentives for farmers to mitigate GHG emissions, although more detailed MRV systems would be required for such farm-specific circumstances (Kerr and Sweet, 2008). The recognition of emissions-mitigating practices or technologies within a farm-level point-of-obligation would require that such data are collected from all ETS participants and verified in a manner that can be reflected within the national emissions inventory.

A crucial requirement for the assignment of liabilities for farm-level emissions is the ability to reflect the use of abatement options or variations in emissions arising from differences in environmental conditions (such as soil type), between-animal characteristics (such as breed differences), and feed and stock management techniques in national inventories. Policy instruments could reward farmers for using abatement options or improving the relative efficiency of livestock production, thereby creating environmental benefits. However, unless mitigation activities are recognized in national inventories, the fiscal liability to government would remain the same as if no mitigation had taken place. At present, farm-level variations in emissions are not reflected in national inventories, although some countries are working towards inventory methodologies that enable this level of specification through process-based models (IPCC, 2006; VITO, 2008; US EPA, 2011). The refinement of national inventories to recognize differences in emissions at narrower spatial scales is therefore linked to selecting the point-of-obligation. Hence, designing the institutional characteristics of market-based policy instruments involves balancing a complex range of priorities and technical considerations.

Under the New Zealand ETS, the point-of-obligation was placed with dairy, meat, and wool processors and fertilizer companies. However, the New Zealand ETS legislation enables the point-of-obligation to be changed to the farm level in the future. Despite the preference of farmer groups and firms for the point-of-obligation to be set at the farm level, the government selected a downstream option in order to minimize transaction and monitoring costs. A farm-level point-of-obligation was also seen as problematic given the vocal and demonstrative political opposition of many farmers to the New Zealand ETS, which raised the prospect of severe difficulties with reporting and compliance (Rosin et al., 2008; ATAG, 2009). At present, the inventory reporting methodology used for livestock emissions cannot recognize differences in emissions between farms and calculates emissions based on stock numbers, modelled estimates of feed intake, and product volume. New Zealand’s emissions inventory currently lacks the ability to reflect livestock emissions abatement activities undertaken at the farm scale. Although refinement of the inventory methodology to enable recognition of farm-
scale differences in emissions and the use of abatement options is under way, the New Zealand government lacks a stated target for including these refinements in the national emissions inventory.

Addressing these issues suggests that rather than excluding agriculture from a market-based instrument, policies should seek to create incentives where abatement actions could be taken while considering the limitations of transaction costs and verification. Additionally, the capacity for policy evolution should be retained to accommodate new technological abatement opportunities.

4.2. Challenges arising from international trade in agricultural commodities and uneven policy responses

As noted earlier, in the absence of cheap abatement options, there is a risk that unilateral measures to impose a cost on non-CO$_2$ emissions from livestock will reduce domestic livestock production. The globally uneven application of mitigation policies to livestock emissions presents countries contemplating such measures with three interrelated challenges: the risk of environmental leakage due to domestic production being replaced by increased production and emissions elsewhere; economic regrets about lost production, skills, and market share; and whether to compensate farmers and/or land owners for reduced equity, loss of land value, or loss of future income.

The premise of the leakage problem is that if global demand for meat and dairy products remains unchanged, any decline in production arising from the cost of GHG abatement in one country may be offset by other countries that increase their production. If production shifts within Annex I countries, emissions would still be covered by existing emissions caps, although domestic political-economy concerns might remain. However, if production shifts from Annex I countries to non-Annex I countries, global emissions could even increase given that the emissions cap for Annex I countries would remain unchanged (Dumortier et al., 2010). The problem could be exacerbated if livestock production systems that are highly efficient in production volume per tonne of CO$_2$e were to shift to countries with less efficient production systems (Lee et al., 2007).

Economic regrets may arise independently of leakage issues but are often treated together in public debates and high-level policy statements. Farmer groups and the general public simply regard it as counterproductive to reduce domestic production if that same production would then occur elsewhere (Federated Farmers, 2009; NSW FA, 2009; Carter, 2010). Complicating the public debate is the fact that the move of activities off-shore may not entail a net economic loss nationally, because the costs of protecting domestic industries may be higher than the loss of economic activity arising from uneven policy settings. This implies that policy choices to manage leakage and economic regrets are inevitably influenced by perceptions of fairness regarding cost-sharing (Kerr and Zhang, 2009).

New Zealand’s first proposal to include agriculture in a broad-based tax (New Zealand Government, 2002) was withdrawn, in part because the sector questioned the environmental effectiveness of this measure based on the potential for leakage. The subsequent design of the New Zealand ETS in 2007, which was intended eventually to cover all sectors and all gases, excluded agriculture during the Kyoto Protocol’s first commitment period. Amendments to the New Zealand ETS in 2009 postponed the date of entry for agriculture from 2013 to 2015, and its actual entry date is subject to further reviews (Carter, 2010). Similar competitiveness and leakage concerns have contributed to the continued exclusion of agriculture from more stringent mitigation policies in other countries (ACCSG, 2008; CCC, 2008).
Few studies have modelled the changes in trade patterns or emissions volumes arising from price or quantity measures applied to livestock or agricultural emissions. A European Commission study (Leip et al., 2010) on the inclusion of agriculture in an ETS modelled a 19.3% reduction of emissions in the EU and a 6% increase in GHG emissions from livestock in the rest of the world.13 Key and Tallard (2012) have claimed that two-thirds of emissions reductions arising from applying a tax on CH₄ emissions from livestock across Annex I countries would be offset by increased production in non-Annex I countries. In their model, however, emissions reductions result only from changes in production levels, because it excludes the potential for technological or farm-management responses to policy. Kerr and Zhang (2009) have argued that in New Zealand agriculture, the risk of leakage may not be as high as often feared given the immobility of land and that high-quality land is unlikely to move out of production. Furthermore, New Zealand is a price taker in agricultural commodities. Thus, any reduction in production is unlikely to significantly affect global prices or the economics of production elsewhere. Intensification and efficiency improvements also offer opportunities to increase farm income to offset some of the additional costs under a domestic emissions charge (de Klein et al., 2009).

The generic policy responses to manage the risk of leakage and economic regrets about lost production, adjustment costs, and loss of market share include:

- increasing the range of countries with quantified emissions targets
- introducing binding sectoral agreements across all countries
- improving the efficiency of production globally
- implementing border adjustments
- providing output-based free allocation of emissions units to industry

These impose stringent (market-based) constraints on GHGs from livestock. The implementation of such options faces particular challenges in the context of emissions from livestock as reviewed below. Although developed countries already face binding emissions targets that include GHGs generated through livestock production, no country – with the exception of New Zealand – has enacted agricultural abatement policies in legislation that require the participation of agricultural GHG emitters or include livestock emissions in the ‘basket’ approach that underpins economy-wide emissions targets (Johansson et al., 2006). This suggests that the acceptance of economy-wide emissions targets alone is insufficient to ensure that countries will enact stringent mitigation policies for livestock emissions, and that domestic political economy considerations are likely to impede the uniform expansion of multilateral reductions in livestock emissions. Even if the number of countries subject to economy-wide emissions targets were to increase under future multilateral agreements, the reluctance of most developing countries to compromise the continued expansion of domestic livestock production, coupled with ongoing concerns about food security, means that mitigation measures at greater than zero cost for livestock production systems are unlikely in the short term. Similarly, the prospects for binding sectoral agreements covering livestock emissions in developed as well as developing countries appear slim.

Increasing the efficiency of livestock production globally would reduce emissions overall for a given demand, but would not alter either leakage or economic regrets from uneven mitigation policies. The risk of both effects would be reduced, but not eliminated, if the emissions intensity of production were
to fall more in countries that apply mitigation measures than in other countries (either due to the sector responding to climate policy or through the benefits of enhanced R&D programmes).

Border adjustments could take the form of import tariffs and/or export subsidies. Import tariffs on livestock products are unlikely to be helpful given the complicated nature of the international trade of these commodities. They also would not assist countries like New Zealand because the export-driven livestock sectors would be concerned about the loss of export opportunities. Export subsidies could assist the livestock industry but would need to be defended against possible challenges under World Trade Organisation (WTO) rules (Grubb et al., 2009; WTO, 2009), and could be seen to undermine broader objectives of liberalizing international trade in agricultural products.

The approach generally preferred by decision makers to address leakage and economic regrets, as well as to provide some form of compensation for stranded assets and uneven distribution emissions liabilities in an ETS, is the free allocation of units (Haites, 2003; Demailly and Quirion, 2006; Kerr and Zhang, 2009). For free allocation to be economically justifiable it has to be assumed that (i) the distortion in international trade patterns that arises from the unilateral introduction of climate policies is only temporary, (ii) free allocation is removed once the pressure on exporting sectors from international differences in climate policies is reduced, and (iii) the pressure on exporting sectors can be attributed to the uneven application of climate policies across jurisdictional boundaries and not just the application of climate policies per se (i.e. free allocation should reduce the economic costs that arise from being an early mover in an evolving international playing field and not shelter the sector from all requirements to reduce emissions) (Carbon Trust, 2009; Garnaut, 2010).

For livestock emissions, none of these conditions are easily satisfied. It appears unlikely that all major livestock-producing countries will apply equally stringent climate policies in the near future. Different types and stringencies of targets are likely to persist in many developing countries, particularly with regard to agriculture, and even countries with binding economy-wide emissions targets may continue to exempt agriculture from domestic market-based measures. Garnaut (2010) has suggested that the economically justified method of determining the level of free allocation to trade-exposed industries should be to compensate only for the balance in export prices between a stringent climate policy being imposed unilaterally and stringent climate policies being imposed on the same sector globally.

Although, in principle, an analysis of the differential effect of unilateral versus multilateral climate policies on agricultural producers could be carried out using global trade models, such an approach for determining the optimal level of free allocation was not used in the studies commissioned regarding the design of the New Zealand ETS (ATAG, 2009; Stroombergen et al., 2009a, 2009b). Kerr and Zhang (2009) have analysed options for the free allocation of units based on three broad objectives – to reduce economic damage and minimize regret from reduced production, to ease adjustment, and to compensate partially for losses. Free allocation based on current emissions (or, if leakage is the main concern, based on emissions from exported products) would minimize regret from reduced production, but would offer little remedy for a decline in land value or regional economic activity associated with reduced production unless the value was passed through to farmers. On the other hand, free allocation based on reduced land values with reference to a specific year would partially compensate farmers for loss of equity, but would not protect future production. It could also result in large individual benefits if farmers receive free allocation for lost agricultural land value and then convert their land to other uses. Free allocation involves trade-offs between the efficiency, equity, and effectiveness of the
policy instrument (Heilmayr and Bradbury, 2011). It is therefore inevitably a technically complex and politically charged component of the policy development process.

In 2009, the New Zealand government opted for an output-based allocation model, with 90% free allocation for emissions-intensive sectors (including agriculture), declining by 1.3% per year after 2015 (subject to agriculture entering the New Zealand ETS in 2015). Allocation at the processor level is intended to be based on the industry-average production intensity, thus offering rewards, in principle, to less emissions-intensive production systems. However, there is no means by which to reward individual farmers for reducing their production intensity unless such mechanisms are developed by individual processors. It has been noted that the phase-out of free allocation by 1.3% per year is extremely slow, which is contrary to the economic principle that industry protection should be only temporary. Furthermore, the net economic cost of maintaining protection is generally much greater than the benefits offered by this protection (Bertram and Terry, 2010).

Although dealing with leakage and economic regrets poses coordination problems within the international policy framework, they are not irresolvable. The evolution of global environmental governance has been marked by the development and diffusion of policy innovations initiated by pioneer countries (Jaenicke, 2005; Huber, 2008). The problem of livestock emissions in Annex I countries is essentially an issue of leadership and learning-by-doing. If countries where non-CO2 gases constitute a relatively large proportion of national emissions fail to develop robust policies for non-CO2 mitigation, global efforts to mitigate non-CO2 emissions will be hindered and iterative policy learning prevented because the incentives for countries with smaller fractions of emissions from livestock will remain weak. The paucity of progress in mitigating non-CO2 emissions from livestock in Annex I countries is partly due to the fact that few countries have given serious consideration to market-based measures for agricultural GHGs. This creates an unhealthy feedback loop whereby a lack of knowledge contributes to limited policy development, which in turn makes it impossible to learn about actual sector responses. Thus, the environmental damages from leakage must be weighed against the much greater long-term environmental damage caused by a failure to reduce global livestock emissions. Accordingly, despite the economic and technical difficulties associated with introducing a price signal for livestock emissions, there is a good case for some countries to experiment with such instruments.

4.3. The role of R&D and other non-market measures

Further research into abatement options and technologies, and monitoring techniques, forms a key part of efforts to advance agricultural mitigation. In 2002, the New Zealand government proposed, under its preferred policy package, the imposition of a levy on livestock animals to support research into mitigation options for agricultural emissions (New Zealand Government, 2002). After vocal protests from the farming community and extensive opposition, the government negotiated an agreement with industry to withdraw any market-based measure until at least 2013 in return for an industry-led and jointly funded research programme into agricultural mitigation options. A Memorandum of Understanding between the Crown and the members of the Pastoral Greenhouse Gas Research Consortium was signed regarding this matter in early 2004, setting a target of reducing New Zealand’s total ruminant CH4 and N2O emissions by at least 20% below business-as-usual emissions by 2012. Taking into account projected increases in livestock numbers over this period, it was estimated that if measures
available by 2012 were to be widely implemented, any rise in CH$_4$ and N$_2$O emissions between 2002 and 2012 would be avoided (PGGRC, 2004). This aspiration contrasts with the average increase in CH$_4$ and N$_2$O emissions from 1990 to 2008 of 0.9% per year (Ministry for the Environment, 2010).

Thus far, no identifiable additional mitigation solutions for CH$_4$ applicable to the New Zealand pastoral livestock system have been brought to the stage of commercial demonstration and deployment. Nitrification inhibitors, which were developed originally to enhance pasture growth and improve nitrogen utilization, are now widely available, but their use and effectiveness varies significantly with season and terrain. The absence of a price incentive further limits their current application by farmers in New Zealand. In 2008, the government increased national mitigation research efforts by forming the New Zealand Agricultural Greenhouse Gas Research Centre, which coordinates the academic and industry research organizations that work on the development of new mitigation options and their on-farm applicability. This domestic research programme is complemented by efforts to enhance and coordinate international research in the development of mitigation options through the Global Research Alliance on Agricultural Greenhouse Gases.

Several lessons can be drawn from this experience. Although the threat of a market-based measure has been an important incentive for industry to enter into a research-based approach, the lack of enforceable targets and the difficulty of distinguishing targeted mitigation research from general efforts to improve production efficiency suggest that research alone is not an effective substitute for market-based incentives and other complementary measures in the longer term. A technological abatement opportunity that comes at a cost to farmers or that requires significant farm-management changes is likely to be regarded as a real solution only if a price on agricultural emissions is applied that is greater than the cost of the technology. This would reinforce the need for climate policy to signal and define long-term mandatory measures, even if concerted R&D efforts were regarded as the dominant climate policy approach in the near term.

### 4.4. Food security and livestock emissions abatement policy

The potential for livestock emissions abatement policies, both voluntary and mandatory, to increase the price of livestock products through constraints and added costs on producers has possible implications for food security (Gill et al., 2010). Modelling the impact of livestock emissions abatement policies in Annex I countries on global food prices is complicated by the interrelatedness of crop and livestock production as sources of human nutrition, the use of grain crops as livestock feed, and the competition for land use between arable and pastoral systems. A comprehensive review of the relationship between livestock emissions abatement and food security is not possible here, but several implications of applying market-based policy instruments to livestock GHGs can be identified.

Garnett (2009, p. 500) has argued that given the related challenges of livestock emissions abatement and food security, ‘the priority should be to develop systems of food provisioning that supply populations with maximum nutrition at minimum greenhouse gas “cost”’. As a global average, livestock production typically requires far greater land and energy resources per unit of food than most other types of agriculture. In many livestock production systems grain and other crops are used as animal feed, rather than for human consumption. If abatement policies in Annex I countries were to reduce the profitability of livestock production and livestock numbers were to fall, a significant portion of the arable production produced for livestock consumption could be used for other kinds of food production.
production, and the relative efficiency of food production (in terms of cost per calorie) would probably increase (Godfray et al., 2010).14 Foley et al. (2011) have identified the potential for significant improvements in food security and the sustainability of agricultural production by shifting crop production away from livestock feed. Similarly, meat from ruminant animals is responsible for substantially more emissions per unit of production than meat from monogastric species (Gill et al., 2010). Including livestock emissions in market-based abatement policies could therefore help in a shift towards more efficient land uses and substitution of meat with lower emissions intensity.

5. Conclusions

The policy issues surrounding the mitigation of livestock emissions, with particular reference to the use of market-based policy instruments, have been examined. Given that roughly three-quarters of global agricultural non-CO₂ emissions are attributable to livestock systems, identifying and implementing robust policies for reducing livestock emissions will ultimately be essential if emissions abatement regimes are to be environmentally effective and cost-efficient. This applies to both developed and developing countries, and will remain applicable unless or until there is a major change to the currently agreed metrics for comparing the warming potentials of different GHGs. Under the Durban Platform for Enhanced Action, agreed in December 2011, it is intended that any post-2020 global climate treaty will apply common, legally binding rules to all Parties, albeit in the context of differentiated responsibilities to reflect national circumstances. Given that livestock emissions constitute approximately 10% of global GHG emissions, and the clear intention of the international community to require all major emitters eventually to take on binding economy-wide emissions limitation and reduction targets, it seems inevitable that the livestock sector will be included in domestic mitigation policies in some way.

As highlighted, however, the challenge for policy makers is how best to achieve this. Currently, there are only limited technological and farm-management options for controlling livestock emissions. These constraints raise significant policy issues, particularly with respect to setting the appropriate point-of-obligation, minimizing transaction costs, and reducing the risks of potential non-compliance or misreporting. Also, the uneven emphasis that national mitigation policies have thus far placed on livestock emissions raises issues of leakage and economic regret. To compound the problems, the prospects for securing coordinated multilateral action to reduce such concerns, whether via binding sectoral or other agreements for livestock production, are limited, at least prior to 2020. Understandably, such considerations have led many to recommend excluding livestock emissions from market-based mitigation measures. However, this approach carries risks. If emissions are to be reduced without a strong price signal, a mitigation technology would be required that is environmentally effective and also reduces emissions at no net cost to producers. The prospect of such a solution in the short to medium term is limited. There is thus a good case for including agriculture in economy-wide market-based measures. Such instruments have the potential to foster policy innovation and learning, incentivize investment in technologies and practices to reduce livestock emissions, and yield wide-ranging co-benefits.

Nevertheless, New Zealand’s experience in designing and implementing a market-based policy that includes livestock emissions provides useful lessons for other countries. First, from a technical standpoint, it is essential, among other things, to develop detailed inventory systems and methodologies
that recognize effective abatement activity at the farm level, to select a point-of-obligation that incentivizes emissions reductions (probably upstream), and to design an allocation plan for free emissions units that avoids windfall profits while minimizing possible leakage. Second, in order to reduce livestock emissions at a relatively low cost there is a good case for significant public investment in the development and dissemination of new technologies and farm-management practices. Such investment is also likely to help diminish resistance from livestock producers to market-based instruments. Third, developing and implementing a policy framework for livestock emissions requires astute and committed political leadership. Opposition from agricultural lobby groups is inevitable, and may be intense. Accordingly, the justification for including livestock emissions in mitigation regimes needs to be carefully articulated. Similarly, policy makers should provide adequate opportunities for consultation with the livestock sector and establish a clear and realistic timetable for policy implementation. A gradualist approach, with periodic opportunities for independent reviews of policy settings and their effectiveness, may help reduce resistance and encourage compliance. At the same time, a degree of policy stability and predictability will also be important to maintain credibility.

In the short term, there appears to be little chance that market-based policy measures will soon be applied to livestock emissions on a widespread basis. In the meantime, however, policy experimentation, and leadership by countries such as New Zealand will be important in identifying potential solutions to the policy challenges of livestock emissions abatement.

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Notes

1. The relative importance of livestock emissions depends on the metric used to compare different GHGs. The most common metric is that of CO2-equivalence based on the 100-year Global Warming Potentials (GWPs), used in reporting under the UNFCCC and in recent IPCC assessments (IPCC, 2007). There is considerable discussion in the scientific community about the appropriateness of and potential alternatives to GWPs (e.g. Johansson et al., 2006; van Vuuren et al., 2006; IPCC, 2009; Shine, 2009; Manning and Reisinger, 2011). The relative importance of non-CO2 emissions in GHG mitigation strategies could change significantly if there were changes to this metric. However, for near-term climate policy purposes, the use of GWPs appears likely to remain in place, even if the numerical values of some GWPs might be updated for future commitment periods (UNFCCC, 2009).

2. EU-15 comprises the 15 member countries of the EU following its enlargement in 1995 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Ireland, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the UK).

3. Subnational governments include local, regional, provincial, and state governments.

4. At present, Alberta’s Greenhouse Gas Reduction Program is the most ambitious offset programme for agricultural producers. It includes ten agriculture-based activities that can earn emissions offsets for sale to large industrial emitters within Alberta’s emissions trading scheme. To date, only one of the ten offset activities, tillage management, has been assigned earned credits (Government of Alberta, 2011).
5. Livestock emissions are included within EU ETS emission caps but are not covered within its price-based mechanisms. The EU ETS will include industrial N₂O from 2013 (http://ec.europa.eu/clima/faq/ets/index_en.htm).

6. Livestock production systems vary significantly across the developed world. New Zealand’s livestock sector is characterized by extensive pasture grazing of dairy cattle, beef cattle, and sheep, low levels of agricultural subsidies, and export of 80–95% of livestock production (Statistics New Zealand, 2011).

7. Others have described and reviewed the range of potential mitigation options (see Clark et al., 2001; Clemens and Ahlgrimm, 2001; Eckard et al., 2010; Gill et al., 2010).

8. The focus here is on direct livestock emissions (CH₄ and N₂O) of extensively farmed animals and not on soil carbon management, offsetting emissions through afforestation, or the consumption of electricity and liquid fuels associated with agricultural production. Accordingly, the scope for, or timescales and implications of, fundamental land-use changes away from livestock agriculture resulting from market-based mitigation measures are not explored here.

9. These studies often assume constant levels of production within a particular livestock category. Models of abatement cost that include the potential for destocking marginally less productive land or shifting between different types of livestock production could yield different results.

10. The technical issues for aligning MRV and incentives may be smaller for some livestock emissions sources, particularly manure management in confined dairy and poultry operations. Non-point-source emissions such as enteric fermentation and animal excreta on soil pose more significant challenges.

11. The exception to this is an inventory provision to reflect use of nitrification inhibitors, an existing mitigation technology for N₂O emissions.

12. In this circumstance, costs are borne by different parts of society (farmers and landowners if agriculture is not protected, or taxpayers if agriculture is fully protected). The issue of economic losses that arises from environmental regulation is discussed in Jaffe et al. (1995). Kerr and Coleman (2008) provide a discussion of the issue in terms of the New Zealand ETS.


14. For example, where cattle are grain-fed, they must consume approximately 7 kg of grain to generate 1 kg of beef (White, 2000). However, in some extensive pastoral systems with low levels of supplemental feeding, such as in New Zealand, livestock production yields protein (meat and dairy) for human consumption from land that could not efficiently produce high yields of grain or other foods (Garnett, 2011).

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