Department of
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GOVERNMENT OF
WESTERN AUSTRALIA

Carbon farming
in relation to Western Australian agriculture

Bulletin 4856

Supporting your success

Department of
Agriculture and Food

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WESTERN AUSTRALIA

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Summary

Carbon farming activities need to return multiple economic and environmental co-benefits to be attractive to land managers. This bulletin summarises concepts underlying carbon farming, how Australia accounts for greenhouse gas (GHG) emissions and the potential for Western Australian (WA) land managers to participate in, and benefit from, carbon farming.

Why Australia needs to mitigate greenhouse gas emissions

Australia's mean annual temperatures have increased by 0.9°C since 1910, and south-western Australia has experienced long-term reductions in winter rainfall. These changes are in line with global climate models. Most experts agree that increased GHG concentrations in the atmosphere are responsible for much of the overall change. In Australia, agriculture is responsible for 14% of the country's GHG emissions, with livestock and agricultural soils the largest sources of the potent GHGs methane (CH_4) and nitrous oxide (N_2O).

If current rates of GHG emissions continue, WA's mean annual temperatures could be 2–5°C warmer by 2070 and rainfall may continue to decline by up to 20% over much of the state. These changes will be superimposed on the state's already large natural climate variability, so wet years are likely to become less frequent and dry years (and drought) more frequent. A warmer, drier and more variable climate presents agriculture in WA with significant environmental, social and economic challenges.

Australia has adopted a number of measures to reduce GHG emissions and remove (sequester) carbon dioxide (CO_2) from the atmosphere with the goal of limiting global warming to less than 2°C. From 2012, the agricultural sector could participate voluntarily in carbon farming abatement projects under the *Clean Energy Act 2011* (*Cth*). However, this legislation is likely to be repealed in 2014, leaving future carbon farming opportunities to be funded under a new mechanism called the Direct Action Program.

Carbon farming

Carbon farming activities aim to help Australia meet its domestic and international GHG obligations by creating financial incentives to undertake abatement (emission reduction) projects on farm and forest land.

Carbon farming activities fall into two categories: sequestering (removing) atmospheric carbon and abating GHG emissions. These activities may involve modifying existing land management practices — such as changing tillage practices to increase soil organic carbon (SOC) or managing savanna (grassland) fires to reduce GHG emissions — and may be largely driven by associated productivity or other environmental benefits. Other activities, such as revegetation and reforestation, involve changing land use completely, while still others involve adopting new technologies, such as covered effluent ponds.

Considerable uncertainty surrounds carbon farming. The institutional arrangements of the Carbon Farming Initiative are in transition to the Direct Action Emission Reductions Fund (ERF). While limited methodologies have been approved for reforestation, livestock, manure, and savanna fire management activities,

methodologies have yet to be developed for SOC, revegetation and N_2O emissions. International markets in carbon offsets have shown prices to be highly volatile in response to changing government policy and economic conditions. It is not yet clear what offset prices will be under the proposed ERF. There are uncertainties over current approvals processes and carbon rights for projects on Crown land and native title lands.

Mitigation rates are highly variable and achieving the highest potential rates will depend on a thorough understanding of the productive capacity of various biological systems at a paddock scale combined with careful project planning and management. Also, any leakage criteria will have to be met and the Act's "permanence obligations" (genuine and lasting reductions) for sequestration projects present new and unique risks for land managers.

Carbon farming activities

Revegetation and reforestation have the potential to sequester the most carbon per hectare. However, these activities are associated with large up-front costs, opportunity costs of changing land use (including food security implications), onerous permanence obligations and cessation of income from carbon offsets once carbon equilibrium is reached. Carbon equilibrium is the point at which the rate of carbon accrual equals the rate of carbon emission, so, net sequestration effectively ceases. Projects on marginal land that use for-harvest forestry systems to maintain income and employment from the project land after carbon equilibrium has been reached may offer less risk.

Rangelands restoration has generally low sequestration potential per hectare, but potentially extensive environmental benefits. While methodologies have yet to be approved, low sequestration rates mean these activities will have to be targeted to areas with the greatest sequestration potential and low validation, input and opportunity costs. Rangelands restoration activities also have onerous permanence obligations.

The principal focus when increasing SOC should be improving agricultural productivity and land resource condition. The sequestration potential of most WA soils is relatively low and strongly dependent on soil type, climate and land use. SOC sequestration projects have onerous permanence obligations.

Nitrous oxide emissions from WA broadacre soils are low and unlikely to warrant investment in emission mitigation. Nevertheless, nitrification inhibitors may provide benefits from reducing inputs in intensive agriculture.

Manure management technologies can be economically viable for larger intensive livestock enterprises or cooperative facilities that use the captured methane to generate heat and electricity. For small operators, the offset value alone is unlikely to warrant the large capital cost of infrastructure.

Techniques to reduce livestock emissions can also increase livestock productivity and resilience. These technologies are more likely to reduce the intensity of emissions rather than total emissions so opportunities to benefit financially from creating offsets may be limited.

Strategic fire management should be an integral part of rangeland enterprises. Emissions avoidance is an opportunity to protect infrastructure and receive payment for a stewardship activity. However, the Western Australian Government has concerns over the current approvals process for emission avoidance projects on Crown land and is seeking a greater role to avoid land-use planning conflicts, sequestration liabilities and land management issues, such as bushfire risk. Inconsistencies exist between the *Carbon Credits (Carbon Farming Initiative) Act 2011* (*Cth*) (CFI) and WA's land management framework. Those contemplating entering into an emissions avoidance project under the CFI should hold appropriate approvals under relevant WA law. For instance, those wishing to undertake burning are obliged to comply with state requirements relating to prohibited burning times. Advice relating to this may be sought from the Office of Bushfire Risk Management within the Department of Fire and Emergency Services.

Conclusion

Anyone considering carbon farming must consider returns on capital, administrative costs and issues pertaining to permanence and land-use change. Given likely low medium-term carbon prices, offset income alone will not be enough to make most carbon farming projects economically viable so carbon farming activities need to return multiple economic and environmental co-benefits to be attractive to land managers.

1 Introduction

Over the past century, Australia's mean annual temperatures increased by 0.9°C, and south-western Australia experienced long-term reductions in winter rainfall (CSIRO and BOM 2012). These changes are in line with global climate models. Most experts agree that increased greenhouse gas (GHG) concentrations in the atmosphere are responsible for much of the change (Hegerl et al. 2007; PWC 2012; World Bank 2012). Atmospheric GHGs trap heat in the atmosphere; in 2005 the total radiative forcing potential of the long-lived GHGs was 2.6 Watts per square metre with carbon dioxide (CO_2) contributing 63%, methane (CH_4) 18%, nitrous oxide (N_2O) 6%, and a suite of gases (principally halons, chlorofluorocarbons and hydrofluorocarbons) contributing the remainder (Solomon et al. 2007). Carbon dioxide concentrations in the atmosphere have increased from a pre-industrial concentration of 278 parts per million (ppm) to over 391ppm in September 2012, with the rate of rise now at 1.8ppm/year (World Bank 2012).

If current rates of GHG emissions continue, the global climate may warm by more than $2^{o}C$ this century (PWC 2012; World Bank 2012). Warming in excess of $2^{o}C$ will present “dangerous” risks to the natural environment and the human systems it supports, including food, water, infrastructure and health (Henson 2011; World Bank 2012). In WA, mean annual temperatures could be 2–5°C warmer by 2070 and rainfall is likely to continue declining by up to 20% over much of the state (CSIRO and BOM 2012). These changes will be superimposed on our already large natural climate variability; so wet years are likely to become less frequent, and dry years (and drought) more frequent (CSIRO and BOM 2012). A warmer, drier and more variable climate presents WA with significant environmental, social and economic challenges; however, scientists agree that the worst effects of climate change can be avoided if GHG emissions are significantly reduced.

As part of international efforts, Australia has adopted a number of measures to reduce GHG emissions and remove (sequester) CO_2 from the atmosphere with the goal of limiting global warming to less than $2^{o}C$. Australia is a signatory to the Kyoto Protocol, an international agreement aimed at mitigating climate change by reducing global GHG emissions (UNFCCC 1998). Australia met its 2008–12 Kyoto Protocol commitment to keep emissions below 108% of 1990 levels and has undertaken to maintain emissions from 2013 to 2020 at 5% below 2000 levels (DCCEE 2012a).

Nationally, agriculture is responsible for 14% of GHG emissions, but is the dominant source of CH_4 and N_2O, accounting for 56% and 73% respectively of Australia's emissions. GHGs are emitted from agricultural lands as a result of a number of processes including:

- decay or burning of biomass
- feed digestion by livestock
- addition of nitrogen fertiliser and animal manure to the soil
- return of crop residues to the soil
- nitrogen fixation
- nitrogen leaching and run-off
- atmospheric deposition

- anaerobic decomposition of organic matter during flood irrigation.

Livestock are Australia's largest source of CH_4 and agricultural soils the greatest source of N_2O (DCCEE 2012a).

The agricultural sector can voluntarily participate in GHG abatement by undertaking carbon farming projects.

This bulletin summarises how Australia accounts for its GHG emissions, discusses some of the concepts underlying carbon farming and examines the potential for WA land managers to participate in (and benefit from) carbon farming.

2 How Australia accounts for GHG emissions

As a signatory to the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC), Australia annually reports its GHG emissions and stores. Australian National GHG Inventory (NGI) estimates are based on internationally agreed methodologies set out by the UNFCCC and the Intergovernmental Panel on Climate Change (IPCC) (DCCEE 2012b, 2012c, UNFCCC 2008).

Emissions from agricultural activities (Table 2.1) are estimated using what are termed Tier 1 or Tier 2 methods (DCCEE 2012b). Tier 1 methods are default equations and parameter values provided by IPCC. Tier 2 methods can use either Tier 1 or country specific equations but use country or region specific parameters in those equations. Tier 2 methods also have more disaggregation of land-use activity. Emissions from land-based activities — generally known as land use, land-use change and forestry (LULUCF) — are estimated using Tier 2 or Tier 3 methods (DCCEE 2012c). Tier 3 methods use higher resolution data, models and inventory measurement systems rather than Tier 1 or 2 methods (Cowie et al. 2012).

As each GHG has a unique residence time in the atmosphere and unique heat-trapping potential, the concept of global warming potential (GWP) is used to express the ability of each GHG to trap heat in the atmosphere relative to CO_2 over a specified period. The IPCC convention is to express the GWP of GHGs in terms of how much CO_2 would be required to produce a similar warming effect over 100 years. This is called the CO_2 equivalent value (CO_2-e) (Solomon et al. 2007).

The GWP of CH_4 and N_2O are 21 and 310 times that of CO_2 respectively, so 1t of CH_4 is equivalent to 21tCO_2 (DCCEE 2012b). Based on the molecular weight of CO_2, the sequestration of 1t of carbon is equivalent to 3.67tCO_2 (DCCEE 2012b). The current GWP values were agreed in 1995 so all the climate change programs and policies around the world, including the Kyoto Protocol, are consistent (Houghton 1996). It is likely that some GWP values will be changed when the next IPCC technical report is published in 2014.

About 60% of the CO_2 reaching the atmosphere is removed within 100 years, with 20–35% remaining in the atmosphere for two to 20 000 years (Mackey et al. 2013). This is far longer than CH_4 and N_2O, which remain in the atmosphere for about 10 and 100 years respectively. Consequently, while 100 years is commonly used to express GHG warming potential, current CO_2 emissions will continue to affect global climate for thousands of years.

Table 2.1 GHG emissions from land use (agriculture) and land-use change, 2009–10.

Greenhouse gas source and sink categories	CO_2-e emissions (Mt)			
	CO_2	CH_4	N_2O	Total
Agriculture	na	62.6	16.9	79.5
Enteric fermentation	na	53.9	na	53.9
Manure management	na	1.7	1.6	3.3
Rice cultivation	na	0.2	na	0.2
Agricultural soils	na	na	13.2	13.2
Prescribed burning of savanna (grassland)	na	6.6	2.1	8.6
Field burning of agricultural residues	na	0.2	0.1	0.3
Land use, land-use change and forestry	17.0	1.0	<0.1	18.1
Land-use change (deforestation)	42.8	1.0	<0.1	43.8
Afforestation and reforestation	-25.8	<0.1	<0.1	-25.8

na = not assessed.

Source: (DCCEE 2012a, 2012b).

Table 2.1 shows Australia's GHG emissions from agriculture and LULUCF activities expressed in terms of CO_2-e. Note, however, that under current accounting rules emissions generated during the manufacture and transport of agricultural inputs — such as fertilisers, herbicides, pesticides and agricultural machinery — are not counted as agriculture or LULUCF emissions; nor are emissions from the fuel used by agricultural vehicles either on farm or in transporting produce. The fuel used to generate electricity consumed on farm is also excluded.

2.1 The Kyoto Protocol

As a signatory to the Kyoto Protocol, Australia committed to maintain average GHG emissions at or below 108% of annual emissions in 1990 for the first commitment period (CP1: 2008–2012) and at or below 99.5% of 1990 emissions for the second commitment period (CP2: 2013–2020). This will equate to an emission reduction of 5% of 2000 emissions by 2020. The CP2 commitment represents an 8.5% reduction on CP1 emissions and a 22% reduction on "business as usual" emissions (Figure 2.1).

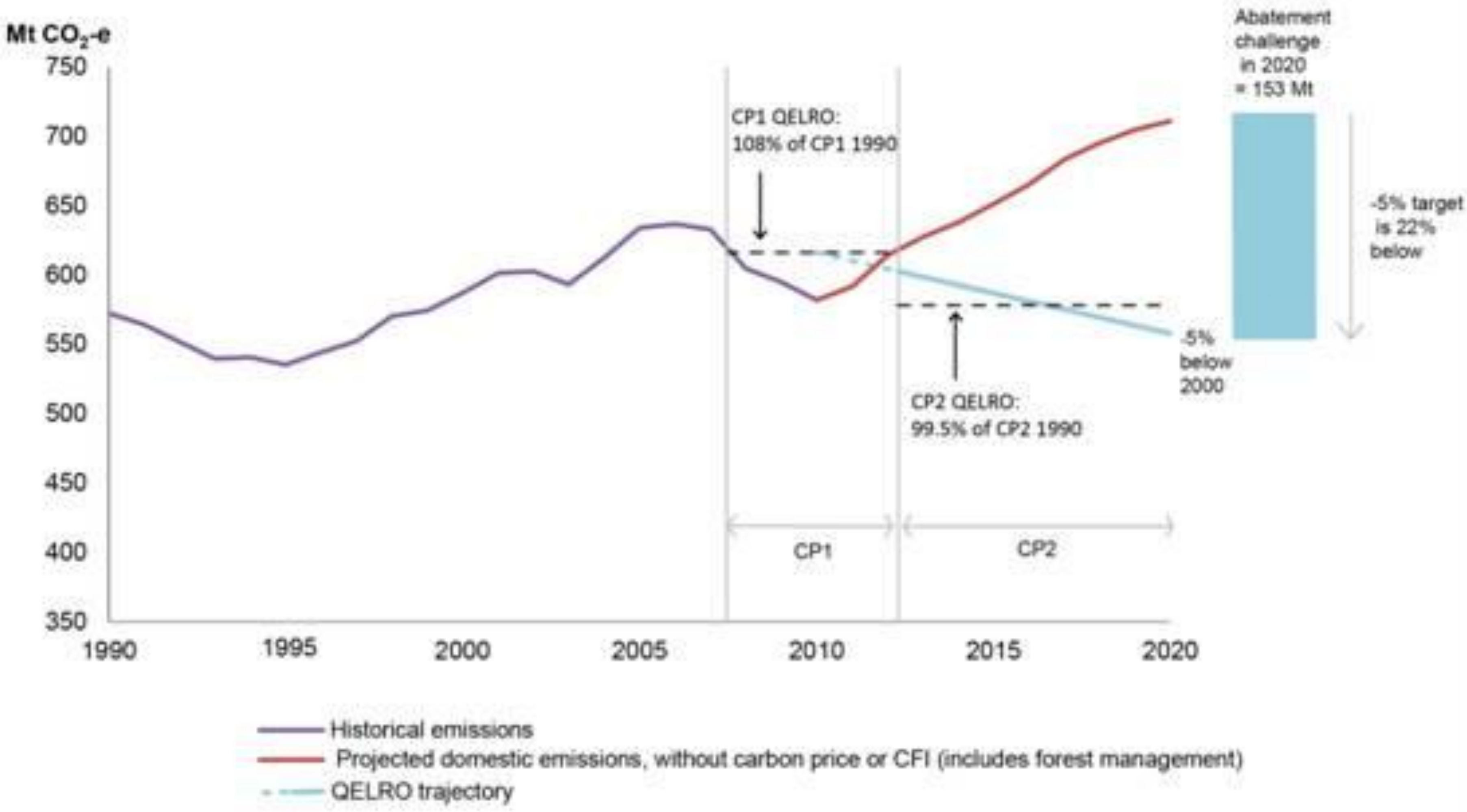

Figure 2.1 Australia's quantified emission limitations or reduction objectives (QELROs) during the first and second Kyoto commitment periods (CP1 and CP2 respectively). Source: DCCEE (2012d).

Articles 3.1, 3.3 and 3.4 of the Kyoto Protocol cover agricultural and LULUCF activities (UNFCCC 1998). Article 3.1 is broad and states:

> The parties... shall... ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases... do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments...

Agricultural activities such as livestock and rice production, manure management, fire management of crop residues and savanna, and emissions from agricultural soils are covered under this article.

Articles 3.3 and 3.4 of the Kyoto Protocol cover LULUCF activities, with Article 3.3 covering:

> … (the) net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks …

To meet the definition of “forest” under Article 3.3, vegetation must occupy a minimum land area of 0.2ha and have greater than 20% mature tree crown cover and mature tree height greater than 2m. Afforestation is the conversion of land cleared for more than 50 years to forest. Reforestation is the conversion of land cleared before 31 December 1989 to forest. Deforestation is the removal of forest from land that was forested in 1990 and its conversion to non-forest land use.

Under Article 3.3, changes in carbon stocks in the above-ground and below-ground biomass, litter, deadwood and soil organic carbon (SOC) forest pools are quantified and reported (including biomass loss due to tree harvest or environmental disturbance).

Article 3.4 covers:

> … additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories …

These activities include forest management, cropland management, grazing land management and revegetation. Crop and grazing land management includes changes to SOC stores and emissions from activities such as liming. Revegetation is defined as the establishment of vegetation (greater than 0.2ha in area) that does not meet the definitions of afforestation and reforestation. Many Australian rangeland ecotypes fall into this category.

Australia reported on activities covered under Article 3.4 during CP1 voluntarily; however, these emissions and sinks (any process that removes carbon from the atmosphere, including vegetation, soils and oceans) were not included in the national inventory for the purposes of meeting Kyoto emission limitation and reduction commitments. For CP2, emissions and sinks associated with soil carbon, revegetation and forest management are included in Australia’s mandatory reporting.

3 Carbon farming

Carbon farming is about changing farming management and practices to reduce GHG emissions from soil, vegetation or livestock or to remove CO_2 from the atmosphere by storing (sequestering) carbon in vegetation and the soil. Carbon farming offers farmers and land managers the potential to benefit financially from reducing carbon pollution and improving resource management (Table 3.1). The reporting, verification and long-term management requirements are likely to be less onerous for emission reduction projects compared to carbon sequestration projects.

Currently carbon farming activities are conducted under rules set out in the Carbon Farming Initiative (CFI) and *Clean Energy Act 2011* (*Cth*). The Commonwealth government has indicated it will repeal the *Clean Energy Act 2011* (*Cth*), with carbon farming activities operating under the Direct Action Emissions Reduction Fund (ERF) beginning in 2014–15.

Table 3.1 Potential carbon farming activities and offset type.

Offset type	Avoided emissions	Carbon sequestration
Kyoto compliant	Reduced emissions from burning crop residues	Improved forest management
	Fertiliser management	Reforestation and afforestation
	Manure management	Native forest protection
	Reduced emissions from livestock	Managed regrowth
	Savanna fire management	Avoided deforestation
		Revegetation
		Rangelands restoration
		Increased soil carbon
		Biochar application
Non-Kyoto compliant	Management of feral animals	

Carbon farming in WA may be facilitated by the *Carbon Rights Act 2003 (WA)* which allows a carbon right to be registered on a land title as a separate interest in that land (Government of Western Australia 2005). Registration of a carbon right over a block of land clarifies the ownership of the benefits and liabilities arising from carbon sequestration or emissions on that land. This legislation could be used for projects undertaken outside of the Commonwealth carbon farming framework, where offsets would be sold into voluntary markets. Anyone considering establishing a carbon farming project should seek advice about the advisability of entering into a carbon right arrangement under WA laws.

The amount of emission abatement that will be achieved via carbon farming (see Table 3.2) depends on various factors, including:

- eligibility rules of the abatement scheme
- international accounting rules that apply to Australia
- technical potential of the relevant sources
- cost of generating the abatement credits
- levels of participation by the relevant sectors
- other relevant policies
- price at which the carbon offsets can be sold (DCCEE 2011).

Under the *Clean Energy Act 2011 (Cth)* eligible carbon farming projects can generate saleable carbon offsets, called Australian carbon credit units (ACCUs). The ACCUs generated from carbon farming projects can be sold to businesses wanting to meet their carbon liability. ACCUs are either Kyoto compliant or non-Kyoto compliant (Table 3.1). Kyoto ACCUs are recognised as contributing towards Australia's Kyoto Protocol target and can be traded on domestic or overseas markets. Non-Kyoto ACCUs are not counted in the national inventory of GHG emissions and sinks and can only be traded domestically on voluntary markets.

Table 3.2 Potential attainable GHG abatements from various carbon farming activities in Australia.

Activity	Abatement in 2020 $MtCO_2$-e/yr		Abatement in 2050 $MtCO_2$-e/yr
Reforestation	1–2*	2–6**	20–70**
Avoided deforestation and managed regrowth on deforested lands	1.5–6*	0–3**	7–10**
Reduced NH_4 emissions from livestock	<0.5–1.3*	0–18**	18–26**
Reduced N_2O emissions from soil	<0.1–<0.5*	<1**	<1**
Livestock manure management	<0.1–1.1*		
Reduced emissions from burning crop residue	0–<0.1*		
Savanna fire management	<0.5–<1*	<1**	1–5**
Improved forest management	~0*		
Revegetation (including rangelands soil and vegetation)	<1–9*	0–5**	4–50**
Increased carbon storage in soils	<0.5–4*	<1**	2–12**
Biochar application	Not able to be estimated		
Feral camel culling	Not able to be estimated		

Source: * DCCEE (2011); ** Battaglia (2012).

Carbon farming activities will continue to be eligible to generate ACCUs under the proposed Direct Action Program, with the Commonwealth government becoming the major buyer of ACCUs via the ERF. Offset providers will contract to sell ACCUs into the ERF via a reverse auction process. The broad outline of how the ERF will operate is set out in the Emissions Reduction Fund Green Paper (DoE 2013a), but details of the ERF are unclear at this stage adding to the uncertainty and risk surrounding carbon farming.

3.1 Carbon offset eligibility

Offsets must meet a number of integrity standards to be eligible under the CFI to ensure real and verifiable abatement and to provide market confidence. Under the Direct Action Program, offset standards may change slightly but they will still have to be able to demonstrate that they are genuine and verifiable (DoE 2013a).

The standards currently include the following internationally recognised conditions:

- additionality, which means the project would not have happened if the offsets market were not available
- permanence, only applies to sequestration projects where carbon must be sequestered for 100 years (this may be reduced to 25 years under the Direct Action Program (DoE 2013a))
- accounting for leakage, that is, if the project causes emissions elsewhere they must be accounted for
- measurable and auditable
- conservative
- internationally consistent, to comply with Australia’s international treaty obligations when compiling Australia’s National Greenhouse Accounts
- supported by peer-reviewed science, that is, where estimation methods differ from those used in the NGI, peer-reviewed science must support the estimation methods.

Project methodologies set out how the project will be undertaken and how the abatement will be estimated (or measured) and reported. Table 3.3 lists the land sector methodologies that have been approved or are being considered under the CFI. Approved methodologies will still be eligible under the ERF, as will the use of methodologies that have been approved internationally (subject to modification for local conditions where required) (Hunt 2013). This list may grow as proposed methodologies are developed and progressed through the approval process.

Table 3.3 Approved methodologies and methodologies being considered at January 2014.

Activity	Approved methodologies	Methodologies under consideration
Reforestation and afforestation	Environmental plantings Human-induced regeneration of a permanent even-aged native forest Human-induced regeneration of a permanent even-aged native forest 1.1 Quantifying carbon sequestration by permanent mallee plantings using the CFI reforestation modelling tool Reforestation and afforestation Reforestation and afforestation 1.1 Reforestation and afforestation 1.2	Measuring carbon sequestration by permanent plantings of native species using in-field sampling Quantifying carbon sequestration by permanent native mixed species environmental or mallee plantings using the Full Carbon Accounting Model
Avoided deforestation	Native forest protection (avoided deforestation)	
Managed regrowth	Native forest from managed regrowth	
Reduced methane emissions from livestock	Reducing greenhouse gas emissions in milking cows through feeding dietary additives climatechange.gov.au	Reducing greenhouse gas emissions in beef cattle through feeding nitrate containing supplements
Livestock manure management	Destruction of methane generated from dairy manure in covered anaerobic ponds Destruction of methane from piggeries using engineered biodigesters Destruction of methane from manure in piggeries Destruction of methane generated from manure in piggeries 1.1	
Increased carbon storage in soils		Sequestration of soil carbon
Revegetation/Rangeland restoration		Rangeland restoration projects
Savanna fire management	Savanna burning Savanna burning 1.1	

3.2 Issues to consider

3.2.1 Permanence obligations

The current permanence requirement that sequestered carbon should not re-enter the atmosphere for 100 years presents some issues that potential carbon sequestration project proponents need to consider:

- Revegetation, reforestation and soil carbon projects can be expected to stop being a net carbon sink 40–100 years after establishment when the soil or vegetation reaches carbon equilibrium. At this time the amount of carbon being sequestered is equal to the amount being emitted as vegetation senesces and rots or soil carbon is oxidised. This means that the administrative and operational costs associated with maintaining a sequestration project may continue after income from carbon abatement has ceased.
- Predicted reductions in rainfall and increased temperatures associated with global warming are likely to offset CO_2 enrichment and reduce the growth rates of plants in some areas of WA (Baldock et al. 2012; ABARES 2011). This means that the selection of suitably resilient species and agricultural and forestry regimes will be critical to the long-term success of sequestration projects.
- Replacing flexible annual-based agricultural systems with sequestration plantings may reduce the ability of landholders to take advantage of future changes in technological, economic and climatic conditions.
- Capital gains for land with carbon rights registered on the title may be less than for unencumbered land.
- The CFI has provision to transfer or terminate a carbon farming project at any time. However native (indigenous) vegetation is protected under WA laws and in some circumstances a clearing permit may be required before it can be cleared. A clearing permit is not required if vegetation is planted with the intent to exploit it commercially; this specifically includes harvesting and may also include afforestation with natives for sequestration purposes.

  A landowner may have to obtain a permit to clear native vegetation, if:

  - its planting was funded (wholly or partly) by a person who was not the owner of the land and it was established for biodiversity conservation or land conservation (including salinity or soil acidity) purposes, or
  - there is some statutory covenant or other form of binding undertaking to establish and maintain it, or
  - it is regrowth of cleared indigenous vegetation and more than 20 years old, or
  - it is regrowth of any age in an environmentally sensitive area, as defined in regulations.

  Advice should be sought from the regulator, that is to say, the Department of Environment Regulation (DER), as to the scope of the relevant exemptions case by case.

The Direct Action Program intends to create a 25-year option for land-based sequestration, which would reduce some of these concerns, however the number of abatement offsets issued for a given amount of sequestration would be discounted to account for the shorter sequestration period (DoE 2013).

3.2.2 Projects on Crown land

Currently, there is uncertainty surrounding carbon rights and additionality in regard to undertaking carbon farming activities on rangelands leased from the state or on unallocated Crown land (UCL). WA's *Land Administration Act 1997* (LAA) states that land under a pastoral lease (and such leases run for up to 50 years) can be used only for pastoral purposes that are defined as grazing livestock, and ancillary activities, or other agricultural or supplementary uses of the land essential to support grazing livestock. The LAA also requires that land under a pastoral lease be managed sustainably. Given these conditions, it is not clear whether sequestration projects on these lands would comply with lease conditions of undertaking livestock grazing activities. Revegetation activities will also have to comply with permanence conditions in the context of 50-year leases and additionality conditions that account for rehabilitating degraded land in the context of the LAA requiring that pastoral land be managed to prevent degradation. The state government is undertaking a Rangeland Reform Program that (among other things) is addressing constraints to participation in carbon farming (DRDL 2011). It is intended under the Rangelands Reform Program to introduce a new tenure instrument that will allow leasing of Crown land for a range of broad-scale uses, including carbon farming. The legislation to introduce this new form of tenure is still being developed.

Applicants for, or holders of, a certificate of entitlement under the CFI for a project in WA should ensure that they hold appropriate approvals under WA law and that they comply with the future acts regime of the *Native Title Act 1993* (*Cth*).

3.3 Participating in the CFI

The Carbon Farming Initiative handbook (DCCEE 2012) sets out how to participate in the CFI. However, as new administrative structures come into force under the Direct Action Program the information contained in the CFI handbook will no longer apply. Up-to-date information about the CFI and the new scheme, as it comes into effect, should be obtained from the Commonwealth Department of Environment website.

4 Carbon farming project activities

Landowners will be motivated to undertake emission reduction or sequestration activities for two primary reasons: they will increase agricultural productivity and enterprise profitability, or they will meet altruistic objectives. Here, we discuss in more detail the technical background to some of these activities. Possible economic returns are discussed in Section 6.

There are important differences between emission abatement and sequestration projects that landowners must consider. Greenhouse gas emissions, for example, can represent a loss of valuable resources from farming systems. Yet, if land managers can enhance the efficiency with which these resources are used, there is potential to reduce greenhouse impacts and improve enterprise productivity. Emission abatement projects also avoid the need to obtain carbon rights on land or meet permanence and maintenance criteria. This allows project operators to benefit from carbon farming without reducing their opportunity to change operational and land-use management in the future. Consequently, activities have been grouped according to whether they are aimed at reducing land sector emissions or at sequestering atmospheric carbon.

4.1 Emission abatement activities

4.1.1 Fertiliser management

Nitrous oxide (N_20) emissions from the soil result from biological and chemical processes that use inorganic nitrogen (N) compounds — (ammonium (NH_4), nitrite (NO_2) and nitrate (NO_3)) — originating from a number of sources (Table 4.1). The processes that release N_2O include microbial mediated nitrification of NO_3 in aerobic soils, denitrification of NO_3 in anaerobic (low oxygen) soils (this process is limited by low SOC concentrations in deeper soil layers), nitrifier denitrification of $NH_{4,}$ and the chemical reduction of NO_2 and NO_3 (Dalal et al. 2003).

For the purposes of the NGI, N_2O emissions from agricultural activities are estimated using Tier 1 or Tier 2 methods (Table 4.1 and Table 4.2.).

Emissions of N_2O from farming systems involve the loss of N, a valuable nutrient resource. Taking action to reduce this loss has the potential to reduce fertiliser costs and may increase agricultural productivity (GRDC 2012a, 2012b). Carbon farming provides a vehicle for returning an additional payment to landowners for the environmental service of reducing GHG emissions.

In the case of emissions resulting from the application of inorganic fertilisers, N_2O emissions are calculated from the amount of N applied in fertiliser multiplied by emission factors. The emission factors for dryland agriculture Australia uses are based on Australian research and are less than the IPCC default values. This has been attributed to comparatively low N fertiliser application rates, slow decomposition of stubbles and low rates of microbial activity (DCCEE 2012b).

Table 4.1 Sources of nitrogen inputs into Australian agricultural systems, selected emission factors (EF) and source of EF used to estimate nitrous oxide emissions.

Source of N	EF kg N_2O N released / kg N applied	EF source
Inorganic fertilisers	see Table 4.2	Tier 2
Applied unprocessed animal manure	0.0156	Tier 2
Applied waste management effluent	0.0040	Tier 2
Grazing animals – faeces	0.0050	Tier 2
Grazing animals – urine	0.0040	Tier 2
Biological nitrogen fixation	0.0125	Tier 1
Crop residues	0.0125	Tier 1
Decomposition of SOC through cultivation		
Atmospheric N deposition		Tier 1
Leaching of inorganic N and subsequent denitrification in rivers and estuaries		Tier 2

Source: (DCCEE 2012b).

Table 4.2 Inorganic fertiliser used for various agricultural activities in WA 2009-10 and emission factors applied in estimating Australia's GHG inventory.

Agricultural activity	N applied* t	EF** kg N_2O-N released / kg N applied	CO_2-e released / kg N applied*** kg CO_2-e
Irrigated pasture	700	0.004	1.95
Irrigated crops	200	0.021	10.23
Non-irrigated pasture	116 000	0.004	1.95
Non-irrigated crops	194 200	0.003	1.46
Horticultural vegetable crops	4 200	0.021	10.23

Sources: * (DoE 2013); ** (DCCEE 2012b); *** calculated using equation 4D1_2 in (DCCEE 2012b).

While a methodology has yet to be developed, the CFI list of positive activities includes the application of urease or nitrification inhibitors to, or with, livestock manure or fertiliser. It should be noted that N_2O has 310 times the global warming potential of carbon dioxide (DCCEE 2012b); this means that avoiding the release of 1t of N_2O would be eligible to receive 310 ACCUs.

Urease inhibitors slow the conversion of urea and urine to NH_4, and nitrification inhibitors slow the microbial conversion of NH_4 to NO_3. They are usually added to fertiliser or animal waste before application to the soil. As NO_3 is easily leached from the soil, urease and NH_4 inhibitors have the potential to improve the efficiency of N use by reducing NO_3 leaching as well as reducing emissions of NH_4 and N_2O.

The financial benefit of avoiding N_2O emissions has to be assessed in light of the operational costs of achieving the abatement (including the costs associated with administering any abatement project), the value of any increase in agricultural production and any reduction in fertiliser costs.

Research in WA shows the opportunity for generating abatement credits from dryland cropping in lower rainfall areas is limited by comparatively low emission rates and the timing of emissions. For example, N losses from wheat, lupin and canola crops growing at Cunderdin were between 0.09 and 0.13kg N_2O-N/ha/yr, with 50% of the losses occurring outside the crop growing season following summer rainfall (Barton et al. 2008, 2010, 2011). This would equate to 44–63kg CO_2-e/ha/yr. It should be noted that these emissions are from all sources, including crop residues and decomposition of SOC. Interestingly, N_2O emissions from biological N fixation by lupin was negligible, indicating the current IPCC default emission factor should be revised downwards or that this source should be omitted from the NGI (Barton et al. 2011).

Tables 4.1 and 4.2 suggest that N_2O emissions are greatest (per unit of N applied) when animal manure is spread over soil or fertiliser applied to irrigated and horticultural crops. Accordingly, modifying these activities offers potentially the greatest opportunities for achieving N_2O emission abatement. But as research at low rainfall sites shows, a robust understanding of local emission factors and patterns of emission is essential before opportunities can be fully assessed.

4.1.2 Enteric fermentation reduction

In Australia, emissions from livestock account for about 70% of the agricultural sectors GHG emissions and 11% of total national GHG emissions. Livestock and the manure they create are the dominant sources of CH_4 and N_2O in Australia. This makes Australia’s livestock the third largest source of GHG emissions after the energy and transport sectors.

The amount of CH_4 emitted by livestock is primarily driven by the number of animals, the type of digestive system they have, and the type and amount of feed consumed (O’Mara 2011). Ruminants are the principal source of livestock CH_4 emissions because they produce the most CH_4 per unit of feed consumed. Methane represents lost energy in the digestion process. It is estimated that 7–10% of a ruminant’s energy intake is lost to enteric fermentation, although it can be closer to 4% for feedlot cattle (Moss et al. 2000). Ruminant livestock (cattle, sheep, buffalo, goats, deer and camels) have a fore-stomach (or rumen) containing microbes called methanogens. These methanogens are capable of digesting coarse plant material that produce CH_4 as a by-product of digestion (enteric fermentation), which is later released by the animal through belching.

Although non-ruminant herbivorous livestock such as horses do not have a rumen, significant fermentation does takes place in their large intestine, allowing the digestion of coarse plant material as well as producing a significant amount of CH_4. Pigs and poultry produce small amounts of CH_4 as the result of the incidental fermentation that takes place during digestion.

There are four main approaches to mitigating livestock GHG emissions: husbandry (feed, genetics and lifespan), management systems, numbers of livestock and manure management (Table 4.3) (Garnett 2007; Indira and Srividya 2012). Measures to mitigate enteric fermentation would not only reduce emissions but may also increase productivity by increasing digestive efficiency.

As the number of animals is a primary determinant of GHG emissions, there are potential conflicts of interest between reducing GHG emissions from livestock and the development objectives of the livestock industry. Livestock industries are vital to many regional communities and earn around $18 billion a year with about $15 billion of this from export earnings, so it is important that any methodology that results in lower emissions also maintains or increases productivity (DAFF 2011).

It should be noted that many of these strategies can lead to increased dry matter intake per animal, and may provide the farmer with an opportunity to increase the stocking rate, resulting in either no net change or even a net increase in CH_4 production. Farm modelling has shown that improving pasture quality and livestock efficiency also improved productivity and lowered emission intensity per unit of product, but the farm's total GHG emissions increased due to increased stocking rates (Eckard et al. 2010). Understanding this concept is important for producers considering participation in emission offset trading schemes.

Table 4.3 Summary of likely reductions in methane emissions from enteric fermentation in livestock.

Activity	Animal	Emission reduction %	Emission reduction tCO_2-e /yr/head	Sources
Breeding	Cattle Sheep	<23 3–10	0.53	Pinares-Patiño et al. 2003; Clark et al. 2005; Waghorn et al. 2006; Alcock & Hegarty 2011; Young et al. 2010
Feed additives	Cattle Sheep	18 1.1	0.41 0.002	Waghorn et al. 2002; Min et al. 2003; Woodward SI 2004; Carulla et al. 2005; Beauchemin et al. 2008; Grainger et al. 2009; Alcock & Hegarty 2011; Young et al. 2010
Improved pastures	Cattle Sheep	20 10–20	0.46	Waghorn et al. 2002; al. 2008; Eckard et al. 2010

4.1.2.1 Animal breeding

There are variations between animals in CH_4 emissions per unit of feed intake and these variations suggest that there may be heritable differences in CH_4 production (methanogenesis) (Clark et al. 2005; Eckard et al. 2010; Hegarty et al. 2007; Pinares-Patiño et al. 2003). Trials suggest that animal breeding could achieve a 10–20% reduction in CH_4 emissions (Table 4.3) (Waghorn et al. 2006).

While breeding for reduced methanogenesis may not be compatible with other breeding objectives, breeding for improved feed conversion efficiency (lower net feed intake) should be compatible and is likely to reduce both CH_4 emissions and the GHG intensity of animal products.

4.1.2.2 Dietary supplements and feed alternatives

A range of dietary supplements and feed alternatives are being trialled to assess whether they can reduce CH_4 emissions from livestock. Supplements being considered include oils, fats, tannins, probiotics, nitrates, enzymes, marine algae and Australian native vegetation (Table 4.3).

Methane abatements of 10–25% are possible by feeding ruminants dietary oils (Beauchemin et al. 2008), with 37–52% abatement achieved in individual studies (Martin et al. 2010). Plant secondary compounds such as condensed tannins (CTs) have been shown to reduce CH_4 production by 13–16% (Carulla et al. 2005; Grainger et al. 2009; Waghorn et al. 2002; Woodward 2004), mainly through a direct toxic effect on methanogens. However, high CT concentrations can reduce voluntary feed intake and digestibility (Beauchemin et al. 2008; Grainger et al. 2009; Min et al. 2003). Plant saponins (natural steroids occurring in several plant families) also potentially reduce CH_4, and some saponin sources are more effective than others, with CH_4 suppression attributed to their anti-protozoal properties (Beauchemin et al. 2008).

There is currently an approved methodology for dietary supplements for dairy cows (Table 3.3).

4.1.2.3 Improved pastures

Improved forage quality with lower fibre and higher soluble carbohydrates can reduce CH_4 production in livestock (Table 4.3) (Beauchemin et al. 2008; Ulyatt et al. 2002). Being structural fibres, cellulose and hemi-celluloses ferment more slowly and yield more CH_4 per unit of feed digested than non-structural carbohydrates (Eckard et al. 2010). Methane emissions are commonly lower with higher proportions of forage legumes in the diet, partly because of the lower fibre content (a faster rate of digestion) and, in some cases, the presence of CTs (Beauchemin et al. 2008). As improved diet increases animal growth and reduces CH_4 production, it has the effect of reducing CH_4 emissions per unit of animal product, that is, the GHG intensity of the animal products.

Pasture quality can be improved in several ways including by plant breeding, changing from C4 to C3 grasses (tropical and temperate perennial grasses, respectively, that use different pathways to capture CO_2), or grazing on less-mature pastures. Several alternative plant forages such as broccoli leaves and some Australian native plants such as *Eremophila glabra*, *Acacia saligna* and a number of saltbush species have been shown to reduce CH_4 emissions in laboratory experiments. Further research is ongoing to confirm these results under field conditions.

4.1.2.4 Stocking rates

Australian livestock emissions have declined since the 1990s. This decline has been driven by a greater than 50% fall in sheep numbers, although partially offset by a rise in beef cattle numbers. Reducing the number of unproductive animals on a farm can potentially improve profitability and reduce GHG emissions. If productivity increases through nutritional and breeding strategies, the number of livestock can be reduced without losing the quantity of meat that is currently produced (Garnett 2007).

Strategies such as extended lactation in dairying — where cows calve every 18 months rather than annually — reduce herd energy demand by 10% (Trapnell and Malcolm 2006) and thus potentially reduce CH4 emissions by a similar amount (Smith et al. 2007). With earlier finishing of beef cattle in feedlots, slaughter weights are reached at a younger age, with reduced lifetime emissions per animal and proportionately fewer animals producing CH_4 (Smith et al. 2007). Trials involving mating replacement merino ewes at seven months of age were successful in reducing GHG emissions by 9–12% through removing an age group of ewes that were previously not reproductive (Alcock and Hegarty 2011).

4.1.2.5 Biological control

Three biological control methods are being examined for their ability to reduce CH_4 production from livestock. The first uses viruses to attack the microbes which produce CH_4; the second uses specialised proteins to target CH_4-producing microbes; and the third uses other microbes (methanotrophs) to break down the CH_4 produced in the rumen into other substances (Sejian et al. 2011).

A fourth possible option — bovine somatotropin and hormonal growth implants — do not specifically suppress CH_4 formation but improve the animal's performance and reduce the GHG intensity of the products (Garnett 2007; IPCC 2007).

4.1.3 Manure management

Livestock urine and manure are significant sources of CH_4 and N_2O when they break down under anaerobic conditions. Nitrous oxide is produced during the nitrification–denitrification of the N contained in livestock waste. Anaerobic conditions often occur where large numbers of animals are managed in a confined area (e.g. dairy farms, beef feedlots, piggeries and poultry farms) and manure is stored in large piles or settlement ponds (de Klein and Eckard 2008).

Ruminants excrete 75–95% of the N they ingest (Castillo et al. 2000; Eckard et al. 2007; Whitehead 1995). Ruminants on lush spring pasture commonly ingest protein (containing N) in excess of their requirements, but are usually energy limited, resulting in higher ruminal NH_4 concentrations being excreted in the urine as urea (Whitehead 1995). Therefore, balancing the protein-to-energy ratios in the diets of ruminants is important in minimising N_2O emissions. Improving N efficiency and reducing excess urinary N can be achieved in three main ways: breeding animals with improved N efficiency; breeding forages that use N more efficiently and have a higher energy-to-protein ratio; or balancing high protein forages with high-energy supplements (Eckard et al. 2010). In 2001, Miller et al. reported that dairy cows on a "high sugar" variety of perennial ryegrass excreted 18% less N in total and 29% less urinary N.

Several measures have been suggested to manage GHG emissions from livestock urine and manure. Manure stockpile aeration and composting can reduce the amount of CH_4 that is produced. Adding urease inhibitors to manure stockpiles can reduce N_2O emissions. Urease inhibitors are chemical additives that stop or reduce the rate that urea (found in animal urine and manure) is converted to N_2O. There is increasing interest in biogas (CH_4) capture-and-use schemes such as covered ponds and the flaring or combustion of the captured biogas to provide heat or power. These systems are common in Europe but uncommon in Australia and may be profitable, regardless of ACCU income, due to energy production and the trading of renewable energy certificates (RECs) (Hertle 2008).

Australian Pork Ltd has released a biogas code of practice: "On-Farm Biogas Production and Use (Piggeries) for Australian producers". The code is focused on covered effluent ponds for the pork industry and provides a basis for appropriate and uniform standards across Australia to improve the standard of installations. There are approved methodologies for manure management in piggeries and dairies (Table 3.3).

4.1.4 Feral animal management

Under the CFI, an introduced (feral) animal includes livestock and any animal other than a native animal as described in the *Environment Protection and Biodiversity Conservation Act 1999 (Cth).* A proposed carbon farming activity is to cull feral animals to stop them emitting CH_4. However, a methodology has yet to be approved and so this not discussed further.

Emissions from feral animal management, including ruminants such as camels and goats, are not included in reporting against Australia's Kyoto Protocol target for reduced GHG emissions. Therefore, activities that reduce emissions though feral animal management would generate non-Kyoto ACCUs.

4.1.5 Savanna fire management

Savanna woodlands and grasslands cover about 25% of the Australian continent, with the majority of savanna fires occurring in northern regions where the cycle of wet and dry seasons make these areas particularly prone to fire. While the typical savanna vegetation structure is grassland with scattered trees, "savanna burning" has been used in GHG emissions accounting to encompass biomass burning in a wide range of northern Australian vegetation types, including tropical and subtropical grasslands, woodlands and shrublands (NGGIC 2007).

Savannas constitute the most fire-prone biome on earth (Dwyer et al. 2000; Roy et al. 2008). Grass and shrubs grow quickly during the five-month wet season (January to May) then cure during the dry season to form a continuous vegetation layer that can carry fire long distances (Andersen et al. 2003).

Only the N_2O and CH_4 emitted during fire events are accounted for in the NGI (NGGIC 2007). Carbon dioxide emissions are not included as it is assumed that an equivalent amount is removed from the atmosphere through vegetation regrowth. Greenhouse gases from savanna fires average 3% of Australia's NGI (DCCEE 2010). Savanna burning contributes to greater than 95% of the burning emissions in WA, making savanna burning a priority area for abatement (DCCEE 2012). In 2009–10, savanna and agricultural residue burning in WA contributed 35%, or 2.3MtCO_2-e of WA's agriculture emissions, equivalent to 3% of total WA emissions for the year.

Fire return intervals are shortest in grasslands and savannas including the landscapes dominated by highly flammable spinifex grasses, which cover extensive areas of inland WA (Heckbert et al. 2012). In northern WA, fires may recur every one to two years (Williams et al. 2002, Walker 1981). Fire intervals tend to increase to the south, along the gradient of decreasing average annual rainfall, from about every five years at latitude 19°S to about every 10 years at latitude 24°S (Heckbert et al. 2012). However, in the more variable rainfall regimes of arid Australia, fire occurrence is irregular since it is determined by antecedent rainfall (Heckbert et al. 2012).

Pastoral managers are concerned about regular, extensive fires because they destroy stock feed, reduce pasture quality in the longer term (e.g. by the replacement of perennial grasses with annuals) and damage infrastructure (fences, bores) (Legge et al. 2011). The Kimberley Regional Fire Management Project (2000–05) suggested that the annual cost of unplanned fires ranged from \$50 000 to \$400 000 per property because of damage to infrastructure and reduced pasture production (Palmer 2004). A study in Cape York Peninsula found the cost of an unplanned fire that affected at least two-thirds of a 1100km^2 property (Kimberley properties are two to three times this size) to be \$32 000 (Drucker et al. 2008).

In addition to wildfires started by lightning strikes, fires are lit to improve pastoral production by stimulating re-sprouting of grasses, to inhibit growth of woody plants, to facilitate hunting by Aboriginal people (and meet other customary obligations), or to protect property (Russell-Smith et al. 2007). Studies reveal that in the absence of traditional Aboriginal land management, historical fine-scale mosaic fire patterns have been replaced by more widespread and intense fires that mainly occur in the latter half of the dry season, and that GHG emissions are much greater from late dry season (LDS) fires than from early dry season (EDS) fires (Russell-Smith et al. 2004).

The West Arnhem Land Fire Abatement (WALFA) project has shown EDS fires are more patchy than LDS fires, leaving 29% unburnt compared to 11% in LDS fires (Russell-Smith et al. 2009a; Price et al. 2003; Whitehead et al. 2009). EDS fires also burn at lower intensity, typically emitting 52% less CH_4 and N_2O per hectare burnt compared with LDS fires (Williams et al. 2003; Russell-Smith and Edwards 2006; Russell-Smith et al. 2009a). A critical assumption regarding GHG abatement is the management efficacy of prescribed burning. Russell-Smith et al. (2009a) suggested an upper potential of 48% reductions in emissions but measurements indicate actual reductions of 34% (Russell-Smith et al. 2009b), with 25% regarded as a conservative estimate of abatement (Heckbert et al. 2011). To avoid emitting 1tCO_2-e/ha, about 26 hectares need to be treated at a cost of \$0.47/ha or \$12.85/tCO_2-e abated (Heckbert et al. 2012), based on projects in the Northern Territory.

In addition to avoiding GHG emissions, EDS prescribed burning can substantially increase living biomass, particularly woody vegetation, which may increase carbon storage through increased biomass (Henry et al. 2005; Hughes et al. 2006; Murphy et al. 2010). Murphy et al. (2009) estimated that fire management alone could sequester 22.3tCO_2-e/ha in additional woody biomass over a 100-year period. Modelling by Douglass et al. (2011) suggested that reducing the area burnt under LDS fires by 13% and reducing cattle stocking density by 50% could sequester 25.6tCO_2-e/ha over 90 years. However, woody vegetation can decrease pastoral productivity and consequently is often cleared or burnt, releasing greenhouse gases (Myers et al. 2004). Furthermore, intensive grazing reduces below-ground carbon (Klumpp et al. 2009; Soussana et al. 2007) and the combined impact of fire and grazing can reduce tree density (Staver et al. 2009).

There is currently an approved methodology for savanna burning in areas receiving more than 1000mm of average annual rainfall (Table 3.3). Under this methodology, land managers can register ACCUs for avoided greenhouse emissions from savanna fires, by shifting burning from the LDS towards the EDS, and reducing the area that is burnt each year. Applicants for, or holders of, a certificate of entitlement under the CFI for an emission avoidance project in WA should ensure that they also hold appropriate approvals under WA law. Proponents of savanna burning projects should contact local government, the Department of Parks and Wildlife and the Office of Bushfire Risk Management within the Department of Fire and Emergency Services for specific advice regarding applicable bushfire regulations.

4.2 Sequestering atmospheric carbon

Plants play a key role in the global carbon cycle. As they photosynthesise, plants take CO_2 from the atmosphere and use it to produce reduced carbon compounds. This uptake of CO_2 causes annual fluctuations in global atmospheric CO_2 concentrations as plants absorb CO_2 during spring and summer in the northern hemisphere (where the greatest landmasses occur) and then release CO_2 and CH_4 from rotting biomass during autumn and winter.

It has been estimated that terrestrial plants produce about 125Gt of dry matter per year (Pallardy 2008), of which about 50% is carbon. This compares to about 750Gt of carbon in the atmosphere (UNEP 2009). Globally, there is about 610Gt of carbon sequestered in plant biomass, of which 77% is in forest ecosystems (UNEP 2009). Over millennia, plants and animals have sequestered an estimated 3360Gt of carbon in the soil (more than half in peat lands and northern tundra) (Tarnocai et al. 2009) and 3300–3700Gt of carbon as fossil fuels (UNEP 2009; Mackey et al. 2013).

Sequestered carbon is released back into the atmosphere when land-use change (LUC) permanently removes or reduces plant biomass or SOC, or when fossil fuels are burnt. Between 2000 and 2008, 85% of human-created carbon emissions were from fossil fuels with the remainder from LUC, primarily deforestation in the tropics (Raupach et al. 2010). In 2011 burning fossil fuels released 31.6Gt of CO_2 (8.6Gt of C) to the atmosphere (IEA 2012). The increase in atmospheric CO_2 concentration from 278ppm in pre-industrial times to 391ppm in 2012 equates to an increase of approximately 233Gt of atmospheric carbon. About 30% and 25% of the human-created CO_2 emitted each year accumulates in land and ocean sinks respectively, while the remaining 45% accumulates in the atmosphere (Raupach et al. 2010).

While LUC is a source of CO_2 emissions, rising atmospheric CO_2 concentrations have boosted plant productivity to the point where the land (plants and soil) is currently functioning as a net sink (Mackey et al. 2013). Land management can help to maintain forest carbon stocks and provide additional carbon sinks in soil and plant biomass.

4.2.1 Soil organic carbon

Soil organic carbon (SOC) represents a critical component of the earth's carbon cycle. Every day about 10 times more carbon moves (via photosynthesis and respiration) between the soil and the atmosphere than is emitted into the atmosphere from burning fossil fuels.

SOC plays a critical role in the health and productive capacity of arable soils (Table 4.4). Healthy soils sustain crop productivity, so maintaining or increasing SOC for this reason alone makes environmental and economic sense (Hoyle et al. 2011). Farmers may gain financially when SOC is given a tradeable value for its carbon sequestration benefits but this should not be seen as the sole reason for managing soils to increase SOC (Sanderman et al. 2010).

Ultimately, determining a soil's potential to act as a carbon sink will require a thorough understanding of the long-term dynamics of SOC and the factors that control carbon sequestration processes over time (Table 4.4).

There are no approved SOC methodologies but there is a proposed methodology (Table 3.3).

Table 4.4 Effect of agricultural management practices on SOC and consequent agronomic effects.

Practice	Agronomic consequences		Soil carbon consequences	
	What we know	What we don't know	What we know	What we don't know
Increase area of perennial pastures	• pasture productivity is greater in high rainfall areas and for deeper soils • increased soil nutrient concentrations	• reduced enterprise flexibility if locking in the area of perennial pasture • do nutrients need to be added or are they captured rather than lost to the system • is there C leakage with greater stocking rates	• increased SOC under kikuyu = 0.25–0.5t/ha/yr on deep sands • decreased SOC in duplex soils (Esperance)	• equilibrium storage • which soil type is SOC increased in and where • which C pool is SOC moving into
Claying	• can reduce yield under some circumstances • generally increased production		• addition of 5% clay can increase SOC by 2–4t/ha at equilibrium	• can verification be linked to clay application • which C pool is increased • is there an upper clay threshold
Biochar	• variable agronomic benefits • increased soil nutrient concentrations • removal of nutrients in biochar feedstock • variable char qualities • trade-off between energy and char production	• where benefits can be assured i.e. low phosphorous (P) soils in Central Midlands • do these nutrients need to be added or are they captured rather than lost to the system • long-term cost and effect on toil biology • Transfer of labile C to protected C pool – effect on productivity • char quality effect on crop/pasture productivity	• variable char qualities • can absorb herbicides	• char quality effect on SOC storage • long-term effect of herbicide absorption

continued

Table 4.4 continued

Practice	Agronomic consequences		Soil carbon consequences	
	What we know	What we don't know	What we know	What we don't know
Rangelands	• management change is principally manipulation of total grazing pressure	• quantifiable relationship between grazing management and SOC concentration • leakage (displaced grazing)	• low capacity of soils to store C • high verification costs • high spatial and temporal heterogeneity	• legally complex issues surrounding native title and C ownership • baseline SOC • lack of clarity around lessees' obligations regarding maintaining rangeland condition — meeting the CF criteria • how to monitor SOC between baseline and subsequent verification assessments
Minimum tillage	• generally improved yield and profitability • reduced erosion risk		• won't increase SOC • rate of SOC decline less than with conventional tillage	
Revegetation & reforestation	• agricultural production displaced • retaining harvest residues (slash) will increase soil C levels • retaining slash will help retain other soil nutrients • reduced soil erosion	• leakage/reduced emissions (altered agricultural intensity on non-forest land) • higher operational costs associated with slash retention • possible increased fire risk from retaining slash	• decrease in SOC following plantation establishment • best chance of increasing SOC in high rainfall zone • increase in SOC with harvest if the slash (residues) left on site • little change in SOC deeper than 10cm • may be decades before net increase in SOC	

continued

Table 4.4 continued

Practice	Agronomic consequences		Soil carbon consequences	
	What we know	What we don't know	What we know	What we don't know
Preventing soil erosion	• erosion control most likely to be driven by associated productivity benefits • erosion associated with large productivity losses		• erosion associated with large SOC losses	No data
Stubble retention	• reduced soil erosion • water conservation • soil C consequences		• should increase SOC	
Increased production (fertiliser, disease & pest management)	• potentially increased profitability		• should increase SOC • potential GHG emissions from increased fertiliser	
Addition of offsite organic matter (compost, manure)	• can reduce nutrient requirements • can increase plant productivity		• should increase SOC	
Reduce fallows (green manure/cover crop)	• loss of income in year green manure grown • water conservation • weed control • can reduce nutrient requirements		• increase plant inputs compared to bare fallow	

Sources: DAFWA soil carbon workshop 2012; Sanderman et al. (2010); CSIRO Land and Water; Paterson and Hoyle (2011).

4.2.1.1 Soil carbon in Western Australian soils

Australian agricultural soils typically have SOC contents between 0.7 and 4%. Soils under native vegetation in the drier parts of south-western Australia are inherently low in SOC, with some sites showing an increase in the level of SOC when converted from native forest to broadacre agriculture (Table 4.5). While many factors interact to influence the amount of SOC, the two overriding natural determinants are clay content and climate (rainfall and temperature) (Carson, 2012). Within the range of “potential” SOC concentrations set by soil type and climate, land use and land management practices have a significant role in determining the “actual” SOC concentration at a particular site (Table 4.5).

Clay can act to protect SOC from decomposition, so soils with naturally high clay contents are capable of holding more SOC than sandy soils (Figure 4.1). In WA, soils used for cereal crops generally have low clay content and SOC ranges between 0.3 and 3%.

Rainfall and temperature influence both the amount of plant biomass produced (i.e. the potential input of new organic matter) and the rate at which the SOC decomposes. Where there is sufficient soil water, higher temperatures increase the rate of breakdown.

Current climate trends and modelling of future climate scenarios suggest that most of the WA agricultural region will become warmer and drier, with greater temperature extremes compared to current conditions. These changes have the potential to impact on both the amount of organic input to the soil and the rate of decomposition. SOC levels are likely to decline in response to predicted declining rainfall in WA where there is a corresponding decrease in biomass production (DAFWA 2013).

Table 4.5 Soil organic carbon (t/ha) for various soils, rainfall zones and land uses in WA.

Location	Soil type	Rainfall zone	Native forest	Plantation ex-pasture	Annual pasture	Perennial pasture	Continuous cropping	Mixed farming	Dairy	Horticulture chemical fert.	Horticulture compost 7 yrs x 30m^3/ha	Horticulture compost 7 yrs x 60m^3/ha
South-west WA[1,5]	Various	High	61[1]	78[1]	78[5]	61[5]	25[5]	36[5]	92–101[5]			
Esperance sandplain[2]	Deep sand	High			40 (100)	46 (76)						
Esperance sandplain[2]	Shallow duplex	High			48 (100)	43						
Albany[3]	Deep sand	Low					29 (40)	39 (50)				
Albany[3]	Deep sand	High			61 (55)	93 (77)						
Albany[3]	Duplex	High			83	91						
Medina[4]	Deep sand	High								11	15	18

Values in brackets are percentage of attainable SOC achieved.

Source: [1] Mendham et al. (2003) calculated to 1m depth; [2] Carson et al. (2012) calculated to 0.3m depth; [3] Soilquality.org.au (2012) calculated to 0.3m depth; [4] Paulin and O'Malley (2008) calculated to 0.15m depth; [5] Murphy et al. (2013) calculated to 0.3m depth.

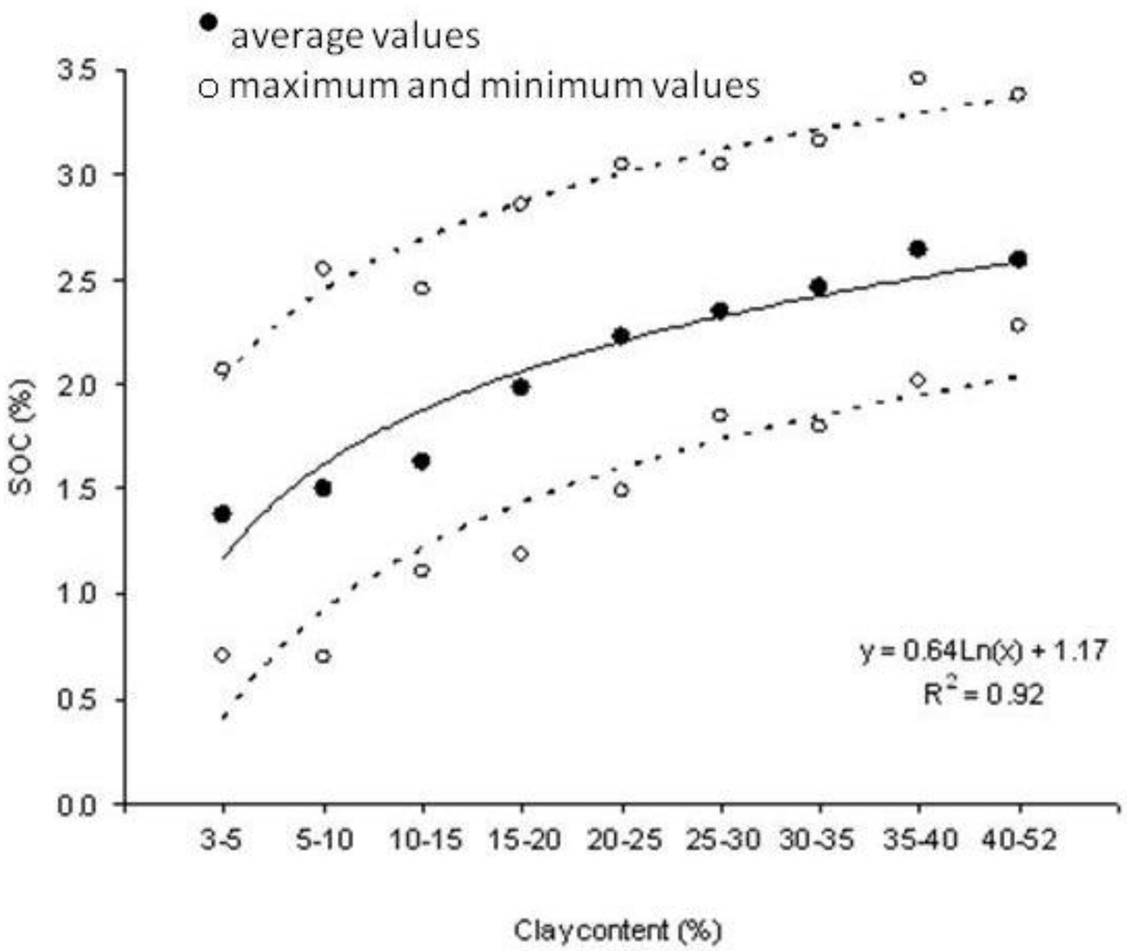

Figure 4.1 Influence of clay content on soil organic carbon (SOC) values under a cereal–legume rotation in the Central Agricultural Region of WA. Adapted from Hoyle et al. (2011).

4.2.1.2 Soil carbon pools

SOC is not a uniform substance but rather comprises four fractions which differ in their chemical composition and stage of decomposition:

- fine plant residues (<2mm in size, either on the soil surface or buried)
- particulate organic carbon ("labile" organic carbon)
- humus (amorphous organic material derived from plant and animal remains)
- resistant organic carbon (similar to charcoal).

Together, these four fractions make up the total organic carbon content of a soil and contribute variously to key soil functions (Hoyle et al. 2010; Pluske et al. 2012; Hoyle et al. 2012). Soils with the same total SOC content can differ significantly in the relative amounts of each fraction (and thus their function), depending on how they have been managed.

In terms of soil health and productive capacity, each fraction contributes differently to various soil functions. For example, the labile pools that turn over quickly (plant residues and particulate organic carbon) drive microbial activity while more intermediate pools, such as the humus fraction, play an important role in soil fertility. In terms of carbon trading, the goal would be to increase the resistant SOC fractions to ensure permanence and thereby reducing the risk of sequestration reversal.

4.2.1.3 Manipulating soil carbon levels

It is relatively easy to build the labile SOC fractions with regular additions of plant residues, imported organic residues such as compost (Table 4.5) or manure to the soil. However, this fraction turns over very rapidly as the microbial population in the soil oxidises it, releasing energy and CO_2. Cultivation aerates soil and exposes previously protected SOC within soil aggregates allowing greater microbial activity. This generally results in a decline in SOC (Maraseni and Cockfield 2011; Valzano et al. 2005). Building the resistant SOC fractions (which make up a large proportion of the total organic carbon mass in soil) can take decades and needs substantial inputs of biomass over many years (Bell et al. 2012).

Limited research has been conducted to determine the potential for increasing SOC levels in WA soils. With the exception of adding extra clay to the soil (known as claying), which shows some promise, agronomic management practices do not alter the maximum carbon capacity of a soil (its potential capacity) — only the rate at which carbon is accumulated or lost to the soil system. This means that soils such as sands with an inherently low capacity to store SOC will always have a relatively lower SOC compared to soils with higher clay content regardless of the management systems imposed on them.

Coarse-textured sandy soils require greater inputs of organic material than clay soils to build and maintain SOC due to more rapid decomposition (Table 4.6). For example, increasing SOC by 0.5% in a sandy loam with base SOC of 1.5% would require the organic inputs to be almost doubled to 8.8t/h/yr for 10 years (Table 4.6). Maintenance of 2% SOC would then require continued higher inputs of organic matter, or SOC levels will decline. By comparison, a sand with similar base SOC will require 10.9t/ha/yr of organic inputs to reach the same SOC and a clay would require 8.1t/ha/yr. These organic matter inputs would require very significant increases in biological productivity in the context of WA’s dryland farming systems.

Table 4.6 Calculated organic matter inputs required to increase soil organic carbon from 1.5 to 2.0% over 10 years (0–10cm) for various soil types (Hoyle, pers. comm.).

Organic inputs (t/ha/yr) needed to	Sand	Loam	Clay
• maintain current SOC		4.8*	
• increase SOC	10.9	8.8	8.1
• maintain 0.5% higher SOC		6.4*	

* Calculated assuming 42% of organic matter is carbon and bulk density is 1.35g/cm^3.

A meta-analysis of Australian research showed that SOC accumulation in the topsoil under perennial pasture (140kg/ha/yr) is greater than conservation tillage (139kg/ha/yr), which is greater than residue retention (62kg/ha/yr), which is greater again than N fertiliser application (47kg/ha/yr) (Lam et al. 2013).

There is evidence that moving from annual cropping and pasture systems to permanent pasture can increase SOC in some regions of WA (Table 4.5), but the opportunity cost of changing land use needs to be carefully considered as it may outweigh any carbon benefits (Kragt et al. 2012). Likewise, the cost of applying N fertiliser to stabilise additional stored carbon can offset any returns from carbon sequestration (Lam et al. 2013).

In the examples given in Table 4.5, SOC would increase by 6t/ha or 32t/ha if annual pastures on deep sands were converted to perennial pastures at Esperance or Albany respectively. In the Albany example, this would equate to about 117tCO_2-e/ha over 40 years (1.2tCO_2-e/ha/yr over 100 years). Modelling suggests this could be increased if soil and agronomic constraints to pasture growth were removed (or at least reduced) so that the percentage of attainable storage was increased. In southern Australia, SOC is generally not increased for at least 30 years after replacing pasture with plantation tree species. It is unclear whether SOC is greater in the longer term under mixed species plantings compared to plantation forestry (Hoogmoed et al. 2012).

4.2.1.4 Biochar

Biochar is essentially charcoal that when added to the soil makes up the most resistant SOC pool (Downie et al. 2011). The longevity of biochar in the soil and its reported improvement of soil fertility and agronomic production have made biochar the subject of intense scientific and public interest. However, a number of uncertainties remain because the physical and chemical characteristics of biochar are dependent on the type of biomass from which it is made and how it is produced (Singh et al. 2011a, McHenry 2008). More importantly, biochar has not been shown to consistently improve the productivity of WA soils (Galinato et al. 2011; Sohi et al. 2010; Sparkes and Stoutjesdijk 2011). Recent research found turnover rates of charcoal in soil is at a centennial rate (<10–600 years, mean 291 years) rather than millennial, which is similar to bulk SOC (Singh et al. 2011b). These decay rates would have to be factored into the 100-year life of a biochar sequestration project.

Ultimately, there is no reason for farmers to use biochar unless clear agronomic benefits can be demonstrated as the same sequestration outcomes can be achieved if biochar is buried at the site of production.

4.2.2 Reforestation, afforestation and revegetation

Revegetation and reforestation activities are not new to WA and have been undertaken to address natural resource management (NRM) issues (e.g. secondary salinity, wind erosion and biodiversity decline), for purely financial reasons (e.g. plantation forestry with softwoods and hardwoods) and combinations of the two (e.g. carbon sequestration forestry under the Greenhouse Friendly program and mallee agroforestry).

There is a great deal of published information relating to forestry and revegetation establishment methods and species selection. Websites, the Forest Products Commission (FPC), local NRM organisations and local nurseries are all good sources of information. Tax deductions and exemptions (related to conservation covenanted native vegetation) may be available, as explained on the Australian Taxation Office and State land tax websites, respectively. There are several approved methodologies (Table 3.3).

Carbon farming presents an opportunity for landowners to benefit financially from ecosystem services (principally carbon sequestration but also biodiversity enhancement, salinity mitigation and amenity values) provided by revegetation and reforestation (George et al. 2012). While large areas of WA are potentially suitable for revegetation and reforestation activities (Harper et al. 2007), uncertainties surround their ability to generate income and hence the future rate and extent of uptake (Battaglia 2012, DCCEE 2011). These uncertainties include the opportunity cost of changing land use, the long-term price of carbon, the rate at which carbon is sequestered (tree growth) and the costs associated with establishing and managing the vegetation.

4.2.2.1 Carbon sequestration rates

Carbon sequestration rates are critical to understanding the economics of carbon forestry in WA. Potential growth rates of the major plantation sawlog and woodchip species are relatively well understood for the traditional forestry areas of WA but there is less information about non-forestry tree species, particularly older stands in the drier areas of the WA wheatbelt (e.g. Sochacki et al. 2007; White et al. 2009; Huxtable et al. 2012). As a result, economic analyses of carbon forestry in WA have largely used modelled tree growth rates (Eamus et al. 2000; Gifford 2000a, 2000b; Paul et al. 2008; Polglase et al. 2011). Comparison of modelled and measured growth rates show that these models (which are also used to estimate forest sequestration for Australia's Kyoto audits) provide conservative growth estimates (Paul et al. 2013a).

To improve estimates of tree growth, models such as FullCAM, which is used in the national carbon accounts, are being updated as more data becomes available. In WA, data collection and analyses are under way for mallee species and mixed species biodiversity plantings.

Research in southern Australia has shown that SOC generally does not increase for at least 30 years after replacing pasture with plantation tree species (Guo et al. 2008; Hoogmoed et al. 2012; Turner et al. 2005). It is unclear whether SOC is greater under mixed species plantings compared to plantation forestry in the longer term (Hoogmoed et al. 2012). In plantation forests, carbon sequestered in leaf litter and deadwood is more significant than changes in SOC but litter dynamics are less well understood than tree growth rates (Mendham et al. 2003).

Proponents of carbon farming projects need to consider the costs and benefits of using a methodology that estimates carbon sequestration using modelled growth rates (likely to give a conservative sequestration rate but with a low verification cost) against an inventory methodology that measures tree growth directly (accurate estimate of sequestration rate but greater measurement and verification costs).

The long-term impacts of climate change on tree growth should also be considered. Studies show that these impacts can be beneficial or deleterious, depending on species and site (ABARES 2011; Simioni et al. 2008).

4.2.2.2 Harvested versus no-harvest sequestration forestry

Currently, there is provision to generate carbon offsets from forest or revegetation that is subject to regular harvest. This could entail handing back offsets for the carbon in the biomass that is harvested, only applying for offsets for the average amount of carbon sequestered over the harvest rotation, or only applying for offsets for the carbon sequestered in the unharvested portion of the biomass. While the number of carbon offsets generated from a harvested project is likely to be less than from a non-harvested project, a number of advantages are inherent in harvested systems:

- The land continues to generate primary produce and income for the life of the project.
- Fewer carbon offsets are generated, reducing the cost of changing land use should that be desired.
- Integrated biomass systems provide some flexibility to respond to future changes in climate, technology and product demand.
- Income for carbon offsets can offset establishment costs and provide early income in longer rotation harvest systems (Polglase et al. 2011; Paul et al. 2013).
- Potential offsets are generated for carbon stored in harvested wood products.

Mallee agroforestry is an example of an integrated farm forestry system that could potentially generate income from carbon offsets, renewable energy certificates and harvested biomass in WA (Flugge and Abadi 2006).

The economics of carbon sequestration from harvested farm forestry systems will be considerably improved with the inclusion of “Improved Forest Management” in the activities on which Australia reports, under the Kyoto Protocol, from 2013. This will allow the crediting of carbon sequestered in forestry products such as paper and timber (Moroni 2012).

Methodologies for harvested sequestration systems are being developed (Table 3.3).

4.2.2.3 Integrated versus block plantings

Reforestation and revegetation of agricultural land can be done in many ways ranging from large block plantings to highly integrated alley systems, with each layout having various pros and cons. For example, block plantings can be used to target particular soil types or areas in the landscape and may be cheaper and easier to establish and manage than integrated plantings. Integrated plantings and particularly narrow linear belts spread the environmental benefits of revegetation over a larger area and provide trees with greater access to resources (particularly water) than blocks. Mallees growing in two row belts can produce 30–80% more biomass (and sequestered carbon) than mallees growing in blocks (Huxtable et al. 2012). This can be particularly important in low rainfall environments or where trees are being grown for harvest (Bartle et al. 2012). Costs are also associated with integrated plantings where trees competing for soil water reduce adjacent crop and pasture growth. In the case of mallees, the average width of foregone agricultural income is 14m and 8–9m on either side of unharvested and harvested belts respectively (Sudmeyer et al. 2012).

These trade-offs need to be carefully considered before undertaking any agroforestry project.

4.2.2.4 Opportunity cost and land

Locating revegetation and reforestation projects on agricultural land with a low opportunity cost (i.e. land that is currently of limited agricultural value) will increase the attractiveness of carbon farming activities for WA landowners. A recent survey found that 75% of farmers in the North-East Agricultural Region are willing to permanently revegetate unproductive soils (Blake et al. 2012), with many already withdrawing these areas from cropping programs or planting them to oil mallees. Such land might be marginally saline, inherently acidic, in areas with low rainfall or non-arable for other reasons. The dispersed nature of these areas and their relatively small size (Lawes and Dodd 2009) makes alternative land uses unpractical.

Carbon farming revegetation of unproductive agricultural land, with no opportunity cost associated with the land-use change, is clearly an opportunity, but it is currently constrained by the lack of knowledge about the carbon sequestration potential of the species that grow in these areas.

4.2.3 Rangelands restoration

Rangelands occupy 87% of WA's land area with 38% of this area covered by pastoral leases for grazing of livestock on native vegetation and 62% UCL and lands vested for conservation and Aboriginal purposes (DRDL 2011).

Pastoral producers in many areas are experiencing financial difficulties due to successive dry seasons, declining terms of trade, difficulties attracting labour and reduced productive capacity as a result of unsustainable grazing practices (Government of Western Australia 2009). Consequently, carbon farming revegetation activities are attracting a lot of interest from pastoralists and NRM groups in the rangelands (Alchin et al. 2010; Witt et al. 2011).

Carbon farming is seen by some as a way to improve the financial and ecological sustainability of pastoral enterprises through reducing grazing pressure, increasing vegetative cover and improving the long-term productivity of the land. For pastoralists, the opportunity cost of changing land use is low and although the sequestration potential is also relatively low on a per hectare basis (Table 4.7), the geographical extent of the rangelands means they have the potential to sequester large amounts of carbon (Table 3.2). It should be noted that carbon sequestration in the rangelands is subject to the cost, price and biophysical uncertainties discussed previously and both plant productivity and SOC can be expected to decline if rainfall declines in future (Dean et al. 2012; Delgado-Baquerizo et al. 2013).

Rangelands restoration on Crown land also has some issues relating to the LAA, as discussed in Section 3.2.2.

While there is a proposed rangelands methodology (Table 3.3), methodology development for the WA rangelands is constrained by a lack of local data and the need to develop low-cost modelling and remote sensing methods to economically cover the extensive and diverse rangelands (Dean et al. 2012; Hill et al. 2003, 2006; Suganuma et al. 2006).

Table 4.7 Carbon sequestration rates and time to equilibrium for soil, biomass and whole landscape in mulga woodland in Queensland (measured) and rates for various landforms in WA (estimated).

State/Region	Vegetation/land system	Management intervention	Soil tCO_2-e/ha/yr	Biomass tCO_2-e/ha/yr	Total tCO_2-e/ha/yr	Time period yr
Qld*	Mulga	Destocking	0.18	0.73 – 0.9	0.92 – 1.1	25
WA**	Average over all rangelands	Destocking and fire management			0.15 – 0.62	20
Pilbara	Various landforms	Destocking	0.05	-0.06	-0.01	30
Pilbara	Various landforms	Intensification	0.04	0	0.04	30
Kimberley	Various landforms	Destocking	-0.04 – 0.01	0.12 – 0.51	0.13 – 0.47	30
Kimberley	Various landforms	Intensification	-0.02 – 0.21	0.08 – 1.66	0.06 – 1.88	30
Kimberley	Various landforms	Destocking and fire management	0.19 – 0.25	1.98 – 2.29	2.17 – 2.55	30

Note: Negative values indicate a net release of carbon.

Sources: * Witt et al. 2011; ** Harper et al. 2007; *** Alchin et al. 2010.

5 Carbon as a tradeable commodity in Australia

Uncertainty surrounds carbon trading in Australia. The Commonwealth government has undertaken to repeal the *Clean Energy Act 2011 (Cth)*, and many of the laws that support it. This will halt the current carbon pricing scheme, although it is intended that the mechanisms for creating and selling ACCUs via carbon farming activities would continue. The government proposes establishing the ERF to purchase emission offsets, including offsets generated by carbon farming activities, such as sequestering carbon in soil and trees. The ERF Green Paper (DoE 2013) suggests offset providers tender to supply the lowest cost per tonne abatement in a type of reverse auction process. While the institutional and funding arrangements around this are unclear at this stage, it is unlikely that domestic offset prices would significantly exceed international prices.

Internationally, the price of carbon offsets has been volatile because of fluctuating demand and over-supply of permits for carbon offsets and emissions. The European Union carbon trading scheme is currently the world's largest and most liquid market with European emission units trading near historic low prices (Figure 5.1).

Until new administrative structures are put in place, as noted above, additional uncertainty and risk surrounds future carbon offset prices in Australia.

6 Economic analysis

This analysis uses published data to provide comparative estimates of the carbon sequestration (expressed as tCO_2-e) and potential annual value of carbon offsets for a range of carbon farming activities (Table 6.1 and Table 6.2). To account for the uncertainties surrounding offset price, values are estimated for a range of tCO_2-e prices. For the sake of simplicity, only returns from the sale of carbon offsets are considered, so the value of any additional environmental, productivity or other benefits are not shown. The analysis assumes that methodologies will be developed and approved, although in reality it may be years before some methodologies are developed and there may be costs for project proponents wanting to develop and use project-specific methodologies.

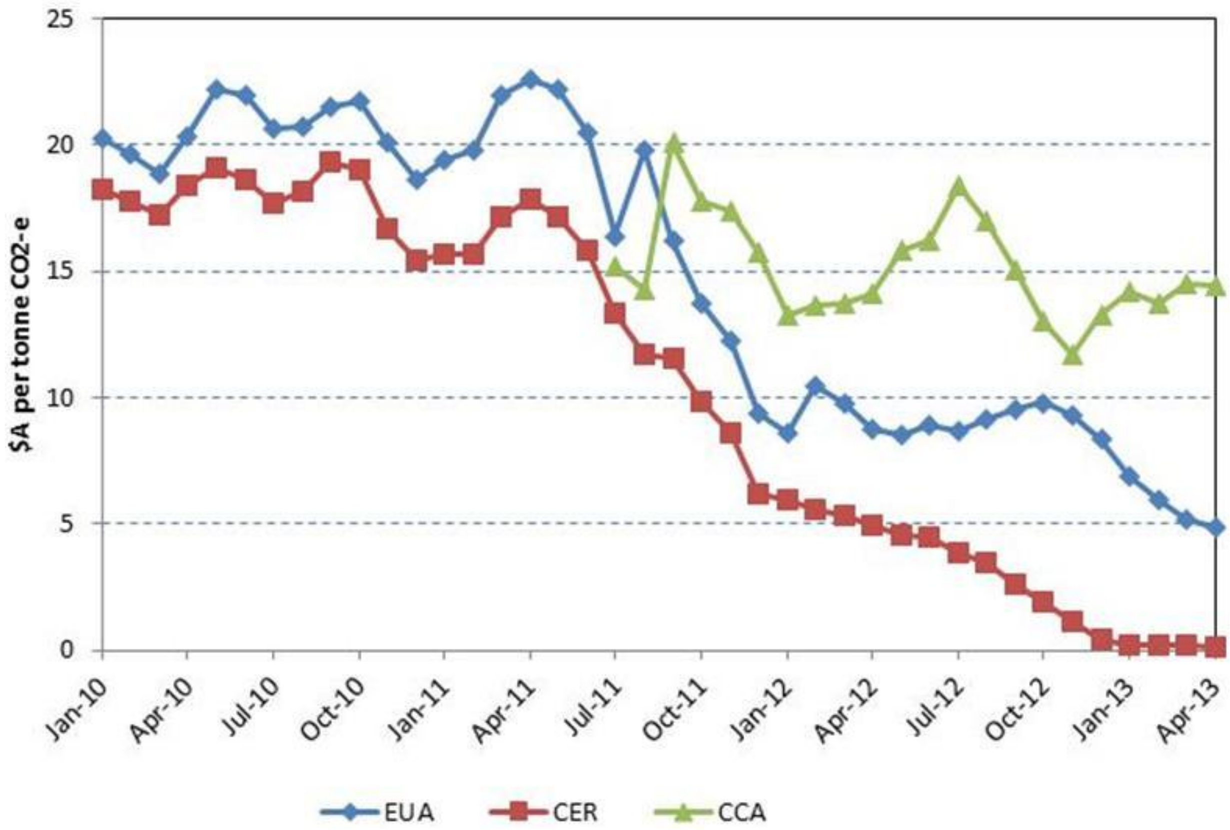

Figure 5.1 Price of European emission allowances (EUA), certified emission reduction units (CERs) and Californian carbon allowance (CCA), 2010–13. Source: Talberg and Swoboda (2013).

Gross margins (GM) (sometimes termed “operating surplus” where GM = cash inflow minus cash outflow) are often used to compare various agricultural activities on an annual basis. This is difficult in the case of carbon farming activities as project costs will vary by project type and size, and the level of annual costs and income may be inconsistent. Where there is a substantial establishment cost, it may be more appropriate to consider an investment or cost-benefit analysis to determine the profitability of an activity.

The costs associated with registering an offset project with the Australian regulator are unclear at this stage. The administration costs for the Greenhouse Friendly program (which ended in July 2010) are indicative: $300 for account set-up; $200 annual account fee; $500 listing fee; $150 to register new credits from existing project; $300 for project transfer/retirement; and $300 for issuance of a certificate document (Hamilton et al. 2009).

Table 6.1 Total sequestration (Seq.) and mean annual value of carbon offsets generated from sequestration activities over the period from establishment until storage equilibrium (Equil.) is reached ($/ha/yr). Offset values have been adjusted for withholding a 5% risk-of-reversal buffer from sale.

Activity	Estimated capital ($/ha) & maintenance costs ($/ha/yr)	Rainfall mm	Equil. yr	Seq. tCO_2-e/ha	Value of carbon offsets $/ha/yr				
					$10 /$tCO_2$-e	$15 /$tCO_2$-e	$25 /$tCO_2$-e	$35 /$tCO_2$-e	$45 /$tCO_2$-e
Reforestation – mixed species[1]	400–1000 establishment by direct seeding, 2000 seedling establishment	300 450	30	56–209 85–425	18–66 27–134	27–99 40–202	44–65 67–336	62–232 94–471	80–298 121–606
Reforestation – single species[2,3]	1250 establishment 25 maintenance	<350	41	566	131	197	328	459	590
Reforestation – single species [2,3]	1250 establishment $25 maintenance	>550	41	894	207	311	518	725	932
Reforestation – mixed species[2,3]	2000 establishment 25 maintenance	<350	41	348	81	121	202	282	363
Reforestation – mixed species[2,3]	2000 establishment 25 maintenance	>550	41	787	183	274	456	638	821
Increased soil C[4,5]	Cost of pasture establishment and management part of livestock system	Medium–high	40						
(1) Move from cropping to perennial pasture				(1) 22	5	8	13	18	24
(2) Move from continuous to ley cropping				(2) 37	9	13	21	30	30
(3) Move from ley cropping to perennial pasture.				(3) 120	28	42	70	97	125

(continued)

Table 6.1 continued

Activity	Estimated capital ($/ha) & maintenance costs ($/ha/yr)	Rainfall mm	Equil. yr	Seq. tCO_2-e/ha	Value of carbon offsets $/ha/yr				
					$10 /$tCO_2$-e	$15 /$tCO_2$-e	$25 /$tCO_2$-e	$35 /$tCO_2$-e	$45 /$tCO_2$-e
Increased soil C[6]	Cost of compost offset by reduced fertiliser costs and increased productivity		7	4	6	9	15	21	27
Addition of compost at 30 & 60m^3/ha				7	10	15	24	34	43
Restoration of rangelands[7,8]	Opportunity cost of destocking		30	0–56					
				3	1	1	2	3	4
	Management/fencing cost of intensification			15	5	7	12	17	21
				30	9	14	24	33	43
Savanna fire management and reduced stocking[9,10]	$0.44/ha/yr foregone income from destocking by 50%, $0.06/ha/yr fire management	>1000	50	26	5	7	12	17	22

Alb. = Albany; Esp. = Esperance.

Note: values for compost are over seven years as it is unclear when equilibrium is reached. Values for rangeland restoration are based on modelled estimates of sequestration which were highly variable according to location and landform.

Sources: [1] FullCAM modelling; [2] Polglase et al. (2008); [3] Crossman et al. (2011); [4] Carson (2012); [5] Soilquality.org.au (2012); [6] Paulin & O'Malley (2008); [7] Harper et al. (2007); [8] Alchin et al. (2010); [9] Douglass et al. (2011); [10] Richards et al. (2011).

Table 6.2 Mean annual value of carbon offsets generated from emission avoidance activities.

Activity	Estimated capital and operating costs	Avoided emissions tCO_2-e/yr	Value of carbon offsets $/yr $10 /$tCO_2$-e	$15 /$tCO_2$-e	$25 /$tCO_2$-e	$35 /$tCO_2$-e	$45 /$tCO_2$-e
Agricultural soils (reduced N_2O emissions, assume 10% reduction in emissions) [1,2]	Cost of urease inhibitors, nitrification inhibitors and modified crop agronomy	0.006/ha (dryland crops) 0.133/ha (irrigated crops)	0.7 1.2	0.1 2	0.2 3	0.2 5	0.3 6
Manure management (biogas from waste pond, DAFWA Medina) [3,4]	$191 000 (pond construction) variable operating costs	270 per pond	2700	4050	6750	9450	12 150
Enteric fermentation (reduced CH_4 emissions) [5,6]	variable costs of feed additives, pasture management, special breeding and genetic modification	Genetics: 0.53 per cow 0.019 per sheep Feed additives: 0.41 per cow 0.002 per sheep Improved pastures: 0.46 per cow 0.037 per sheep	 5 0.2 4 0 5 0.7	 8 0.3 6 0 7 1	 13 0.5 10 0 12 1	 19 0.7 14 0 16 1	 24 0.9 18 0 21 2
Savanna fire management (>1000mm rainfall) [7,8,9,10]	$12.8/$tCO_2$-e/yr operational and administrative costs ($0.5/ha)	0.04/ha (average over entire project area)	0.4	0.6	1.0	1.4	1.8

Sources: [1] Barton et al. (2008); [2] Barton et al. (2011); [3] Payne (2009); [4] Heubeck & Craggs (2010); [5] Alcock & Hegarty (2011); [6] Waghorn et al. (2002); [7] Heckbert et al. (2012); [8] Russell-Smith et al. (2007); [9] Heckbert et al. (2011); [10] Heckbert et al. (2011).

Similar costs are charged by international registries, such as the American Carbon Registry Standard, Gold Standard and Climate Action Reserve (Hamilton et al. 2009). Table 6.3 provides some additional estimates of carbon farming participation costs.

As some of the costs associated with project registration and set-up are "fixed", it makes financial sense to aggregate projects to share costs. The high cost of physically measuring carbon stores or emissions also makes it likely that methodologies will use modelling approaches, rather than direct measurement, where possible.

Table 6.3 Carbon market participation costs.

Project type	Establishment	Annual	Audit	Brokerage $/tCO_2$-e
General[1]	$1500–50 000/project			1–2
Cattle[2] (500 head)	$6500/project	$2500/ project	$2500/ project	
Revegetation[3]	$100/ha		$10/ha	1

Sources: [1] Mark Canney (Northern Agricultural Catchment Council, pers. comm., 2012); [2] AFI (2011); [3] Paul et al. (2013a).

Information is available for some activities relating to the capital cost ("sunk cost") of establishing the activity and ongoing operating costs. Available costs are indicated in Table 6.1 and Table 6.2. These capital costs need to be considered when determining the return or profitability of investing in various activities.

6.1 Risk

Since carbon farming projects will not be risk free, the risk/return trade-off will be critical in determining at what rate of return carbon farming projects will hold appeal for investors. Before commencing a carbon farming project, independent financial and legal advice about the particular circumstances of the project should be sought. Some of the critical risk factors to be considered include;

- sequestration and mitigation rates
- offset price trajectory
- cost of sequestration
- permanence in the case of sequestration projects
- additionality
- lack of experience and knowledge of carbon farming.

While the concept of additionality does not represent a risk for ongoing projects, it is a risk to methodology developers or those planning to use a particular methodology in future. If an activity is widely adopted and deemed to become "common practice", then that activity and related methodologies will no longer be eligible to generate offsets.

For those undertaking sequestration projects, it is essential to understand the issues and risks associated with the concept of permanence (see Section 3.2). These include:

- sequestering carbon for 25 or 100 years
  - effect of natural events such as drought, fire and disease
  - effect of predicted climate change
- maintaining sequestration rates for extended periods
  - effect of predicted climate change
- opportunity cost of permanent land-use change
  - effect of technology and market changes
  - effect on capital gains
- offset income only generated for 30–50 years until equilibrium reached
- permanence obligation rests with landowner if sequestration company is wound up.

For landowners wanting to participate in carbon farming, engaging third-party managers to provide knowledge, business acumen and managerial capacity, and the ability to pool projects and capital investment could reduce risk.

6.2 Carbon farming project activities

6.2.1 Reforestation

The sequestration rates shown in Table 6.1 are for afforestation and reforestation activities on arable land. Returns have to be comparable with agriculture for these activities to be financially attractive to landowners. With annual operational costs at \$25/ha, administrative costs at \$5/ha and offset prices ≥\$15/tCO_2-e, the annual GMs for single species plantings would be similar or better than from agriculture over the first 40 years of the project. But for the 60–70 years after storage equilibrium has been reached, there would be no offset income while annual operational costs continue. Annual administrative costs would cease unless something happened to alter the amount of stored carbon, in which case the change would have to be estimated, reported and rectified.

The ERF Green Paper (DoE 2013) suggests that sequestration project proponents could opt to sequester carbon for 25 years. This would eliminate the problem of maintaining sequestered carbon after equilibrium is reached but the Green Paper also suggest that the number of offset issued would be discounted to reflect the shorter sequestration period. Until the detail around this is developed it is not clear how this would affect the economics of a shorter sequestration project.

While the opportunity cost of reforesting or revegetating marginal land is low, the sequestration rates would be similar to the lower rates for mixed plantings shown in Table 6.1. Consequently, careful consideration is required to ensure that offset income would exceed project costs.

The costs of estimating sequestration rates will be critical to the economic viability of this type of project. The lowest costs will be achieved using a modelling approach such as that taken with the approved “Environmental Plantings” methodology. A field measurement approach has been approved and may provide measurements that are more accurate but will cost more.

Tree establishment costs ($1250–2000/ha), lack of income and ongoing costs after equilibrium, and other risks associated with permanence all have to be considered in determining whether permanent sequestration plantings present an attractive investment proposition.

It may be that many of the permanence risks associated with reforestation are reduced if the trees are regularly harvested. In this scenario, offset income is still available (though reduced to account for biomass removal) but income from tree products will continue for the entire 100-year life of the project. Regular harvesting also means that improved tree selections or even different species can be planted over the life of the project in response to technology, climate and market changes. Offset income has the potential to make plantation forestry on cleared agricultural land in WA (which is currently economically unviable) viable at offset prices >$10/tCO_2$-e in the case of hardwood pulp production and >$30/tCO_2$-e in the case of softwood sawlogs (Paul et al. 2013).

6.2.2 Soil carbon

Given comparatively low sequestration rates for soil carbon projects, the development of cost-effective verification methods will be critical. The spatial variability associated with SOC means activities will have to be highly targeted in the landscape. The returns from generating offsets (Table 6.1) are unlikely to exceed administrative costs at $5/tCO_2$-e, regardless of sequestration rate. Though returns may exceed project administration costs at higher offset prices and sequestration rates, they may not be sufficient to compensate for any opportunity costs entailed in moving from cropping to livestock-based activities (Kragt et al. 2012).

The sequestration rates used in Table 6.1 were achieved by changing from annual to perennial pastures, moving from continuous to ley cropping or using compost in a horticultural system (Table 4.5). In these examples, it was assumed that the changes were made to improve enterprise productivity and there was no direct cost associated with increasing carbon storage (except the costs associated with registering and administering the project). If there were a direct cost incurred by increasing the stored carbon, for example, increased fertiliser costs (e.g. Lam et al. 2013), the cost of adding manures or biomass sourced offsite, or foregone cropping income, then returns would only exceed costs at higher offset prices and sequestration rates.

It should be noted that the international experience is that uncertainties around measuring and maintaining SOC can result in more than 5% of the carbon sequestered having to be held as an unsold “risk-of-reversal buffer” (Actionaid 2011, Hug and Ahammad 2011). This could make carbon farming of SOC financially unviable except at very high offset prices and sequestration rates.

While income from agricultural activities would continue after storage equilibrium is reached and offset income ceases, sequestering soil carbon still suffers the permanence risks of having to maintain the store in the face of climate variability and climate change and possibly limiting long-term flexibility in land use.

Estimating a GM for generating offsets by adding biochar to soil is highly speculative given current high costs for producing, supplying and applying biochar. These costs are likely to decrease if biochar is produced as a by-product of bioenergy production in future. Biochar will only be added to agricultural soils if it provides an agronomic benefit but this has yet to be consistently shown for WA.

6.2.3 Rangeland restoration

Sequestration potential is highly variable across landforms/vegetation associations; consequently, targeting activities to those areas with greatest sequestration potential will be critical. Generally low sequestration rates mean that returns from carbon offsets are likely to be less than $14/ha in the medium term (to 2020). All costs associated with rangeland restoration projects need to be very low. The fixed project administration costs need to be offset by income from a large project area (possible in the rangelands). This requires verification to be carried out using low-cost and extensive modelling or remote sensing. Direct operational costs, such as those associated with rotational grazing or destocking, also will have to be minimal.

Sequestration-based rangeland restoration suffers the same permanence risks that have been discussed previously. The attractiveness of investing in these activities will need to be carefully considered given the low expected returns in the short term.

6.2.4 Agricultural soils

Emissions of nitrous oxide from WA farming systems (particularly dryland systems) are generally low. In the case of dryland agriculture, it is unlikely that nitrification inhibitors would significantly reduce already low emission rates. Consequently, the potential to generate emission offsets for both irrigated and dryland farming systems is low and unlikely to exceed the additional costs of using fertilisers containing nitrification inhibitors and the costs of registering and maintaining an abatement project even at a tCO_2-e price of $45 (Table 6.2).

6.2.5 Manure management (anaerobic ponds)

Methodologies have been approved for this activity. The values in Table 6.2 are for a small 1400 standard pig unit with a 1500m^2 anaerobic waste pond at Medina (Payne 2009). If the CH_4 produced by this activity was used for heating and electricity rather than being flared, this could save an estimated $30 000 in heating costs while generating electricity could save $1200/year. If electricity and heat are generated, the project payback may start from the 10th year; if the CH_4 is flared, this project will never pay back the costs.

An assessment of anaerobic ponds and engineered digesters for variously sized piggeries, dairies and beef feedlots showed that using the capture of CH_4 to generate heat, electricity and renewable energy certificates could result in payback periods ranging from 3–14 years, with faster paybacks for larger installations (Hertle 2008).

Anaerobic ponds and engineered digesters can also overcome environmental problems associated with odour and nutrient loss offsite.

6.2.6 Savanna fire management

Table 6.1 and Table 6.2 suggest that offset income from savanna fire management for both emission abatement and sequestration projects (or combined) can exceed total project costs where offset prices are above \$13/tCO_2-e. The low offset returns on a per hectare basis need to be considered in light of the very large areas that would be included in this type of project and low returns (per hectare) of conventional livestock production on these rangelands. A savanna burning methodology has been approved and several landowner groups have undertaken savanna burning projects in other states. Strategic fire management as required under the savanna burning methodology can reduce the incidence and extent of late dry season fires, and so, protect built infrastructure and dry forage.

6.2.7 Reduced emissions from not burning crop residue

This has not been assessed as the wide adoption of conservation practices has largely reduced stubble burning to a strategic practice to manage weeds and disease. Therefore, this activity is unlikely to meet additionality criteria.

6.2.8 Livestock emission enteric fermentation

Methane emissions from livestock can be reduced by applying four different techniques: dietary additives, alternate pasture species, removing unproductive animals, and genetic traits. These same techniques are already common practice in the livestock industry to increase livestock productivity and resilience. To pass the additionality test practices to reduce CH_4 emissions from livestock will need to demonstrate that they are not already common practice.

Generally, CH_4 emissions from livestock vary by animal type, weight and breed. For simplicity, we chose to compare cattle and sheep on a per head basis as the carrying capacity of grazing systems are variable, which makes per hectare comparisons unfeasible. It should be noted that while all four techniques could be applied simultaneously it is not clear if the emission reductions would be cumulative. The removal of unproductive animals or age classes through methods such as mating ewe lambs was not examined due to dependency on the condition score of the flock.

Methane represents lost energy from digestion. Reducing CH_4 emissions from livestock can increase feeding efficiency and enable producers to increase stocking, which would increase overall farm emissions. Consequently, these techniques might facilitate a reduction in the emissions intensity of livestock production but not in total emissions. At low carbon prices, the increased income from increased stocking will outweigh any benefit from carbon farming.

7 Conclusions

Given likely medium-term carbon prices, offset income alone will not be enough to make most carbon farming projects economically viable. Consequently, carbon farming activities will have to return multiple economic and environmental co-benefits to be attractive to land managers.

Carbon farming activities fall into two categories: those sequestering atmospheric carbon and those abating GHG emissions. Activities such as increasing SOC or savanna fire management involve modifying existing land management practices and may be largely driven by associated productivity or other environmental benefits. Other activities, such as managing effluent ponds, involve adopting new technologies, and still others, such as revegetation or reforestation, involve changing land use.

Considerable uncertainties surround carbon farming activities. Methodologies are yet to be developed for most activities and offset prices linked to international markets are volatile and at historical lows. It is not clear how the institutional and pricing arrangements will operate after the Commonwealth government moves carbon farming from a market-driven carbon pricing mechanism to a government-funded reverse auction system. Mitigation rates are highly variable and achieving acceptable rates will depend on a thorough understanding of the productive capacity of various biological systems at a paddock scale combined with careful project planning and management. Additionality and leakage criteria will have to be met and the permanence obligations of sequestration projects present new and unique risks to land managers. It is also necessary to obtain the appropriate approvals under WA law, particularly for projects on Crown land or savanna burning activities on any type of land tenure.

As most carbon farming activities are likely to be undertaken to realise multiple benefits, it is useful to know if it is worth registering a project to generate offsets. Given likely medium-term offset prices (<$20 to 2020), carbon farming activities fall into three broad groups based on the likelihood of annual offset returns exceeding annual project administration costs (recording keeping, validation and brokerage):

1. Activities where offsets are less than project administrative costs (e.g. reduced N_2O emissions from agricultural soils).
2. Activities where offsets are greater than project administrative costs only at higher mitigation rates (e.g. increasing SOC, rangelands restoration, managing livestock emissions and savanna fire management).
3. Activities where offsets are greater than project administrative costs at most mitigation rates and offset prices (e.g. revegetation and reforestation, covered anaerobic ponds).

If undertaking a carbon farming activity entails additional operational or input costs that are not recovered through productivity improvements — or if there is an opportunity cost involved in modifying or changing the existing land use or management — then it is likely that activities listed in point 2 above would have negative gross margins, except at the highest sequestration rates and offset prices.

Finally, the trade-off between risk and return for these activities needs to be considered before investment. This involves consideration of capital costs (particularly for reforestation and covered anaerobic ponds which have high establishment costs) and, in the case of reforestation, revegetation and SOC, issues pertaining to permanence and land-use change.

Shortened forms

Form	Meaning
ACCU	Australian carbon credit unit
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
BOM	Bureau of Meteorology
C	carbon
CER	certified emission reduction unit
C3	plants with a C3 pathway for carbon fixation in photosynthesis
C4	plants with a C4 pathway for carbon fixation in photosynthesis
CFI	Carbon Farming Initiative
CH_4	methane
CP1	First Kyoto commitment period
CP2	Second Kyoto commitment period
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent value
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CT	condensed tannins
DAFF	Department of Agriculture, Fisheries and Forestry
DAFWA	Department of Agriculture and Food, Western Australia
DER	Department of Environment Regulation
DCCEE	Department of Climate Change and Energy Efficiency (now Department of Environment)
DRDL	Department of Regional Development and Lands (now Government of Western Australia Department of Lands)
DoE	Department of Environment
EDS	early dry season
EF	emission factor
ERF	Emission Reduction Fund
ETS	emission trading scheme
EUA	European Union emission allowance
FPC	Forest Products Commission
GHG	greenhouse gas
GM	gross margin

continued

Shortened forms continued

Form	Meaning
Gt	gigatonne (t x 10^9)
GWP	global warming potential
ha	hectare (10 000 square metres)
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
LAA	*Land Administration Act 1997*
LUC	land-use change
LDS	late dry season
LULUCF	land use, land-use change and forestry
m	metre
N	nitrogen
NGI	Australian National GHG Inventory
NH4	ammonium
N_2O	nitrous oxide
NO_2	nitrite
NO_3	nitrate
NRM	natural resource management
ppm	parts per million
QELRO	quantified emission limitations or reduction objectives
REC	renewable energy certificate
ROE	recognised offset entity
SOC	soil organic carbon
t	tonne
tCO_2-e	tonnes of carbon dioxide equivalent value
UCL	unallocated Crown land
UNFCCC	United Nations Framework Convention on Climate Change
WA	Western Australia
WALFA	West Arnhem Land Fire Abatement
yr	year/s

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