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Costs and potential of agricultural emissions abatement in Australia

A quantitative assessment of livestock abatement under the CFI

Linden Whittle, Beau Hug, Sarah White, Edwina Heyhoe, Kate Harle, Ezaz Mamun and Helal Ahammad

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Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)
Postal address GPO Box 1563 Canberra ACT 2601
Switchboard +61 2 6272 2010|
Facsimile +61 2 6272 2001
Email info.abares@daff.gov.au
Web daff.gov.au/abares

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While agricultural emissions are not directly subject to a carbon price under the Australian emissions pricing scheme, the agricultural sector can still play an important role in Australia's emissions abatement through generating carbon offsets under the Carbon Farming Initiative. The Carbon Farming Initiative is an offsets scheme that allows farmers and other land managers to earn Australian carbon credit units by reducing emissions or storing carbon on the land and in plants. This study explores the technical and economic abatement potential of the Australian agricultural sector in the context of the Carbon Farming Initiative, with a particular focus on livestock activities.

Technical abatement potential refers to the reduction in emissions that would be biophysically feasible from all available abatement technologies. In contrast, economic abatement potential refers to the reduction in emissions that can be achieved in an economically viable way.

Preliminary estimates of the technical abatement potential for individual abatement technologies and practices are based on outcomes from recent research, including projects undertaken as part of the Climate Change Research Program. The estimates are subject to the uncertainty around the emissions reduction potential of individual abatement technologies and the applicability of findings from the Climate Change Research Program under a wide array of conditions.

For quantitative estimates of economic abatement potential, this study focuses on livestock activities because these account for a substantial share of Australia's agricultural emissions, and the Climate Change Research Program and current policy settings provide useful information for an abatement costs assessment for these activities. However, the estimates of economic abatement potential for the livestock sector are limited to those technologies that are likely to be eligible to generate Australian carbon credit units under the Carbon Farming Initiative. The estimates are therefore indicative of the potential supply of Australian carbon credit units from livestock-related abatement activities.

The estimates of economic abatement potential are generated using a bottom-up model of the Australian livestock sector called the Farm Size Model. The Farm Size Model uses data from ABARES farm surveys, the Australia Bureau of Statistics, and the Australian Greenhouse Emissions Information System to disaggregate total livestock emissions into farm groups based on size, jurisdiction, livestock type and manure management system. The economic viability of implementing various abatement technologies at the farm level is calculated for each farm type using a net present value approach. Marginal abatement cost curves are then constructed by aggregating the economically viable abatement across farm types for various carbon prices.

The results suggest that the effect of the Carbon Farming Initiative on agricultural emissions are highly sensitive to the carbon price and will be modest at low to medium carbon prices. Under current carbon prices in Australia, farmers would not adopt many of the known emissions abatement technologies for livestock without a significant reduction in their cost.

Of the technologies considered, the destruction of methane from manure generated in piggeries offers the cheapest abatement opportunities. Supplementing the diets of milking cows with fats and oils also offers opportunities, but only at significantly higher carbon prices. In terms of the total amount of abatement, anti-methanogen vaccines have the potential to offer the most significant reductions given their wide applicability. In comparison, abatement generated by

other technologies or practices, such as methane destruction and feed supplementation on dairy farms, are limited by their relatively narrow applicability.

The estimates of economic abatement potential presented in this report do not measure any market or actual emissions reduction outcomes because they will depend on the final uptake of abatement strategies. The economic abatement potential estimates have not considered any issues or complexities associated with the individual adoption decision or process or any institutional barriers to adoption, which in certain circumstances may be formidable.

1 Introduction

Background

Since the start of the Carbon Farming Initiative (CFI) in December 2011, Australian farmers and other landholders have been able to generate and sell Australian carbon credit units (ACCUs) by undertaking eligible greenhouse gas emissions reduction or sequestration (henceforth, abatement) activities. The CFI is an important component of the Australian Government's Clean Energy Future Package, simultaneously encouraging abatement in the land-based sector and reducing the overall cost of meeting national emissions abatement targets.

Landholders' participation in the CFI is voluntary. Many potential abatement technologies or practices are available to farmers involving animal diet manipulation, animal waste management and fertiliser application (DAFF 2012). Final uptake of these activities will depend on a range of factors including biophysical suitability, policy compliance, economic costs and benefits, and social and institutional settings for technology and practice adoption, as perceived by farmers and other landholders. The personal characteristics, goals and beliefs of individual farmers and landholders are likely to affect the decision to adopt a new technology or practice, making estimation of final abatement challenging. However, estimates of technical or economic abatement potential can provide a good approximation to maximum possible final abatement.

Technical abatement potential refers to the maximum emissions abatement that can be achieved from implementing given abatement technologies or practices based on purely biophysical attributes and suitability. These estimates are often based on expert judgement and an understanding of the biophysical applicability and emissions abatement potential of the technologies considered. When estimating technical abatement potential, the relative costs and benefits of implementing the various scientifically proven technologies or other factors that might enter the individual adoption decision are not considered (Figure 1).

Figure 1 Schematic view of the various types of abatement potential

Technical potential	• Available technologies • Biophysically and technologically constrained (for example, soil type and climate)
Economic potential	• Chosen measure of economic viability • Financially/economically constrained (for example, high cost)
Final abatement	• Landholders' adoption decision • Socially and institutionally constrained (for example, lifestyle and personal values)

In contrast, economic abatement potential refers to the emissions abatement that can be achieved in an economically viable way. The abatement activities that are economically viable will be a subset of the technically viable abatement activities and depend on the expected carbon price. Estimates of economic potential require a clearly defined measure of economic viability; net present value is the most commonly used measure. Economic abatement potential is important because it recognises the importance of financial incentives in the adoption decision. However, it is likely to overestimate the actual or realised emissions abatement potential because social and institutional factors are often not considered.

Research programs, such as the Australian Government's Climate Change Research Program (CCRP), have helped progress abatement technologies to a farm ready stage and contributed to administration of the CFI by sponsoring development of emission measurement technologies. The Department of Agriculture, Fisheries and Forestry and the Department of Climate Change and Energy Efficiency are working together to facilitate the uptake of abatement technologies by developing a CFI 'positive list' and a range of CFI methodologies (also known as 'offset protocols') through industry consultation. Nevertheless, gaps remain in the understanding of the cost effectiveness of implementing these technologies and potential opportunities in domestic and international markets.

Scope and objectives

This report aims to: (1) highlight the technical abatement potential of selected abatement technologies or practices available to Australian farmers and (2) estimate the economic abatement potential in the Australian livestock sector from selected abatement activities.

The discussion on technical abatement potential draws on research outcomes from the CCRP and provides an up-to-date assessment of the emissions abatement potential of selected abatement technologies and practices. Abatement technologies and practices included in the discussion cover methane emissions from enteric fermentation and animal waste, and nitrous oxide emissions from cropping.

This report includes an economic abatement potential estimate for livestock methane emissions because of the relative importance of livestock emissions, which accounted for about 70 per cent of Australia's total agricultural emissions in 2010 (Australian Government 2012a). Any major agricultural emissions abatement efforts in Australia must target these emissions. No attempt has been made to estimate the economic potential for reducing nitrous oxide emissions from animal waste or fertiliser use in cropping. Given the current state of knowledge and data, scientifically sound methodologies for these activities are less developed and any estimates of abatement potential would be highly uncertain. The economic abatement potential of the forestry sector, another important source of net emissions in Australia, was assessed in an earlier ABARES study (Burns et al. 2011).

Unlike other studies that include a large number of potential abatement technologies and strategies (for example, McKinsey & Co. Australia 2008), this study only considers activities that are likely to be eligible to generate ACCUs under the CFI. By doing so, the estimates of economic abatement potential presented in this report are synonymous with estimates of the potential supply of ACCUs from livestock abatement activities under the CFI. The supply of ACCUs from the livestock sector is part of the land-based sector's contribution to the domestic supply of carbon permits and the national abatement effort.

The next section describes the policy settings, including the CFI and related domestic and international emissions trading schemes. Section 3 outlines the process of technology adoption from an individual decision-makers perspective and discusses the role of policy in the adoption of abatement technologies and practices. Section 4 draws on the CCRP for an up-to-date assessment of the technical potential of selected abatement technologies and practices. Section 5 presents the economic potential of selected abatement technologies and practices available to the livestock sector. Section 6 summarises the key findings of the current study and outlines future research direction.

2 Generating and selling CFI credits: the policy settings

Carbon Farming Initiative

The CFI, which came into effect in December 2011, is the first federally legislated long-term policy mechanism to encourage land-based sectors—not liable under the Australian carbon pricing scheme—to participate in Australia's greenhouse gas abatement effort. Together with the Clean Energy Future (CEF) Package, the CFI provides farmers and landholders with incentives to undertake abatement activities.

The current legislation lists a number of activities eligible for credits under the CFI. These are broadly classified into Kyoto-compliant credits, which may be sold into the international or domestic compliance markets, and non-Kyoto credits, which may be traded in the CFI Non-Kyoto Carbon Fund (Table 1). Both sets of certified credits may also be traded in voluntary markets.

Table 1 Kyoto and non-Kyoto CFI-eligible activities

Kyoto-compliant activities	Non-Kyoto activities
Reducing emissions from livestock	Soil carbon management
Reducing emissions from fertiliser use	Feral animal management
Reforestation	Non-forest revegetation
Avoided deforestation	
Improved forest management	
Reducing emissions from waste deposited in landfills before July 2012	

Source: DCCEE (2013d)

The Clean Energy Regulator is the statutory authority responsible for administering the CFI as well as the Carbon Pricing Mechanism, the National Greenhouse and Energy Reporting scheme and the Renewable Energy Target. The regulator's responsibilities for the CFI include:

- approving CFI projects
- issuing CFI credits
- managing the holding, transfer, retirement, relinquishment and cancellation of units through the Australian National Registry of Emissions Units (the Registry)
- approving CFI auditors (DCCEE 2013a).

Participation in the CFI is voluntary. To take part, an applicant must first become a Recognised Offsets Entity and open a registry account, for which they are required to pass a 'fit and proper person' test. Once registered, applicants may submit their project application to the Clean Energy Regulator for approval. Applications are assessed based on criteria about the eligibility and legality of the project. For example, projects must use an approved methodology, meet additionality requirements and not include any activities that are on the 'negative list' (discussed later). The application must also have necessary regulatory approvals, a statement of consistency with relevant natural resource management plans, and proof of consent of other parties with an eligible interest in the land.

To ensure the integrity of CFI offsets, they must be:

- additional—the activity would not have been undertaken in the absence of the CFI
- permanent—carbon sequestration (or carbon sinks) should be maintained on a net basis for 100 years
- measurable and verifiable—must use an approved CFI methodology
- supported by peer-reviewed science
- consistent with Australia's international emissions accounting obligations
- genuine—account for leakage and variability.

For more details, see DCCEE (2013e).

While farmers are able to submit projects for approval on an individual basis, the government has proposed mechanisms to streamline the assessment and approval of abatement projects. One such mechanism is the 'positive list' of abatement activities identified by the government as activities that are not common. These are automatically deemed to be additional and will be included in the CFI regulations. Items currently on the positive list include:

- vegetation and wetland restoration projects, such as
  - establishment of permanent plantings on or after 1 July 2007
  - human-induced regeneration, on or after 1 July 2007, of native vegetation
  - restoration of natural wetlands
- legacy landfill gas projects, such as
  - capture and combustion of methane from waste deposited in a landfill facility before 1 July 2012
- livestock management and other activities, such as
  - capture and combustion of methane from livestock manure
  - reduction of emissions from ruminants by manipulation of their digestive processes
  - application of biochar to soil.

The CFI regulation also identifies a 'negative list', which includes activities that may have an adverse effect on the environment or communities including risks for water availability, biodiversity conservation and land access for agricultural production. Such projects are ineligible for CFI credits.

Being on the positive list of activities is only one part of the policy process that makes a project eligible for CFI crediting. The CFI Handbook outlines five stages that a landholder or project proponent must check to determine if the proposed activity is eligible for CFI credits (Australian Government 2012b). Included in these stages is that projects must adhere to one of the approved CFI methodologies that establishes a project's baseline of 'usual' emissions, against which abatement is measured.

Appendix A provides a summary of CFI methodologies that have been approved or are under review by the Domestic Offset Integrity Committee (DOIC), as at 1 March 2013.

Australian carbon market and its international exposure

The Australian Government implemented a price on carbon from 1 July 2012 as part of its Clean Energy Future Package. Around 350 of Australia's largest emitters are expected to pay for their individual emissions (CER 2012). For the first three years, legislation will set the carbon price, starting at $23 per tonne of carbon dioxide equivalent emissions produced, rising at 2.5 per cent a year in real terms. This will transition into an emissions trading scheme (ETS) with a fully flexible, market-determined carbon price from 1 July 2015 (Australian Government 2011).

The Australian Government has indicated its intention of linking the domestic ETS to the European Union emissions trading scheme (EU ETS) from July 2015. Only one-way linking has been proposed, by which Australian liable entities will be able to purchase international permits to meet up to 50 per cent of their obligations. However, the amount of international Kyoto offsets (that is, Certified Emissions Reductions from the Clean Development Mechanism) that liable entities can use to meet their emissions liabilities will be capped at 12.5 per cent. While domestic units—ACCUs—cannot yet be exported to the European Union, there are plans to implement full linking by July 2018. Details of the linking, including whether the EU ETS will accept CFI credits, are subject to negotiation.

On 28 August 2012 the government announced that the carbon price floor—previously planned to be in place once emissions permit trading commenced in 2015—will not be implemented. However, the European unit price will effectively operate as a price ceiling. This may lead to increased volatility to the returns on projects under the CFI, depending on the degree of exposure of domestic prices to the EU market. While current prices under the EU ETS are low, the European Commission's future measures are expected to increase and stabilise these prices over both the short and long term (Ashurst Australia 2012).

The Australian Government is expected to consider links with other international schemes—such as the New Zealand scheme—on a case-by-case basis.

The market for CFI credits

The type of CFI credits will determine the potential markets to which these may be sold. During the initial period from 2012 to 2015 when the fixed carbon price applies, liable entities in Australia are able to meet up to 5 per cent of their emissions liability with the Kyoto-compliant ACCUs, which are eligible for surrender under the Carbon Pricing Mechanism established under the *Clean Energy Act 2011* (Cwlth). After 1 July 2015 there will be no limit on the amount of ACCUs liable entities can use to meet their emissions liabilities.

Credits gained for non-Kyoto activities (that is, non-Kyoto ACCUs) are not eligible to count toward offsetting emissions by Australia's liable businesses; instead, these may be purchased by the Australian Government using the CFI Non-Kyoto Carbon Fund as well as by individuals or businesses that wish to voluntarily offset their emissions. Past studies suggest that the voluntary market for carbon offset credits is likely to remain a small fraction of the size of regulated markets (Hug & Ahammad 2011). However, the Australian Government's Non-Kyoto Carbon Fund will increase demand for non-Kyoto ACCUs.

At the international level, potential buyers for CFI credits may include governments with obligations under the next phase of the Kyoto Protocol, companies with emissions obligations under national or regional schemes, and organisations voluntarily offsetting their emissions. In December 2012 the Kyoto Protocol was amended to continue from 1 January 2013, with the second commitment period to last eight years.

Under the interim one-way linking with the EU ETS, it is expected that the price of Australian carbon units (particularly, Kyoto-compliant ACCUs) will be determined by the European Union Allowance price. This arrangement will give Australian businesses access to a source of credible international units, providing another way to meet up to 50 per cent of their emission reduction targets. At the same time, it would also expose ACCU prices to EU market dynamics.

Full linking of the Australian and EU carbon markets would provide scope for welfare enhancing trade in carbon permits, and for reducing the costs of meeting the combined emissions abatement targets of both regions. However, conventional economic rationale would suggest that, despite Australia's overall gains from international trade in carbon permits, some parties within Australia will benefit while others may lose. Under the scenario where Australia is a net importer of permits, farmers, landholders and other offset project proponents will be worse off than with no international linking scenario, with most gains from linking accruing to other sectors of the economy. The opposite will happen where Australia is a net exporter. The extent of these gains and losses will depend on how international linking affects the domestic carbon permit price.

The agriculture sector may benefit indirectly from low international carbon prices. This is because, even where Australia is a net importer of permits, international linking provides the opportunity for liable parties, including those in the energy sector, to lower their costs of abatement and carbon policy compliance. This may benefit the agricultural sector through lower energy prices.

Outside the European Union and New Zealand, there are currently few established carbon markets. Regional schemes exist in Canada and the United States; Japan and the Republic of Korea have previously proposed the possibility of introducing an ETS, but little progress has been made in either country. China has also expressed its intention to establish a national carbon market—with a number of regional pilot schemes having commenced in 2012 as part of its 12th five-year-plan.

3 Factors affecting uptake of abatement technologies

Theory behind the adoption process

The uptake of an abatement technology or management practice is the result of many individuals' adoption decisions. Ultimately, an individual farmer or landholder will adopt an innovation if doing so will help achieve their personal goals. Goals will differ between individual landholders and may include, but are not limited to, wealth and financial security, environmental protection and enhancement, social approval and acceptance, personal integrity and ethical standards, and balance of work and lifestyle (Pannell et al. 2006).

The adoption decision is often characterised as a process of learning and evaluation. For example, according to Barr and Cary (2000), five basic steps need to take place before complete and permanent adoption of a change in management practices can occur:

1) an awareness of a need or opportunity for change
2) collection and evaluation of information
3) a trial of the innovation
4) adoption of the innovation on larger scale
5) evaluation of decision and possible continuation.

Any factor that affects the learning and evaluation process or the extent to which an innovation contributes to the landholder's personal goals will affect the timing or scale of adoption. These factors may be characteristic of the farm, landholder or innovation itself. As such, theoretical and empirical studies have identified a large number of factors as being determinants of adoption; many of these factors are interactive and have overlapping rationales.

For example, Rogers (2003) identifies five general characteristics of an innovation that are likely to affect its adoption—relative advantage, compatibility, complexity, trialability and observability. All of these characteristics either refer to the extent to which the innovation is perceived to offer an advantage over alternative practices or affect the ease with which the steps identified by Barr and Cary (2000) can be carried out. For example, the relative advantage of an innovation, and its compatibility with current practices and beliefs, refers to the benefits the innovation offers over alternative actions, taking into account the landholders' personal goals and objectives. Innovations that can be trialled on a limited scale (trialability) or have easily observable outcomes (observability) are more likely to be adopted, or adopted more quickly. These characteristics make evaluation of their relative merits easier and reduce uncertainty around the future costs and benefits of adoption. In contrast, the adoption of innovations that are more complex is likely to be slower, or never occur, as the collection and evaluation of information may take longer or be too costly.

Economic models of adoption typically assume that landholders choose the timing or scale of adoption to maximise some measure of wealth or welfare. Emphasis is placed on the effect of uncertainty, landholders' risk preferences, human capital and farm size on the incidence, extent or timing of adoption (Feder et al. 1985; Sunding & Zilberman 2000).

In contrast, the social literature places more importance on landholders' non-financial objectives and the social aspect of the adoption decision process. In doing so, social networks, landholders'

personalities, family situation and personal circumstances become important factors (Pannell et al. 2006). In a meta-analysis of the empirical literature undertaken by Prokopy et al. (2006), personal attributes such as education level, income, access to information, and awareness and participation in social networks were all found to generally have positively influenced adoption.

Role of policy in encouraging uptake

Policy can play an important role in encouraging abatement in the agricultural sector by helping farmers and other landholders overcome the technical, economic and social barriers to adoption. Policy can influence participation in the CFI through at least three potential channels (Table 2).

Table 2 Potential channels for policy influence

Channel	Method	Current policy
Technical abatement potential	Fund research into new and emerging technologies Improve the applicability/effectiveness of existing technologies	Climate Change Research Program Filling the Research Gap
Economic abatement potential	Improve the cost effectiveness of known technologies through research and development Provide additional financial incentives	Carbon Farming Initiative Clean Energy Future Package
Final uptake	Accelerate the adoption process through information delivery and trial projects	Extension and Outreach Action on the Ground

First, policy can influence participation by increasing technical abatement potential. This is done by undertaking or investing in research to develop new abatement strategies and improve the emissions abatement potential or applicability of existing ones. Under the CCRP, considerable research has been undertaken to identify or develop new practical on-farm management strategies to reduce agricultural emissions and take these strategies to a farm-ready stage.

Second, policy incentives can encourage farmers and landholders to undertake activities that have been shown to reduce emissions. The CFI and the Australian carbon price scheme provide landholders the opportunity to earn additional income through generating and selling carbon credit units from eligible abatement activities. In doing so, the government programs under the CEF Package can increase overall Australian abatement by encouraging uptake of existing technologies. By providing financial incentives for undertaking on-farm abatement, the Australian carbon price scheme may encourage new abatement technologies to be developed.

The third way to encourage uptake is to accelerate or support the learning and evaluation process needed for adoption to occur. Two key components of the Carbon Farming Futures Program are designed to do this: Extension and Outreach and, to a lesser extent, Action on the Ground. Extension and Outreach will fund information delivery and extension services while Action on the Ground funds on-farm trials and demonstrations of abatement technologies and practices. Extension and outreach programs can inform farmers of the potential benefits of new abatement strategies, reducing the time and costs of information gathering. Demonstration projects verify that abatement technologies or practices can be implemented on-farm and increase farmers' awareness and understanding of the viability of strategies and how to implement them. This reduces speculation and perceived uncertainty around the costs and benefits of adoption and accelerates the rate of diffusion of technologies in the farming community.

4 Abatement technologies and practices: technical potential

This section draws on the findings of the recently completed CCRP to assess the technical potential of selected abatement technologies and practices. Technical abatement potential refers to emissions abatement that could be achieved by implementing a given abatement technology or practice based on purely biophysical attributes and suitability. Estimates of technical emissions abatement are based on scientific evidence from field or laboratory trials of a particular technology or practice under defined conditions.

The CCRP progressed many on-farm greenhouse gas abatement technologies and practices toward on-farm application. Some technologies or practices are farm-ready and have CFI methodologies either approved or under consideration by the DOIC. Others have been applied in field trials with promising results, but further work is needed to develop robust evidence for the emissions abatement potential of the technology or practice and its effects on productivity. Other technologies or practices have been tested and found to provide promising laboratory results that warrant field-testing or demonstrate proof-of-concept. CCRP research also contributed to administration of the CFI by sponsoring development of emission measurement technologies, a critical factor in enabling Australia to accurately demonstrate its greenhouse gas emissions and abatement, and accelerating development of CFI methodologies.

The following discussion focuses on abatement technologies and practices relating to methane emissions from enteric fermentation and animal waste; nitrous oxide emissions from cropping, fertilisers and animal waste; and soil carbon sequestration. The underlying technologies involve dietary management of ruminants, rumen manipulation through anti-methanogen vaccines, breeding of low-methane cattle, animal waste management, fertiliser application and changes in farm management practices (DAFF 2012). Some abatement technologies or practices reduce emissions on an absolute basis (for example, per hectare per day or per animal per day), while others reduce emissions based on production (for example, per volume milk yield or per kilogram carcass weight). Many technologies or practices reduce both absolute and relative emissions levels. To be CFI-eligible, a project must reduce absolute emissions.

Livestock

Significant advances have been made in recent years in identifying and testing technologies to reduce methane emissions from Australian livestock. A large part of this research has been carried out under the CCRP. However, much of this research is preliminary. Greenhouse gas emission mitigation strategies require differing degrees of research effort before delivering practical on-farm solutions to producers. The effects of strategies that are available today are mostly transitory (or dependent on continued application), while technologies likely to be developed in the intermediate or longer term are targeted at more permanent solutions (for example, breeding livestock that produce lower methane emissions).

Controlling methane production in the rumen

Preliminary results from the CCRP and wider research (for example, Beauchemin et al. 2008 and Hegarty 2009) indicate that diet can influence the microbiology of the rumen in ways that can reduce the amount of methane produced as a by-product of enteric fermentation. A number of potential feed supplements have been explored including lipids, fatty acids, proteins, tannins

and fat-tannins. All have reduced methane emissions in trials and some have productivity benefits such as live weight gain and milk yield (DAFF 2012).

Most abatement technologies or practices offer up to a maximum 20 per cent abatement (Eckard 2012), and results are only applicable in certain sectors and production systems. In particular, many dietary management strategies are only suitable for intensive livestock systems.

Dietary management for ruminants—dietary oils

Analysis of results obtained from the CCRP, as well as other key studies, demonstrate that for each increase of 10 grams per kilogram of dry matter in dietary lipid concentration (about 1 per cent of dry matter), enteric methane emissions are generally reduced by 0.79 grams per kilogram dry matter intake (around 3.5 per cent reduction in methane on a dry matter basis) (Moate et al. 2011). Results for different dietary oils vary around this average. For example, whole cottonseed meal for dairy cows reduced methane by an average of 2.9 per cent for every 1 per cent added supplement in the diet. Brewer's grain for dairy cows reduced methane by 9 per cent per litre of milk (or about 8 per cent per cow a day). Hominy meal for dairy cows reduced methane by 14 per cent per litre of milk (about 10 per cent per cow a day). Sunflower oil feed to beef reduced emissions by 19 per cent per cow a day.

Dietary management for ruminants—plant secondary compounds (tannins, grape marc)

Grape marc (fed to late-lactation dairy cows) was shown in a field trial to reduce emissions by about 17 per cent (ensiled grape marc: grams of methane per cow a day) or 20 per cent (dry grape marc: grams of methane per cow a day). Condensed tannins (*Acacia mearnsii*) reduced daily methane emissions from lactating dairy cows (by 14 per cent for a lower dose and 29 per cent for a higher dose), but with significant adverse effects on milk, fat and protein yield. More research examining effects of condensed tannins at lower doses is needed.

Dietary management for ruminants—nitrates

Nitrates provided in commercial lick-blocks to sheep in the paddock were found to reduce methane emissions by about 8 per cent per sheep a day. This practice may only be suitable in low-quality forage areas, such as those in northern Australia, because of the risk of nitrate poisoning in high-quality forage areas.

Dietary management for ruminants—novel supplements, novel forages and Australian natives

CCRP projects examined novel supplements, novel forages and Australian natives as fodder alternatives and feed supplements in laboratory experiments and found significant reductions in methane. They were not tested in animal trials. Promising options include almond hull, oculata algae, various tannins, forgae plants (turnip, winfred, chicory, plaintain), tropical legumes (such as species of *Leucaena* and *Desmanthus*) and plant extracts (for example, from *Eremophila glabra* and *Santalum spicatum*).

Dietary management for ruminants—wheat feed for dairy cows

A CCRP trial feeding dairy cows a diet supplemented with either crushed wheat or crushed corn showed a nearly 50 per cent reduction in methane emissions in the cows on the wheat-based diet relative to those on the corn-based diet. There were significant reductions in milk fat yield associated with the wheat diet. More research is needed to investigate the effects of lower supplement levels on methane emissions and milk composition.

Rumen manipulation—anti-methanogen vaccines

Anti-methanogen vaccines stimulate an immune response in ruminant livestock, resulting in production of antibodies. These antibodies can then inhibit methanogen (the methane-producing microbes present in livestock rumen; Wright et al. 2004) activity and, therefore, methane production. Wright et al. (2004) found that methane production in sheep was reduced by about 8 per cent a kilogram dry matter intake following a two-step immunisation process. More research and development is needed before a vaccine could be made available to producers. However, there is much interest in vaccines for methane reduction in livestock, as it is a technique that could be used across the livestock sector, including in Australia's extensive grazing systems.

Breeding low-methane producing cattle

Research results suggest sires could be selected whose progeny would produce between 11 per cent and 24 per cent less methane than high-methane-producing progeny of other sires in the same herd. This result provides proof-of-concept that breeding solutions may reduce methane emissions from livestock.

Livestock waste management

Methane capture and destruction from animal waste lagoons

Methane is a by-product of the anaerobic decomposition of organic matter in animal waste. As such, more methane emissions are generated from manure stored in anaerobic liquid-based systems such as tanks or lagoons than manure stored in dry or aerobic conditions (Australian Government 2008).

Capture and flaring (that is, burning-off) of methane from animal waste lagoons significantly reduces greenhouse gas emissions. Flaring methane reduces emissions because it converts a potent greenhouse gas, methane, into a much less potent one, carbon dioxide.

The potential reduction in methane emissions depends on the efficiency of capture from the lagoon. A fully covered wastewater lagoon can collect nearly all the methane produced, with no or very minimal losses. A floating cover may capture less.

Flaring will destroy almost all the methane collected. The methodology for methane capture and flaring in piggeries applies a 98 per cent reduction in emissions. Some sites may not treat all their waste in covered lagoons, so the potential for a site to reduce their total waste methane emissions will depend on the proportion of waste treated in lagoons, the proportion of the lagoons that are covered and the type of cover used.

Managing manure and urine in the paddock

Research from the CCRP has demonstrated substantial reductions (from 35 per cent to 74 per cent) in nitrous oxide emissions from dairy urine when the nitrification inhibitor *dicyandiamide* is applied to the paddock. The application regimes that produce large emissions reductions are unlikely to be practical for on-farm implementation.

Cropping and fertilisers

The most significant greenhouse gas emitted from Australian cropping systems is nitrous oxide. CCRP research found that nitrous oxide emissions can increase significantly after irrigation events, high rainfall and the application of nitrogen fertilisers. The risk of an increase in nitrous oxide emissions rises where soil carbon content is high, and the application of nitrogen fertiliser occurs close to an increase in soil moisture (such as caused by rainfall or irrigation).

A range of strategies for reducing nitrous oxide emissions identified by the CCRP, include:

- efficient management of irrigation and fertiliser application
- use of enhanced efficiency fertiliser
- liming
- incorporating legumes into crop rotations.

Irrigation management

Based on analysis of nitrous oxide emissions following nitrogen fertilisation and irrigation events in Queensland cotton-farming systems, CCRP researchers identified management of the timing and amount of irrigation as a strategy for avoiding high nitrous oxide emissions. They recommended applying small volumes of water at regular intervals when water content is depleted and avoiding large water volumes following application of nitrogen fertilisers or when soil nitrate content is high.

Fertiliser management

Based on CCRP research on a range of cropping systems around Australia, the following strategies were identified for preventing high nitrous oxide emissions:

- avoiding the application of large amounts of fertiliser before planting
- avoiding application of nitrogen fertiliser before irrigation or high rainfall events
- improving fertiliser management to better match crop nitrogen needs with soil nitrogen supply.

Enhanced efficiency fertilisers

CCRP researched the potential of enhanced efficiency fertilisers (EEFs) containing the nitrification inhibitors *dimethylpyrazole phosphate* (DMPP) or *dicyandiamide* (DCD) to reduce nitrous oxide emissions following fertiliser application. Use of EEFs containing DMPP reduced nitrous oxide emissions from a corn rotation in Queensland by 60 per cent. Its use on sugar cane in Queensland reduced emissions by 34 per cent. The use of EEFs containing DMPP or DCD on ryegrass pastures in Victoria resulted in a 64 per cent or 35 per cent reduction in emissions, respectively. Evidence suggests the potential reductions from using EEFs will change with soil type, rainfall and irrigation practices.

Liming

Increasing soil pH by applying lime is a potential approach to reducing nitrous oxide emissions from semi-arid cropping soils following rainfall events. Research from the CCRP showed that annual liming fertilised acidic cropping soils in Western Australia and can decrease nitrous oxide emissions by up to 30 per cent following summer or autumn rainfall events. However, the total greenhouse gas emission balance of the farming system depends on these greenhouse gas emissions reductions being greater than those associated with producing, transporting and dissolving the lime. Further research into the use of liming is needed.

Crop rotations

Incorporating grain-legumes in crop rotations can reduce the need to apply synthetic fertilisers. Reducing synthetic fertiliser use reduces the emissions associated with their production and transport. Results from the CCRP suggest the use of grain-legumes as a rotation crop often has no effect on on-farm nitrous oxide emissions, but in some circumstances can lead to spikes in nitrous oxide emissions after the legume is incorporated into the soil. Further research is needed to fully test the potential of this strategy for reducing greenhouse gas emissions.

Soil carbon and biochar

Increasing the amount of carbon stored in soils is a potential way to reduce Australia's emissions of greenhouse gases from agriculture by offsetting a portion of the total amount of carbon dioxide emitted into the atmosphere. The focus of current and recent research is accurate measurement of soil carbon and identification of land regions and farming practices with potential for increasing soil carbon content. The use of biochar to increase soil carbon is also being investigated.

The influence of farm management practices

Research under the CCRP into the effect of farm management practices on soil carbon levels produced mixed results. Research revealed that, in a given region, soil carbon levels were generally higher in pasture systems than in cropping systems. This suggests that soil carbon levels in mixed farming systems can be increased—or at least loss of soil carbon can be slowed—by replacing crops with pastures. There is some evidence that soil carbon levels are higher under perennial pastures compared with annual pastures.

For example, in southern parts of South Australia and Western Australia, soil carbon levels were higher in kikuyu-based perennial pasture systems than in annual pastures. However, in the Northern Agricultural District of Western Australia, perennial pastures of panic and Rhodes grass had similar soil carbon levels to annual pastures. Results of studies in Australia's rangelands demonstrated that increased vegetation cover would lead to increased soil carbon content. Field sampling of sites in New South Wales showed that management strategies such as rotational grazing and pasture cropping appear to have little effect on soil carbon levels. Results for the effect of minimum tillage on soil carbon were mixed, with some long-term studies suggesting this practice can slow the breakdown of soil carbon.

Biochar

Biochar is a carbon-rich, stable form of charcoal that is applied to soils for production and environmental benefit (such as increased soil fertility, increased agricultural productivity and greenhouse gas mitigation). Biochar is produced by pyrolysis—a process in which biomass sources such as wood chips, crop waste or manure are heated to high temperatures (400–700°C) with little or no oxygen. Pyrolysis sequesters carbon by converting biomass that would typically decompose (releasing carbon dioxide to the atmosphere) into a much more stable charcoal form.

Results from the CCRP showed that biochars are composed of high levels of stable carbon; this stability is influenced by factors such as biomass type and production temperature. Biochars produced at higher temperatures tend to have higher levels of stable carbon than biochars produced at lower temperatures. Wood-derived biochars are more carbon rich, so these may offer better options for carbon storage. In contrast, biochars produced from manures have higher nitrogen and phosphorus levels, which may be more suitable for agricultural uses.

The CCRP also showed that biochars applied to soils are highly resistant to decomposition and can therefore provide long-term carbon sequestration benefits. Biochar stability in soil decreases with rising soil temperature and is affected by soil type.

Applying biochar to soils can reduce nitrous oxide emissions when soil conditions favour denitrification of nitrate to nitrous oxide. The reduction in nitrous oxide emissions was also shown to be affected by soil type and the type of biochar used. The nitrous oxide reducing processes associated with biochar are not yet fully understood and require further research.

More research is needed before use of biochar and management practices to increase soil carbon can be realistically incorporated into the CFI. This research is being undertaken through Australian Government research funding programs—Filling the Research Gap and the Biochar Capacity Building Program.

Technical abatement potential at a national scale

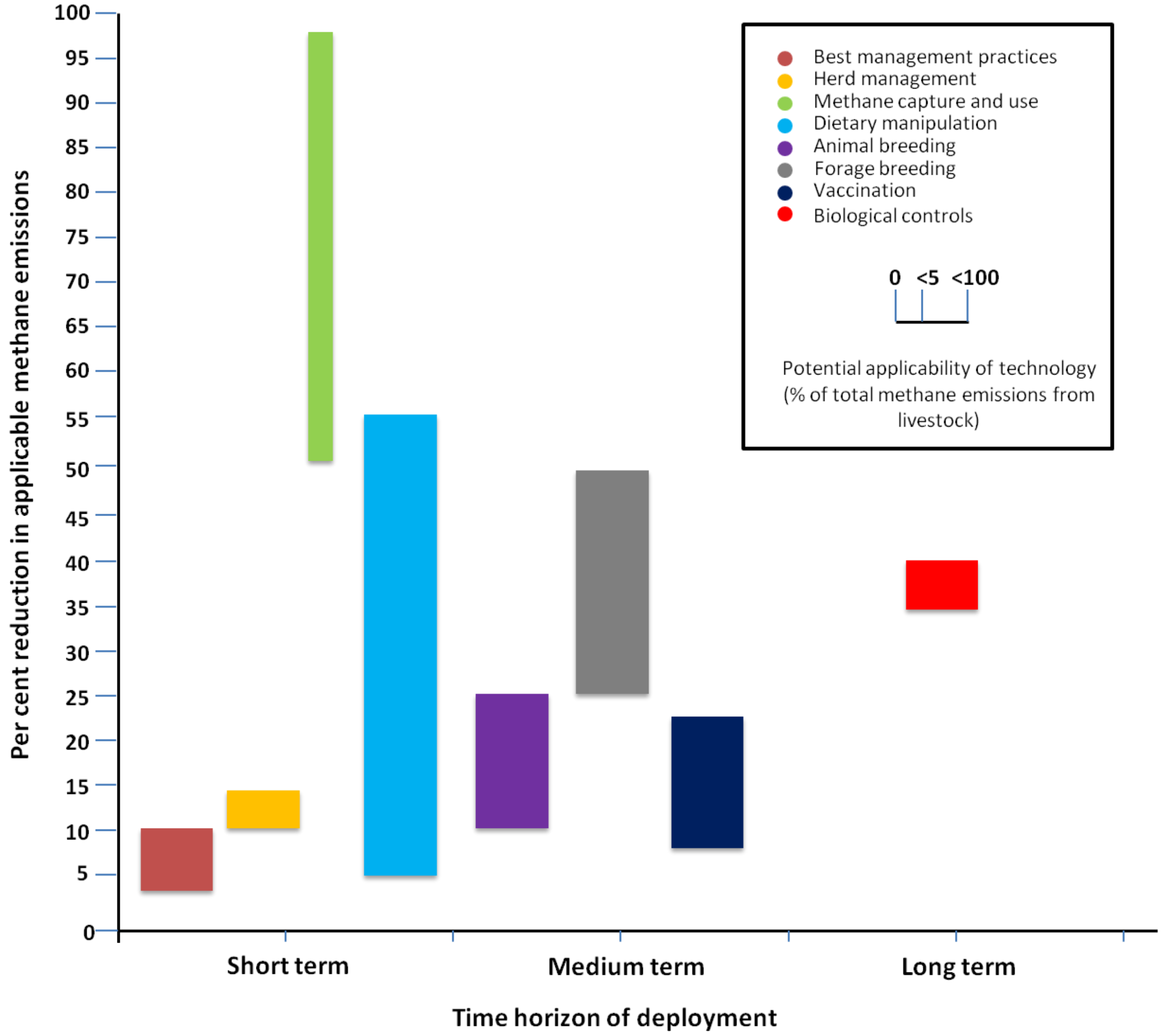
The technologies described in this chapter are all in various stages of research and development, so have varying capacity to contribute to the reduction of greenhouse gas emissions from Australian agriculture. Some, such as reduction of nitrous oxide emissions through management of irrigation and fertilisation practices, have the potential to be applied immediately. Others require significantly more research before they are deployable. Even then, it is unlikely that they will be able to be used with 100 per cent success across the Australian agricultural sector because climatic and soil conditions are too variable. Nevertheless, it is useful to examine what the technical abatement of national greenhouse gas emissions could be, should it be possible to fully implement these technologies successfully. This will provide an understanding of their maximum possible technical abatement potential.

The potential of various technologies and practices to reduce greenhouse gas emissions from the agricultural sector (technical abatement potential) will depend on a combination of their ability to reduce emissions from a specific source and the contribution that this source makes to national emissions. For example, capturing methane emissions from animal waste ponds has the potential to reduce emissions from these enterprises by up to 98 per cent. However, emissions from animal waste contribute less than 5 per cent to the methane emissions from livestock, thus reducing the overall technical abatement potential of this technology.

Figure 2 shows the possible ranges of emission reduction potential, possible applicability (given current knowledge) and anticipated time frame of deployment of a number of abatement technologies and practices targeting methane emissions from livestock. These estimates are based on results from individual research projects undertaken as part of the CCRP, as well as previous research. Considerable uncertainty surrounds the emission reduction potential and applicability of the various abatement technologies and practices considered here. Many of the technologies and practices explored under the CCRP and other research initiatives have only been tested *in vitro* or under very specific conditions. As such, the extent to which these findings are applicable to other regions, climactic zones, soil types, animal breeds and specific management practices is highly uncertain. Figure 3 shows similar information for technologies targeting nitrous oxide emissions from soil.

In addition to uncertainty around technical abatement potential, many of these activities may never be implemented, or only implemented on a small scale, as the associated costs outweigh any potential productivity benefits or financial incentives offered by the CFI. The next section extends this discussion by estimating the economic abatement potential of three key technologies or practices under the CFI: methane capture and destruction, diet supplementation with fats and oils, and application of anti-methanogen vaccines. These technologies were chosen because, given current knowledge, they are most likely to meet the requirements to generate offsets under the CFI. By limiting the analysis to CFI-eligible activities, the estimates indicate the potential supply of ACCUs from livestock methane abatement activities under the CFI.

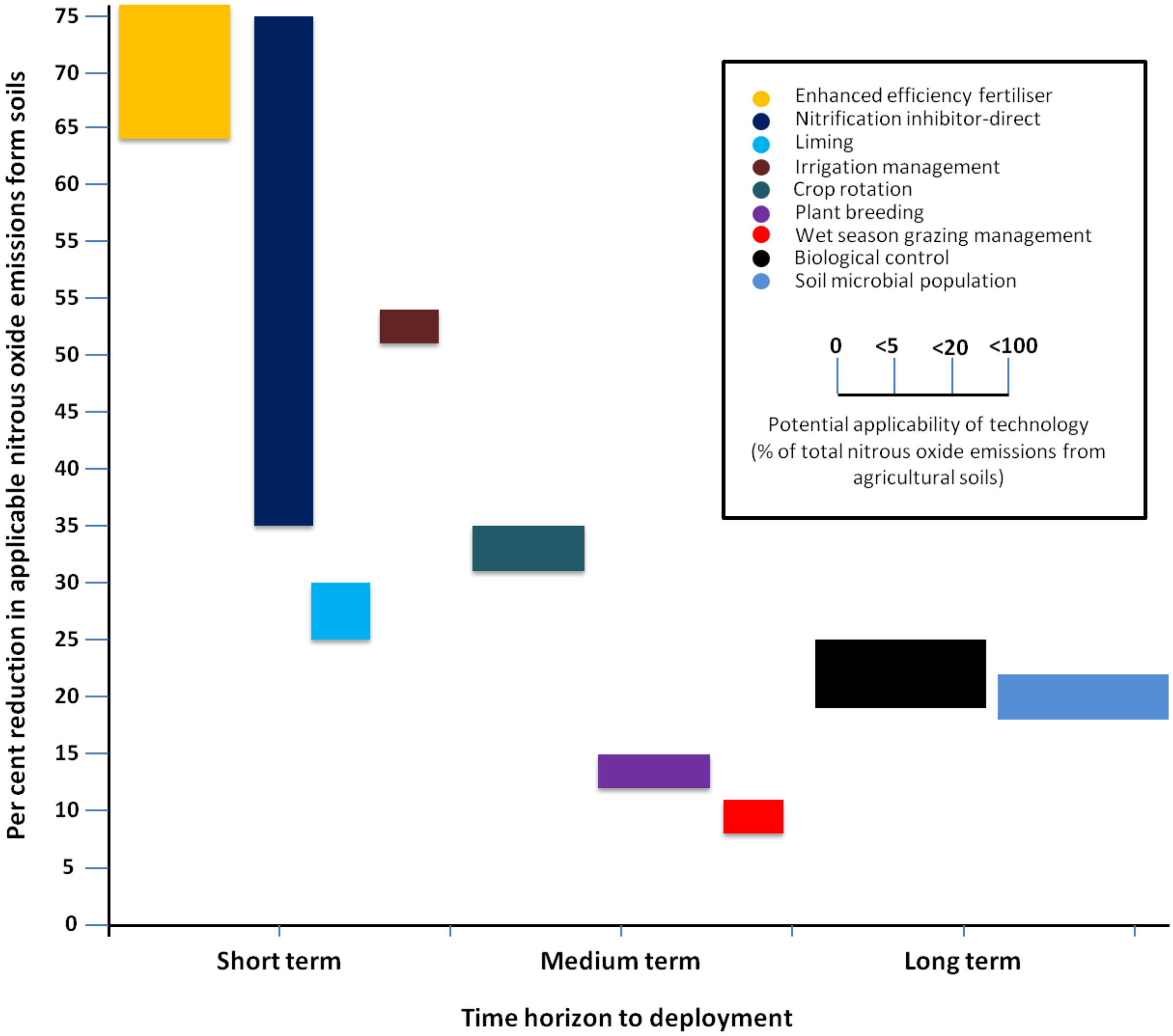
Figure 2 Technical abatement potential of technologies targeting methane emissions from livestock



Note: The height of the bars (vertical axis) reflects the range of emissions reduction potential as applied to a specific source (for example, animal manure, or methane emissions from the rumen of dairy cattle). The widths of the bars reflect the proportion of total national methane emissions from livestock potentially targeted by the technology. The anticipated period of deployment is reflected in the position of the bars and measured by the horizontal axis. The biological control category includes experimental procedures such as phage therapy and enhancing natural competitive processes like acetogensis.

Source: Data for this graph have been obtained from the final report of the Climate Change Research Program, Reducing Emissions from Livestock Research Program (Davison et al. 2012; Eckard et al. 2010).

Figure 3 Technical abatement potential of technologies targeting nitrous oxide emissions from soils



Notes: The height of the bars (vertical axis) reflects the range of emissions reduction potential as applied to a specific source (for example, application of enhanced efficiency fertilisers to crops). The widths of the bars reflect the proportion of total national nitrous oxide emissions from agricultural soils potentially targeted by the technology. The anticipated period of deployment is reflected in the position of the bars and measured by the horizontal axis. The biological control category included experimental procedures such as phage therapy and enhancing natural competitive processes like acetogensis. Source: Data for this graph have been obtained from the final report of the Climate Change Research Program, Nitrous Oxide Research Program (de Klein & Eckard 2008; Grace unpublished; Wright 2013).

5 Economic abatement potential in livestock

This section presents estimates of economically viable abatement of Australian livestock methane emissions under the CFI. The estimates are generated using a dynamic, bottom-up model of the Australian livestock sector called the Farm Size Model (Box 1).

Economic abatement potential under the CFI will depend on the relative costs and benefits of implementing abatement strategies at the farm level. These include additional expenditure on material inputs, machinery and equipment, structures, labour, changes in productivity and additional income earned through generation and sale of ACCUs. Changes in productivity may be positive or negative depending on the nature of the abatement technology.

The Farm Size Model is used to calculate economic abatement potential at a range of carbon prices and to construct marginal abatement cost (MAC) curves, which show the cost of incremental reductions in emissions at varying levels of total abatement. MAC curves are a simple but important tool for abatement policy analysis as they provide a basis for measuring the overall cost of meeting a given emission target or the reduction in emissions that can be achieved from a given carbon price. The MAC curves in this section show the combined potential economic abatement of methane emissions from five livestock activities: grazing beef cattle, grain-fed beef cattle, sheep, dairy cattle and swine.

Methane emissions from livestock were chosen for this exercise because of their relative importance in agricultural emissions (70 per cent of total agricultural emissions in 2010; Australian Government 2012a), the existence of previous studies examining forestry based abatement (Hug & Ahammad 2011) and data limitations associated with disaggregating emissions from cropping and fertiliser use.

The list of abatement technologies considered here is not exhaustive and only incorporates technologies that are expected to have a working CFI methodology in place by 2020. As such, the MAC curves presented in this section are unique to the policy settings around the CFI and provide a measure of the potential supply of ACCUs from livestock abatement under the CFI. Further details on the emissions reduction potential and costs and benefits of livestock emissions abatement technologies considered are provided in Appendix B.

Net present value (NPV)—the aggregate discounted flows of net benefits accruing from an abatement project over its lifetime—is used as the sole measure of economic viability in generating these MAC curves. While there are some limitations to this approach (discussed in Section 5), the estimates generated here provide important insights into the extent to which the CFI will encourage uptake of selected abatement technologies in the Australian livestock sector at various carbon prices, under certain market conditions.

Box 1 The Farm Size Model

The Farm Size Model is a dynamic bottom-up model of the Australian livestock industry developed by ABARES to estimate the potential reduction in agricultural emissions from abatement activities. Estimates of potential economic abatement at various carbon prices are based on the farm-level costs and benefits of implementing various abatement technologies.

Database
The Australian livestock sector consists of a large number of heterogeneous emitters. The Farm Size Model emissions database captures some of this diversity by allocating total methane emissions from livestock to over 200 groups of farms differentiated by jurisdiction, livestock activity, farm size and, in the case of piggeries and dairies, manure management practices. Jurisdiction is defined at the state and territory level while livestock activities are defined according to the categories set out in the national greenhouse gas inventory report (Australian Government 2008). These livestock categories include grazing beef cattle, grain-fed beef cattle, sheep, dairy cattle and swine. Farm size is defined by the number of animals of a given type kept on the farm. In the case of dairies and piggeries, farms with anaerobic lagoons are differentiated from those without.

The allocation of livestock emissions to various model farms is based on emissions data and livestock numbers from the national greenhouse gas inventory database (Australian Government 2012), and indicative farm distributions obtained from ABARES farm surveys (ABARES 2012) and industry publications (ALFA 2012; Australian Pork Limited 2011). Where estimates of the total number of animals differed from that published by the Australian Bureau of Statistics, a scaling factor was applied to the number of farms to align the two estimates.

Detailed distributions of grazing beef cattle, sheep and dairy farms by state and size were obtained from ABARES 2009–10 farm surveys data (the most recent data at the time of writing). Applying these distributions to aggregate livestock numbers for each state determined the number of farms and average scale of farm operations for each model farm. Similarly, a distribution of piggeries by state and size was obtained from ABS survey data reported in the *Australian Pig Annual 2009–10* (Australian Pork Limited 2011). A distribution of grain-fed beef cattle enterprises (feedlots) by state and size could not be obtained from farm surveys or public data. As such, a rough distribution was estimated using data from the Australian Lot Feeders' Association (ALFA 2010). For each size threshold in each state, a utilisation rate based on an historical average was applied to an assumed average carrying capacity to give the average number of cattle on feed. Dividing the total herd by this number gave the number of feedlots in that size category and state. The average number of cattle on feed for each feedlot type was then adjusted to be consistent with the ABS estimates of the total number of beef cattle on feedlots.

While in practice, multiple livestock activities may be undertaken on the same farm the emissions database separates activities as if they were undertaken on individual farms. For example, a farm that stocks grazing beef cattle and sheep is conceptually treated as two different farms; one that stocks only beef cattle and another that stocks only sheep. This makes categorisation of farms by size much simpler but means that potential economies of scale from joint production will not be captured in the analysis. It also means the total number of farms recognised by the database will exceed the actual number of livestock enterprises.

Baseline and model dynamics
A baseline scenario in the Farm Size Model reflects projected industry and emissions growth without implementation of abatement technologies under the CFI. Annual changes in animal numbers and baseline emissions per animal were based on ABARES projections of agricultural activity and emissions (ABARES 2011). The Farm Size Model accounts for changes in animal numbers by modelling a proportional increase in farm sizes keeping the number of farms fixed. While the number of farms will likely change over time, it is uncertain how it will change. The average annual change in animal numbers and emissions per animal, for each sector and emissions type, are summarised in Table 3. Changes in animal numbers and emissions per animal, for each sector and emissions type, were assumed to be the same across states and farm sizes.

Table 3 Assumed growth in animal numbers and baseline emissions per head

Sector	Average annual change in animal population (%)		Average annual change in emissions per head (%)	
	2010–2020	2010–2030	2010–2020	2010–2030
Grazing beef cattle and feedlots	1.10	1.77	–0.01**a**	0.01**a**
Sheep	0.56	1.33	–0.07**a**	0.13**a**
Swine	0.64	1.41	0.34**b**	–0.17**b**
Dairy	0.11	0.30	0.05**a**	–0.06**a**
Dairy	0.11	0.30	–0.11**b**	–0.30**b**

a Refers to emissions per animal from enteric fermentation. **b** Refers to emissions per animal from manure management. Changes in these emissions may arise from increases in emissions per animal and/or changes in manure management systems at the aggregate level. In this table, the figures were taken as the growth in emissions per animal, independent of manure management system.

Source: Figures derived from ABARES (2011)

Measuring economic viability

Economic abatement potential is estimated in the Farm Size Model by first calculating the NPV of implementing a particular abatement technology on the average farm for each model farm. A positive NPV is used as the sole indicator of economic viability and acts as a trigger for adoption. NPV calculations are based on farmers' expectations of the net benefits of implementing the abatement practice at the farm level. These will depend on farmers' expectations of farm size, baseline emissions per animal, and the emissions reduction potential of the given abatement technology. Farmers' expectations of changes in farm size and baseline emissions, over the life of a project, were assumed to be equal to the observed historic average annual change between 2010 the year in which the project begins (Table 3). The emissions reduction potential of abatement technologies, as a percentage of targeted emissions, were assumed to remain constant over time.

Farmers were also assumed to form expectations around changes in the carbon price. In this report, farmers and landholders were assumed to expect a 2.5 per cent real increase in the carbon price, each year, regardless of the carbon price at the beginning of the project.

A flat discount rate of 7 per cent per annum was applied to future costs and revenue flows to account for farmers' time preferences and risk; all projects were assumed to have a time horizon of 14 years. A discount rate of 7 per cent is consistent with guidelines suggested by the Office of Best Practice Regulation (Australian Government 2010) while a 14-year project time horizon equates to two crediting periods. The terminal values of all projects were assumed to be zero. Scale will not be captured in the analysis. The total number of farms the database recognises will exceed the actual number of livestock enterprises.

The carbon price at which an abatement technology becomes economically viable (a positive NPV) is called the threshold carbon price. Threshold carbon prices for a given abatement technology will differ between farm types (that is, between different model farms) because of differences in emissions factors between states and livestock activities and because of differences in farm size when there are fixed capital costs associated with abatement projects.

The costs of undertaking a CFI-related abatement project include the costs of the underlying technology or practice adoption plus registration, administrative and compliance costs associated with participation in the CFI. The benefits include the expected revenue from generation and sale of carbon credit units, which depends on farmers' expectations of the carbon price, farm size, and the abatement generated by the technology over the life of the project, and any productivity benefits or costs savings expected to arise from implementing the technology.

An important feature of the Farm Size Model is its capacity to distinguish between farms of varying size. When abatement technologies have upfront costs that are invariant to farm size and variable costs are proportional to farm size, the scale of farm operations may play an important role in the economic viability of abatement technologies at the farm level. Specifically, an abatement technology that is profitable on a small scale will be at least as profitable on a larger scale. This implies that project scale

will be limited by farm size and means the price needed for the project to be economically viable are likely to be lower on larger farms than smaller farms for a given abatement technology. The Farm Size Model is designed to capture economies of scale.

After calculating threshold carbon prices for each abatement technology and farm type, a MAC curve for methane emissions from livestock can be constructed by aggregating the potential economic abatement across all farm types and abatement technologies for a range of carbon prices.

Abatement technologies

The quantitative analysis in this report only considers abatement technologies or practices that are likely to have CFI methodologies in place by 2020. A summary of the applicability, emissions reduction potential, and costs and benefits of these technologies and practices is in Table 4 and further details are in Appendix B.

Choice of technologies

The list of technologies or practices (Table 4) includes those that have an approved methodology, a well-developed methodology under consideration, or show promise for having a methodology that will meet offset integrity standards in the future. Abatement technologies or management practices unlikely to be eligible to generate credits under the CFI have been excluded from the analysis. Technologies or practices found to be economically viable only at extremely high carbon prices were excluded from the analysis (this includes, for example, application of the enzyme, urease, to manure and urine excreted on pasture).

Although the CCRP and wider literature has identified numerous strategies for reducing livestock emissions, there are a number of reasons for these activities not being eligible to generate credits under the CFI. For example, many activities that reduce emissions are also common practice or are likely to be common practice in the absence of the CFI. This is more likely to be the case for activities that have clear productivity benefits, such as feed supplementation, which is common on most beef cattle feedlots.

It is also possible that some activities are common in terms of the number of farms undertaking the activity but uncommon in terms of the scale of the activity. For example, it is common to have areas of improved pasture on grazing cattle properties in northern Australia but the extent of these areas is extremely small. Whether these practices are common or uncommon will be determined under the common practice test as data from the Land Management Practice Survey become available.

Costs, benefits and emissions reduction potential

Table 4 also provides a summary of the expected economic costs and benefits, and emissions reduction potentials of the abatement technologies considered in this report. These figures are based on published scientific findings. However, the cost and emissions reduction potential of abatement technologies will likely differ significantly between individual farms depending on management practices and local market conditions. In addition, in many cases, published findings are contradictory or apply only to specific farming practices. As such, the emissions reduction potential and costs of implementation are highly uncertain.

Table 4 Livestock abatement technologies and practices considered

Abatement technology	Applicable livestock activity	Methodology status	Reduction in emissions	First year capital costs		Ongoing annual costs/benefits	
Destruction of methane from manure stored in anaerobic lagoons	Swine	Approved	98%	Registration	$2 000	Monitoring, reporting and verification	$1 000
				Design and installation of cover and flare	$75 000 + $50 * A * M**a**	Maintenance costs	3% of capital costs
				Diversion of biogas to existing boiler	$50 000 + $10 * A * M**a**	Benefits from heat generation	$32/t CO_2-e
	Dairy cattle	Approved	98%	Registration	$2 000	Monitoring, reporting and verification	$1 000
				Design and installation of cover and flare	$75 000 + $640 * A * M**a**	Maintenance costs	3% of capital costs
				Diversion of biogas to existing boiler	$50 000 + $130 * A * M**a**	Benefits from heat generation	$32/t CO_2-e
Reducing methane emissions from dairy cattle with feed supplements	Dairy cattle	Under review	12.25%**b**	Registration	$2 000	Monitoring, reporting and verification	$1 000
						Additional feed costs	$50 * A
						7.5% increase in milk yield	($39–$49) * A
Reducing methane emissions from ruminants through anti-methanogen vaccines	Grazing and feedlot beef cattle, sheep and dairy cattle	Not yet developed	15%	Registration	$2 000	Monitoring, reporting and verification	$1 000
						Vaccines	$15 * A
	Sheep	Not yet developed	15%	Registration	$2 000	Monitoring, reporting and verification	$1 000
						Vaccines	$5 * A

Note: See Appendix B for details on the assumptions used in this report. **a** 'A' refers to the number of pigs or milking cows and 'M' refers to the proportion of manure from pigs or milking cows stored in anaerobic lagoons. **b** Feed supplements were assumed to result in a 12.25 per cent reduction in emissions of the remaining emissions after anti-methanogen vaccines are applied.

The expected costs of undertaking an abatement project include upfront project-related capital costs and ongoing project-related expenses. The ongoing costs also include administrative and compliance costs associated with participation in the CFI including for registration and monitoring, verifying and reporting abatement outcomes under the project. Some portion of total project costs is assumed to be fixed, regardless of farm size, for all abatement technologies. In some cases, the portion of fixed costs in total project costs is large (for example, methane destruction) and in other cases the fixed cost portion may be quite small (for example, feed supplementation).

The expected benefits of participating in the CFI include potential productivity increases, cost savings and revenue earned from generation and sale of ACCUs. The number of credits received for implementing a given abatement technology or practice on-farm is determined by the level of baseline emissions targeted by the technology and the percentage reduction in those emissions generated by implementing the technology or practice. The percentage reduction in baseline emissions generated by a given abatement technology is referred to, in this report, as the emissions reduction potential of that technology. Some technologies also generate productivity benefits or cost savings. For example, manipulating the diet of dairy cows has been shown to have positive effects on milk yield, and methane captured from animal waste can be used for heating or generating electricity. These productivity benefits and cost savings can be important factors in determining the economic viability of abatement technologies.

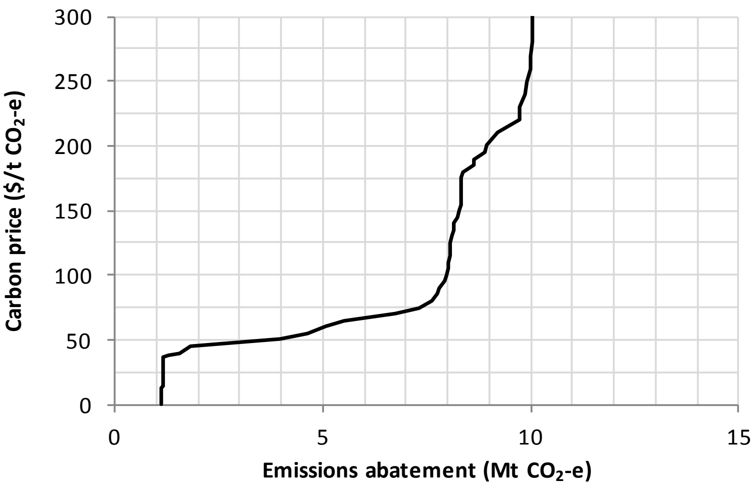
Estimated marginal abatement cost curves

A MAC curve provides a schedule for cost-effective greenhouse gas emissions mitigation potential from a particular mitigation technology or practice under a range of carbon prices, and is based on a set of assumptions about other variables including the underlying technology and its implementation costs. MAC curves are defined for a specific point in time; in this study, 2020 and 2030. MAC curves are based on a set of specific assumptions about input and output quantities and prices and, therefore, tend to change their shapes and positions with changing policy settings, input and output quantities and prices and/or (actual or expected) opportunities for other mitigation technologies or practices.

The relationship between economic abatement potential and carbon price is driven by differences in the costs of abatement across activities as well as variations in the costs of implementing a given abatement activity on farms of varying size, livestock activity and location.

Figure 4 shows the estimated MAC curves for livestock methane for 2020 based on the methodologies and abatement technologies described above and in Appendix B. MAC curves derived for discrete abatement technologies are often characterised by a series of steps at specific carbon prices or levels of abatement with each step representing the threshold carbon price for a specific abatement technology or practice. In the case of the Farm Size Model, there is the added dimension of farm type, such that a specific farm type can attribute each step in the MAC curve to adoption of a particular abatement technology. The greater the number of technologies and farm types the smoother the estimated MAC curves are likely to be.

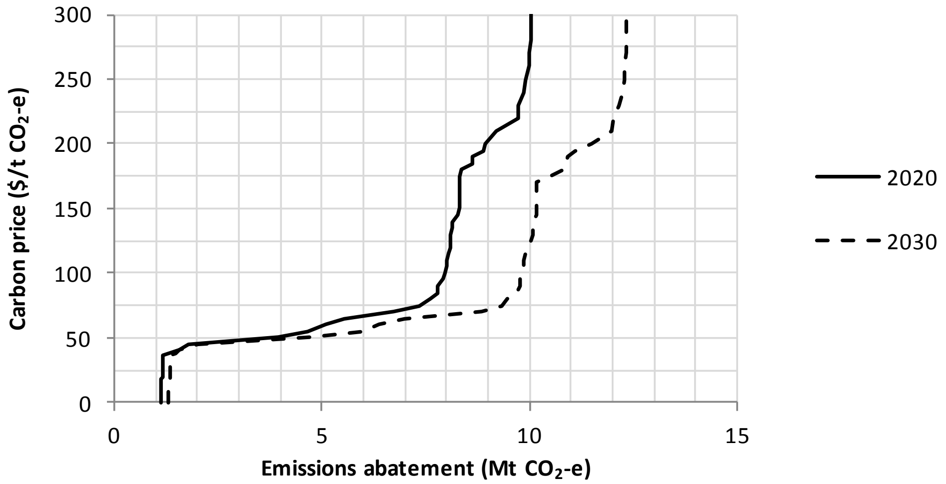
Figure 4 Marginal abatement cost curves for livestock methane, 2020



Source: ABARES estimates using the Farm Size Model

Estimates of economic abatement potential under the CFI will change over time due to changes in livestock numbers, baseline emissions per animal and the emissions reduction potential of abatement technologies. To illustrate these effects, MAC curves are also developed for the year 2030 (Figure 5).

Figure 5 Marginal abatement cost curves for livestock methane, 2020 and 2030



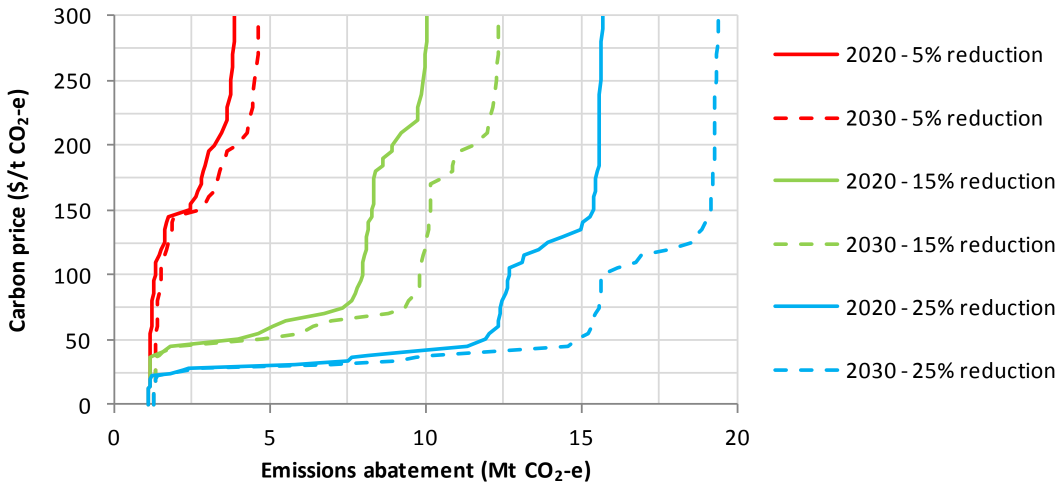
Source: ABARES estimates using the Farm Size Model

The reason for the increase in economic abatement potential in 2030, relative to 2020, is the growth in total livestock emissions, which are assumed to arise from increases in farm size. An increase in farm size has two effects on the estimated MAC curves. First, the greater opportunities to capture economies of scale reduce the threshold carbon prices for all abatement technologies but particularly those with high upfront fixed costs, other things remaining the same. This results in a downward shift in the MAC curves over time. Second, a given percentage reduction in farm level emissions will translate to a bigger reduction in absolute emissions as baseline emissions increase, other things remaining the same. This results in a rightward shift in the MAC curves over time.

These effects are partially offset by decreases in baseline emissions per animal over time. Under the assumption that abatement technologies generate a fixed percentage reduction in baseline emissions, a fall in baseline emissions intensity means emissions abatement per animal will fall over time. This has two effects. First, it increases threshold carbon prices, which results in an upward shift in the MAC curves over time. Second, it reduces the amount of abatement realised from implementing an abatement technology on farm resulting in a leftward shift in the MAC curves over time.

Both MAC curves in Figure 5 are based on an assumed 15 per cent emissions reduction potential of anti-methanogen vaccines. However, to capture the range of estimates of technical abatement potential of anti-methanogen vaccines, two additional scenarios were developed corresponding to a 5 per cent and a 25 per cent emissions reduction potential of anti-methanogen vaccines (Figure 6).

Figure 6 Marginal abatement cost curves for livestock methane under three vaccine scenarios, 2020 and 2030



Source: ABARES estimates using the Farm Size Model

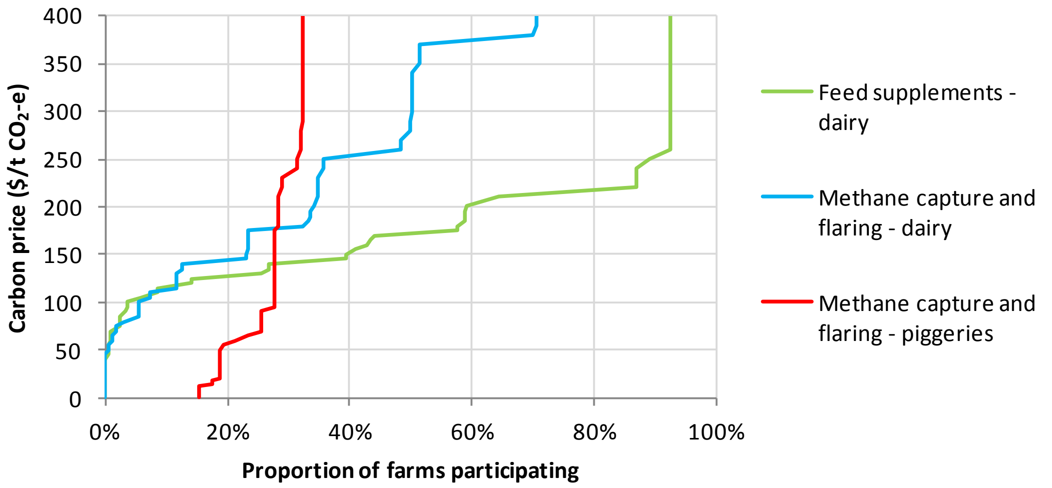
In addition, a sensitivity analysis was conducted around the assumed real discount rate of 7 per cent a year. The sensitivity analysis, which considered a real discount rate of 15 per cent, showed that higher discount rates increase threshold carbon prices for all abatement projects and model farms, shifting the MAC curves to the left. Changes in threshold carbon prices varied between abatement technologies and model farms; however, the overall effect on economic abatement potential (as shown by the MAC curves in Figures 4, 5 and 6) was relatively small.

Estimated uptake rates

While MAC curves illustrate economic abatement potential, the degree of uptake of specific abatement technologies at various carbon prices is also of interest. Figures 7 and 8 show uptake rates for specific abatement technologies and livestock industries in 2020, under the 15 per cent anti-methanogen vaccine scenario. These figures show the percentage of farms in each sector (horizontal axis) taking up the technology at various carbon prices (vertical axis). Estimates of uptake rates at various carbon prices provide broad comparison of the cost effectiveness of different technologies as well as highlighting the significant variation in threshold carbon prices for a given technology across farm types. The degree of variation in threshold carbon prices for a specific technology and livestock industry is dependent on the cost structure of the technology,

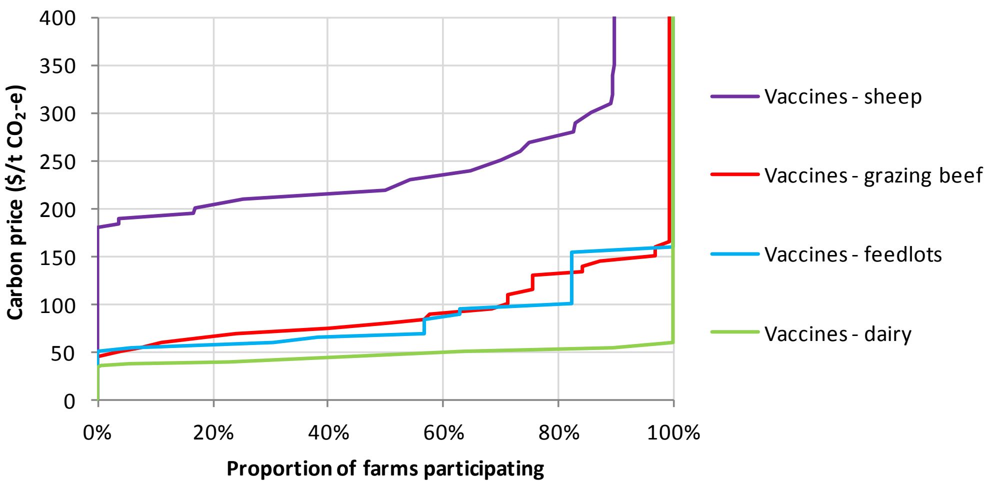
differences between emissions intensities of production across states, and distribution of farms by size. For example, threshold carbon prices for destruction of methane swine manure vary significantly across the farm population because methane capture and flaring has a large fixed cost component while threshold carbon prices for anti-methanogen vaccines used in dairies does not.

Figure 7 Uptake of methane destruction and feed supplementation in 2020, 15% anti-methanogen vaccine scenario



Source: ABARES estimates using the Farm Size Model

Figure 8 Uptake of anti-methanogen vaccines in 2020, 15% anti-methanogen vaccine scenario



Source: ABARES estimates using the Farm Size Model

Destruction of methane from swine manure on large-scale piggeries offered the cheapest abatement with uptake being economically viable at low carbon prices. Smaller piggeries require significantly higher prices because of a large fixed-cost component (Appendix B). While it appears that uptake at higher carbon prices is limited, the percentage reduction in swine manure is large because large-scale piggeries that store manure in anaerobic lagoons account for the vast majority of manure management emissions. At carbon prices of around $50 per

tonne of carbon dioxide equivalent, dairy farms may also begin to practice methane destruction. The variation in threshold carbon prices for methane destruction in dairies is less than in piggeries because there is relatively less variation in farm sizes within the dairy sector.

Feed supplements may begin to be applied on large dairy farms at carbon prices of $45 per tonne of carbon dioxide equivalent. Figure 7 shows considerable variation in threshold carbon prices across states and farm sizes. In the absence of a fixed cost component for feed supplements this reveals the importance of cost associated with participation in the CFI (the cost of registration, monitoring and reporting). The emissions reduction potential of feed supplements was assumed to vary with the emissions reduction potential of anti-methanogen vaccines if both technologies were applied simultaneously. For example, further analysis not reported here suggests that feed supplements would only be adopted at carbon prices in excess of $50 per tonne of carbon dioxide equivalent, when anti-methanogen vaccines are assumed to have an emissions reduction potential of 25 per cent. In contrast, assuming that anti-methanogen vaccines have an emissions reduction potential of 5 per cent, feed supplements could be adopted at carbon prices as low as $35 per tonne of carbon dioxide equivalent.

Anti-methanogen vaccines also provided low-cost abatement opportunities for intensive livestock farms (feedlots and dairy farms) and grazing beef cattle farms (Figure 8). Large dairy farms may adopt the practice at carbon prices as low as $35 per tonne of carbon dioxide equivalent. For application to beef cattle, prices in excess of $50 per tonne of carbon dioxide equivalent would be required. In contrast, sheep farms would not find the practice economically viable at carbon prices below $175 per tonne of carbon dioxide equivalent under the 15 per cent vaccine scenario and cost assumptions outlined in Appendix B. Differences in threshold carbon prices between beef, sheep and dairy farms arise primarily from differences in emissions per animal. There was also greater variation in threshold carbon prices for beef cattle than for dairy cattle; this is the result of there being relatively less variation in farm size in the dairy sector than in the beef cattle sector.

It is important to note that under current carbon prices and cost assumptions, many farms would not find the livestock abatement technologies or practices considered here economically viable. This suggests that adoption of these technologies or practices would be modest.

However, new technologies and research will provide further opportunities for emissions reductions in the agricultural industry in the future. Two technologies considered here—feed supplements and vaccines—are in the very early stages of development. Over time, the emissions reduction potential and costs of these technologies may change, improving their economic viability. As such, uncertainty around applicability, availability and emissions reduction potential of these abatement technologies and others, as well as future economic conditions, imply that the marginal abatement cost curves presented here are highly variable.

Issues with the framework

While these estimates provide an important understanding as to the likely effects of the CFI on livestock emissions at various carbon prices, under certain market conditions, a number of issues should be taken into account when interpreting the MAC curves earlier in this section.

One set of issues relates to uncertainties around the carbon price path, interactions between abatement activities and other management practices, and the biophysical effects of climate change.

The carbon price path forms the basis for farmers' expectations upon which NPV calculations were based. In this report an expectation that the carbon price was increasing by 2.5 per cent a year, in real terms, was assumed. However, in practice farmers will form their own expectations. Changes in the expected growth path will change the NPV of abatement projects and, hence, the estimated amount of economically viable abatement at a given carbon price.

Interactions between abatement projects, production, other farm practices and the broader economy are complex and are not captured in the analysis. If other farm practices that compete with livestock production are undertaken, the scope for abatement in the livestock sector may be affected. This might include uptake of environmental plantings. In addition, uptake of livestock abatement activities may affect production activities. For example, increases in milk yield through application of feed supplements to dairy cattle may result in reduced herd size if output remains constant and/or decrease in farm-gate milk prices. Finally, the effect of additional income earned through the CFI on levels of production has not been taken into account.

The effects of climate change on livestock emissions are also uncertain. For example, research has shown that methane emissions from enteric fermentation vary seasonally with pasture quality, which will be affected by changes in mean temperature and rainfall as well as weather variability. Capturing these types of changes over time requires in-depth analysis of the effects of climate change; this is outside the scope the current study.

Another set of issue relates to use of NPV as a measure of economic viability and trigger for uptake. For numerous reasons a positive NPV may be a poor predictor of actual uptake rates when the full adoption process is considered (see Section 3).

First, while NPV is a practical tool for framing economic decisions it does not incorporate the non-financial benefits and costs of adoption. As highlighted earlier, farmers have a number of personal goals; financial wealth may be of secondary importance. Non-financial benefits and costs, such as social approval and acceptance, are difficult to value and therefore incorporate into a traditional NPV analysis.

Second, assuming that all benefits and costs can be expressed in monetary terms, barriers may still prevent adoption of apparently economically viable projects. Differences between the relative advantage of a new innovation and landholders' perceptions are one explanation. This may arise because the potential costs and benefits of the technology are not well understood, which can also increase the perceived riskiness of the innovation. It is also assumed that landholders have access to the information, credit, supporting markets and infrastructure needed to implement the innovation.

Third, the traditional NPV approach assumes that the investment opportunity is a now-or-never decision with no opportunity to change the timing or scale of the project. As such, the traditional NPV approach discounts some of the complexities around the dynamics of the investment decision with regard to uncertainty, learning by doing and accumulation of resources over time (Feder et al. 1985). For example, real options theory suggests there may be benefits to delaying investment in projects with large irreversible costs if uncertainty around the future costs and benefits of the project might be resolved at some time in the future. By delaying investment in new abatement technologies or management practices under an uncertain carbon price, the risk of investing in projects with lower than expected returns is reduced. Similarly, farmers also have the option of varying the scale of a project over time. Trialling projects on a smaller scale before complete adoption can help resolve some uncertainty while potentially improving the relative advantage of the technology or management practice through learning by doing (see Section 3).

For these reasons, estimates of abatement potential using a NPV approach are likely to differ from actual uptake rates. However, the estimates of economic abatement potential presented in this report do provide a practical starting point for understanding the potential for abatement in the livestock sector.

6 Conclusion

The extent to which the CFI will encourage abatement in the livestock sector will depend on the set of eligible abatement technologies and the emission reduction potential and the cost-effective applicability of those technologies. Some technologies and management practices may reduce emissions but will be ineligible to generate credits under the CFI because they are common practice or because of difficulties around monitoring and verification.

Estimates of economic abatement potential are indicative of the potential supply of ACCUs from livestock methane abatement under the CFI and, therefore, the contribution the livestock sector may make to Australia's overall abatement effort under the Australian Government's emissions trading scheme.

Estimates of uptake generated by the Farm Size Model capture the heterogeneous nature of the livestock industry and illustrate how the economic viability of abatement technologies varies across farm types. The results presented in this report also highlight that participation in the CFI will be low under the assumed range of carbon prices. However, a small number of the largest emitters in some cases will likely achieve the majority of potential abatement under the CFI. The most prospective technology for low cost abatement in the livestock sector was found to be destruction of methane from manure generated in large-scale piggeries. However, a likely future abatement technology based on anti-methanogen vaccines may have a larger effect on total emissions due to its wider applicability.

In this study, a sensitivity analysis around the emissions reduction potential of anti-methanogen vaccines was undertaken. However, the Farm Size Model may be used to undertake further analyses. For example, future work may explore the role that aggregators might play in reducing transaction costs and the overall costs of abatement, changes in farmers' expectations of the carbon price, discount rates, project time horizons, and changes in the relative costs, benefits and applicability of technologies.

Outside of the Farm Size Model, further work could be undertaken on the amount of economically viable abatement and final uptake under the CFI. While some abatement technologies flagged by the CCRP are close to a farm ready stage, many technologies are still in the early stages of development. The applicability, emissions reduction potential, and costs and benefits of these technologies are highly uncertain. Future research should provide a greater understanding of these attributes. The economic viability and scope of abatement technologies should be revisited as new information becomes available. In addition, while the role of social and institutional factors in the uptake of new technologies has been examined extensively in the literature, further work needs to be undertaken to better understand how these factors may affect participation in the CFI specifically.

Appendix A: Methodologies

Approved methodologies

At 1 March 2013 the Domestic Offset Integrity Committee (DOIC) had approved 10 methodologies (three livestock, four vegetation and four landfill and alternative waste treatment).

Livestock

- Destruction of methane generated from dairy manure in covered anaerobic ponds.
- Destruction of methane from piggeries using engineered biodigesters.
- Destruction of methane generated from manure in piggeries.

Vegetation

- Environmental plantings.
- Human-induced regeneration of a permanent even-aged native forest.
- Reforestation and afforestation.
- Savanna burning.

Landfill and alternative waste treatment

- Avoided emissions from diverting waste from landfill for process engineered fuel manufacture.
- Capture and combustion of landfill gas.
- Capture and combustion of methane in landfill gas from legacy waste: upgraded project.

Methodologies under consideration

At 1 March 2013 DOIC was reviewing 13 methodologies (one soil carbon, one fertiliser, eight vegetation, and three landfill and alternative waste treatment).

Soil carbon

- Sequestration of soil carbon.

Fertiliser

- Avoided nitrous oxide emissions through application of manufactured organic based agricultural activities and conditioners.

Vegetation

- Carbon sequestration through afforestation and/or reforestation of degraded mangrove habitats using the CFI reforestation modelling tool and sampling techniques for soil organic carbon.
- Measuring carbon sequestration by permanent planting of native species using in-field sampling.
- Quantifying carbon sequestration by permanent plantings of native mallee eucalypt species using the CFI reforestation modelling tool.
- Rangeland restoration projects.

- Measurement-based methodology for farm forestry projects.
- Native forest from managed regrowth.
- Native forest protection projects (Redd Forests).
- Quantifying carbon sequestration by permanent tree plantings on marginal agricultural land using sampling techniques.

Landfill and alternative waste treatment

- Avoided emissions from diverting legacy waste from landfill through a mechanical processing and separation, and enclosed aerobic composting alternative waste treatment facility.
- Avoided emissions from diverting legacy waste from landfill through a mechanical separation, autoclaving and composting alternative waste treatment facility.
- Avoided emissions from diverting waste from landfill through a composting alternative waste treatment technology.

Appendix B: Technical assumptions

This appendix provides details of technical assumptions relating to applicability, emissions reduction potential, and costs and benefits of the three abatement technologies or strategies considered in Section 5; methane destruction, feed supplementation, and anti-methanogen vaccines. For the purpose of this report, the assumed emission reduction potential of technologies is based on published scientific findings. However, the costs and emissions reduction potential of abatement technologies will likely differ significantly between individual farms depending on management practices and local market conditions. In addition, in many cases published findings are contradictory or apply only to specific farming practices. As such, the emissions reduction potential and costs of implementation are highly uncertain.

While research under the CCRP will provide a greater understanding of abatement practices in terms of methodology and emission reduction potential the costs of implementation and emissions reduction potential assumed in this report were conservative.

Destruction of methane from manure stored in anaerobic lagoons

Background

The methane destruction strategies considered in this report are based on currently approved methodologies; *Destruction of methane generated from manure in piggeries,* and *Destruction of methane generated from dairy manure in covered anaerobic lagoons* (DCCEE 2013b). Both methodologies require installation and operation of lagoon covers, and methane capture and combustion equipment to existing uncovered lagoons or replacement of conventional lagoons with covered lagoon systems. Methane is combusted using flares, internal combustion engines, and/or gas boilers.

A third methodology, *Destruction of methane from piggeries using engineered biodigesters*, (DCCEE 2013b) refers to an alternative range of anaerobic digestion technologies. Biodigesters are anaerobic tanks that use heat to accelerate the digestion process. As such, they are more efficient than covered anaerobic lagoons but require substantial upfront capital costs and operating costs. As such, they are likely to be only economically viable on large-scale farms (in excess of 11 000 standard pig units according to FSA Consulting (2000)). Farms of this size are not considered in the Farm Size Model and, as such, biodigesters are not considered in this study. For similar reason, benefits from power generation are also not considered in this study.

Applicability and project scale

Methane destruction is only applicable to farms that currently use an uncovered anaerobic lagoon. This includes some dairy farms and piggeries but excludes feedlots where manure is typically composted in open-air facilities (Australian Government 2008).

The Farm Size Model emissions database distinguishes dairies and piggeries with anaerobic lagoons from those that employ other manure management systems. Estimates of the proportion of dairy farms with anaerobic lagoons, by size, were obtained from the ABARES dairy industry technology survey (Dharma et al. 2012). Estimates in the report were at the national level but were assumed to apply to all states in the absence of more detailed data (Table 5).

Table 5 Proportion of dairies with an anaerobic lagoon, by farm size

Number of cows	Proportion of farms
<200	64
200–299	80
300–399	80
400–450	80
450–750	80
>750	80

In the absence of similar up-to-date data for piggeries, the proportion of farms with anaerobic lagoons was based on an assumed distribution (Table 6). Past surveys (Kruger et al. 1995; McGahan et al.1996) estimated that 59 per cent of piggeries at the national level and 90 per cent of piggeries in Queensland had an anaerobic lagoon in place, respectively. Based on the assumptions in Table 6 and the distribution of piggeries by herd size obtained from Australian Pork Limited (2011), 60 per cent to 65 per cent of all farms outside Queensland and 87 per cent of all farms in Queensland are assumed to have an anaerobic lagoon in place. These estimates are considered reasonable given the trend toward increasing farm size and more intensive operations.

Table 6 Proportion of piggeries with an anaerobic lagoon, by farm size

Number of pigs		Proportion of farms
	Queensland	All other states and territories
<50	80	60
50–100	85	65
100–400	90	70
400–1000	95	75
>1000	100	80

The proportion of manure being diverted to an anaerobic lagoon at the farm level was assumed to be the same across all farm sizes within each state. This proportion was determined endogenously to ensure total emissions were consistent with those reported for 2010 (Australian Government 2012a), based on emissions factors for the respective manure management systems, the number of piggeries or dairies with an anaerobic lagoon, and the proportion of total swine or milking cow manure going to anaerobic lagoons at the state level (Australian Government 2008).

Emissions reduction potential

Consistent with the methodologies for destruction of methane from manure in piggeries and dairies (DCCEE 2013b), a 98 per cent efficiency factors was assumed for methane flared or combusted. Under both methodologies, carbon dioxide emissions are assumed part of the carbon cycle and as such do not detract from the amount of emissions abatement. That is, complete combustion of methane is assumed to result in a 98 per cent reduction in emission from manure.

Costs

The components of the simplest methane capture and flaring system include a lagoon cover, gas collection system, enclosed flare and remote monitoring equipment. If an existing boiler uses methane to generate heat or electricity, additional costs will be incurred.

Upfront capital costs can be significant and will vary across specific projects due to differences in lagoon size (a function of the volume of manure, temperature, rainfall, loading rates and concentration of volatile solids) and design specifics of the cover and flaring system.

Numerous cost estimates have been published based on trial projects for various sized piggeries and dairies as well as hypothetical farms. For example, the US Department of Agriculture released a technical note (USDA 2007) reporting costs for various biogas capture projects across a range of piggeries and dairies. The costs of covering an existing lagoon and installing a flaring system ranged from $25 000 to $360 000 (2006 US$) depending on farm size and other project-specific factors. The Rural Industries Research and Development Corporation published estimates of various methane capture options for hypothetical piggeries, dairies and feedlots of varying size (RIRDC 2008). Estimates for covering an existing lagoon (excluding electricity generation) ranged from $350 000 to $1 390 000 for piggeries and $500 000 to $2 000 000 for dairies. Cost estimates for individual projects also vary substantially. For example, Skerman and Collman (2012) report costs of $259 192 for a trial project at a 1265 SPU piggery in Grantham, Queensland. This included $56 650 in upgrades that would not be needed in an appropriately designed system. Another project undertaken at a 15 500 SPU piggery in Parkville (RIRDC 2008) reported costs of $410 000 for covering one of two existing anaerobic lagoons. Both projects used the captured methane in an existing boiler for heating.

The applicability of these estimates to other piggeries or dairies is limited without knowledge of specific details relating to the project or farm. For simplicity, cost functions used in this report are based on the number of swine or milking cows (Tables 4 and 5) and the proportion of manure being stored in anaerobic lagoons.

A portion of initial capital costs was assumed to be invariant to farm size with the remainder being proportional to the volume of manure stored in anaerobic lagoons. The portion of costs that are invariant to farm size primarily account for the minimum equipment needed to capture and flare methane (flare, condensate trap, hydrogen sulphide scrubber and possibly pipeline/ modifications to boiler). The portion of costs that vary with the volume of manure stored in anaerobic lagoons (based on animal numbers and the percentage of manure diverted to the lagoon) account for the additional costs associated with covering a larger lagoon, purchasing and installing additional/larger flaring equipment and design/installation costs. Maintenance costs were assumed to be linearly related to the volume of manure stored in the lagoon. The cost functions shown in Table 7 are roughly comparable to cost figures reported in the literature (RIRDC 2008; Skerman & Collman 2012; USDA 2007).

Table 7 Methane destruction cost assumptions

	Dairies	Piggeries
Initial capital costs for lagoon cover and flare	$75 000 + $640*A*M	$75 000 + $50*A*M
Initial capital costs for using methane in existing boiler (optional)	$50 000 + $130*A*M	$50 000 + $10*A*M
Ongoing maintenance costs	3% of capital costs	3% of capital costs

Note: ‘A’ is the total number of swine (milking cows) on farm in the case of piggeries (dairy farms) and ‘M’ is the proportion of manure from swine (milking cows) diverted to the anaerobic lagoon.

Ancillary benefits

While additional benefits, such as revenue from the sale of digestate as fertiliser and the generation of electricity, are not included in the analysis it was assumed that a portion of captured methane may be diverted to an existing boiler to displace liquid petroleum gas (LPG)

use. The amount of methane that can be used for heating will vary throughout the year as biogas production and heating needs depend on temperature. For example, in colder months or colder regions, heating energy requirements are likely to exceed the amount of methane available. In which case, all methane captured by the system may be used as an LPG substitute for heating. In contrast, in warmer months or warmer regions, the amount of methane will likely exceed heating requirements. At these times, the amount of methane used for heating will be low and a larger portion of capture methane will be flared.

For simplicity, it was assumed that 50 per cent of captured methane would be used for heating, with the remainder flared (Skerman & Collman 2012). In practice, this amount will differ between regions and individual farms due to differences in rates of biogas production and heating needs.

The assumptions used to determine the monetary value of methane as an LPG substitute are summarised in Table 8. The value of methane as an LPG substitute is highly dependent on the assumed price of LPG and density of methane gas. Given the additional costs associated with using biogas in an existing boiler, not all farms will find this option economically viable. It is assumed that for these farms, all captured methane will be flared.

Table 8 Energy value of methane as a replacement for natural gas

Variable	Units	Value
Assumed cost of fuel	$/MJ	0.025**a**
Assumed energy content of methane	MJ / m^3 CH_4	35.8**b**
Assumed weight of methane	kg CH_4 / m^3 CH_4	0.662**c**
Global warming potential of methane	t CO_2-e / t CH_4	21
Calculated energy value of methane (by weight of CO_2-e)	$ / t CO_2-e	64.38

Note: **a** Based on a retail price of 62.5 cents per litre and energy content of 25 MJ per litre. **b** RIRDC (2008) **c** Australian Government (2008).

Due to the limited size and heating needs of dairy farms, using biogas as an LPG substitute is not an economically viable option. As such, the above discussion applies only to piggeries.

Reducing methane emissions from intensively managed livestock with feed supplements

Background

Currently, no methodologies for reducing emissions from ruminants through feed supplementation are approved for use in generating carbon credits. While two methodologies were put forward for DOIC consideration—*Reduction of emissions of methane through the application of a feed supplement to dairy cows* and *Addition of feed additives to reduce methane emissions from enteric fermentation in ruminants* (DCCEE 2013c)—neither was endorsed due to failure to satisfy the requirements for a methodology determination specified in Section 112 of the *Carbon Credits (Carbon Farming Initiative) Act 2011* (Cwlth). However, it is expected that future methodologies will meet these requirements.

In this report, feed supplementation refers to supplementation of ruminants' diets with fats and oils during the summer months when pasture oil content is low. Fats and oils have been chosen over other potential supplements (such as tannins and additives) because, while the magnitude of their emission reduction potential is still uncertain, their negative effect on emissions has been established for longer period of time.

A specific supplement has not been specified, for the purposes of this report, as several types of fats and oils have been shown to have similar potentials and in practice market prices and acceptability will determine which supplements are used. However, in practice, methodologies will need to address individual supplements and feeding strategies. The assumed emissions reduction potential and costs of feed supplementation in this report are indicative only.

Applicability and project scale

Supplementing with fats and oils will only result in a genuine emissions reduction if applied on farms where supplementation does not already occur and at times of the year when pasture provides inadequate levels of fats and oils.

While feed supplementation is uncommon on extensive livestock properties (grazing beef cattle and sheep), infrequent and uncontrolled contact with the herd make precise modifications to animals' diets difficult for the purposes of crediting abatement as part of a CFI methodology. As such, grazing beef cattle and sheep properties are excluded. In contrast, while feed supplementation is possible on more intensive livestock operations it is likely to be common practice for beef cattle feedlots and dairies that use a hybrid or total mixed ration (TMR) feeding system. As such, these enterprises will be ineligible to earn carbon credits.

The proportion of eligible dairy farms (those that do not employ hybrid or TMR feeding systems) differs between states and farm sizes. Across states, the proportion of dairies that employ less intensive feeding systems (and are therefore eligible to earn credits) ranges from 84 per cent to 100 per cent (S Little 2012, Dairy Australia, pers. comm., November 11). At the national level, cows are more likely to feed exclusively on pasture. In the absence of data relating farm size to feeding systems, by state, it was assumed that the prevalence of intensive feeding systems for each farm size was equal to the state average (Table 9). As a result of this assumption, the applicability of feed supplementation will likely be overstated for larger dairies and understated for smaller ones.

Table 9 Proportion of dairies with 'non-intensive' feeding systems

State	Proportion of farms
NSW	84
Vic.	94
Qld	92
SA	91
WA	91
Tas.	100

Source: Dairy Australia, personal communications, November 11, 2012.

It was assumed that only milking cows are provided with supplements during the summer months. There are three reasons for only applying supplements to milking cows. First, regular contact with milking cows in small groups or as individuals allows precise modifications to diet to be made. Second, the infrastructure needed to provide feed supplements is more likely to be in place for milking cows. Third, milking cows have a much higher methane emissions factor than non-milking cows (Australian Government 2008) providing greater scope for emissions reductions.

Emissions reduction potential

On average, fats and oils have been shown to reduce methane emissions by 3.5 per cent for every 1 per cent increase in dietary fat (see Section 4). Assuming that dietary oil content is increased by 3.5 per cent, for 12 weeks in the summer months, a reduction in methane emissions of 12.25 per cent a cow may be achieved.

However, the fat content of pasture may be higher for some herds, which will reduce the scope for emissions reduction through feed supplements. Further, it is uncertain how fats and oils might interact with other abatement strategies that also target emissions from enteric fermentation. For example, early evidence suggests there may be little to no additional benefit to adding fats and oils in conjunction with tannins. The only other abatement technology or practice that targets methane from enteric fermentation, considered in this report, is application of anti-methanogen vaccines. For simplicity, it was assumed that feed supplements would generate a 12.25 per cent reduction in the emissions remaining after vaccines have been applied. Future research will increase understanding of the mechanisms at work around the likely emissions reduction potential from multiple abatement strategies applied at once.

Costs

The costs of supplementing feed with fats and oils will depend on the exact supplements used. Table 10 shows the amount of supplement needed to increase diet lipid concentration by 3.5 per cent a kilogram of dry matter intake (DMI) for a range of supplements, assuming 12 kilograms of DMI in the absence of supplements.

Table 10 Cost of various feed supplements

Supplement	Price ($/t DM)	Oil content (g/kg DM)	Amount of supplement required (kg/animal/d)	Total costs over summer period ($/animal)
Whole cottonseed	260–320**a**	0.226**b**	1.9	45–55
Canola meal	230–400**a**	0.120**c**	4.9	103–210
Hominy meal	240–295**d**	0.161**c**	3.3	73–90
Brewers grains	135–320**e**	0.110**c**	5.6	69–164

Notes: **a** Based on 2012 unit export value from ABS trade extracts (ABS 2013). **b** Grainger (2008). **c** Moate et al. (2011). **d** University of Missouri Extension (2013). **e** ABBA (2008) and NSW DPI (2007).

Assuming that farmers choose the cheapest option, and all supplements have a similar effect on methane emissions, whole cottonseeds would likely be the cheapest feed supplement abatement option given the range of market prices in Table 10. Based on the estimates in Table 10, the cost of feed supplements was assumed to be $50 per cow a year. However, the cost estimates in Table 10 are highly sensitive to the assumed market prices, oil content and DMI; variations in any of these will significantly change the costs of reducing emissions through feed supplements.

While additional labour and infrastructure costs may be associated with providing milking cows with supplements on farms that do not currently do so, the extent of these costs will vary with the type of milking shed used and current feeding arrangements. However, it is assumed that only minor or no modifications would need to be made and as such these costs are not included in the analysis.

Ancillary benefits

Feed supplements have been shown to increase productivity through increases in milk yield (Grainger et al. 2008). The calculated threshold carbon prices for feed supplement (Section 5)

are highly dependent on the assumed productivity benefits. Based on the assumptions used in this report, increases in milk yield of 8 per cent to 10 per cent would be sufficient to make the practice economically viable in the absence of a carbon price for larger dairy farms. In contrast, ignoring the potential productivity benefits greatly increases the threshold carbon prices. For the purposes of this report, it was assumed that supplementing the diets of milking cows with fats and oils would increase milk yield by 7.5 per cent over summer. Table 11 summarises the financial benefits of a 7.5 per cent increase in milk yield based on current milk yields and farm-gate milk prices in each state. These were used to derive the results presented in Section 5.

Table 11 Productivity benefits of feed supplementation, by state

State	Average milk yield[a]	Average farm gate milk price[b]	Increase in revenue over summer period
	(litres/cow/year)	(cents/litre)	($/milking cow/year)
NSW	5001	48.3	45.29
Vic.	5340	42.0	42.06
Qld	4119	53.0	40.94
SA	5813	38.0	41.42
WA	5935	43.4	48.30
Tas.	4905	43.0	39.54

Notes: **a** Australian Government (2008) **b** Dairy Australia (2013).

Reducing methane emissions from ruminant livestock through anti-methanogen vaccines

Background

One potential future abatement technology, currently being explored in Australia and New Zealand, is application of anti-methanogen vaccines to ruminant livestock. These vaccines fight against methanogenic bacteria living in the animal's rumen, reducing methane emissions from enteric fermentation. It is expected that with further research an effective vaccine may become available by 2020 (Science*Daily* 2001).

Applicability and project scale

It was assumed that vaccines would be applicable to all intensive livestock enterprises (feedlots and dairies) and sheep farms. However, vaccines may not be applicable to some extensive livestock properties (grazing beef cattle) where contact with the herd is limited. For example, many northern beef industry enterprises only muster cattle once or twice a year due to costs, distance and seasonal weather patterns. As most cattle vaccines require two or more doses to be effective, application may prove difficult.

To account for this, anti-methanogen vaccines were assumed to be applicable to only a fraction of farms, based on size (Table 12). For most states, most farms have less than 3000 head of cattle on average. However, in the Northern Territory numerous farms have cattle numbers in excess of 3000 and even 8000 head. For farms that apply vaccines, it was assumed that vaccines would be administered to the entire herd.

Table 12 Assumed applicability of anti-methanogen vaccines, by farm size

No. of grazing beef cattle on farm	Farms to which vaccines are applicable (%)
<3000	100
3000–8000	90
>8000	80

Emissions reduction potential

Various studies exploring use of vaccines have estimated a range of potential emissions reductions. Wright et al. (2004) reported a 7.7 per cent reduction in rumen methane production, corrected for dry matter intake level but only a fraction of methanogens were targeted by the vaccine. As such, a broader more general vaccine could have a much larger effect on reducing methane production. The CSIRO suggested a 20 per cent reduction over the medium to long-term could be feasible and other studies found larger effects on methane production (Science*Daily* 2001).

This study makes the conservative assumption that anti-methanogen vaccines would reduce methane emissions from enteric fermentation by 15 per cent. As discussed in the body of this report, high and low scenarios were also considered whereby anti-methanogen vaccines were assumed to generate emissions reduction of 25 per cent and 5 per cent respectively.

Costs

Current vaccine and other treatment costs for common livestock diseases range from 23 cents to $10 per head, with most vaccines under $5 per head (NSW DPI 2006). In the absence of better information about the likely cost of anti-methanogen vaccines, this report assumed costs of $15 per head cattle and $5 per sheep a year. The costs of administering anti-methanogen vaccines (such as mustering costs) are not considered, as only farms that currently vaccinate cattle were assumed to be likely to adopt the practice. As such, the additional cost incurred for applying an additional vaccine will likely be minimal for farms where contact with the herd is regular.

Ancillary benefits

Application of anti-methanogen vaccines was assumed to generate no ancillary benefits.

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