Current status and future prospects for carbon forestry in Australia

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Summary

Carbon forestry is part of a suite of land-based activities that can be used to mitigate carbon emissions, and also provide a range of other environmental co-benefits. Components are included in the *Carbon Credits (Carbon Farming Initiative) Act 2011*. There is large divergence in Australian estimates of the areas of land that may be used for carbon forests and there has been a vigorous public debate about carbon forestry, partly based on concerns about displacement of food-producing land. We identify four distinct afforestation or reforestation (AR) activities that involve carbon mitigation and suggest a terminology based on these. These are (1) 'plantations' that also produce timber and wood products, (2) 'carbon-focused' sinks, (3) 'environmental' or natural resource management plantings and (4) 'bioenergy' plantings for use either as a feedstock for stationary energy production or transport fuels. After accounting for AR projects established for other purposes (e.g. timber and pulpwood), we estimate that the current area of carbon forests in Australia is 65 000 ha. Despite the national *Renewable Energy (Electricity) Act 2000* and its 2010 amendments there are few extant biomass projects. However this may change with the development of new technologies and the imposition of a carbon price on electricity production. The reasons for the gulf between actual and potential carbon AR activity are proposed to include (1) the absence of a formal carbon compliance scheme, (2) challenges in managing carbon through an entire product cycle, (3) the degree of understanding of carbon forestry by financiers, (4) landholder preference, (5) technical barriers and (6) regulatory uncertainty. We suggest an extension of the National Plantation Inventory from traditional plantations to carbon forestry, so that future policy can be developed on the basis of good-quality underpinning information that can be disaggregated to analyse trends in AR for different purposes. To encourage innovation in the sector, we also suggest either the extension or establishment of research and development funding arrangements, similar to those already existing for other rural industries.

Keywords: carbon sequestration; bioenergy; farm forestry

Introduction

It is well recognised that the land-based sector of our economy has a role in mitigating the carbon balance and thus future climate change (Kojima 1994; Schlamadinger and Karjalainen 2000). The basic concept is that a change in land-use results in a store of carbon greater than previously held ('carbon sequestration'), and this can include a range of activities across agriculture and forestry. Forests have four major roles in carbon mitigation (Canadell and Raupach 2008) and these were incorporated into the arrangements for those countries with emission reduction targets in the Kyoto Protocol (UNFCCC 1997) in the following ways:

1. The establishment of new forests on previously cleared farmland to store carbon. These forests can be for carbon sequestration alone, or developed to also produce timber, enhance or rebuild biodiversity, or manage landscape hydrology. These are activities that fall within the definitions of afforestation or reforestation (AR) within Article 3.3 of the Protocol, and involve the establishment of new forests on land that was cleared on 31 December 1989 (Schlamadinger and Karjalainen 2000). Afforestation is the establishment of forests on land that has not been forested for at least 50 years, whereas reforestation is the establishment of forests on land that was previously forested and subsequently converted to non-forested land (UNFCCC 2002). In Australia, both classes of activity are likely to occur—that is, activity on both previously forested and non-forested land, and on land that was forested more than 50 years previously.
2. The avoidance of deforestation, which is the removal of forests and conversion to farmland ('avoided deforestation'). This falls within Articles 3.3 and 3.7 of the Kyoto Protocol, as it applies to Annex B countries.
3. The management of existing forests and plantations in such a way as to increase the net storage of carbon ('forest management'). This can be through silvicultural interventions such as rotation length, fertilisation or fire management and falls within Article 3.4 of the Kyoto Protocol (Sampson and Scholes 2000).
4. The use of forest materials to substitute for fossil fuels ('bioenergy'). This is accounted for in Kyoto Protocol targets when fossil fuel emissions are reduced. Wood also represents a long-term carbon store and the use of this material instead of other building materials (e.g. cement or steel) can reduce the net emissions associated with construction (e.g. Gustavsson *et al.* 2006).

Other processes, including voluntary market arrangements, can use alternative accounting approaches and baseline dates to those used in the Kyoto Protocol, but Australian emission reduction schemes have generally aimed to be 'Kyoto compliant'. Much of the interest in investing in carbon mitigation in Australia has revolved around the first option, with AR included in schemes such as the New South Wales Greenhouse Gas Reduction Scheme (GGAS), the Australian Government's Greenhouse Friendly voluntary program and prototype state-based (National Emissions Trading Taskforce 2006) and national schemes (Australian Government 2008a, 2010b). Whilst Australia will meet its Kyoto Protocol targets of 108% of 1990s emissions by including the reduction in emissions from land-clearing in the period 1990 to 2008–2012, this reduction has been reported only at national levels and is not based on financial transfers to individual landowners or any form of cap and trade arrangement between land-owners.

For a range of reasons, the other two options, forest management and bioenergy, have generally not been adopted. Forest management was not included as an activity for Australia's targets for the first Commitment Period of the Kyoto Protocol because of difficulties in establishing a baseline estimate and potentially large emissions in any particular commitment period from fire and drought (Australian Government 2008b).

There has been sporadic interest in developing bioenergy as an option for power generation, particularly with the passage of the Australian *Renewable Energy (Electricity) Act 2000*, and its 2010 amendments. Despite this, the current contribution of forestry to bioenergy activities is modest, with the burning of wood waste in 2005 contributing 8.5 MW of installed capacity out of a total contribution from biomass of 646 MW (Schuck 2006); biomass energy production is dominated by bagasse. In contrast, the total capacity of Australia's electricity grid is around 50 GW (ESAA 2010). Nonetheless, we have included this activity as a type of carbon forestry in Table 1, as this sector may develop in the future if second-generation technologies for converting biomass to liquids are resolved and become commercially viable (Chum *et al.* 2011). Biomass in the future may contribute as a feedstock not only to electricity production but also transport fuels (Warden and Haritos 2008).

Consequently, this paper concentrates on the first option, AR. There have been some large and quite divergent estimates of the role that carbon forestry will play in Australia's and indeed global climate change mitigation strategies. This has played out in the public debate with concerns that carbon forestry will displace food production, echoing previous concerns about the impact of plantation expansion on water supplies (O'Loughlin and Nambiar 2001; Zhang *et al.* 2001). These debates can be contrasted with the very real prospects that carbon farming could provide funding for land-repair in Australia at the scale needed, but unlikely to come from the public purse (Harper *et al.* 2007; Garnaut 2008).

The intention of this paper is to review the estimates of the potential of carbon forestry, provide a comparative analysis of the approaches used to develop these estimates and to assess the factors likely to limit their being achieved, particularly in the short term (next 10–20 years). These broad-scale studies of potential carbon forestry across Australia are compared with current investments in carbon forestry from formal public statements, such as audited annual reports. The preparation of this paper has been particularly challenging given the very rapid changes in market regulation and, more importantly, intended market regulation.

Debates about carbon forestry

While there has been an ongoing discussion about carbon forestry, several debates in the Australian Senate in relation to the taxation treatment of carbon sink AR are particularly illuminating, in terms of the issues raised. Although the debates were ostensibly about tax regulations, they were also entangled with broader issues of managed investment schemes (MIS) for plantation establishment on farmland and the recurrent issue of native forest management. In this broader sense, carbon plantings could include not only those established for carbon and left unharvested (which is the specific object of these amendments), but also managed plantings that also produce other products such as pulp or timber, such as those established under managed investment schemes.

These debates commenced with the *Tax Laws Amendment (2008 Measures No. 1) Bill 2008*. The Senate passed this bill, which allowed tax deductions for plantations established primarily for carbon sequestration, on 17 June 2008. Schedule 8 of the Act provides for tax deductibility specifically for non-harvest carbon sink plantings, in a similar manner to other managed forestry activities. This became Subdivision 40-J of the *Income Tax*

Table 1. A proposed terminology for several different types of carbon forestry

Activity	Detail
Plantations	Monetisation of carbon within the harvested plantation estate. Kyoto Article 3.3 compliant plantations, established after 31 December 1989
	Improving the economics of plantation establishment through: • monetising carbon storage • currently commercial species • non-commercial species (e.g. oil mallees) intended for harvest
Carbon-focused	Establishment of 'for purpose' carbon sink plantations
Environmental	Primarily planted for biodiversity, soil erosion, amenity or groundwater management (salinity). Often termed natural resource management (NRM) plantings
Bioenergy	Plantings established for the production of biomass that can be used for co-firing for electricity and heat production, transport fuels

Assessment Act 1997, and was related only to non-harvest carbon sink plantings, and not those used for other purposes, such as for wood production. In subsequent debate on this Bill on 24–26 June 2008 (Australian Senate 2008a) broader issues regarding the use of agricultural land for carbon sinks were raised.

As a result of this debate the Senate Standing Committee on Rural and Regional Affairs and Transport (SSCRRAT) undertook an enquiry into the implementation, operation and administration of the legislation underpinning 'Carbon Sink Forests' and any related matter (Senate Standing Committee on Rural and Regional Affairs and Transport 2008). While the Committee concluded that the tax deductions represented '… a valuable policy addition that will promote greenhouse gas reductions …' there were two dissenting reports. This was followed by debate on the *Tax Laws Amendment (2008 Measures No. 5) Bill 2008* on 1 December 2008, with Senators from across the political spectrum moving an amendment to remove the tax deductibility for carbon sinks from the Tax Laws (Australian Senate 2008b). This amendment was defeated and the bill passed with bipartisan support from the major parties.

The major concerns related to carbon forestry in the SSCRRAT report (Senate Standing Committee on Rural and Regional Affairs and Transport 2008) appear to revolve around several issues, these including (1) the perception that large areas of farmland could be converted into carbon sinks with subsequent impacts on food production and water availability, (2) ongoing debates about the utilisation of native forests and the maintenance of carbon stores in these, and (3) getting the best use from land, rather than permanently 'locking it up' in carbon sinks. The parliamentary debate has subsequently been mirrored with reports from various advocacy groups that canvass similar issues.

Estimates of the potential of carbon sequestration

Some of these concerns over carbon farming in the political arena have been related to the potential scale of AR that may take place if a carbon price is introduced and carbon forestry offsets are incorporated. Over the past decade there have been a variety of attempts to estimate the amount of land available for AR projects within the arrangements of the Kyoto Protocol. Although these have been summarised to some extent elsewhere (GHD Hassall 2010), it is useful to provide a short account here of the more significant assessments that have been undertaken.

Firstly, we define carbon forestry, and this encompasses a range of discrete activities that are summarised in Table 1. The Australian definition of forests is a minimum of 20% crown cover, with the potential to reach 2 m in height on a minimum area of 0.2 ha (Australian Government 2008c).

We have identified four distinct AR activities that result in carbon mitigation (Table 1) and consequently suggest a consolidated terminology based on these. These are (1) plantations that also produce timber and wood products (termed 'Plantations'), (2) projects specifically designed to sequester carbon ('Carbon-focused' plantings), (3) activities that aim to address a range of environmental problems including salinity, biodiversity decline or erosion control ('Environmental' plantings—Australian Government 2008c) and (4) plantings either for use as a feedstock for stationary energy production or transport fuels ('Bioenergy' plantings). Environmental plantings have also been termed NRM (natural resource management) or Landcare plantings (Shea *et al.* 1998). Other forestry activities that may also be used to mitigate carbon, such as forest management, are not included.

A summary of the studies undertaken to assess the potential of forestry as a mitigation strategy is presented in Table 2. Arguably, the most comprehensive of these was an Australia-wide assessment by Polglase *et al.* (2008) that used a series of biophysical layers, including those derived from the physiological growth model 3-PG, to develop estimates of existing productivity and carbon sequestration potential and then used an economic model to identify 'areas of opportunity', considered to be those areas where land use may change. It was estimated that at a carbon price of \$20 t CO_2-e^{-1} plantings for carbon alone could be profitable over 9 million ha and produce carbon sequestration equivalent to one-quarter of Australia's total emissions in 2005. This figure was subsequently used by Garnaut (2008, 2011) and by the Wentworth Group of Concerned Scientists (2009) to form policy recommendations for the contribution of land-based sinks to Australia's emission reduction effort. Other studies have developed carbon sequestration estimates of specific regions in a similar fashion, such as for Western Australia (Harper *et al.* 2003, 2007), Queensland (CSIRO 2009) and South Australia (Crossman *et al.* 2010), or for specific catchments (e.g. Harper *et al.* 2005).

Taking a different approach, ClimateWorks, a joint venture between Monash University's Sustainability Institute and the Myer Foundation, developed a marginal abatement cost-curve (ClimateWorks Australia 2010) using the method of McKinsey and Company (2008). This study described the suite of activities (1) reduced deforestation and regrowth clearing, (2) AR of marginal land with environmental forests and (3) strategic AR of non-marginal land with environmental forests, as the 'forestry sector'. This combination of activities at an average abatement cost of about \$21 t CO_2-e^{-1} was estimated to contribute 28% of the total 2020 lowest-cost emissions reduction opportunity for Australia, delivering emissions reductions of 70 Mt CO_2-e in 2020. Seventy percent of this opportunity is estimated to come from AR and most of the remainder from reduced deforestation.

ABARE's study by Lawson *et al.* (2008) and subsequent work (Burns *et al.* 2009) suggested that, under a \$20.88 price scenario, 3 047 000 ha of hardwood plantings and 2 740 000 ha of environmental plantings would be economically viable. Variations of this work were also provided in the context of the proposed Carbon Pollution Reduction Scheme (Calford *et al.* 2010). This scenario is broadly consistent with the 5% reduction in emissions by 2020 target that is current Australian Government policy. According to the study these plantings would occupy 1.4% of Australia's farmland, although this estimate includes both cropping and rangelands.

Garnaut (2008) estimated that there are 9 100 000 ha of land where returns would be over \$100 ha^{-1} more than from current land-use, water interception less than 150 mm y^{-1} and a permit price of \$20 t CO_2-e^{-1}. Most recently, Garnaut (2011) updated this assessment of the potential abatement from carbon forestry from 143 Mt CO_2-e to 750 Mt CO_2-e, essentially it appears on the basis of Eady *et al.* (2009). Unfortunately, the explanation for this revised estimate,

Table 2. Australian studies that have investigated carbon sequestration potential through various types of carbon forestry

Study	Study scope, boundaries and key inputs	Methodology	Estimates
Shea *et al.* (1998)	Western Australian study based on previous proposals for funding to the Australian Government. A series of case studies for the potential of carbon sequestration across plantation species (*Pinus pinaster*, *Eucalyptus globulus*), oil mallees, 'Landcare' species (Environmental Plantings) and grazing land management.	Broad assessment of potential for carbon sequestration by a range of species and growing systems based on existing knowledge of plantation species growth rates. Assumption of a 10-year establishment period and a 30-year project life. Also assumed a credit for carbon stored in wood products.	Carbon sequestration potential over 30-year period estimated in terms of annual rainfall zones: >600 mm: 0.6 Mha and 42.5 Mt CO_2-e 400–600 mm: 1.5 Mha and 91.5 Mt CO_2-e 250–400 mm: 1.0 Mha and 29.0 Mt CO_2-e
Kirschbaum (2000)	National. Reforestation, afforestation meeting Kyoto Article 3.3 requirements. One management case: Extension of existing plantation estates using currently commercial species. Carbon price not considered. Study intended to identify potential of Article 3.3 to meet Australia's Kyoto obligations.	Standing biomass calculated from Richardson equation for conifers (*P. radiata*) and eucalypts, with biomass expansion factors from National Greenhouse Gas Inventory. Study extrapolated from empirical establishment rates (25 000 ha y^{-1} to 100 000 ha y^{-1}). Area of suitable land based on previous studies.	Potentially suitable land: 18.4 Mha Area of land reforested: maximum of 1.75 Mha at establishment rates up to 100 000 ha y^{-1} from 1990 to 2012 to yield 0.6–7 Mt C y^{-1} during 2008–2012.
Burns *et al.* (2009)	Constrained to existing plantation regions: Green Triangle (Victoria, SA) and Tasmania all within National Plantation Inventory areas. Study intended to identify the area of land likely to become profitable for commercial plantations with a carbon price. Management cases as described: • plantation • farm forestry —both scenarios include harvesting. Carbon price: $5.45 t CO_2-e^{-1}	Agricultural returns based on ABARE[A] survey data. Forestry based on current commercial forestry returns. Potentially suitable land taken from literature estimates.	Potentially suitable land: 19 Mha Up to 633000 ha of forests established.
Harper *et al.* (2003, 2007)	Constrained to Western Australia. Study includes cropland and grazing land management. Reforestation and afforestation meeting Kyoto Article 3.3 requirements. Potentially suitable land defined simply as area of land meeting required criteria under Article 3.3. Examined: Carbon prices: $5, $10, $15, $25 and $50 t CO_2-e^{-1}, with and without land rental cost ($25–$400 ha^{-1}). Discount rate of 7% over 60 y. Three rainfall zones, three management treatments (varied species and harvest) in two rainfall zones and two management treatments (oil mallees and native forest).	Biophysical model (VAST[B]) used to determine spatial C-sequestration rates. Returns to agriculture estimated from discounted cash flow analysis for NPV[C] of profit at full equity. Farm profitability based on Bankwest benchmark survey. Forestry NPV calculated for a variety of cases; 'carbon only' returns included here.	Area of potentially suitable land: 11.7 Mha. Total sink capacity 2091 Mt CO_2-e^{-1}. Across the full range of scenarios, areas considered profitable for reforestation vary from 0 to 9.2 Mha. Carbon sinks profitable at $15 t CO_2-e^{-1}.

Table 2. Australian studies that have investigated carbon sequestration potential through various types of carbon forestry (continued)

Study	Study scope, boundaries and key inputs	Methodology	Estimates
Lawson *et al.* (2008) and Burns *et al.* (2009)	National, with results disaggregated by state. Carbon price: \$20.88 t CO_2-e^{-1} commencing 2010 (CPRS-5)[D] and \$45 t CO_2-e^{-1} (CPRS-15). Two management cases: • timber plantations (harvest) • environmental planting (no harvest)	Compares NPV returns of forestry investments to corresponding NPV of agriculture. Developed spatial modelling framework with data from ABARE farm surveys (to determine profitability), land use and vegetation cover from the Bureau of Rural Sciences and forest growth and sequestration data from Dept of Climate Change.	Area of potentially suitable land not identified. Under CPRS-5 carbon price, additional timber plantations of 3.05 Mha and 2.74 Mha of environmental planting by 2050. Under a CPRS-15 carbon price scenario, additional timber plantations of 4.514 Mha and 21.8 Mha of environmental plantings by 2050.
Polglase *et al.* (2008)	National. Single carbon price of \$20 t CO_2-e^{-1}. Ten agroforestry systems (management cases) grouped as sawlog systems, short-term rotations and carbon plantings. For carbon plantings two main management cases: • oil mallee • environmental plantings.	Biophysical model (3-PG)[E] used to produce spatial C-sequestration rates. Discounted cash flow analysis used to calculate NPV of profit at full equity for preceding land use compared with new (forestry) land use. Profitability from 2006 farm survey.	Identifies areas of opportunity. Total area of opportunity is 18.4 Mha For oil mallee with net annual economic returns >\$150 ha^{-1} A more constrained estimate with net annual economic return >\$150 ha^{-1}, water yield reduction <150 mm y^{-1} the area of opportunity is 9.1 Mha with total carbon sequestration of 142 t CO_2-e y^{-1}.
Garnaut (2008)	Identifies 'technical potential' for three cases: • removal by pre-1990 forests • removal by post-1990 forests • carbon farming (plantations)	Literature review. Appears to be significantly based on Polglase *et al.* (2008). Accounts only for those areas where returns would be >\$100 ha^{-1} y^{-1} greater than those for current land use.	Area of land: • 2 Mha of Kyoto compliant post-1990 forest (includes areas already established) • 9.1 Mha for carbon farming
Eady *et al.* (2009) (referred to by Garnaut (2011) as CSIRO (2009)	Confined to Queensland. Examines broad range of carbon sequestration opportunities. Of relevance to this paper: • change land use to carbon forestry • sequestration in post-1990 plantations Assumption is for a business-as-usual increase in plantation area with increases in plantation estate as uplift due to carbon price Carbon price: CPRS-5 and CPRS-15	Changed land-use scenario appears to follow method of Polglase *et al.* (2008). Sequestration is calculated from extant plantation establishment post-1990 with projected establishment based on meeting Australian Government 2020 plantation forestry target and with establishment up-lift due to carbon price.	Change land use to carbon forestry: • 17 Mha profitable area for carbon forestry Annual sequestration 152 M t CO_2-e^{-1} with a total of 6120 over 40 y. Post-1990 plantations; area: • 3 Mha by 2050 (business as usual, no carbon price) • 5 Mha by 2050 under CPRS-5 • 6 Mha under CPRS-15
ClimateWorks Australia (2010)	National in scope, assesses all abatement options across all sectors. 'Forestry' consists of several options. Consistent with afforestation/reforestation in this paper: • reforestation of marginal land with environmental forest • reforestation of non-marginal land with environmental forest. Defined as 'planting small tree stands/forests selectively on productive land to create wind breaks, shade and erosion protection on waterways.' Other forest management scenarios also assessed	Marginal abatement cost-curve. Note that the outputs of the study are amount of abatement at a given price. Areas of sequestration are modelled using the following assumptions: • For reforestation of marginal land case: planting is undertaken on 3.5 Mha of land (5 Mha by 2030). Planting occurs more rapidly from 2010–2020, at 350 000 ha y^{-1} and then at 150000 ha y^{-1} from 2020 to 2030. Technical emissions reduction potential. • For reforestation of non-marginal land: planting is on 2 Mha of land (5 Mha by 2030) at a constant rate of 200 000 ha y^{-1}	Land suitable—not assessed Total land area 5.5 Mha. Societal cost of carbon is \$26 and \$27 t CO_2-e^{-1} for 44.5 Mt CO_2-e y^{-1} sequestered in 2020.

Table 2. Australian studies that have investigated carbon sequestration potential through various types of carbon forestry (continued)

Study	Study scope, boundaries and key inputs	Methodology	Estimates
Crossman *et al.* (2010)	South Australia. Carbon prices: \$10, \$15, \$20, \$30, \$45 t CO_2-e^{-1}. Discount rate = 7% Management cases: • Tasmanian bluegum (*E. globulus*) • Eucalypt blend (*E. cladocalyx* and *E. camaldulensis*) • Oil mallee (*E. kochii*) • Mixed environmental. Study also included four agricultural commodity price scenarios: 50% of baseline, 'baseline' (pre 2008 average returns for each commodity), 150% of baseline, 200% of baseline.	C-sequestration calculated for each species using 3-PG. Agricultural productivity modelled using APSIM. Annual profit at Full Equity calculated for commodities: wheat, field peas, beef and sheep.	Area of suitable land not identified. Under 'baseline' agriculture, returns profitable for carbon areas were as follows: At \$20 t CO_2-e^{-1} • 1.4 Mha *E. globulus* • 7.9 Mha *E. kochii* (mallee) • 1.8 Mha Eucalypt blend • 5.1 Mha Mixed environmental At \$30 t CO_2-e^{-1} • 1.4 Mha *E. globulus* • 9.0 Mha *E. kochii* (mallee) • 3.1 Mha Eucalypt blend • 5.1 Mha Mixed environmental
Garnaut (2011)	National scope. Updates 2008 Garnaut report. Now follows CSIRO (Eady *et al.* 2009) nomenclature of: • Post-1990 plantations • Carbon forests.	Literature review—cites CSIRO (2009)	Area estimates not given. Post 1990 plantations: 400 M t CO_2-e^{-1} Carbon forestry: • Biodiversity
Polglase *et al.* (2011)	National. Multi-factorial scenario analysis. With parameters as follows: Carbon price: \$5, \$10, \$15, \$20, \$30, \$40, \$50 t CO_2-e^{-1} Establishment cost: \$1000, \$3000 ha^{-1} Carbon sequestration rate: as modelled and –30% Water cost: 0 or included at \$2000 ML^{-1} Discount rates: 1.5%, 5% and 10%	Used updated sequestration surface from 3-PG2. Water cost calculated from estimate interception rates based on Zhang curves[F] and cost calculated on assumed price. NPV of agriculture calculated from carbon sequestration and different economics treating land as an upfront capital cost.	Area of suitable land: 104 Mha. Within the 105 scenarios run, the profitable area for carbon forestry varies from 0 ha to all land identified as suitable being reforested/afforested.
DCCEE (2011)	Departmental report designed to indicate likely range of abatement attained and qualifying for the Carbon Farming Initiative.	Methodology not described, other than estimates are based on Lawson *et al.* (2008) and assumed 25% and 50% of their establishment rate.	Implied area of reforestation to 2020 is 133 600–267 200 ha. Establishment rates: 16 700 and 33 400 ha y^{-1} Annual abatement in 2020: 1–2 M t CO_2-e^{-1}

Notes to table:
[A]ABARE is the Australian Bureau of Agricultural and Resource Economics
[B]For VAST see Barrett (2002)
[C]NPV is net present value
[D]CPRS-5, CPRS-15 etc. are forward carbon price curves developed by Australian Treasury to meet specified future emission reductions targets as developed by Australian Treasury for the Australian Government for the Carbon Pollution Reductions Scheme. A summary is accessible at: www.treasury.gov.au/lowpollutionfuture/summary/downloads/Australias_Low_Pollution_Future_Summary.pdf
[F]For 3-PG and 3 PG-2, see Sands (2004) and Sands and Landsberg (2004)
[F]For Zhang curves see Zhang *et al.* (2001)

with a plethora of 'definitional issues', is not transparent; a much larger area of land available for 'conversion', or in some cases estimated revised rates of sequestration, contributing to the revised assessment.

It is difficult to compare the results from the different studies since there is relatively little comparability between definitions. For example, in some studies environmental plantings constitute largely those plantings that are not traditional hardwood or softwood plantings; whereas other studies distinguish between carbon plantations that are plantations intended for carbon sequestration purposes and other plantings established for other environmental purposes. This points to the need to produce a set of agreed Australian definitions for this emerging sector (Table 1).

The studies also use different models to estimate key biophysical parameters such as net photosynthesis (NPP) that are critical to forecasts of anticipated carbon density across the landscape. Even at this level there is considerable uncertainty or variation in model estimates, as seen in the study of Roxburgh *et al.* (2004) that compared the output of 12 commonly used models. The estimated productivity varied five-fold. In addition, there are large uncertainties about the future trajectory of climate change in many regions of Australia, and the impact of these changes on future forest growth is similarly uncertain.

Bottom-up estimates of carbon plantings established

'Top-down' studies of biosequestration potential (Table 2) do however consistently indicate that there is considerable scope for storing carbon in Australian landscapes. However, very little, if any, information or analysis appears to be published that assesses *in toto* the amount of land that has actually been used for carbon plantings to date. Although there is a national inventory of the conventional plantation estate (Parsons and Gavran 2010), this does not include carbon plantings as it was primarily intended to provide an assessment of national wood supply capacity, including from smaller-scale, farm forestry plantings, although assessment of the latter is intermittent. Moreover, many carbon plantings occur outside the geographic and activity areas covered by the National Plantation Inventory. For this reason we present the first estimates of carbon plantings that have been established to date. We suggest that future National Plantation Inventories include various types of carbon forestry, so that the emerging public policy debate can proceed on the basis of solid evidence. This may be relatively straightforward if there is a compliance scheme that includes carbon forestry, as there will be a register of eligible projects that have been used to generate carbon units.

In order to compile our estimates we reviewed a number of sources. These included the Carbon Off-Set Guide[1] to identify entities active in the market-place. We further assessed whether those entities were directly responsible for carbon planting establishment. Other entities were identified from web searches, public announcements and the authors' knowledge. One of the challenges in reviewing the available material is that much of it is forward-looking, often identifying planned establishment rather than documenting actual plantings.

Furthermore, we have been mindful of the risk of double-counting plantation establishment. Double-counting errors arise because some plantations have come under new management and thus appear twice in primary sources. In other cases plantings associated with government program such as the National Heritage Trust, Bushtender, Eco Tender (Victoria) and the EcoFund (Queensland) have either been established for reasons other than carbon sequestration, even though carbon benefits are sometimes claimed, or the same planting appears in the inventory of the contractor or entity that undertook the planting. For these reasons plantings from these programs were not included in our estimates, except where they appear as part of the inventory of the service providers. This avoids both double-counting and definitional issues.

In reviewing the available material it is apparent that announcements of carbon agreements by market participants are not necessarily reliable guides to actual plantation establishment since commercial arrangements commonly contain option or uplift clauses that are not necessarily exercised.

We have taken a conservative approach to environmental plantings by excluding from our estimates plantings likely to have been established primarily for ecological restoration purposes, even though voluntary donations towards greenhouse abatement may have been one revenue source for their development. As one example, the well-known Gondwanalink Project coordinated by Greening Australia[2] in Western Australia is estimated to have covered 4086 ha. This project includes remnant vegetation protection as well as new ecological plantings.

As a result we have relied heavily on entities' annual reports to shareholders, annual reports to subscribers, and commercial-in-confidence material that is required by law not to include material misstatements. We have also focused on those entities that are demonstrably undertaking carbon transactions.

The results shown in Table 3 provide an estimate of what might be thought of as Australia's current carbon estate—that is, plantings undertaken primarily or significantly for carbon sequestration. As such it does not include most of Australia's post-1990 plantation estate since this was planted primarily for forest products such as pulpwood or sawlogs (Plantation 2020 Vision Implementation Committee 1997), although this is contained in Australia's national carbon account (Australian Government 2010a), where it is estimated to represent annual abatement of 23 Mt CO_2-e y^{-1}. Included within Table 3 is a 7000 ha estate planted for the Tokyo Electric Power Company (TEPCO) and since acquired by the State of NSW and reincorporated into the NSW State Forests Estate. It also includes a maritime pine (*Pinus pinaster*) carbon estate established for BP Australia in Western Australia, starting in 1998. The TEPCO and BP projects were the first significant forestry carbon sequestration projects in Australia. In total this estimate is about 65 000 ha (out of the 9.1 million ha identified by Garnaut 2008).

This first estimate may be regarded as incomplete as records from organisations such as catchment management authorities are not easily accessible or interpretable. For example, the reports from

[1] www.carbonoffsetguide.com.au/ RMIT 2010

[2] www.gondwanalink.org

Table 3. Estimated area of carbon forestry plantings in Australia as at March 2011

	Number of entities	Type of entity	Planting type	Area (ha)
	3	For-profit company	Mallee	24413
	2	For-profit company	Biodiverse	5500
	2	Government business enterprises	Maritime pine/mallee/hardwood *Pinus radiata*	14600
	5	Not-for-profit	Biodiverse, mallee	8840
	2	Individuals	Mallee	11775
Total	**14**			**65128**

the NSW catchment management authorities suggest that a total of 17653 ha of environmental plantings have been established in that state but there does not appear to have been any attempt to include a monetised carbon benefit from these plantings. However, and despite the caveats outlined here, we consider it highly unlikely that extensive areas of carbon forestry are absent from this survey. Our assessment also reveals that the activity that has occurred has involved diverse participants. Moreover, many of the programs that led to the plantings listed within Table 3 have been discontinued or are associated with organisations that either no longer operate a carbon business or have been wound up.

Discussion

This bottom-up assessment of land planted primarily for the purpose of carbon storage reveals that, despite the large estimates of the potential for AR for carbon offsets, the amount of land in which land-use change has occurred is actually very modest. The data also suggest that carbon forestry has moved away from the higher-rainfall zones into the 300–600 mm rainfall zone, where it is not in direct competition for land with high-value agriculture. This appears to be complemented by some relatively small-scale plantings of generally less than 100 ha with intended high-biodiversity outcomes in higher-rainfall areas. Overall, there appears to be a gulf between perceptions of the significance of carbon plantings either already established or likely to be established and the empirical evidence associated with their establishment.

There are likely to be several reasons for this:

1. Absence of a compliance scheme

First is the absence of a compliance scheme to drive market demand. Australian policy-makers have been discussing the need for a carbon price, either through taxation or some form of emissions trading scheme for a number of years. The earliest public attempts by government in Australia to generate discussion about emissions trading occurred more than ten years ago (Australian Greenhouse Office 1999). Since then a variety of market-based schemes have been proposed both with the involvement of state governments (National Emissions Trading Taskforce 2006), the Australian Government's Carbon Pollution Reduction Scheme (Australian Government 2008a) and more recently the *Carbon Credits (Carbon Farming Initiative) Act 2011* (Australian Government 2010b, 2011) which received Royal Assent in September 2011.

Interestingly, the establishment of the NSW Greenhouse Gas Reduction Scheme in 2003 does not appear to have significantly accelerated plantation establishment. It is hard to disaggregate the rate of planting that would have occurred in the absence of a carbon mechanism, given the large annual variation in rates of plantation establishment (see for example Parsons and Gavran 2005, 2007, 2010). The most likely reason for this is that low credit (NGAC) prices were insufficient to stimulate the investment necessary for widespread plantation establishment.

2. Managing carbon through an entire product cycle

In terms of voluntary market activity, there appear to be several major challenges in bringing carbon sequestration through an entire product cycle. Few, if any, programs that sponsored plantings by individual landholders have been able to produce significant quantities of carbon units. The reasons for this are again several and varied, but include the lack of regulatory stability, greater complexity in carbon accounting than is often recognised and the need to provide marketable parcels to big emitters. Given the current state of development of the market there is insufficient scale to provide the industry intermediaries required for a market. In other words, with low volumes and regulatory uncertainty, market participants, particularly project proponents, are subject to very high transaction costs. If carbon volumes increase and regulatory arrangements stabilise, transaction costs are likely to reduce.

These problems are of course not insurmountable, as evidenced by the evolution of Australia's timber plantation industry. A key factor will be significant and coordinated research and development (R&D) to overcome the obstacles and develop new operational procedures, particularly as carbon forestry will occur in regions without an existing plantation estate and thus with growing conditions and soils different from those where plantation forestry has been traditionally practised.

In the past, state forestry departments have largely subsidised plantation forestry R&D activities. They have, however, now largely exited this role, this being part of a long-term decline in forestry-related R&D expenditure (Turner and Lambert 2011). It can be argued that the responsibility for coordinated research and development on factors such as species and site selection, genetic improvement, silviculture, protection and carbon stock assessment and modelling will now lie with the emerging carbon companies. Yet there are strong arguments for public investment in agriculture R&D because of the 'spill over' benefits accruing to the sector as a whole that cannot be constrained using IP arrangements. R&D will lead to innovation and more efficient methods of delivering carbon sequestration. However, it is necessary for regulators to enable those R&D investors wishing to achieve a return on their R&D investment to retain rather than socialise IP. For example, regulatory arrangements that require publication of data-sets or the compulsion to use publicly available methods for production models or carbon accounting approaches will create disincentives for the necessary investment in R&D and resultant innovation to generate productivity improvement. In simple terms, there is no incentive for an entity to invest the large sums necessary to develop carbon-related technologies, such as the prediction of likely rates of carbon sequestration, if these are not recognised in accounting systems or are turned over into the public domain.

This also points to the need to establish funding arrangements for ongoing research and development such as already exist for agricultural industries (e.g. Grains Research and Development Corporation) and the traditional forestry industry (e.g. Forest and Wood Products Australia). These corporations are funded through a mixture of grower or processor levies and Australian Government contributions, with a portfolio of projects developed following competitive calls and with industry consultation.

3. Understanding of carbon forestry by financiers and financial regulation

The major third barrier to achieving the scale of land-use change anticipated by the broad studies (Table 2) relates to the nature of a carbon forestry investment. In common with other types of plantation forestry, carbon sinks essentially require a large up-front capital investment with returns potentially being achieved over subsequent decades. Thus, in a commercial environment, carbon sink establishment has features often associated with large infrastructure developments. Within this model there is a regular revenue stream (annual, bi-annual to five-yearly) from the creation and monetisation or retirement of carbon units. Indeed carbon forests can be thought of as environmental infrastructure (Hull 2011). Arguably, this is a new asset class that is unfamiliar to financial markets and, in common with asset classes with similar attributes, long-run regulatory certainty is required for significant capital investment. It is noteworthy that despite Australia's plantation estate almost doubling in the last 20 years to 1.97 million ha (Parsons and Gavran 2010), most of this investment was within short-rotation (e.g. 10-year) pulpwood rather than 30–40-year rotation higher-value timber plantations. Carbon markets will involve the establishment of carbon-focused plantations for at least 70–100 years. Carbon income can commence earlier in the growth cycle, overcoming some of the problems from an investment perspective for long-rotation timber plantations because revenues do not commence until the first commercial thinning, thus providing relatively low internal rates of return (or low / negative net present values when normal commercial discount rates are applied). However, there are still significant issues with facilitating capital investment in carbon farming ventures that have a long-term income stream in an uncertain and potentially volatile future market.

Greater prudential and regulatory arrangements are also required to avoid the problems associated with MIS, in which forest-based investments were often driven by taxation benefits, underpinned by cheap debt, and not linked to the productive capacity or likely future income streams from harvest and sale of timber. These became financially unsustainable once the financial environment changed.

4. Landholder preference

Some landholders are simply not interested in AR, whatever the returns as illustrated by the expansion of short-rotation eucalypt plantations. Even in districts highly favoured by plantation developers, and despite returns in excess of existing farming practices, not all landholders leased or sold their land for plantation development. There are often strong cultural or social views about larger-scale tree planting replacing agricultural land uses and many farmers do not see forestry as being consistent with their current land uses (Schirmer and Bull 2011).

5. Technical barriers

Potentially the largest barriers to achieving large-scale sequestration, and a factor that is often overlooked, are technical. Although perceived to be straightforward, carbon forestry is complex, as outlined in Table 4. Importantly, each of the technical barriers identified has a tangible commercial consequence that if not adequately addressed increases project risk.

6. Regulatory uncertainty and complexity

In tandem with the lack of a market through the absence of a compliance scheme as already discussed, the experience to date also suggests that the modest amount of plantation establishment for the purpose of carbon sequestration is also a function of a dynamic regulatory environment. The history of regulation in relation to carbon forestry is in part a reflection of the wider debate that we have already outlined. The example of 'Greenhouse Friendly' which was closed in anticipation of a national emissions trading scheme (the Carbon Pollution Reduction Scheme) that did not eventuate is symptomatic of this uncertainty. Similarly, there was an expectation that projects established post-1990 and following Kyoto rules would be eligible to gain credits under the Carbon Farming Initiative (CFI). However, only sequestration occurring after 1 July 2010 is eligible to generate credits. Other aspects of the CFI, such as the practical requirements in relation to permanence, mean that early projects may not qualify.

The legislative, rather than programmatic, base of the CFI is intended to provide a more stable regulatory platform for carbon forestry. However, there is considerable complexity in the legal arrangements, particularly provisions around consent, consistency with regional NRM plans (which may take some time to develop), legal ownership rights and Native Title. In addition, the potential need for those selling credits from carbon forestry to hold financial services licences is likely to be a significant barrier to implementation of carbon farming projects at a larger scale. Requirements related to 'additionality', including artificial and non-evidence-based barriers relating to water and the exclusion of timber-production-related AR projects will also limit the capacity for synergistic and resilient projects that provide landowners or investors with alternative income sources as market arrangements change.

Table 4. Some of the technical risks that need to be addressed in order to create forest carbon units

Technical risk	Commercial impact
Growth forecasts	
Can forecast growth models be adequately calibrated for the species?	Total carbon yield (t CO_2-e ha^{-1})
Are there data sufficient to match landscape attributes with growth performance?	Yield variation
	Land cost ($ t CO_2-e^{-1})
Seed and genetics	
Seed supply: is sufficient seed available?	Viability of planting scale
	Seed cost
Once seed has been secured is there sufficient knowledge to adequately propagate seed?	Propagation (nursery) costs
Propagation success	Seedling cost
Propagation time	Seedling cost
Is anything known about genetic variation within the species?	Carbon yield risk
Establishment	
Are impediments to establishment known and understood?	Establishment cost ($ ha^{-1})
Are the relationships between planting density and growth understood?	Establishment cost
Anticipated establishment survival rates	Replant cost
Longevity	
Are there adequate data to provide confidence that once planted within landscapes the species will survive?	Delivery risk
Carbon inventory	
Can non-destructive measures be related to carbon stored?	Carbon yield
Can non-destructive measures be cost-effectively sampled with sufficient statistical confidence to meet requirements of customers and regulators?	Carbon yield

Prospects

A consistent theme in public debate over Australian forestry over the past several decades can be encapsulated in terms of the social licence to operate. In the context of carbon forestry this issue is expressed through a current debate that broadly argues that carbon forestry in some way threatens or is competing with other forms of primary production. Part of the intention of this paper is to provide data to assess the observable impact of carbon forestry in Australia to date.

Much of the public rhetoric is suggesting that carbon sink forestry, or other forms of plantation forestry, pose a risk to 'prime' agricultural land. We argue that this is not supported by the available evidence. The scientific literature suggests the reverse: carbon sink forestry has the potential to complement if not enhance environmental risks that if left unaddressed would result in a decline in agricultural productivity (Stirzaker *et al.* 2002; Harper *et al.* 2007). For example, carbon mitigation investment may help restore water quality in degraded catchments (Townsend *et al.* 2012) in areas where reforestation is not currently economic by itself. Similarly, there may be prospects for carbon mitigation on abandoned agricultural land (Sochacki *et al.* 2012), although the long-term sustainability of such AR has to be considered (Stolte *et al.* 1997; Archibald *et al.* 2006).

Concern over the relationship between carbon sink development and the use of 'prime' agricultural land may be, at least in part, a function of the nature of the studies into the potential for carbon emissions mitigation through AR. Earlier studies often focused on looking at the implications of carbon in regions where forestry already occurs (Kirschbaum 2000). While this may not be an unreasonable starting point for analysis, given that it built on Australia's experience up to that time, the evidence based on empirical observation of what has actually happened presents a different story. Many public debates are often intertwined with long and often bitter histories, and cannot be taken on face value (Dargavel 1995). For example, the debates about plantations on farmland have a genesis in the conversion of native forests to *Pinus* plantations in the 1950s onwards, and the debates about bioenergy from wood are connected to the debates about native forest utilisation.

The public discussion about carbon sinks can reflect problems with logic. At the outset of the discussion one of the key science questions being addressed was: 'Is Australia's land-base sufficiently extensive to make a 'meaningful' or significant contribution to national abatement?' The fact that most assessments suggest that there is potential for such abatement has been used to imply that it is inevitable that conversion will occur.

Economics suggest that if there is an increase in demand for land then the price will increase, whereas the studies often make an assumption that land prices will be invariant with demand. The dynamics of land pricing and cost are much more complex than this. At a macro-scale, Garnaut (2011) points out that over the coming decade, concurrent with the introduction and development of carbon pricing, there is expected to be strong demand across all soft commodities. The study also draws attention to recent changes in Australian farmers' terms of trade, which is argued to be a reflective of significant global economic changes. Such trends should not be ignored. Crossman *et al.* (2010) commenced the process of investigating the potentially complex dynamics between agricultural commodity prices and carbon prices, showing that substantial increases in commodity prices can significantly affect the relative profitability of carbon farming and traditional agriculture.

From a regional perspective, experience with MIS showed that in regions where plantation establishment was significant, local demand for land did increase with a commensurate effect on land prices. This had benefits for those in marginal agricultural enterprises who were able to exit their business on good financial terms, as well as for those remaining in agriculture with increased equity in their business and greater capacity to borrow for further development.

Carbon plantings are not constrained to areas where infrastructure such as suitable roads and ports is available or there is access to processing facilities, so this pressure may not emerge in a similar manner and therefore planting activities may also be more dispersed. It is also possible that other demands, such as land required for coal seam gas developments or other large-scale extractive industries and the location of other energy infrastructure (such as wind farms) may have a larger influence in particular regions. The recent study by Polglase *et al.* (2011), when contrasted to the authors' previous work (Polglase *et al.* 2008), shows that results are sensitive to assumptions in relation to not only land price, but also to how the cost of land is treated within the project context. Full up-front payment of the capital cost of the land will constrain establishment and there are challenges in reaching the very long-term lease agreements required to secure carbon plantings. An interesting approach was used in the Collie (WA) catchment AR programme in the 1980s. Here it was considered that partial AR would reverse salinity; reforested areas were subdivided and placed on a separate title.

Similarly, the cost of establishing carbon plantations is unlikely to be invariant with scale. If carbon sink forestry were to compete with other forms of agricultural production, the expected increased demand for agricultural commodities—due to global population growth and industrialisation in developing countries—over the coming decades would suggest that the dynamics between potential land-uses will change and will be other than forecast.

Conclusions

Taken together the studies that assess the potential of carbon sequestration in the Australian landscape suggest that carbon management offers an opportunity to assist in national greenhouse gas abatement objectives. The carbon forestry that has been undertaken to date has been undertaken by a wide variety of organisations that include government business enterprises, not-for-profit non-government organisations, publicly listed companies, privately held companies and individuals.

However, bottom-up analysis provides evidence suggesting that the realisation of this potential will be more challenging than is currently perceived. Suggestions that the introduction of carbon forestry will lead in the short or even medium term to significant competition for prime agricultural land, or that carbon forestry will rapidly increase to fulfil the immediate potential suggested by top-down studies, are not supported by the available empirical evidence.

Many see climate policy and carbon trading as providing for forest protection or conservation, or funds for sustainable management. However, a more multi-functional view is required if there is to be widespread acceptance of the different forms of carbon forestry in rural landscapes and if we want to sustain the many things we value in forests in the longer term. This will involve explicit recognition and resourcing of the management for these different values. Many feel that the solution to providing for future timber needs lies in developing landscape management systems that integrate production of food, water, fibre, energy, conservation, carbon and other values in multi-functional landscapes. This will require flexible and adaptable legislative and market arrangements. Monitoring and verification of multiple values will be critical to demonstrating performance and the ability of carbon investments to provide different values or services. There is clearly a role for Australian Government agencies such as the Australian Bureau of Agriculture and Resource Economics and Sciences to recognise carbon forestry as an emergent industry sector distinct from plantation forestry. The carbon forestry classification proposed in this paper may provide a useful framework. In particular, the collection of relevant industry data such as the area under management and the nature and type of carbon forestry being undertaken would provide future public discourse with a solid base of data and information instead of supposition or broad-scale forecasts inadequately supported by observation. Reconciling the broad-scale assessments of the type currently available with bottom-up or microeconomic perspectives will assist the public and policymakers achieve a realistic understanding of the potential of carbon forestry.

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