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Options for on-farm mitigation of greenhouse gases in Australia

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Key points

- The rural sector is an important component of Australia's economy and is a significant source and sink of greenhouse gases. Together, livestock, crops and soils, burning and land use change contributed about 23 per cent to Australia's net greenhouse gas emissions in 2009.
- In August 2011, Parliament passed legislation on the Carbon Farming Initiative, which will inform farmers, foresters and landholders on how to generate offset credits for sale in carbon markets.
- There is a range of options for reducing net greenhouse gas emissions from Australia's rural sector. Strategies include: directly reducing greenhouse gas emissions; increasing carbon sequestration;

and developing technologies to avoid fossil fuel emissions.

- Potential options for directly reducing greenhouse gas emissions include: improving feed quality and digestibility, and breeding livestock for high net feed efficiencies; optimising fertiliser application; improving cropping practices; and improving management of animal effluent.
- Options for increasing carbon storage on agricultural land include agroforestry and soil carbon sequestration. The potential amount of carbon storage varies regionally and there is a risk that it could be lost over time.
- Recent technological advances in the production of biofuels and biogas as alternative sources for energy generation provide potential options to minimise or avoid greenhouse gas emissions from fossil fuels.
- Undertaking a rigorous life-cycle assessment helps ensure real reductions in greenhouse gas emissions from any mitigation strategy. These assessments should include analyses of the key eligibility criteria under the Carbon Farming Initiative: additionality, permanence, carbon leakage, productivity, measurability and verifiability.

The issue

The rural sector manages about 52 per cent of Australia's land and contributes substantially to the national economy. Climate change resulting from increased atmospheric concentrations of greenhouse gases (GHGs) may compromise the future viability of this important sector, with impacts varying between locations and over time.

Methane, carbon dioxide and nitrous oxide are the most significant GHGs emitted by the rural sector (which includes agricultural industries and land use change). Together, these gases accounted for 23.2 per cent of Australia's emissions in 2009, according to the United Nations Framework Convention on Climate Change (UNFCCC 2011). Therefore, the rural sector has an important role in contributing to Australian efforts to reduce GHG emissions.

Implementing alternative management practices, especially for livestock and cropping systems, can reduce these on-farm GHG emissions. There are also options to increase carbon storage on agricultural land and to increase the use of biofuels and biogas as alternative energy sources. However, with the implementation of any on-farm mitigation strategy, there are also technical and economic challenges that must be overcome for farmers and landholders to undertake mitigation activities.

Rural land use patterns in Australia

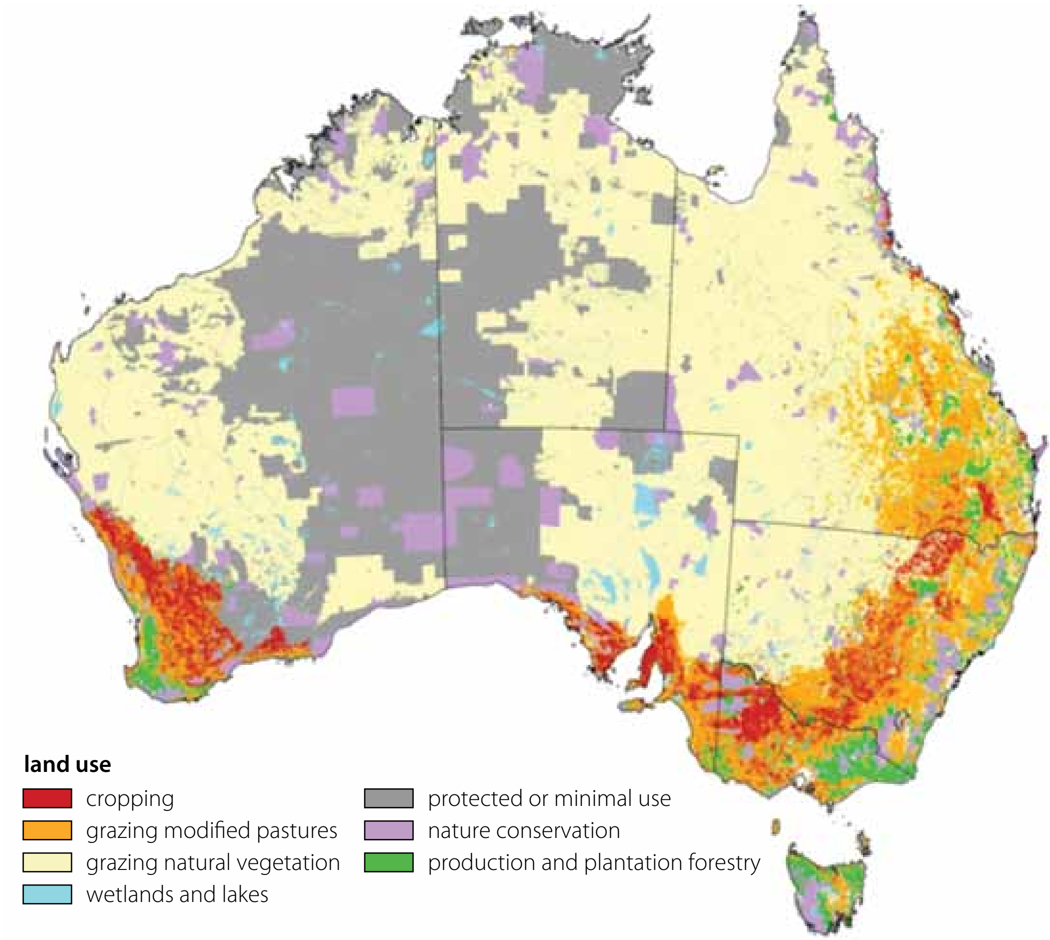
Around 52 per cent of Australia, or 399 million hectares, was used for agriculture in 2009–10. Livestock grazing is the most extensive land use in Australia. The Australian herd consisted of 68 million sheep, 24 million beef cattle and 2.5 million dairy cattle in 2009–10 (ABS 2011), with grazing occurring on 373 million hectares, mostly in arid and semi-arid regions (map 1).

Australia's croplands show a natural divide between northern and southern regions. Production in the northern region is dominated by sugar cane, grain sorghum and cotton. Southern cropping regions are dominated by winter crops, especially wheat, barley, oats, lupins and canola.

Horticulture and intensive animal production occupy much smaller land areas but still contribute significant income to the Australian economy.

Sources and sinks of rural greenhouse gases

map **1** Australia's rural land use, broadly divided into cropping and grazing activities



Note: These land use classes are based on the Australian Collaborative Land Use and Management Classification. Intensive practices like horticulture and feedlots do not show at this resolution
Source: ABARE–BRS 2010

Carbon dioxide, methane and nitrous oxide are the three main GHGs emitted from the rural sector. The relative contribution of different GHGs to global warming is measured in carbon dioxide equivalents (CO_2-e) and partly depends on the lifetime of the gas in the atmosphere and its ability to trap heat in the earth's atmosphere. For example, over a 100-year time frame, one tonne of methane is equivalent in warming potential to 21 tonnes of carbon dioxide, and one tonne of nitrous oxide is equivalent to 310 tonnes of carbon dioxide (table 1).

These gases—and the carbon and nitrogen they contain—cycle between different 'pools', including the atmosphere, plants, plant litter, livestock and soils

1 Relative lifetime global warming potential of the main rural greenhouse gases to global warming, measured in the carbon dioxide equivalents (CO_2-e) that are used in Australia's carbon accounting systems

gas	lifetime in atmosphere (years)	global warming potential over 100 years (tonnes CO_2-e)
carbon dioxide	50–200	1
methane	12	21
nitrous oxide	120	310

Note: Although, subsequently, global warming figures have been revised (Forster et al. 2007), the IPCC 1996 global warming potentials are used in this publication as these are used for national accounting purposes for Kyoto Protocol reporting and all international negotiations thus far.
Source: IPCC 1996

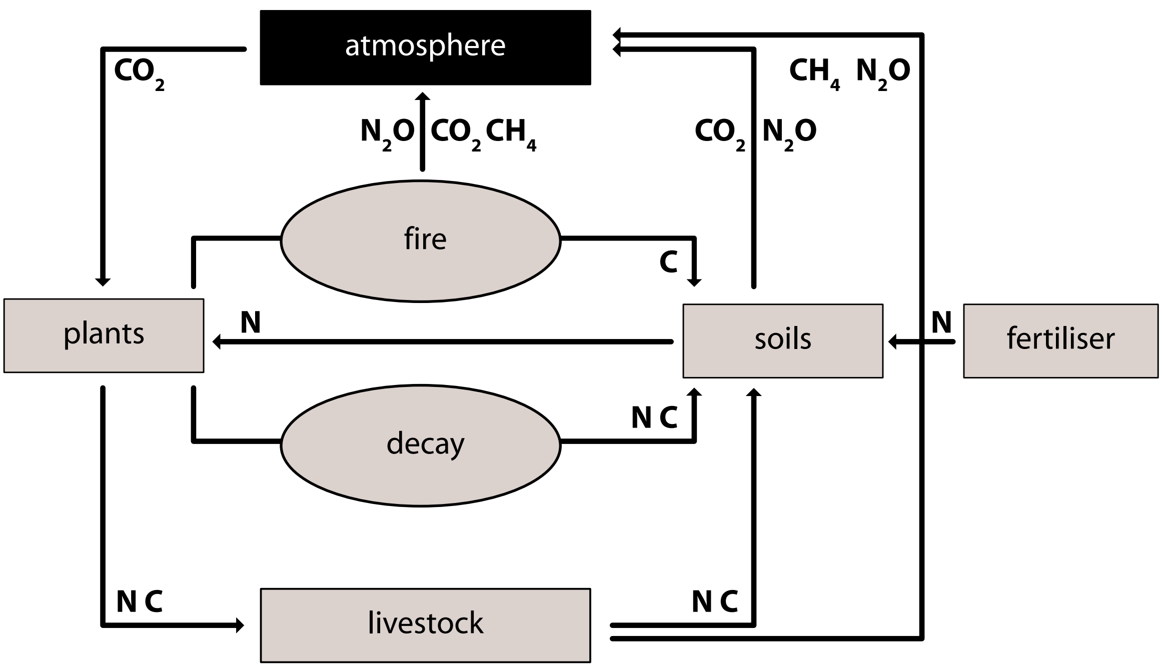
(figure 1). Oceans are also a significant part of the global carbon cycle, acting as major sinks of carbon dioxide. Agricultural management practices and land use changes influence the flows of carbon and nitrogen between pools and result in what is known as anthropogenic (human induced) emission or removal of GHGs.

Most rural emission sources and sinks are reported annually in Australia's National Inventory Report (box 1) to the United Nations Framework Convention on Climate Change. Those categories that apply specifically to the rural sector include livestock; crops and soils; burning; and land use, land use change and forestry (LULUCF). Within LULUCF, there are six broad categories:

- **forest land**, including all land with a tree height of at least 2 metres, crown canopy cover of 20 per cent or more and minimum land area of 0.2 hectares
- **cropland**, including all land that is used for continuous cropping and land managed as crop–pasture rotations
- **grassland**, including pastures (ranging from highly productive, improved introduced pastures to native grasslands), shrub land and woodland
- **settlements**, including areas of residential and industrial infrastructure
- **wetlands**, including areas of lakes, rivers, natural wetlands and man-made dams
- **other land**, including all areas not included above; typically occurring in arid regions and generally unmanaged (see DCCEE 2011b for more information).

It should be noted that wetlands, settlements and other land comprise a minor component of LULUCF and are not further discussed within this document. In 2009, the major

1 A simplified diagram of the carbon (C) and nitrogen (N) cycles in agriculture



Note: The figure shows the flows of C, N and the greenhouse gases—carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Agriculture management practices and land use changes influence these flows of carbon and nitrogen between 'pools'.

box 1 Accounting for greenhouse gas emissions in Australia

The United Nations Framework Convention on Climate Change (UNFCCC) was established in 1994 to provide a framework for international efforts to tackle climate change. Under the convention, governments gather and share information on national greenhouse gas (GHG) emission policies and best practices, including national GHG emissions inventories (http://unfccc.int).

In 2005, a number of nations approved an addition to the treaty—the Kyoto Protocol—that sets legally binding targets for the reduction of GHG emissions. The targets for the first commitment period of 2008–2012 are set to the baseline year of 1990. For Australia, the Kyoto Protocol requires reporting of:

- emissions from the agriculture sector (Article 3.1), including methane and nitrous oxide emissions from ruminant digestion, manure management, rice cultivation, agricultural soils, prescribed burning of savannas and field burning of agricultural residues
- human-induced emissions (Article 3.3) from afforestation, reforestation and deforestation since 1990.

Grazing and cropland management (Article 3.4) can be voluntarily reported in the Kyoto Protocol, but is not counted in Australia's Kyoto national account. Australia chose not to include Article 3.4 activities because of the potential impacts of natural disturbance and inter-annual climate variability on carbon stocks during the commitment period (see figure 3). For example, major fires or droughts can lead to emission spikes and may lead to a liability in Australia's Kyoto accounts. However, these emissions are reported in the National Inventory Report to the UNFCCC and are presented in this publication.

GHG emission sources from Australia's rural sector were from livestock and land use change—58.1 million tonnes CO_2-e and 54.0 million tonnes CO_2-e, respectively (table 2).

Emissions vary between individual farm enterprises because of differences in commodity mix, management practices and location. There are also variations between years due to changing land use and management practices; climate impacts on productivity and decomposition rates (such as plant residues and manure); and the occurrence of large-scale natural disturbances such as droughts, floods and bushfires (figure 2).

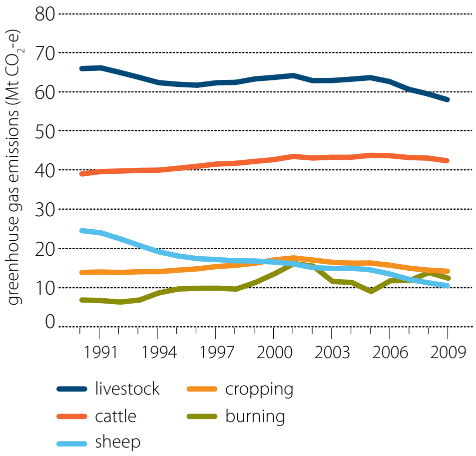
Livestock

2 The four broad sources and sinks of GHGs in the rural sector that together contributed 23.2 per cent to Australia's net GHG emissions in 2009

	emissions		
Source	(million tonnes CO_2-e)	(% of total rural emissions)	(% of Australia's net emissions)
Livestock **a**	58.1	41.9	9.7
Crops and soils **b**	14.2	10.2	2.4
Burning **c**	12.5	9	2.1
LULUCF **d**	54	38.9	9
Total rural sector	138.8	100	23.2

Notes: Sources for 2009 include the following UNFCCC reporting categories:
a enteric fermentation and manure management
b rice cultivation and agricultural soils
c prescribed burning of savannas and field burning of agricultural residues
d land use, land use change and forestry, including: forest land, management of crop and grazing lands, settlements and wetlands.
See box 1 for how the UNFCCC estimates differ from the estimates for Australia's Kyoto Protocol reporting obligation.
Sources: DCCEE 2011b; UNFCCC 2011

2 Trends in net greenhouse gas emissions from agricultural sources in Australia



Note: Emissions from cattle and sheep are part of those from livestock
Sources: DCCEE 2011b; UNFCCC 2011

The livestock sector produced 41.9 per cent of Australia's total rural GHG emissions in 2009, which includes emissions from enteric fermentation and manure management (table 2).

Methane is a by-product of enteric fermentation—a digestive process in ruminants (cattle and sheep) and some non-ruminant livestock—and is a significant component of livestock emissions (figure 1). Methane is largely released through the animals' mouths.

Emissions associated with the decomposition of manure from manure management systems are a minor contributor to the rural sector's emissions (UNFCCC 2011). However, strong growth in the intensive feedlot industry has led to an increase of 62 per cent or 1.3 million tonnes of CO_2-e in manure management emissions since 1990 (DCCEE 2011b; UNFCCC 2011). Declining stock numbers have also contributed to the changes in GHG emissions seen in figure 2.

Crops and soils

Use of fertilisers is the major source of GHG emissions from crops and soils. Crops and soils produced 10.2 per cent of Australia's total rural GHG emissions in 2009, which includes agricultural soils and rice cultivation (table 2).

Nitrous oxide is a significant component of these emissions. The nitrogen in animal wastes and fertilisers that are added to the soil to promote plant growth are the primary sources of nitrous oxide. Microbial activity in the soil converts the nitrogen into nitrous oxide, particularly when conditions are wet and warm (for example, in the tropics) and when the supply of soil nitrogen is in excess of that required for plant growth. Even nitrogen that is biologically fixed by legumes (such as peas, lupins and clover) can be converted into nitrous oxide if it is not used by plants.

Rice cultivation contributed less than 1 per cent of the rural sector's emissions in 2009. Because all rice cultivation is flood irrigated, this industry has been severely affected by drought—emissions from rice cultivation in 2009 were 91 per cent or 0.4 million tonnes CO_2-e lower than in 1990 (data from UNFCCC 2011). However, annual emissions from rice production vary depending on water availability. When seasonal conditions improve, such as in summer 2010–11, production is expected to increase, increasing emissions associated with rice production. For example, rice production in 2010–11 is expected to increase fourfold (89 000 hectares are estimated to be sown) compared with the previous year, due to abundant supplies of irrigation water and favourable seasonal conditions (ABARES 2011).

Burning

Burning is used in the rural sector to reduce fuel loads, improve pasture conditions and dispose of agricultural residues. These burnings often generate large amounts of methane and nitrous oxide (figure 1). Prescribed burning of savannas and field burning of agricultural residues produced 9.0 per cent of Australia's total rural GHG emissions in 2009 (table 2).

Land use, land use change and forestry

Clearing land for agriculture and some agricultural and forestry management practices lead to short-term emissions of carbon dioxide from the loss of above-ground biomass (through decay or burning of residues) and longer term emissions from the soil.
Land use, land use change and forestry produced 38.9 per cent of Australia's total rural GHG emissions in 2009,

including emissions from the conversion of forest land to cropland and land converted to grassland, and adjusting for sinks from afforestation and reforestation (table 2).

Importantly, grassland and cropland can switch from being an emissions sink (as in 2004) to an emissions source, depending on on-farm management practices and external factors such as production conditions, droughts, floods and bushfires (figure 3). For example, the net emissions from land use, land use change and forestry were particularly high in 2002 and 2007 because of extensive droughts causing loss of vegetation to all cover types (including grasses, shrubs, crops and trees), which in turn increased emissions from forest, crop and pasture lands. Yet these same lands became significant sinks in 2004 with better seasonal conditions and regrowth as part of the recovery from the bushfires of 2003. In other years, the net effect is reduced because the emissions/sinks on these lands tend to counterbalance each other.

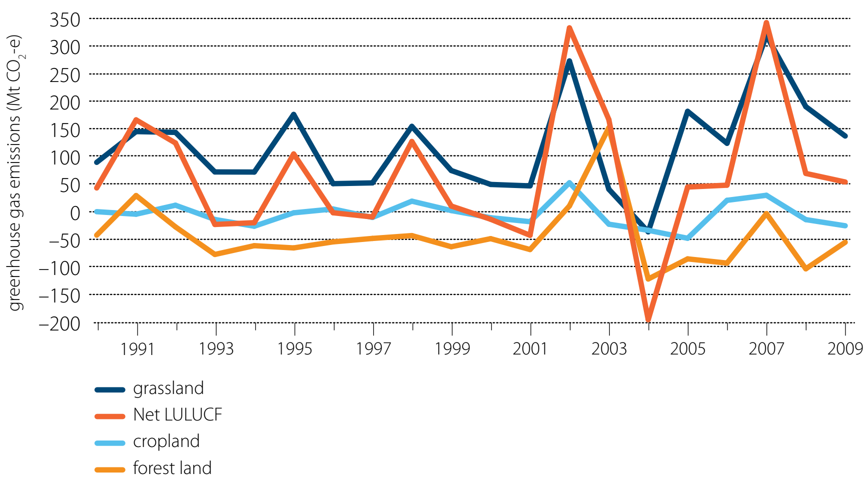
Options for on-farm mitigation

There are many options to reduce agricultural GHG emissions in a changing climate. Strategies include reducing emissions (box 2); increasing carbon sequestration (box 3); and developing technologies to avoid fossil fuel emissions (box 4). Each strategy varies in its current scientific and technological advancement, ability to mitigate GHGs, ease of implementation, economic viability and effectiveness over time.

Some options to reduce on-farm emissions from one source may also affect other on-farm or downstream emissions. For example, improving pasture quality (digestibility) may reduce methane emissions, but is also likely to increase dry matter intake (Eckard et al. 2010). To ensure a net reduction in emissions, an evaluation of the whole cradle-to-grave process is required, usually as a life-cycle assessment (box 5). Ideally, this approach also assesses the potential for implementing management practices and analyses the effects on net emissions from all on-farm emission sources. Undertaking an analysis to estimate the economic viability of changed practices is also crucial when assessing likely uptake of abatement activities.

Governments and Rural Research and Development Corporations are funding research into mitigation

3 Trends in net greenhouse gas emissions from land use, including bushfires and soil carbon



Note: Emissions/sinks from forest land, cropland and grassland are part of those from land use, land use change and forestry.
Sources: DCCEE 2011b; UNFCCC 2011

and adaptation options (DAFF 2010; MLA 2011; CSIRO Livestock Industries 2011). Current research is focused on reducing GHG emissions, improving soil management and improving resilience of the livestock, cropping and land use sectors to climate change. This research aims to provide practical management solutions to farmers and industries.

Livestock

Improved livestock management practices employed in Australia over recent years have contributed to improving livestock productivity and helped to reduce net GHG emissions (Charmley 2009). Agricultural emissions could be further reduced if livestock feed efficiency is improved through enhanced genetics and using higher quality feeds, and through methanogenic immunisation.

Under the Australian Government's climate change initiative, the Department of Agriculture, Fisheries and Forestry is funding the Climate Change Research Program (CCRP) to help prepare Australia's primary industries for climate change (DAFF 2010). Research into reducing emissions from livestock is focused on breeding ruminants for low methane emissions; manipulating the rumen environment for better feed efficiencies; and improving manure management practices. To accurately measure any potential reductions in net GHG emissions, researchers are also developing new measurement techniques.

Crops, soils and land use change

Modifying cropping practices provides some of the obvious GHG abatement opportunities for the agriculture sector. Reduced tillage and improved fertiliser application—through correct timing and use of appropriate fertiliser forms and application rates—could reduce both GHG emissions and production costs (Smith et al. 2007). Conversion of agricultural land to forest land and conversion of land to cropland could remove carbon dioxide from the atmosphere; for example, land converted to forest land across Australia absorbed 15.0 million tonnes CO_2-e from the atmosphere during 2009 (DCCEE 2011b). In addition, improving pasture and natural grassland management through optimising grazing intensity and timing may also provide opportunities to reduce emissions (Smith et al. 2007).

Under the CCRP, researchers are: assessing the potential of biochar to reduce GHG emissions while maintaining productivity; assessing different methods to reduce nitrous oxide emissions such as crop rotations and more efficient nitrogen fertiliser use; and looking at options to improve soil carbon sequestration (DAFF 2010).

Emissions abatement potential

box 2 Reducing emissions

Livestock

A number of strategies to reduce greenhouse gas (GHG) emissions from ruminant livestock are being investigated. Improving the digestibility of fodder may increase daily feed intake (decreasing the rate of passage of feed through the rumen). This increased intake may lead to a rapid increase in live-weight gain, resulting in a sharp decrease in GHG emissions per unit production (Hegarty 2001). However, warmer climates projected for much of Australia may reduce feed quality and limit the benefits of this strategy.

Animals bred for high net feed efficiencies may decrease feed consumption without inhibiting growth rates and may also reduce relative GHG emissions. Estimates suggest that over 25 years, it may be possible to reduce annual GHG emissions by approximately 3 per cent when herds are bred for greater feed efficiencies (Alford et al. 2006). The potential to immunise animals to biologically reduce GHG emissions is also being investigated (Charmley 2009).

Although these strategies may decrease methane emissions per unit of production (such as live-weight gain and milk yield), total emissions from livestock depend on net feed intake and livestock numbers. To ensure a real reduction in methane emissions, stocking rates for ruminants should either be maintained at current levels or be reduced. However, large declines in sheep numbers over the past two decades have resulted in only small reductions in total methane emissions from the agricultural sector because of offsetting increases in cattle (figure 2).

Crops and soils

It is possible to reduce GHG emissions from crops and soils without having major effects on productivity. This can be achieved by matching nitrogen supply with crop demand and carefully choosing the timing, amount and type of fertilisers used. Fertilisers can also be modified to improve nitrogen use efficiency through changing the balance of other plant nutrients (for example, phosphorus), slowing the release of nitrogen and including nitrification and urease inhibitors (Eckard et al. 2010).

Alternative strategies include the use of legume crops for nitrogen fertilisation, reducing soil water logging, promptly incorporating animal effluent (primarily from intensively managed livestock) into soils, and converting from tillage to no-till cropping practices (see, for example, Robertson and Vitousek 2009).

Burning

The sugar industry is moving away from burning its residues and toward a system of incorporating cane trash into soils (known as green cane trash blanketing). This reduces GHG emissions, increases soil carbon and nutrient levels, and reduces the long-term demand for fertilisers (Robertson and Thorburn 2007). Similar agricultural benefits can be obtained with retaining crop stubble.

Tropical savannas and temperate grasslands are burnt to revive pastures, reduce fuel loads and reduce the risk of high-intensity wildfires. Although these fires produce substantial GHG emissions, there is a risk that reducing these practices could potentially increase the number of large, high-intensity fires, resulting in even more GHG emissions overall (Steinfeld and Wassenaar 2007). In tropical savannas, controlled burning early in the dry season reduces the risk of high-intensity, high-emission fires occurring later in the dry season.

box 3 Increasing carbon sequestration

Greenhouse gas (GHG) emissions from the rural sector can be offset by storing carbon—known as carbon sequestration. Trees and shrubs can be integrated into farming landscapes for both conservation and revenue. Depending on tree species, location, climate and forestry and farming practices, they can also be used to store carbon. For greenhouse accounting purposes, it is assumed that forestry practices are carbon neutral if the area is regenerated after deforestation (DCCEE 2011b). The fate of harvested timber determines its carbon sequestration potential over the longer term. While GHGs are released rapidly from paper, cardboard and firewood, the process takes much longer from furniture and building materials (DCCEE 2011b). Although the Kyoto Protocol rules do not recognise carbon stored in harvested wood products, this may change in future international negotiations.

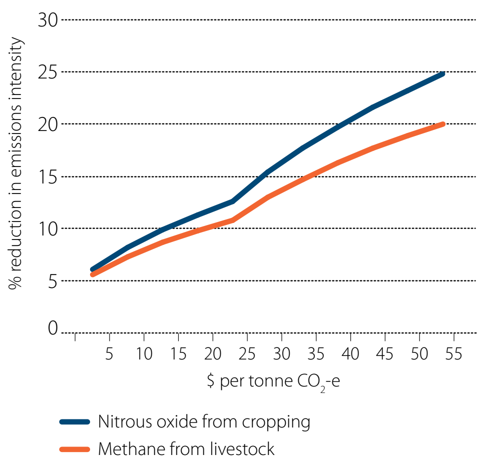
There is also the potential to increase carbon sequestration through the production of biochar. Biochar is a type of charcoal produced when biomass, such as crop residues, wood or municipal wastes, are heated to above 400 degrees centigrade in an oxygen-limited environment (Krull 2009). The carbon in biochar is in a very stable form and evidence suggests it may persist in soils for much longer than carbon in a non-charred state (Dalal et al. 2009). While the addition of biochar might also improve soil productivity, research to date remains inconclusive.

Carbon can also be sequestered in soils by converting croplands to permanent pasture or increasing pasture phases in rotational cropping systems. However, many soil carbon sequestration processes are slow, taking decades or more before substantial benefits are realised (Walcott et al. 2009). Further, the ability of a soil to absorb additional carbon depends on many factors including soil type, climate and how the land is managed. Soils will also reach their maximum potential to store carbon (saturate) over time. Increasing pasture phases may also increase the livestock component of the farming system and this should be taken into consideration when assessing the real potential of this mitigation technique for net GHG abatement.

Some mitigation options will have trade-offs between benefits. For instance, while planting more drought-resistant pasture species might increase soil carbon, it could also provide a continuous fuel source that increases the risk of wildfires and associated emissions, and would encourage farmers to carry additional livestock on these pastures during drought periods. Overall, the real benefits may be less than first expected and some processes to increase sequestration may have other environmental impacts (Bruce et al. 2010).

The costs in reducing emissions (measured as emissions intensity) for Australia's livestock and cropping sectors are shown as marginal abatement cost curves (figure 4). These curves show the reduction in emissions intensity (emissions per unit output) from available methods over a range of emissions prices, but do not incorporate sequestration (carbon storage) options. The potential for reducing emissions are relatively greater for cropping than for livestock in per cent terms; however, the higher emissions intensity of livestock production means that, in absolute terms, abatement potential is higher for livestock industries.

4 Marginal abatement costs of achieving reductions in emissions intensity (emissions per unit output) for Australia's livestock and cropping sectors



Source: Ford et al. 2009, p. 15

Challenges for mitigation

Mitigating on-farm GHG emissions has some big challenges. To be effective, any mitigation strategy must be scientifically sound, measurable, relatively easy to implement and economically viable, and must remain effective over the long term. Changes in emissions can be readily estimated for farm forestry and wind farms, but are more difficult to determine for soil carbon or for altered livestock practices, such as improved feed efficiency. Long-term sequestration in soil carbon stores and forests is also limited by their maximum potential to store carbon (saturation) and uncertainties about measurements and losses.

Another important challenge is the impact of climate on GHG emissions. The effects of a changing climate are likely to be mixed and change with time. For example, increased atmospheric carbon dioxide may increase inputs of carbon to plants and soil; however, increased temperatures may hasten breakdown of organic matter and increase carbon dioxide emissions. Research suggests that projected warmer and drier climates for much of southern Australia could increase the release of carbon dioxide from soils, thereby increasing GHG emissions (Walcott et al. 2009).

Incentives for mitigation

box 4 Avoiding fossil fuel emissions

Emissions of greenhouse gases (GHGs) from fossil fuels can be reduced or even avoided by obtaining more energy from renewable sources such as biofuels (ethanol and biodiesel), biogas, wind, solar and geothermal. Biofuels and biogas are alternative fuel sources particularly relevant to the rural sector. Biofuels are produced from crop by-products (for example, sugar trash and grain residues) or from crops grown specifically for producing biofuels. During 2008–09, Australia produced 209 million litres of ethanol from by-products of sugar milling and waste starch, and 85 million litres of biodiesel from oilseeds (soybean, rapeseed/canola, sunflower and cottonseed), used frying oil, palm oil and tallow (Geoscience Australia and ABARE 2010). Research and development is focusing on second-generation processing of biofuels based on lignocellulosic feedstocks such as sugarcane bagasse, forestry waste and wheat stubble (O'Connell et al. 2007). Cellulose, hemicellulose and lignin are the major components of woody biomass (such as wood and crop stubble) and can be used to produce electricity, fuels and chemicals (for example, methanol, synthetic gasoline, hydrogen and dimethyl ether) (Brown 2009).

Biogas can be produced by anaerobic digestion from a broad range of organic waste materials, including effluent from intensive livestock industries. In Australia, methane capture for biogas is still in its infancy, with profitability varying between regions and processing equipment. Anaerobic combustion of plant material will also produce biogases suitable for energy generation. Recent technological advances may reduce costs and make renewable energy sources more competitive (O'Connell et al. 2007).

Incentives may be required to encourage farmers to mitigate more GHG emissions. For example, a carbon offset market that allows farmers and landholders to generate offset credits and earn revenue may encourage farmers to apply methods to mitigate GHGs in ways that best suit their circumstances. Offset credits for GHGs are important for encouraging on-farm mitigation practices.

The Carbon Farming Initiative (CFI) is an Australian Government legislative scheme for carbon offsets crediting within Australia (DCCEE 2011a). The scheme will help farmers, foresters and landholders generate offset credits for sale in domestic voluntary and international carbon markets. Carbon credits can be generated by landholders for Australia's Kyoto Protocol compliant activities and non–Kyoto Protocol compliant activities (box 1) and may include:

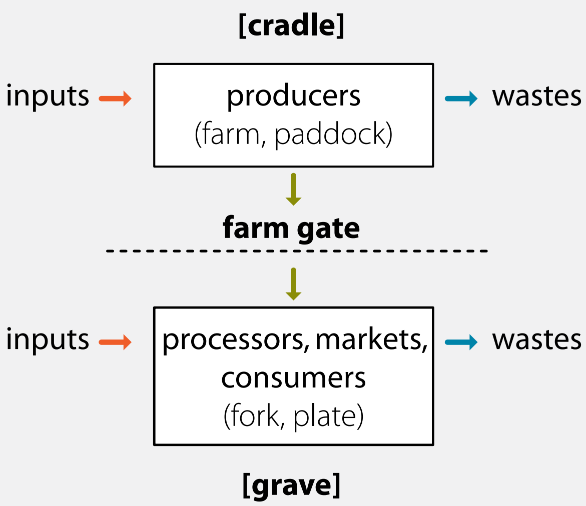
- reforestation and regrowth
- native forest protection
- reduced methane emissions from livestock
- manure management
- reduced fertiliser emissions
- reduced emissions from rice cultivation
- prescribed burning of savannas
- enhanced forest management
- revegetation and vegetation management (establishment and management of woody biomass that does not meet forest criteria [see page 4, LULUCF forest land categories])
- cropland and grazing land management (reduction or sequestration of GHG emissions from soil, cropping and vegetation).

Participation in the CFI is voluntary. Whether farmers and landholders will participate in the CFI process to generate carbon offset credits will be determined by the

box 5 Life-cycle assessment

A production chain links the stages that deliver a product to the final consumer. It includes all the activities involved in the delivery of a product, such as production, storage, packaging, marketing, sale and transport (figure 5).

5 A simplified rural sector production chain



Note: Inputs include GHG emissions from the production of fertilisers, fuel, fodder, electricity and chemicals. Wastes include GHG emissions, offal, grease, spoils and dirt.

Life-cycle assessment (LCA) is a standardised method (ISO14040:2006 and ISO14044:2006) for identifying improvements to the production chain, such as reducing inefficiencies or wastes (Horne et al. 2009). Ideally, rigorous LCA for greenhouse gas (GHG) emissions should analyse the full life cycle ('cradle-to-grave'). However, on-farm activities are likely to be more variable in their emissions and sequestration potential than post-farm stages, which are more concentrated (Harris and Narayanaswamy 2009). Consequently, LCAs applied to the rural sector are often restricted to 'cradle-to-farm-gate' or 'on-farm' (Harris and Narayanaswamy 2009). Until recently, there were few LCA data relevant to Australian production systems.

On-farm LCAs determine the sources and sinks of GHGs in detail, providing an overall measure of net GHG emissions and indicating areas for improving overall outcomes of emission reductions. Consequently, if properly carried out, LCAs can often be the basis of 'carbon footprints' of the whole supply chain and the assessment can be expressed in terms of emissions per tonne of product, or annual emissions per hectare of productive land (Harris and Narayanaswamy 2009).

perceived nature and size of such markets and whether such participation is practically feasible, economically beneficial and is not deemed as common practice.

Some mitigation practices may be technically and economically viable without extra incentives. For example, in certain circumstances, no-till practices that reduce production costs and increase productivity through improving soils may become cost-effective. Targeted soil nutrient application and improved animal feed efficiency may also be attractive, as they have the potential to reduce input costs (Smith et al. 2007). However, without incentives or a well-designed market, these options may not be realised effectively or widely.

To make informed decisions, farmers need to understand the potential benefits, trade-offs, sustainability and policy environment of alternative mitigation strategies. In addition to the direct costs of implementing any mitigation activity, farmers should consider the opportunity and transaction costs of taking action.

For their contribution, governments can sponsor research that identifies low-cost GHG mitigation practices, provide information, facilitate the creation of reliable GHG accounting systems and ensure long-term policy certainty.

Conclusions

GHG emissions from the rural sector can be reduced by implementing alternative management practices, increasing carbon sequestration and reducing fossil fuel emissions. An on-farm life-cycle assessment will help to identify optimal GHG mitigation strategies for each property and, when combined with economic analyses, will indicate the lowest cost path to GHG abatement. The potential to mitigate on-farm GHG emissions is greatest where the science is sure and easy to implement at low cost. Policy certainty and financial incentives, such as a carbon offset market, may also encourage mitigation activities by Australia's primary producers.

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