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Opportunities for carbon forestry in Australia:

Economic assessment and constraints to implementation.

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We are grateful to all those who had subsequent input and helped to refine the research questions and revise the methodology and assumptions, particularly Peter Cosier and Claire Parkes (Wentworth Group of Concerned Scientists) who facilitated much of the stakeholder interaction and for review of this report. Also for providing review we thank from CSIRO Brett Bryan and Michael Battaglia.

Contents

1. EXECUTIVE SUMMARY

New tree plantings can be established in agricultural landscapes to sequester carbon dioxide and help-offset greenhouse gas emissions. Already there are several commercial off-set companies who are operating in a voluntary carbon market and selling credits. New tree plantings offer one of the most robust ways for the land use sector to off-set greenhouse gas emissions because amounts of carbon sequestered are generally measurable and verifiable. They may also be used to derive other benefits such as biodiversity enhancement, control of erosion and salinity and as shelter for stock. Conversely, there have been some concerns over potential impacts on the availability of land for agricultural production and on water security.

In assessing the potential impacts of a carbon offsets scheme, a common question typically is 'to what extent might agricultural land be converted to tree plantings?' Here we begin to address at least part of that issue through analyses of economic returns from tree plantings to offset carbon emissions and discussion of practical constraints to wide-spread expansion of these planting types. The economic analyses acknowledge that calculated profitability depends upon assumptions used in the modelling.

Economic returns (net present value) over a 40-year period were calculated spatially (1 km grid cell resolution) across the whole of the cleared land area in Australia for 'environmental carbon plantings' which usually, but not always, include mixed-species systems established specifically for carbon sequestration (not harvested) and biodiversity benefit. The sensitivity of modelled results to changed input assumptions was tested through 105 scenarios that encompassed 3 discount rates (1.5, 5 and 10%), 7 carbon prices (5, 10, 15, 20, 30, 40, \$50 t CO_2^{-1}), 2 costs for establishment of plantings (\$1,000, \$3,000 ha^{-1}) and 2 comparative rates of carbon sequestration (the modelled baseline rate which varied spatially according to site conditions and 30% less than that rate across each 1 km^2. This served as a more conservative estimate to account for uncertainty in model estimates and risk). A subset of the scenarios also included a cost for licensing plantings for water interception. Land values for local government areas were also used an input cost.

The results from each scenario should be viewed as identifying areas of opportunity for that set of model assumptions and not predictions of the extent of land use change to forests, for which many other social and market factors need to be considered.

The areas of opportunity ranged from nil ha for tightly constrained scenarios (e.g. very low carbon price or the higher establishment cost and discount rate) to almost the whole of the cleared land for the lower discount rate and highest carbon price.

Assuming plausible estimates for establishment cost (\$3,000 ha^{-1}) and commercial discount rate (10%), no areas were identified as profitable until a carbon price of \$40 t CO_2^{-1} was reached and no areas were ever profitable if the growth rates were all decreased by 30%. However, if a social discount rate of 1.5% was applied then potentially large areas of land are profitable, even for establishment cost of \$3,000 ha^{-1}, depending on carbon price. Including a cost for a water license significantly decreased calculated areas of opportunity.

There are many practical constraints to the rate at which new plantings can be established including supply of seed and labour, infrastructure and availability of land and market capital. Because of these limitations and the short period of time left to meet 2020 targets, new tree plantings could make only a modest contribution to decreasing national emissions by 5% compared with 2000 levels.

Carbon forestry can be a useful activity to help off-set greenhouse gas emissions and restore landscapes but it should be viewed as a long-term project. It would take decades to establish enough new plantings to have significant beneficial impact. For the currently known or plausible market conditions and policy settings (e.g. carbon price) there are few areas economically viable in Australia. To the contrary, additional incentives (gap payments) may be needed to target trees in the right places to achieve other NRM objectives such as enhancement of biodiversity.

2. INTRODUCTION

Several recent research reports have assessed at national or regional scales the economic potential for new forests to be established under a carbon market in Australia (e.g. Lawson *et al*. 2008, Polglase *et al*. 2008, Eady *et al*. 2009, Crossman *et al*. 2011, Patterson and Bryan 2011). The analyses generally combine a spatial layer for estimated rates of carbon sequestration in new forests with those required to calculate economic returns. In some cases, biodiversity and/or water impacts have been assessed but with varying levels of sophistication.

The results from all of these economic analyses are highly dependent on the particular model construct and the assumptions they contain. For example, uncertainty analysis shows that assumed rates of carbon sequestration, carbon price and establishment costs can all greatly affect calculations (Polglase *et al.,* 2008). Furthermore, the area identified as being plantable is one of the most important but uncertain input assumptions to these types of analyses.

In a previous study (Polglase *et al*., 2008) we developed a detailed spatial framework for identifying areas of opportunity for the various types of planted forestry systems in Australia, including pulpwood and sawn timber plantations, bioenergy crops and (non harvested) carbon plantings and included cursory assessment of water and biodiversity impacts. A limited number of scenarios were presented to demonstrate the utility of the spatial framework and suggested that further improvements in scenario development were required.

We concluded that, compared with industrial tree plantations, forestry carbon farming conferred some potential economic advantage for reasons that included:

- There are no costs associated with harvesting and transport, which can be up to about 50% of the total for harvested systems.
- The location of carbon plantings is not constrained by proximity to processing facilities or processing capacity, enabling them to be dispersed across the landscape. By avoiding large, concentrated plantings, the risk from individual events such as from drought, fire, pests and storms, can be mitigated.

- Similarly, potentially negative impacts on water security can be managed through: (a) selecting catchments where there would be little impact on consumptive water users and environmental flows, or (b) not having large, concentrated and contiguous blocks that can impact upon local down-stream users, if not on regional water flows.

Conversely, there may be a trade-off between the often large areas required for maximum biodiversity benefit and implications for other values.

In this study we revise the original methodology of Polglase *et al*. (2008) based on extensive consultation with a range of stakeholders and present a wider range of scenarios to indicate the impact of various assumptions on calculated results. We consider only 'environmental plantings' which are defined as non-harvested systems established for a variety of reasons that include any combination of biodiversity enhancement, carbon sequestration, shelter for stock and from wind, salinity mitigation and amenity value. For biodiversity enhancement they are most often mixed species systems but may be monocultures if used for say recharge control.

As with our previous analyses, those presented here should not be interpreted as projections of the consequences of a carbon market on land use change. Rather, the purpose here is to:

- Show how results vary according to different assumptions,
- Discuss the practical constraints to establishment of carbon forestry over time, and
- Indicate the potential for new tree plantings to meet emission reduction targets.

3. METHODS

The background and details on some of the methodological approach can be found in Polglase *et al. (*2008) but there were some significant differences in this revised analysis. In brief, the method was:

- A prototype generic economic spreadsheet model was developed and which was then translated into a spatial GIS economic model using Microsoft Visual C#.
- Costs and returns were calculated at 1 km scale across the whole of Australia and masked by the area of cleared land.
- Rates of carbon sequestration were estimated from the 3-PG2 model of growth, calibrated and validated against data for environmental plantings.
- Input costs included the value of land and those associated with establishment of plantings.
- Costs and returns were varied to show the sensitivity of calculated profitability to different assumptions.

The main changes from the original analyses were:

- A revised method for calculating areas of profitability from carbon forestry that is consistent with current Australian policy.

- Use of land values for Australia in the economic calculation rather than an estimate of current farm profitability ('profit at full equity', Hajkowicz and Young 2002) against which returns from carbon forestry could be compared (opportunity cost).
- A revised layer for the plantable area and which includes an updated (and significantly larger) area of cleared land for Queensland, and
- The running of 105 scenarios across Australia to demonstrate the range of outcomes possible given changes in assumed establishment costs, the amount of carbon sequestered (accounting for potential impacts of climate change), discount rate, carbon price and the inclusion of the cost of a water license.

The calculated areas of profitability from each scenario are then defined as an 'area of opportunity' for those set of assumptions.

3.1 Scenarios

In total we developed 105 scenarios to indicate the impacts of a range of example assumptions on calculated profitable areas of opportunity and associated rates of carbon sequestration (Table 1). The first 84 scenarios covered the factorial of combinations of seven different carbon prices (5, 10, 15, 20, 30, 40 and 50 \$ t CO_2^{-1}), two establishment costs (\$1,000 or \$3,000 ha^{-1}), two rates of carbon sequestration (the baseline condition and a 30% decrease in the baseline condition) and three discount rates (1.5, 5.0 and 10%).

The 30% decrease in carbon sequestration rate is arbitrary to show the impact of using a more conservative assumption on predicted results and potentially the impacts of climate change. Our calibrations of the 3-PG model to growth of environmental plantings were based on historical climates and it may be expected that growth over the coming decades will differ from those calculated here. Battaglia *et al*. (2009) assessed the potential for climate change (increased atmospheric CO_2, and temperature, changing rainfall) on *Eucalyptus globulus* and *Pinus radiata* forests in Australia and suggested that, when drought risk was included, a 30% decrease in average growth rate over the rotation of the forestry system was possible (Jody Bruce, pers. comm.). Furthermore, a 30% decrease can be considered as something of a risk buffer to account for loss of carbon stock due to disturbances such as drought death, fire, browsing, frosts, cyclones or floods.

Scenarios 85-105 repeat Series 1 (Scenarios 1-21, establishment cost of \$1,000 ha^{-1}, baseline rate of carbon sequestration) but include the cost of a water license which varies spatially.

Table 1. Assumptions used in the scenarios.

Series number	Scenario numbers	Establish't cost ($ ha^{-1})	Carbon sequestration rate	Water cost	Discount rate (%)	Carbon price ($ t CO_2^{-1})
1.1	**1-7**	1,000	baseline	no	1.5	5, 10, 15, 20, 30, 40, 50
1.2	**8-14**	1,000	baseline	no	5.0	5, 10, 15, 20, 30, 40, 50
1.3	**15-21**	1,000	baseline	no	10	5, 10, 15, 20, 30, 40, 50
2.1	**22-28**	3,000	baseline	no	1.5	5, 10, 15, 20, 30, 40, 50
2.2	**29-35**	3,000	baseline	no	5.0	5, 10, 15, 20, 30, 40, 50
2.3	**36-42**	3,000	baseline	no	10	5, 10, 15, 20, 30, 40, 50
3.1	**43-49**	1,000	-30%	no	1.5	5, 10, 15, 20, 30, 40, 50
3.2	**50-56**	1,000	-30%	no	5.0	5, 10, 15, 20, 30, 40, 50
3.3	**57-63**	1,000	-30%	no	10	5, 10, 15, 20, 30, 40, 50
4.1	**64-70**	3,000	-30%	no	1.5	5, 10, 15, 20, 30, 40, 50
4.2	**71-77**	3,000	-30%	no	5.0	5, 10, 15, 20, 30, 40, 50
4.3	**78-84**	3,000	-30%	no	10	5, 10, 15, 20, 30, 40, 50
5.1	**85-91**	1,000	baseline	yes	1.5	5, 10, 15, 20, 30, 40, 50
5.2	**92-98**	1,000	baseline	yes	5.0	5, 10, 15, 20, 30, 40, 50
5.3	**99-105**	1,000	baseline	yes	10	5, 10, 15, 20, 30, 40, 50

3.2 Cleared land area

The area available for establishment of new forests in Australia is a critical input but not known with reasonable certainty. We based the potentially plantable area across Australia on an estimate of the currently cleared land area. No attempt was made to differentiate between land that was cleared prior to 1990 (as required for afforestation projects under Article 3.3 of the Kyoto Protocol) or subsequent to that date. The cleared land area was based on a combination of the Integrated Vegetation Cover layer for Australia and data from the Statewide Landcover and Trees Study (SLATS) of the Queensland Department of Environment and Resource Management. In total this gives an area of about 104 M ha of cleared land across Australia.

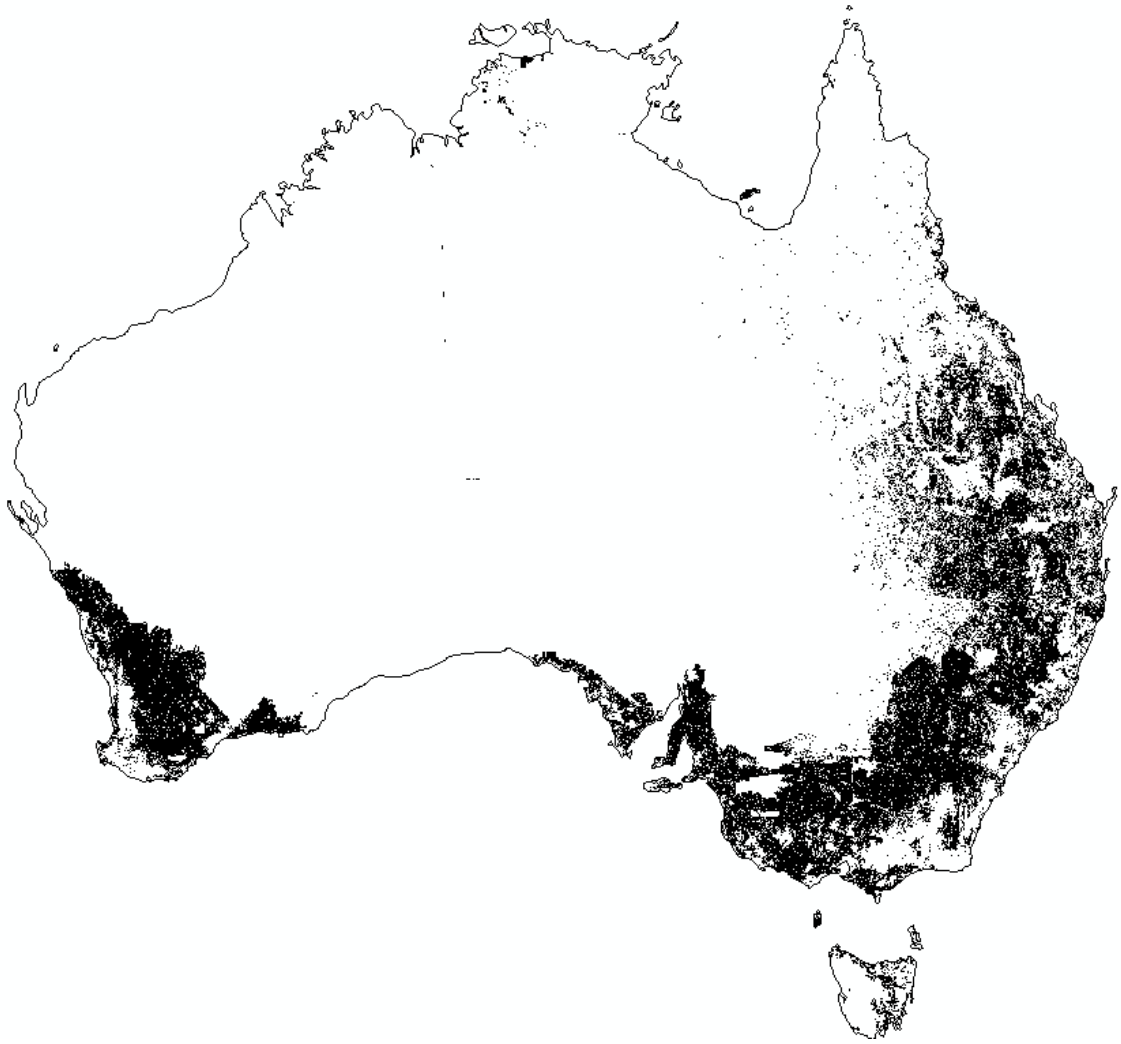

Figure 1. Cleared land area in Australia.

3.3 Carbon sequestration

It is important to have reasonable spatial estimates for rates of carbon sequestration. For many of the commercial forestry species there is a wealth of good data against which to calibrate and validate growth models, in contrast to environmental plantings for which good data are relatively scarce. Furthermore, environmental plantings are by definition a mixture of systems that may include for example monocultures planted for control of recharge or erosion, shelter for stock, or mixed species planting primarily for enhancement of biodiversity or amenity value. Each of these systems may have inherently different rates of growth for any given set of site conditions but have been combined in this and similar exercises for the purposes of model calibration.

The 3-PG2 version (in Excel™ VB™ script) of the 3-PG model was used to model growth. A full description of 3-PG has been provided by Landsberg and Waring (1997), Sands and Landsberg (2002), and Sands (2004). 3-PG predicts stand development and mass of stem, root and foliage components, stand water use, and available soil water.

The 3-PG2 version has a number of improvements over the original that essentially

provides a more robust method for calculating plant available water, stand water use, biomass partitioning and inclusion of understorey as opposed to modelling only a single stratum of trees (Almeida *et al.* 2007).

The model was calibrated against 53 sites and validated against 16 sites for environmental plantings, mostly in south-eastern Australia and the lower (<800 mm) rainfall zones. Data required to run 3-PG2 include monthly climate data (air temperature, vapour pressure deficit, solar radiation, rainfall and number of frost days), site factors (latitude, soil texture, maximum available soil water storage and soil fertility rating), initial stocking rate and management conditions (e.g. fertiliser application).

Spatial rates of carbon sequestration were generated using soil property and climatic layers for Australia as inputs.

Across most of Australia, and particularly in the low-medium rainfall zones, the availability of water is the primary determinant of plant productivity. Adequate description of soil water dynamics is therefore important if model predictions are to be applied across the whole of the plantable area with confidence and in many cases those areas will be outside the regions to which the model was calibrated.

In 3-PG, soil water availability is calculated based on soil depth and the critical soil water contents at permanent wilting point, field capacity and saturation. Critical soil water contents are based on soil textural class in accordance with a soil attributes table in 3-PG (Almeida *et al*. 2007).

Spatial data for soil depth and texture for the A and B horizons up to 2 m depth were derived from the Australian Soil Atlas polygons (McKenzie *et al*. 2000) and converted to raster layers of 1 km cell size in a GIS. To extend estimates below 2 m, a soil terrain analysis technique (MRVBF, Gallant and Dowling 2003) was used that calculated a weighted-average soil texture from data on the depth and textural class of A and B horizons. The values for weighted average soil texture were then aligned with the texture classes used in 3-PG, based on clay content.

For the purposes of *model calibration and validation*, daily climatic data were obtained from SILO Data Drill for the period from time of planting up until the time of the last growth measurement at the site (Jeffrey *et al.* 2001). These daily data were converted to average monthly maximum and minimum air temperature, total monthly rainfall, number of rain days per month, average monthly solar radiation, vapour pressure deficit, and number of frost days per month (i.e. minimum air temperature < 0^{o}C).

For the purposes of *applying the model* to predict rates of sequestration across Australia (Figure 2), climate layers of long term monthly rainfall, maximum and minimum temperature and solar radiation were derived from the ESOCLIM (Houlder *et al.* 2000) program based on 1 km resolution of latitude, longitude and elevation (derived from the NASA Space Shuttle Terrain Mission - SRTM Digital Elevation data - DEM, acquired by CSIRO L&W) across the country. A 1 km Digital Elevation Model was derived from the SRTM.

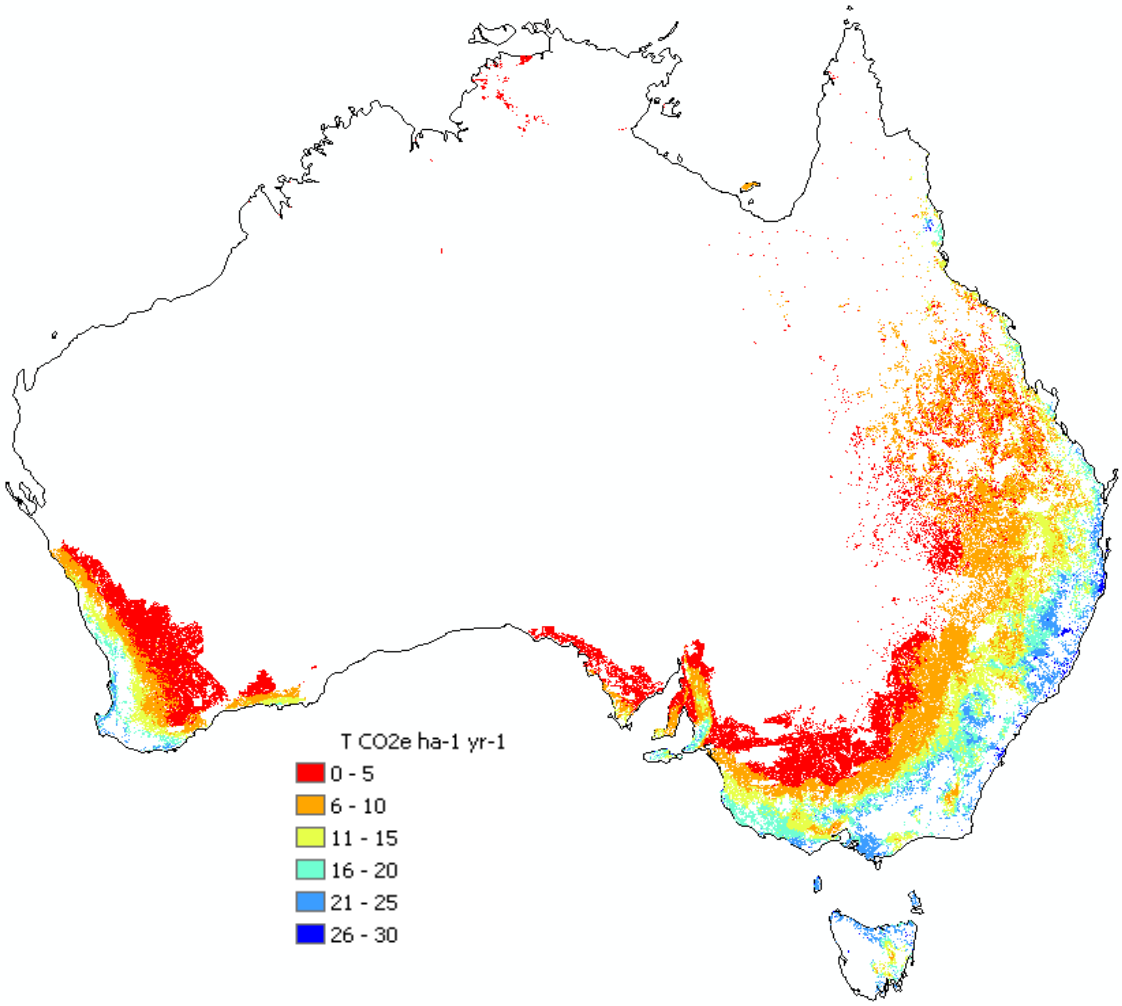

Figure 2. Rates of carbon sequestration averaged over 20 years masked by cleared land area.

Additional long term monthly climate surfaces for both frost (i.e. number of days with average minimum temperature <0^{o}C) and rain days (i.e. 0.2 mm from 9:00 am to 9:00 am next day) were obtained from J. Kesteven (pers. comm.). These had previously been created for the Australian Greenhouse Office (now the Department of Climate Change and Energy Efficiency).

3-PG uses an empirical index of soil fertility (FR) to describe nutrient availability as it affects growth. Each site was assigned a fertility rating (*FR*) that was based on a decision tree. Generally, sites from which data were collated were well managed (good weed control and fertiliser applied) on land previous under improved pasture. Site *FR*s were therefore generally assumed to be between 0.7 and 0.9, or between 0.4 and 0.6 where it was known that soils were particularly infertile or growth was impeded by salinity, shallow soil depth or poor drainage.

Rates of growth and carbon sequestration in live vegetation (including in roots) were estimated monthly for each 1 km cell across Australia for the first 20 years only. The rates of sequestration in each subsequent 20 year period were then decreased by a applying a 'growth decline factor' which is user entered and accounts for decline in

growth over time. In this study the factor was set at 0.7 and extended estimated rates of growth to a 40-year period.

3.4 Economics

The net present value (NPV) was calculated in every 1 km^2 cell for each scenario over the period 2011-2050. The NPV combines upfront and ongoing costs and revenues, expressing them as a single figure in current dollar terms. A positive NPV indicates that reforestation is profitable in that particular location over the life of the project under the assumptions used in the model. To calculate an NPV, future revenues and costs are discounted to convert them into current dollar values. The discount rate represents the rate by which future costs and benefits are discounted compared to the present. A high discount rate indicates a preference in which current income is weighted relatively highly compared to future income. The appropriate choice of discount rate for long term public investments is inevitably a controversial and value-laden exercise as it involves trading off the economic welfare of current and future generations. It also has a major impact on the NPV, particularly for investments in which most of the costs are incurred upfront. The higher the discount rate the greater the weighting applied to the initial costs compared to the ongoing benefit streams offered by forest carbon projects.

Our scenarios included discount rates of 1.5, 5 and 10%. The middle discount rate of 5% is typical of those used in benefit-cost analyses for public projects. It is similar to the government bond rate, i.e. the amount of interest that a government would have to pay if it borrowed money to finance a project. The upper value of 10% is closer to the rate that would be applied by private enterprises comparing alternative investment opportunities. Businesses such as farms or forestry enterprises have higher costs of capital than governments and so must pay higher real interest rates on money borrowed to make investments. As a consequence, higher rates of return are sought and they are also likely to have a broader range of profitable investment opportunities. The 1.5% rate represents a particularly low social discount rate, similar to that used by Stern (2006), which places a relatively low discount on future income (some of which will accrue to future generations) compared to current income.

The costs of establishing a forest carbon project include site preparation (which could include ripping and mounding), weed and pest management, purchase of seeds (or tube-stock), fertiliser application, fencing and the labour required for planting. Our scenarios include two alternative establishment costs: (i) a lower value of \$1,000 ha^{-1} which would reflect a relatively low cost direct seeding method of establishing mixed species carbon plantations, and (ii) a higher value of \$3,000 ha^{-1} which is more representative of establishment costs involving ripping and mounding of soil, planting of tube stock and fencing.

We have deliberately kept the economic model construct simple by not including any ongoing management costs such as ongoing weed and pest control or transaction costs associated with converting an existing enterprise to carbon farming and participating in a carbon market. Rather, we have used the range of establishment costs and discount rates as surrogates for other costs, to illustrate the range of modelled responses to changed input assumptions. Previous sensitivity analyses

(Polglase *et al.* 2008) have shown that the impact of including on-going management costs on calculated profitability is relatively small.

In our model the value of land on which the plantation is established is an upfront cost for the project, which was estimated spatially from local government data (Figure 3). An alternative would be to consider the opportunity cost of the land, represented by comparing the annual profitability of alternative agricultural uses. However, establishing forestry projects is not simply analogous to switching crops; the land under forests needs to be committed for decades (at least), and hence it is a difficult and costly decision to reverse. A farmer establishing a carbon forest loses the option to readily switch crop types in response to future market opportunities. It is therefore also unlikely that land locked into carbon forestry will increase in value at the same rate as other agricultural land (except perhaps for some small scale plantations which may add amenity value to a property). For this reason we consider that land value provides a better measure of the opportunity cost of converting that land to forestry, whether the forestry project is carried out by the existing landholder or a new investor such as a forestry company. It is also representative of a third party investor model in which land is purchased (or sometimes leased) rather than a farmer as the investor and in which the main decision is to switch land use.

In the economic model, costs and revenues were accrued over a 40-year period. Land purchase and forest establishment costs were accrued at the beginning of the project. Carbon revenues were accrued annually, based on average annual sequestration rates in each of two 20-year periods. Seven different carbon prices were modelled, ranging from \$5 and \$50 t CO_2^{-1} and held constant (in real terms) over the 40 years.

In some scenarios (95-105) a licensing cost for water interception ws also included which was applied to the estimated amount of run-off intercepted by plantations compared to the pre-existing (agricultural) land use. The National Water Initiative (NWI) requires that large-scale plantation developments be included in water sharing plans and which could lead to the imposition of water licensing arrangements for some jurisdictions. However, policies are still being developed for whether or how to include new plantings (and potentially other forms of land use change and management) into water sharing plans.

Amounts of water interception were calculated spatially using the ‘Zhang curves’ and equations that describe the differences in water use between forests and grass. Zhang *et al*. (1999, 2001) undertook a thorough analysis of the world-wide literature on vegetation water use to derive generalised relationships between water use (or evapotranspiration) and rainfall for generic ‘forest’ and ‘grass’. The basis of their analysis is that in very dry climates, water use is limited by water availability due to low rainfall, whereas in very wet climates, water use is limited by available energy and that in most cases, actual water use is between these two extremes.

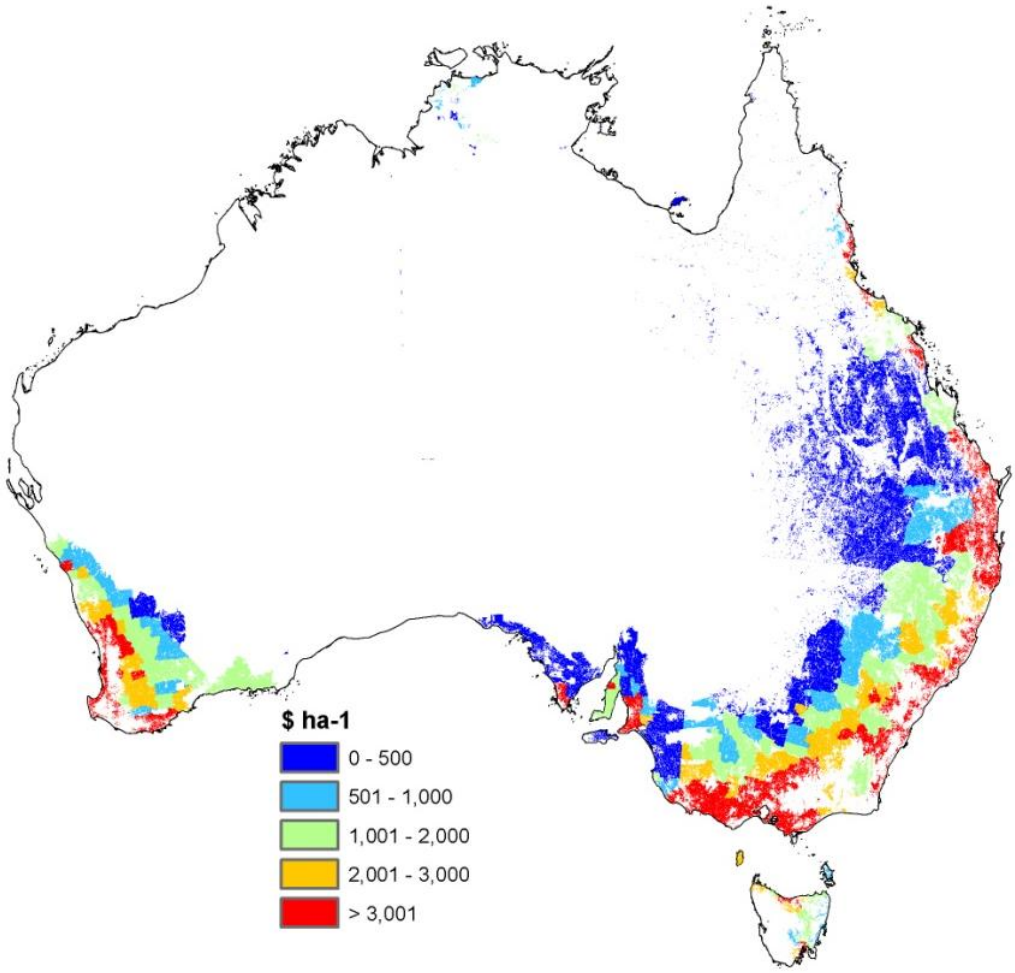

Figure 3. Land values for 2009 masked by cleared land area.

The difference in amounts of water used by grass (or an assumed average, agricultural condition) and forest can be calculated for any given rainfall, from which the difference in run-off (assumed to be water interception) can be derived. Amounts of expected water interception vary with rainfall, from about 213 mm in a mean annual rainfall zone of 1000 mm to 39 mm in a 400 mm rainfall zone. The difference in water use between forests and grass becomes increasingly small and variable as rainfall decreases (say below 700 mm) and thus the confidence in predictions also decreases.

The estimated rates of water interception have a number of important caveats including: they are generalised curves only for average, equilibrium conditions; the difference in water use between grass and forests is dependent on local site and management factors, forests that are newly established will take time to build up to maximum rates of water use.

We assumed that a water licence had to be purchased at the time of establishment to cover this volume of water. In some parts of Australia, notably the Murray-Darling Basin, water markets are well developed. Water licences (for permanent, high-security entitlements) have traded for around \$2,000 ML^{-1} in recent years (NWC 2010); for sites within the Murray-Darling Basin we used this value as our water cost. Elsewhere

in Australia the cost of water is less clear. The 2000 National Land and Water Resources Audit identifies some catchments as being over-developed in terms of water diversion (NLWRA 2011). In these catchments we applied a cost of \$1,000 ML^{-1}, and elsewhere used a default cost of \$500 ML^{-1}.

4. RESULTS

Figures 4-6 show the results from all scenarios and the effects of different assumptions on profitable area and annual amount of carbon sequestered. The profitable area is an 'area of opportunity' in which it is potentially viable to establish forests under each scenario. It is not suggestive of the area that would, could or should be planted.

As expected, the results are highly dependent on all the assumptions considered and there appear to be strong interactions between them. The profitable area increases linearly or curvilinearly with the price of carbon for most scenarios, the shape of the curve being strongly affected by discount rate.

Increasing the establishment cost substantially decreases the area of profitability. For example, at an establishment cost of \$3,000 ha^{-1} and discount rate of 10%, no areas are profitable until a carbon price of \$40 t CO_2^{-1} is reached for the baseline rate of carbon sequestration (Figure 4b). Increasing the establishment cost from \$1,000 ha^{-1} (Series 1 scenarios) to \$3,000 ha^{-1} (Series 2 scenarios) causes the areas of profitability identified to decrease by up to 50 M ha for some of the scenarios (Figure 5a). For example, at a carbon price of \$20 t CO_2^{-1} and discount rate of 5%, the profitable area is 32 M ha for establishment costs of \$1,000 ha^{-1} compared with 1.0 M ha for establishment cost of \$3,000 ha^{-1}. There was a strong interaction between establishment costs, carbon price and discount rates (Figure 4), the magnitude and direction of change due to increased establishment cost varying according to carbon price and discount rate.

Decreasing the rate of carbon sequestration by 30% significantly decreased the profitable areas but to a lesser extent than increasing the establishment cost from \$1000 ha^{-1} to \$3,000 ha^{-1} (Figures 4c, 4d, 5b). The combined effect of increasing the establishment cost and decreasing rate of carbon sequestration was more or less additive; at a discount rate of 10%, no areas of profitability were identified even at the highest carbon price (Figure 4d).

Including a cost for water interception essentially increases the establishment cost and also significantly altered results (Figures 4e, 5d), making all areas in the Murray Darling Basin not profitable, even with an establishment cost of \$1,000 ha^{-1} for the assumptions in that scenario of 5% discount rate and carbon price of \$20 t CO_2^{-1} (Figure 6d).

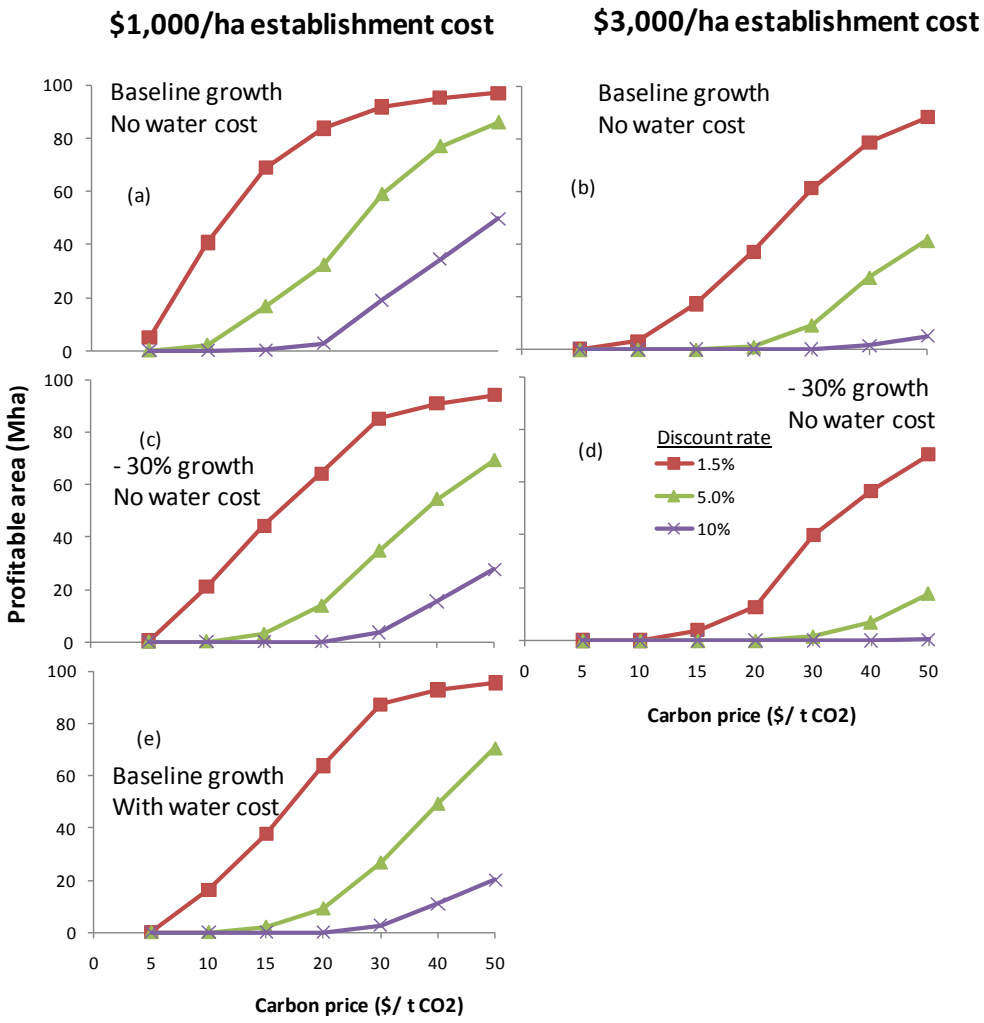

Figure 4. The impact of changing carbon price and discount rate (1.5, 5 and 10%) on profitable area for: (a) $1,000 ha^{-1} establishment cost, baseline rate of carbon sequestration and no water cost, (b) $3,000 ha^{-1} establishment cost, baseline rate of carbon sequestration and no water cost, (c) $1,000 ha^{-1} establishment cost, -30% rate of carbon sequestration and no water cost, (d) $3,000 ha^{-1} establishment cost, -30% rate of carbon sequestration and no water cost, and (e) $1,000 ha^{-1} establishment cost, baseline rate of carbon sequestration including a water cost for a water license.

Trends in rates of carbon sequestration among scenarios were similar to those of profitable area. The mean rate of sequestration is generally inversely proportional to the profitable area and especially when the profitable area is small (Figure 7). This means that when the economic model is highly constrained by, for example, establishment cost of $3,000 ha^{-1} and 10% discount rate, areas can only be profitable when the rate of CO_2 sequestration is sufficiently high, in some cases approaching 20 t CO_2 ha^{-1} yr^{-1} (Figure 7). At higher carbon prices (or lower discount rates and establishment costs) regions with lower sequestration also become profitable, reducing the overall average sequestration rate. It should be noted that the majority of sites used for calibration and validation of the 3-PG growth model were from rainfall zones below 800 mm and where rates of growth were less than the higher values predicted here and which thus carry some degree of uncertainty.

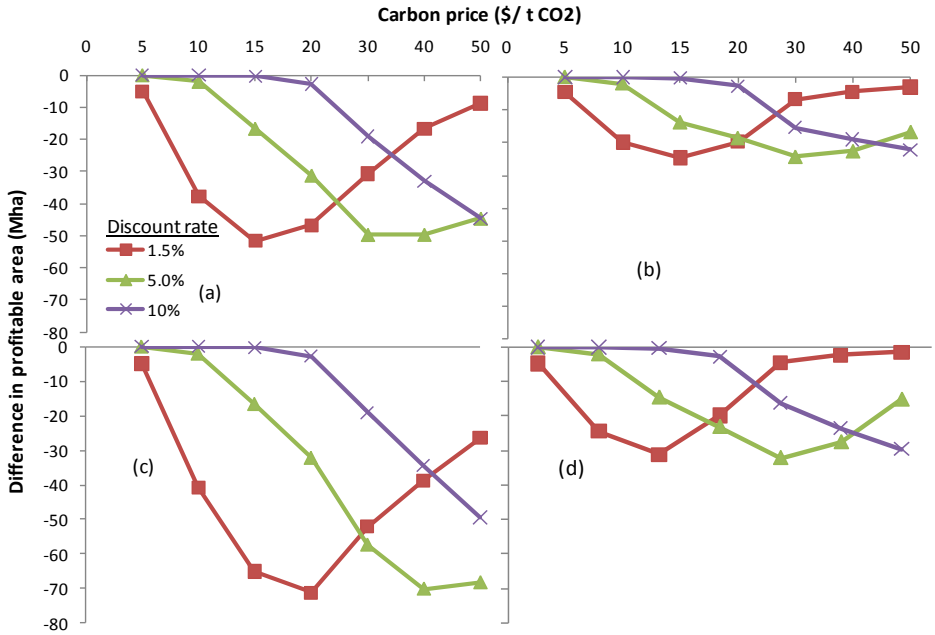

Figure 5. The difference in profitable areas caused by: (a) increasing establishment cost from $1,000 to $3,000 ha^{-1} (Series 2 – Series 1 results), (b) decreasing the rate of carbon sequestration by 30% from the baseline condition (Series 3 – Series 1 results), (c) increasing establishment cost from $1,000 to $3,000 ha^{-1} and decreasing the rate of carbon sequestration by 30% from the baseline condition, and (d) including a cost for a water license.

The mean rate of carbon sequestration across the whole 103 M ha of available land was 7.4 t CO_2 ha^{-1} yr^{-1} over a 40-year period for the baseline rate of sequestration and was 5.2 t CO_2 ha^{-1} yr^{-1} when decreased by 30%. Traditionally, the unit of 'mean annual volume increment' of tree stems (MAI, m^3 ha^{-1} yr^{-1}) has been used to assess growth rates and it is useful here to compare that metric with units of CO_2 sequestration. We estimate that an average rate of sequestration of 7.4 t CO_2 ha^{-1} yr^{-1} is equivalent to an MAI of about 5 m^3 ha^{-1} yr^{-1}for *Eucalyptus globulus* (Tasmanian blue gum) growing over a 10-year rotation, and 2 m^3 ha^{-1} yr^{-1}for *E. cladocalyx* (sugar gum) growing over a 40-year rotation. Both these values would be considered very low in a commercial context.

5. DISCUSSION

5.1 Economics

The results of our scenarios identify potential areas of opportunity for any given set of input assumptions. They do not (cannot) forecast the future extent of land use change to forestry.

The results show that the area of opportunity essentially ranges from zero ha (low carbon price or combination of high carbon price, establishment cost and discount rate) to almost all the available land area being profitable at low establishment cost, discount rate and relatively high carbon price (Figure 4). Note that the calculated area of profitability for each scenario includes any positive (>0 $/ha) value for NPV and as such many areas are in the least profitable (orange colour-coded) category of $1-500 $/ha (Figure 6). This raises the question of whether such profitability may be sufficient to motivate land use change compared with other land uses and transaction costs.

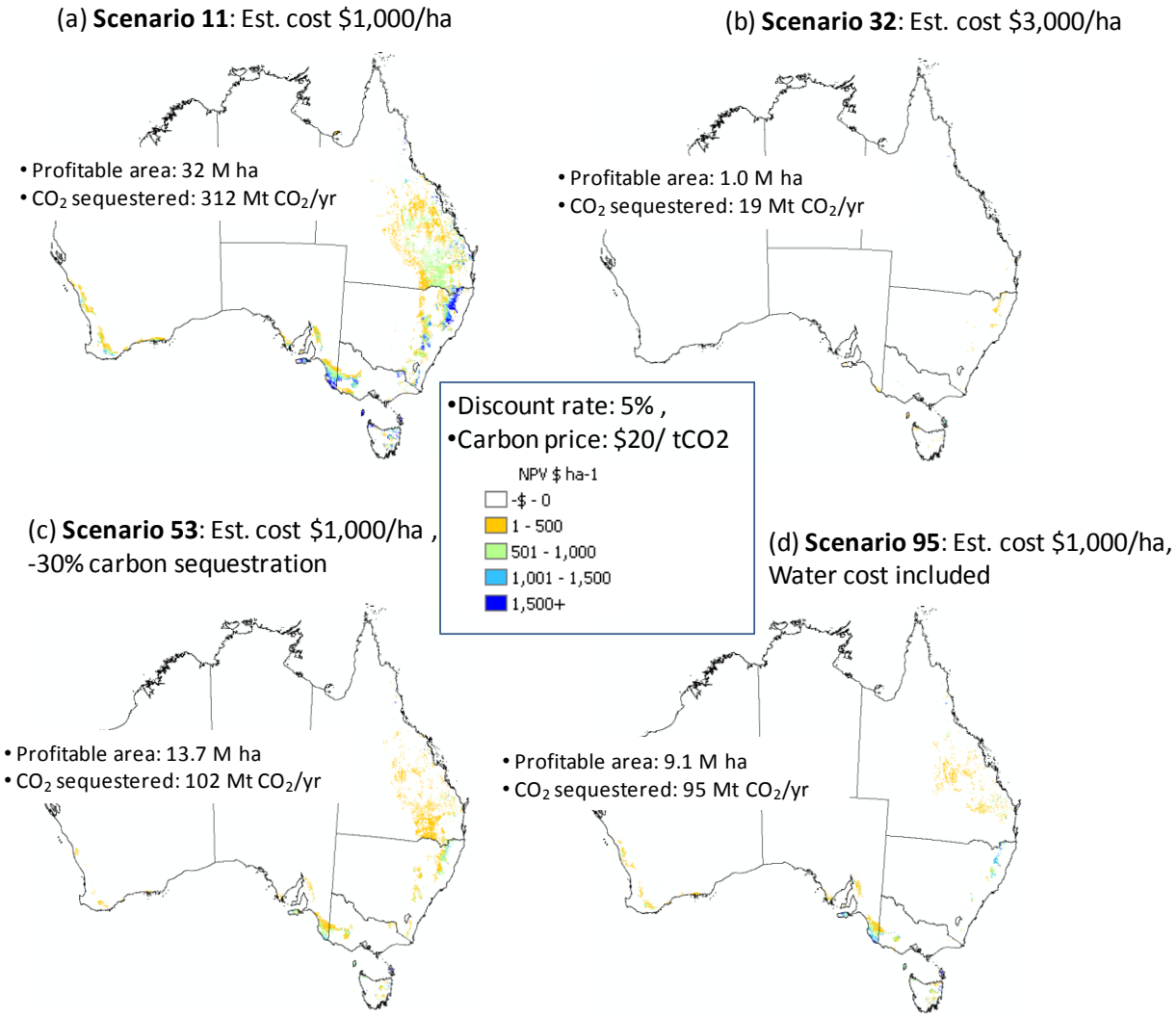

Figure 6. Example results from four scenarios that each use a discount rate of 5% and carbon price of $20 t CO_2^{-1} and: (a) establishment cost of $1,000 ha^{-1}, baseline rate of carbon sequestration, (b) establishment cost of 3,000 ha^{-1}, baseline rate of carbon sequestration, (c) establishment cost of $1,000 ha^{-1}, -30% rate of carbon sequestration, (d) establishment cost of $1,000 ha^{-1}, baseline rate of carbon sequestration, water cost included. The purpose here is to illustrate areas of relative profitability for select scenarios.

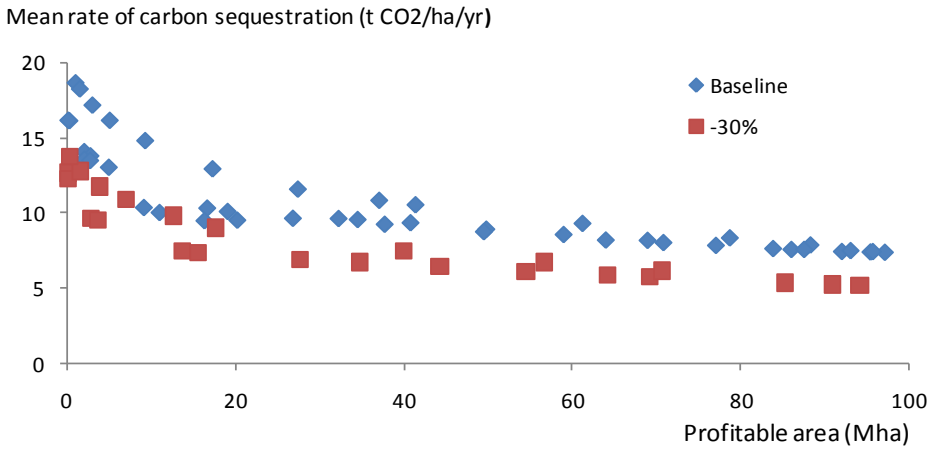

Figure 7. The mean annual rate of carbon sequestration averaged across each profitable area for all 105 scenarios using either the baseline rate of carbon sequestration (Series 1, 2 and 5) or the -30% rate (Series 3, 4). The figure shows that tightly constrained scenarios (e.g. high establishment costs, high discount rate and low carbon price) can only ever be profitable (low profitable area) when the estimated mean rate of carbon sequestration is highest.

When interpreting the results, a primary consideration is the many different types of investor in carbon forestry, each of which has their own business model. Broadly, investors fall into one of two categories - third party investors (e.g. carbon off-set companies) who lease or purchase land and farmers who may choose to convert at least part of their land to trees. The business model of third party investors can vary markedly to include those who establish forests mostly for: (i) carbon offsets (e.g. mallee plantings), (ii) biodiversity enhancement, (iii) landscape restoration and capital gain on property value, and (iv) agroforestry where production of agricultural and forest products are combined. It is apparent that most of the carbon off-sets sold to date in a voluntary market have been from forests established by commercial companies. Farmers may choose to establish and manage carbon forests in partnership with commercial companies (e.g. lease land) or use their own resources to change land use but for which a substantial cost may be involved.

Our scenarios are designed to cover a wide range of values for input costs, returns (carbon price) and discount rate for possible future market and policy settings. But which ones are the most plausible given current conditions? Although a discount rate of 5 to 7% is often used for economic calculations it does not necessarily reflect commercial reality and a discount rate of 10% may be more appropriate. Costs of forest establishment vary widely and are dependent on site conditions (e.g. the need for ripping and mounding) and whether sites are direct seeded, planted with tube stock or grazing pressure is excluded and sites left to regenerate naturally. For mixed species plantings that have biodiversity objectives, direct seeding is the only viable option on a large scale and costs about \$2,500 ha^{-1} (D. Freudenberger, Greening Australia, pers. comm.). Costs of establishing tube stock are usually greater. However, we are aware of at least one company that has kept direct seeding to about \$200 ha^{-1}; with such works involving direct seeding on ex-agricultural, relatively flat land using indigenous species including chenopods (Malory Weston, Kilter, pers.

comm.). This example is at the very low range and costs of \$2000-3000 ha^{-1} are more common.

With establishment cost set at \$3,000 ha^{-1} and discount rate at 10%, no profitable areas are identified when the baseline rate of carbon sequestration is decreased by 30% (Figure 4d) and only modest areas are identified when the baseline rate of sequestration is applied and the carbon price is \$40 t^{-1} CO_2 or more (Figure 4b).

For all our scenarios, economic returns would be higher if the carbon price were to increase at a faster rate than other prices in the economy, as may happen if significant constraints are placed on emissions at some point in the future. However, any such benefit (or cost if prices were to decrease due to, for example, rule changes or new technologies) may not accrue to a landholder if the carbon rights were sold upfront.

We conclude that, based on our current and best available understanding, not only would economic incentives be limited in a carbon market to motivate large-scale environmental plantings; rather it may be that further financial incentives such as biodiversity payments would be necessary to encourage establishment of forests in say areas where landscape restoration and biodiversity enhancement is needed (Bekessy and Wintle 2008, Crossman *et al.* 2011). However, the results are particularly sensitive to assumed establishment cost, which forest and carbon off-set companies seek to limit as much as possible to increase financial viability without overly comprising growth.

Including a cost for water interception has a large impact on calculated profitability for most scenarios. However water sharing plans are still being developed by jurisdictions and whether or how to include interception by large-scale plantations. It is possible that, where new plantings occupy say less than 10% of any farm, that there will be no requirement for a water license (Polglase and Benyon 2009).

5.2 Constraints to implementation

While environmental plantings may offer in some circumstances a cost-effective opportunity to off-set greenhouse gas emissions there are a range of barriers which will limit their uptake.

Social factors will be important in moderating land use change. Decisions by landholders to change land use are not simply a matter of comparing calculated economic returns. Reforestation on agricultural land involves a major change in land use which will be neither cheap nor easy to reverse. This loss of management flexibility and its concomitant risk is not readily captured in a simple NPV calculation. For some landholders environmental carbon plantings may fit with their land management aspirations, but for others they will not.

There will also be barriers in terms of the availability of the capital required to invest in tree plantations. Landholders and commercial offset companies will be limited by access to market capital. Given the regulatory uncertainties and sovereign risks inherent in carbon markets, it is questionable whether capital will be made available to such projects. Forest carbon offset projects, which involve upfront costs but generate revenues over decades, are particularly susceptible to future rule changes, along with

a host of other risks, and so may not be an attractive investment despite having a positive NPV.

Another key issue is competition with other types of plantings. Because mixed species plantings usually include an understorey component and traditional plantation species have been bred for good growth, the rates of carbon sequestration of monocultures may be greater than that of environmental plantings (Polglase *et al*. 2008). Such monocultures may be more competitive than mixed species plantings although there is trade off with cost of establishment; monocultures usually being established with tube-stock and often with some form of site preparation such as ripping and mounding. Mixed species systems offer additional benefit such as biodiversity which may attract a premium in the marketplace (Crossman *et al*. 2011). There is also the question of whether mixed species systems that aim to replicate native ecosystems have the potential to store more carbon due to greater structural complexity and are more resilient to change and can hold carbon stocks longer than the industrial monocultures which are bred for fast, early growth. Note that mallee species make an interesting case study, being selected by some off-set companies for their extreme resistance to disturbance and thus ability to hold carbon for the required period.

In the real world, economies of scale are a key feature of the economics of forestry investment. Some costs, such as seed, are directly proportional to the number of hectares being planted, while others, such as registration and certification costs, have a large fixed component. In order to be viable, the fixed costs need to be spread out across a reasonable area; currently in Australia around 100 hectares appears to be a minimum requirement for commercial offset projects.

Central to any expansion of tree plantings will be demand for carbon off-sets that, at present, is relatively weak (Hug and Ahammad 2011). Future demand will depend on domestic policy such as whether the Carbon Farming Initiative and a carbon price are legislated and future international agreements beyond the Kyoto Protocol. It should also be noted that our model assumes prices are constant. If there were to be a major expansion of forests to generate carbon credits there would be considerable upward pressure on land and water prices and the costs of establishing plantations due to increased demand. At the same time, downward pressure would be placed on the carbon price as the supply of offsets expands. This would act to limit the profitability of further expansion.

5.3 Potential to off-set Australia's carbon emissions

A commonly asked question is the extent to which new plantings could decrease national greenhouse gas emissions. The most simple answer to that is to state:

$P = A \times C$, where,

P is the potential to offset emissions (t CO_2 yr^{-1})
A is the area planted (M ha), and
C is the annual, average rate of carbon sequestered across that area over 40 years (t CO_2 ha^{-1} yr^{-1}).

The value for C is the one in which we have the most relative confidence, being a value per hectare and which is based at least on measured or estimated rates of carbon sequestration for a variety of environmental plantings. It should be noted that there still remains a good deal of uncertainty in this number for any given mixture of species at any given site and time in the future

The value for A is by far the greatest unknown in this context, not being well constrained and thus not able to be predicted with a great deal of confidence. At best, all we can do at present is to illustrate the effect of assumed land area on off-setting national emissions for two, averaged, areal rates of carbon sequestration (Table 2). The numbers show that new plantings ultimately could make a modest difference to off-setting national emissions, of the order of 1.0 to 1.4% of 2010 emissions (543 Mt CO_2 yr^{-1}) for every 1 million ha of new environmental plantings.

The Australian Government has an objective of decreasing national emissions by 5% by 2020 compared to the 2000 baseline. This is effectively a reduction of 28 Mt CO_2 yr^{-1} compared with 2000 emission but a much greater reduction against anticipated 2020 levels. A recent report by the Department of Climate Change and Energy Efficiency (DCCEE 2011) suggests that the contribution by new carbon forests to meeting that target would be only about be 1-2 Mt CO_2 yr^{-1}. The practical constraints to establishing forests would support the notion that new forests can make only a modest contribution to meeting 2020 targets.

Table 2. Percentage of 2010 emissions (543 Mt CO_2 yr^{-1}) that can be off-set by environmental plantings for assumed areas of planting and two assumed rates of carbon sequestration – the average across the whole of the cleared land area (7.4 t CO_2 ha^{-1} yr^{-1}) and when decreased by 30% (5.2 t CO_2 ha^{-1} yr^{-1}). Numbers are for plantings that have reached an average rate of carbon sequestration, calculated over a 40-year period.

Area planted (M ha)	Proportion of 2010 emissions sequestered (%)	
	7.4 t CO_2 ha^{-1} yr^{-1}	**5.2 t CO_2 ha^{-1} yr^{-1}**
1	1.4	1.0
5	6.8	4.8
10	13.6	9.6
20	27.3	19.2

There are limitations on the rate at which new plantations can be established. After a long history of plantation development driven firstly by state agencies to establish pine plantations and followed by Managed Investment Schemes to establish hardwood plantations (mostly blue gums) there are currently 1.97 M ha of plantations in Australia. At the height of the MIS expansion schemes the largest area of plantation established in any one year was about 140,000 ha in 2000 (BRS 2009). Averaged across five years at the peak of the expansion period (1998-2002) about 86,000 ha of plantations were established. These are useful numbers to reference when considering the potential for expansion of carbon plantings in the short-term.

The availability of seed, tube-stock, machinery and labour all limit the rate of establishment, along with the area of suitable land that becomes available over time. It also takes time to build up a suitable infrastructure to support plantation establishment. In the next 9 years it would only be possible to expand new carbon plantings to any significant extent after say a 5-year lag period. Assuming that 500,000 ha in total was

established by 2020, that would equate to carbon sequestration of about 3.7 Mt CO_2 yr^{-1} for an assumed average rate of carbon sequestration of 7.4 t CO_2 ha^{-1} yr^{-1} (i.e. 0.5 x 7.4). However, that number needs to be further discounted because plantations are established over time and their initial rates of growth and carbon sequestration are low before they reach a maximum after some years. Thus, there would be perhaps 2 Mt CO_2 yr^{-1} or less of abatement by 2020 for the example used here, or less than 0.4% of 2020 emissions and which is consistent with the DCCEE (2011) estimate.

However, over the longer term (by say 2050) there may be opportunity to establish enough new plantings to help contribute to emission reduction targets and derive other benefits while managing trade-offs. For example, 10 to 20 Mha of plantings targeted towards and dispersed across marginal land where biodiversity need is greatest ultimately may contribute about 50-100 Mt CO_2 yr^{-1} in emissions off-sets (or about 10-20% of current emissions) for an assumed average rate of carbon sequestration of 5.2 t CO_2 ha^{-1} yr^{-1} (Table 2).

We conclude that use of carbon plantings to help off-set national emissions is a long-term project. New plantings may be incrementally established over time and a carbon market could be used to help drive biodiversity outcomes. In such a case, supplementary (or gap) payments may be needed to make environmental plantings profitable and to target trees in the areas most in need.

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