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Abatement potential from reforestation under selected carbon price scenarios

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Report prepared for the Australian Treasury as input to its carbon price modelling

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Contents

Figures

Maps

Summary

The Australian Treasury has commissioned the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) to estimate the abatement potential from reforestation under the Carbon Farming Initiative (CFI), incorporating expert advice from the CSIRO regarding the assumptions and estimates presented in this report. For this study, reforestation refers to long rotation hardwood plantations and carbon plantings, which are assumed to be credited for carbon sequestration under the CFI; other reforestation regimes, such as softwood or short rotation hardwood plantations, can compete for agricultural land, but are assumed to be unable to receive carbon sequestration credits. The estimates and the analysis have been provided to the Treasury as input to its climate change policy modelling. Unless otherwise noted, the assumptions used for this study have been developed jointly by ABARES, and other relevant divisions of the Department of Agriculture, Fisheries and Forestry (DAFF), the Department of Climate Change and Energy Efficiency (DCCEE) and the Australian Treasury.

The aim of this report is to describe the methodology and assumptions underlying ABARES estimates and analysis under specific carbon pricing policy settings. The Treasury has modelled two global action scenarios—'medium' global action scenario and 'ambitious' global action scenario—corresponding to the stabilisation of atmospheric greenhouse gases at 550 parts per million (ppm) and 450 ppm, respectively, by around 2100. This report provides reforestation estimates for two different world carbon price series necessary to achieve these stabilisation targets. In the medium global action (550 ppm) scenario, the world carbon price is projected to begin at around \$23 per tonne of carbon dioxide equivalent (/ t CO_2-e) in 2012–13, and in the ambitious global action (450 ppm) scenario, the world carbon price is projected to begin at around \$47/ t CO_2-e in 2012–13. In both scenarios, the carbon price, expressed in 2009–10 Australian dollars, is projected to increase at an average rate of about 5 per cent a year to 2049–50.

Direct emissions from agricultural and forestry activities are not covered under the Australian Government's proposed domestic carbon pricing mechanism. However, under the Australian Government's proposed CFI framework, landholders have the potential to earn carbon credits for reforestation activities (as well as for emissions reductions from agricultural activities). Generators of the CFI credits are assumed to be able to sell these into the global carbon markets at the world carbon price for each scenario; these markets may include the domestic voluntary carbon market and, once established, the domestic carbon price mechanism.

In projecting carbon sequestration potential from reforestation, this report updates some of the data and assumptions used in previous work by the former ABARE (Lawson et al. 2008), incorporating the proposed CFI settings including the risk reversal buffer, potential water interception costs for reforestation projects, updated Kyoto compliant land and native vegetation restrictions, and an additional timber plantation regime. Additionally, several price and cost assumptions have been updated for this analysis. It should be noted that this report represents a scenario analysis, and hence all results are contingent on the combination of data and assumptions employed for each scenario. Some assessment of the sensitivity of the results of this analysis is provided in the report.

Under the medium global action scenario, the area of agricultural land that is economically viable for reforestation between 2012–13 and 2049–50 is estimated at 0.35 million hectares, representing about 0.1 per cent of agricultural land in Australia (table A). Approximately 45 per cent of this estimated reforestation area (0.16 million hectares) is projected to be carbon plantings. In comparison, under the ambitious global action scenario, the land area economically viable for reforestation between 2012–13 and 2049–50 is projected to be significantly higher, reaching around 4.9 million hectares, or about 1.3 per cent of Australia's agricultural land. Of this, carbon plantings are projected to account for approximately 76 per cent (3.7 million hectares).

A Carbon sequestration from economically viable reforestation activities under alternative scenarios for selected years

	medium global action scenario			ambitious global action scenario		
	2012–13	2019–20	2049–50	2012–13	2019–20	2049–50
Cumulative additional area of reforestation ('000 hectares)						
Long rotation hardwood plantations	<1	1	190	28	222	1 174
Carbon plantings	1	8	157	50	404	3 743
Total	1	9	347	78	626	4 917
% of 2010 agricultural land area **a**	<0.1	<0.1	0.1	<0.1	0.2	1.3
Carbon sequestration (Mt CO_2-e/year)	<0.1	0.2	5.7	1.2	9.4	40.6

a Agricultural land area based on ABS (2011).
Source: ABARES estimate

As with the Lawson et al. (2008) analysis, the results presented in this report represent the entire land area that is economically viable for reforestation activities. Consequently, the results do not reflect other factors that may affect the uptake of CFI compliant reforestation projects, such as socio-cultural factors that may favour agricultural land use. The methodology neither takes into account the land use preferences of landholders, nor incorporates the margin by which returns from reforestation must exceed those from agriculture to induce changes in land use.

While incorporating such factors is beyond the scope of the present study, more detailed analysis of the results does indicate that a significant proportion of the economically viable land area for reforestation generates returns that are significantly above the corresponding agricultural land value. For example, under the medium global action scenario, around 40 per cent of the area projected to be economically viable for reforestation was estimated to derive a return more than 25 per cent above the corresponding agricultural land value; in the ambitious global action scenario, around 85 per cent of projected reforestation was estimated to derive a return more than 25 per cent above the corresponding agricultural land value. This suggests that the results, particularly the finding that a significant proportion of the agricultural land area to be economically viable for reforestation, are relatively robust.

A comparison of the results under the two global action scenarios indicates that the proportionate increase in the area of land economically viable for reforestation exceeds the proportionate increase in the carbon prices between the scenarios. This is similar to a previous finding by Lawson et al. (2008) for the two carbon price scenarios called CPRS –5 and CPRS –15, and arises because each area of land has a threshold carbon price, above which reforestation (either long rotation hardwood plantations or carbon plantings) will become economically viable. In other words, this threshold represents the price required to make reforestation viable against existing land uses for each land area. The results presented in this report suggest that, for a relatively large area of land, the threshold returns lie between the carbon price under the medium global action scenario and the higher carbon price under the ambitious global action scenario.

Overall, the results in this report suggest that reforestation does respond to a carbon price. In particular, high carbon prices, such as projected under the ambitious global action scenario, can substantially enhance the economic viability of CFI reforestation activities in Australia.

1 Introduction

The aim of this report is to document the methodology and assumptions underlying the estimates by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) of potential abatement from reforestation under the Carbon Farming Initiative (CFI). Reforestation in this study is defined to include long rotation hardwood plantations and carbon plantings. These estimates have been provided to the Treasury as input to its climate change policy modelling. The assumptions underlying the estimates have been developed jointly by ABARES, and other relevant divisions of the Department of Agriculture, Fisheries and Forestry (DAFF), the Department of Climate Change and Energy Efficiency (DCCEE), and the Treasury, unless otherwise noted. The CSIRO has provided expert advice regarding the assumptions and reviewed the results.

This study on reforestation potential is an update of previous work by the former ABARE (Lawson et al. 2008), which was provided to the Treasury as part of the Australian Government's *Australia's Low Pollution Future* report (Australian Government 2008). The updated analysis in this report includes changes such as the CFI settings, including the risk reversal buffer, water interception costs for reforestation projects, updated Kyoto compliant land and native vegetation restrictions, and an additional timber plantation regime. Many of the assumptions relating to the prices and costs associated with reforestation have also been updated, and are described in this report.

The potential abatement from reforestation is estimated under two global action scenarios—medium global action scenario and ambitious global action scenario—corresponding to the stabilisation of atmospheric greenhouse gases at 550 parts per million (ppm) and 450 ppm, respectively, by around 2100.

The following section describes the opportunities for carbon plantings and long rotation hardwood plantations under the CFI. Section 3 outlines the analytical framework for the modelling, including the assumptions employed and the scenarios analysed. The projected reforestation and resulting sequestration potential under the scenarios are presented in section 4. Section 5 concludes the paper.

2 Carbon Farming Initiative

The Australian Government's proposed CFI would provide new opportunities for farmers and landholders to participate in international and domestic markets for greenhouse gas emissions offset credits (DCCEE 2010). The CFI will set out what farmers, foresters and landholders need to do to generate carbon credits. The Australian Government will establish an independent regulator to verify carbon credit claims. Once the credits are verified, they can be traded at the world carbon price, generating revenue while reducing carbon pollution. Abatement credited under the CFI must meet the following internationally recognised standards, which are designed to ensure that abatement is genuine and verifiable:

- additionality
- permanence
- avoidance of leakage
- measurable and verifiable
- conservative
- internationally consistent
- supported by peer reviewed science
- accounting for variability.

DCCEE (2010) provides further details on these 'integrity standards'.

The CFI legislation is yet to be passed by the parliament and the associated regulations, including the common practice test, are under development. However, for the ABARES analysis of reforestation potential, it is assumed that carbon plantings and a limited number of timber plantations such as long rotation hardwood plantations that comply with all state native vegetation legislation will be eligible for CFI offset credits. It is possible that not all long rotation hardwood regimes modelled will be eligible for the CFI offset credits and that other reforestation activities such as mallee plantings have the potential to meet CFI eligibility criteria. The latter have been excluded from this analysis as mallee growth data were not available at the time of analysis. Future research can incorporate alternative policy settings and datasets.

3 Analytical framework

Methodology

The analysis presented in this report employs the same methodology developed by the former ABARE (Lawson et al. 2008), with some important modifications. The framework is spatially explicit, and is used to estimate the opportunities for land use change via reforestation and the associated carbon sequestration by CFI eligible plantings on Kyoto compliant cleared agricultural land (that is, land that was cleared before 31 December 1989). These opportunities are determined spatially by comparing the net present value (NPV) of returns from CFI compliant reforestation activities with estimates of agricultural land values. The analysis is undertaken for 1 km grid cells, using spatially explicit datasets for forest growth and agricultural returns, and calculates the area projected to be economically viable for CFI compliant reforestation, excluding land that is not available to these activities. Although the CFI allows for crediting of carbon plantings on non-Kyoto land, these have not been included in this analysis. The analysis presented in this report includes results from two global action scenarios, and employs a number of simplifying assumptions.

The Lawson et al. (2008) methodology has been modified for the present analysis to include some key factors that are likely to limit land use change from agriculture to carbon plantings and other Kyoto CFI compliant reforestation activities, as discussed below.

First, in the current study, the estimates of discounted returns to reforestation include water interception costs. The specific assumptions relating to the water price analysis are described in the assumptions section below. Because no such requirement currently exists for forest owners in Australia, a set of generalised water interception policy settings has been assumed for this analysis, but does not necessarily reflect current or intended government policy. Second, for this study, the area of land available for reforestation has been updated with an estimate of Kyoto Protocol compliant land and the exclusion of land that may be subject to native vegetation restrictions. These datasets are also discussed below. Finally, in this study, restrictions have been placed on the extent of timber plantation development to reflect potential infrastructure constraints over the period to 2049–50. The infrastructure-related restrictions were applied outside the spatially explicit framework, and hence are not reflected in the maps of potential land use change presented in appendix A.

The methodology described here projects reforestation to perpetuity. The infrastructure-related results were then used to determine the rate of reforestation over time. The results presented in this report represent the projected reforestation and associated carbon sequestration between 2012–13 and 2049–50.

It should be noted that the estimates in this report are sensitive to the assumptions used. Polglase et al. (2011) have illustrated such sensitivity of land use change to various assumptions relating to forest costs, returns and policy options. This report represents a scenario analysis, and hence all results are contingent on the combination of data and assumptions employed for each scenario. The report provides some assessment of the sensitivity of the results presented.

Modelling assumptions

The assumptions used for estimating abatement potential from the CFI reforestation activities have been developed jointly by ABARES, other relevant divisions of DAFF, DCCEE and the Australian Treasury in consultation with the CSIRO, unless stated otherwise. These assumptions are described below under the following broad headings:

- types of plantings and carbon sequestration rates
- costs of plantings and plantation management
- returns to forestry
- returns to agriculture: land use and land value
- returns from carbon sequestration
- Kyoto CFI compliant land availability and native vegetation restrictions
- water interception rates and water prices
- other key assumptions.

Types of plantings and carbon sequestration

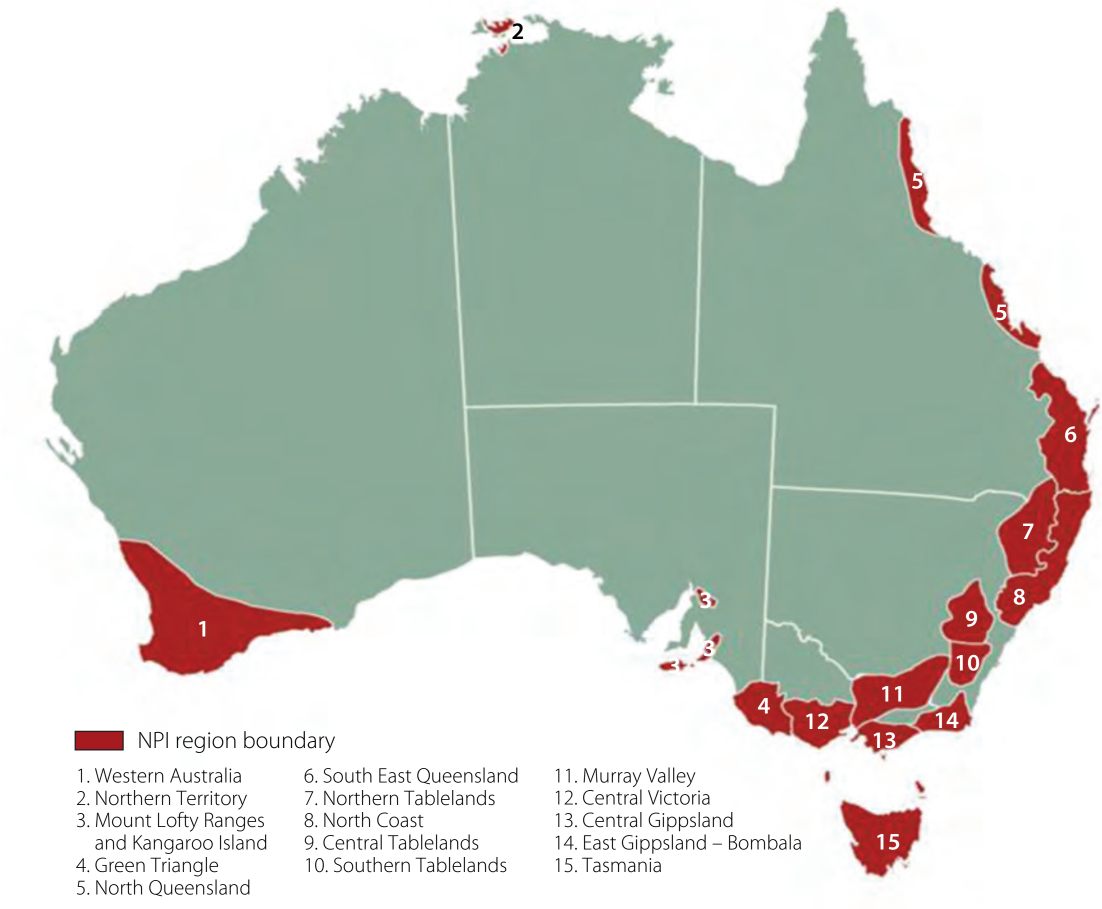
The amount of carbon that can be sequestered in carbon plantings and other Kyoto CFI compliant reforestation activities are derived from the National Carbon Accounting System (NCAS) datasets. The NCAS datasets describe productivity and growth functions for several timber plantation and carbon planting regimes across 20 regions of Australia, comprising the principal timber plantation regions as described in the National Plantation Inventory (NPI), as well as less productive areas in some states. The NPI regions are shown in map 1.

The NCAS data include several forestry regimes, including the two that are treated in this study as CFI compliant: carbon plantings and long rotation hardwoods. For each forestry regime, the NCAS data include yield tables for timber plantations, growth curves for carbon plantings and a forest productivity index (FPI), which are used to estimate timber supply and carbon sequestration. A discussion of the FPI estimates is available in AGO (2005). Table 1 presents data relating to the CFI compliant plantation species, rotation lengths for timber plantations, annual growth rates, and carbon dioxide sequestration rates (per hectare a year) assumed in this analysis. Other (non–CFI compliant) timber plantation species were also included in this analysis but are not incorporated in the reported estimates. The corresponding assumptions for non–CFI compliant timber plantation species are provided in appendix B.

The rates of carbon sequestration estimated using the FPI are consistent with the NCAS methodology that is used for Australia's National Greenhouse Gas Inventory. Additionally, in this analysis a 5 per cent 'risk of reversal buffer'—as outlined in the Carbon Credits (Carbon Farming Initiative) Bill 2011 (Parliament of Australia 2011)—was applied to the calculation of carbon permits entitlements for investors in reforestation. The risk of reversal buffer is to insure the national carbon offset credit scheme against temporary losses of carbon while carbon stores are recovering after a natural disaster such as fire or drought, and losses as a result of wrongdoing by the project proponent that cannot be remedied (for example, if the project proponent leaves the country).

Table 1 shows that the rotation ages of long rotation hardwood plantations range from 25 to 45 years, which were derived from the DCCEE's NCAS. The mean annual increment (MAI) and sequestration rates in table 1 are indicative rates for each region. The actual rates used are adjusted according to the FPI of each square kilometre grid cell in each region. As explained previously, there are likely to be other carbon plantings such as mallee that may meet CFI eligibility criteria but are not included in this report as the relevant data were not available at the time of analysis. Where a region is not listed, no regime of the relevant type was modelled.

map **1** National plantation inventory regions



Source: National Plantation Inventory (2006)

1 Assumed Kyoto CFI compliant plantation species and growth rates by region

Long rotation hardwoods	species	rotation	MAI a	carbon dioxide sequestration
Region		years	m^3/ha.yr	tCO_2-e/ha.yr b
Central Gippsland	*E. nitens*	45	9	14.5
Central Victoria	*E. globulus*	45	9	14.5
Green Triangle	*E. globulus*	25	14	24.2
Murray Valley	*E. globulus*	45	9	14.5
North Coast	North Coast eucalyptus	45	9	14.5
Northern Queensland	North Coast eucalyptus	45	9	14.5
Northern Tablelands	North Coast eucalyptus	45	9	14.5
South East Queensland	North Coast eucalyptus	45	9	14.5
Tasmania	*E. nitens*	25	14	24.2
Western Australia	*E. globulus*	25	14	24.2
South Australia (Mt Lofty)	*E. globulus*	25	14	24.2
Carbon plantings				
Region			m^3/ha.yr	tCO_2-e/ha.yr c
Bombala – East Gippsland	Mixed native		3.3	7.6
Central Gippsland	Mixed native		3.3	7.5
Central Tablelands	Mixed native		2.3	5.3
Central Victoria	Mixed native		2.2	5
Green Triangle	Mixed native		2.1	4.9
Murray Valley	Mixed native		2.2	5
North Coast	Mixed native		4.4	10
Northern Queensland	Mixed native		3.2	7.4
Northern Tablelands	Mixed native		2.5	5.8
Southern Tablelands	Mixed native		2.1	4.8
South East Queensland	Mixed native		2.9	6.5
Tasmania	Mixed native		2.8	6.3
Western Australia	Mixed native		1.1	2.4
South Australia	Mixed native		1.9	4.3
Northern Territory	Mixed native		2	4.6
Rest of NSW	Mixed native		1.1	2.6
Rest of Victoria	Mixed native		1.2	2.7
Rest of Queensland	Mixed native		0.7	1.5

a MAI = mean annual increment, which measures the average annual growth over the entire rotation length, including thinning. **b** Carbon dioxide sequestration rate measures tonnes of carbon, expressed in carbon dioxide equivalent, sequestered annually on average over the entire rotation period, measured prior to final harvest (excluding carbon sequestered then lost during thinning). These estimates have not been adjusted to reflect the application of the CFI risk of reversal buffer rule. **c** MAI and average carbon dioxide sequestration measured over 45 years for carbon plantings, over which around 82 per cent of carbon is sequestered. The average growth and sequestration rates for carbon plantings are based on an average of all cleared agricultural land estimated in each region. These estimates have not been adjusted to reflect the application of the CFI risk of reversal buffer rule.
Source: DCCEE's National Carbon Accounting System (NCAS)

Costs of plantings and plantation management

The costs of long rotation hardwood timber plantation and carbon plantings are derived from a number of sources. The costs for timber plantations are based on estimates used by Roberts (2007). These cost estimates are provided in table 2. All prices and costs have been converted to 2009–10 dollars using the consumer price index. The establishment costs include land preparation, planting and fertiliser application, which are assumed to occur only during the year the forest is established. In comparison, the management, harvesting and transport costs incurred by timber plantations are dependent on the plantation size and the volumes of logs harvested, and vary over the rotation length of the plantation. Because this analysis is designed to assess potential reforestation on a national scale, the costs used in this analysis are assumed to be uniform across all timber plantations, regardless of species or rotation length; more specific regional-scale analysis could include more detailed cost assumptions that reflect some of the regional resource constraints, plantation types and establishment and management costs appropriate for the region.

The costs of carbon plantings used in the present analysis are derived from a report undertaken for the DCCEE by the former ABARE (2008) and presented in table 2. While there may be significant infrastructure and resource constraints that limit the annual level of reforestation of timber plantations, these constraints are less likely to impinge on carbon plantings. This is because the establishment of these carbon plantings may, in many cases, be less resource intensive compared with timber plantations; for example, by using direct seeding method of establishing mixed species carbon plantings rather than the planting of tube stock seedlings.

2 Log prices and costs of plantings: long rotation hardwood plantations and carbon plantings

			LRHW timber plantations a	carbon plantings
Establishment costs	$/ha	year 1	2 740	3 200
Management costs	$/ha.yr	year 2–30	200	150
		year 30+	200	50
Roading	$/ha	year of first thinning	300	na
Marking	$/ha	each thinning	100	na
Harvesting	$/m^3	thinning and harvesting	22	na
Transport	$/m^3.km	forest to mill	0.2	na
Log price	$/m^3	at mill-door b	61–87	na

a LRHW = long rotation hardwood. **b** Mill-door prices differ by age of log and state; based on ABARES forestry gross value of production (GVP) data. **na** Not applicable.
Source: Roberts (2007); ABARE (2008); ABARES (2011).

Returns to forestry

The net present value (NPV) from reforestation under the CFI is determined using an annual real discount rate of 7 per cent over a 100-year time horizon. This rate is consistent with guidelines suggested by the Office of Best Practice Regulation (Australian Government 2010) and represents the weighted average of before-tax market returns on investment in Australia, after-tax returns on investments and the marginal cost of borrowing foreign funds.

The returns to logs produced from long rotation hardwood plantations are estimated using average mill-door log prices derived from ABARES log production survey data, using the average prices from hardwood and softwood plantations and native forests for each state (ABARES 2011). While softwood and short rotation hardwood plantations are assumed to be ineligible for carbon sequestration returns in this analysis, they are included in the present analysis because some areas may be competitive for these plantations even without carbon returns. Because the National Carbon Accounting System—Forest Productivity Index data do not distinguish between log types (for example, sawlogs or pulp logs), only one price is estimated for hardwood (broadleaved) and softwood (coniferous) logs, representing a weighted average of log types estimated in ABARES log production data. As shown in table 2, on average, hardwood logs are valued at between \$61 per cubic metre (m^3) and \$87/m^3 at mill-door. Prices for each regime differ based on the location (state) and the rotation length of the plantation (long rotation hardwoods are between 25 and 45 years rotation in this analysis).

Returns from timber plantations are calculated based on an assumption of even aged development, so that an investor will plant an equal area of forest each year. Consequently, for land identified as viable for timber plantations, the entire area will be fully planted in the same year that the forest planted in the first year reaches clear fall harvest age. At this point, the area planted each year is equal to the area harvested, a constant volume of timber is harvested each year, and the forest is said to be in a 'steady state', which means that the assumed volume of biomass and sequestered carbon in the forest remains constant for all subsequent years. Hence, under the CFI, long rotation hardwood timber plantations will receive carbon credits each year until the first clear fall harvest age is reached, after which the investors neither receive any further carbon credits nor pay for emissions associated with harvesting timber.

Table 3 provides the average annual growth rates in prices and costs assumed in this analysis over the period 2012–13 to 2049–50. The rates of growth in carbon prices, timber prices and agricultural land values were based on Treasury's modelling results provided to ABARES. For this analysis, ABARES has assumed that forest costs grow at the same rate as forest product prices. This assumption reflects the increasing marginal costs of production associated with increasing prices and an expansion of forest production, arising from constraints on inputs such as infrastructure, labour and land. However, various factors may mitigate such cost increases, such as economies of scale and 'learning by doing' in the nascent carbon planting sector. Future analysis could take account of these other factors affecting the cost of reforestation.

This analysis also assumes that water prices grow by an average of 5 per cent a year in real terms, which, in line with the assumed growth in agricultural land values and carbon prices, reflects the expectation that demand for water resources will continue to increase. Supporting this assumption, the Centre of Policy Studies simulations reported in Wittwer (2010) indicate that demand for water will continue to increase and strong growth of water prices is consistent with the overall expansion of the economy.

3 Average annual growth in real prices and costs over the period to 2049–50, by state and territory

	timber prices %	forest costs %	agricultural land values %	water prices %	carbon prices %
Medium global action scenario					
NSW	3	3	5	5	5
Vic	3	3	5	5	5
Qld	3	3	5	5	5
SA	3	3	5	5	5
WA	2	2	5	5	5
Tas	3	3	5	5	5
NT	6	6	5	5	5
Ambitious global action scenario					
NSW	3	3	5	5	5
Vic	3	3	5	5	5
Qld	3	3	6	5	5
SA	3	3	5	5	5
WA	2	2	5	5	5
Tas	4	4	5	5	5
NT	7	7	5	5	5

Sources: ABARES; Treasury

Returns to agriculture: land use and land value

In this analysis, the value of agricultural land represents the opportunity cost of reforestation. These data were based on 10-year averages of estimated agricultural land values collected through ABARES farm surveys, expressed in 2006–07 Australian dollars. The land value data were updated to 2009–10 values using the Australian Bureau of Statistics (ABS) time series of agricultural land values (ABS 2010).

Spatial datasets of potential agricultural land values for four aggregated industries (grains, livestock, dairy and sugar) were derived by applying a kernel smoothing algorithm to the ABARES farm survey data. A uniform horticulture land value was estimated for each state based on ABARES farm survey data. These estimated land values were then matched spatially to the estimated agricultural land use data from the Australian Collaborative Land Use Mapping Program (ACLUMP) version 4 (ABARES 2010a). Areas identified as cropping were allocated a grains land value derived from ABARES farm survey data; irrigated pastures were allocated a dairy land value; and sugar and horticulture land uses were allocated the ABARES farm survey land values for sugar and horticulture, respectively. For areas identified in the ACLUMP land use map as dryland livestock, an ABARES estimate of the likely rotation of these areas with cropping activities was used to evaluate the appropriate land value. Areas estimated to be cropping dominant were allocated the grains land value derived from ABARES farm survey data; areas estimated to be sown pasture dominant were given a livestock land value; and areas estimated to be part of a crop and sown pasture rotation were allocated the maximum of the grains and livestock land values.

As in the Lawson et al. (2008) analysis, the average annual growth in land values was based on the Treasury modelling, in which the average growth in the land values was estimated to range from 4 to 6 per cent a year across the states and territories during the study period (table 3).

Returns from carbon sequestration

The CFI allows project proponents to choose when to report on their project, provided that the reporting cycle is not shorter than 12 months or longer than five years. For this analysis, the returns generated from carbon sequestration are assumed to be received annually based on the estimated annual volume of carbon sequestered in that year according to the NCAS growth rates, less 5 per cent that is set aside for the carbon risk reversal buffer as outlined under the proposed CFI (DCCEE 2010). No transaction costs and no allowance for uncertainty are assumed in this analysis. As a result, the analysis is not able to account for the likely effects of different reporting cycles.

The carbon price trajectories, in 2009–10 Australian dollars, have been provided by the Treasury from 2012–13 to 2049–50. In each of these scenarios, the real carbon price grows at around 5 per cent a year from 2012–13 to 2049–50 (table 3); for the subsequent period, ABARES has assumed a growth rate of 4 per cent a year.

As mentioned earlier, this analysis assumed that only long rotation hardwood plantations and permanent carbon plantings are eligible for carbon sequestration credits; other timber plantations are assumed not to qualify for the 'common practice additionality' requirements for activities under the CFI. However, they may be competitive based solely on their timber returns, and hence have been included in this analysis but not incorporated in the reported results.

Carbon plantings are assumed to be permanent and investors in these reforestation activities are assumed to receive carbon credit returns annually. Once the reforestation planting ceases to receive sequestration returns, the forest is assumed to remain in a steady state, such that the landholder is assumed to continue to incur management costs for the forest, but does not receive any further returns, nor incurs any costs associated with emissions from the forest, so long as the forest is maintained.

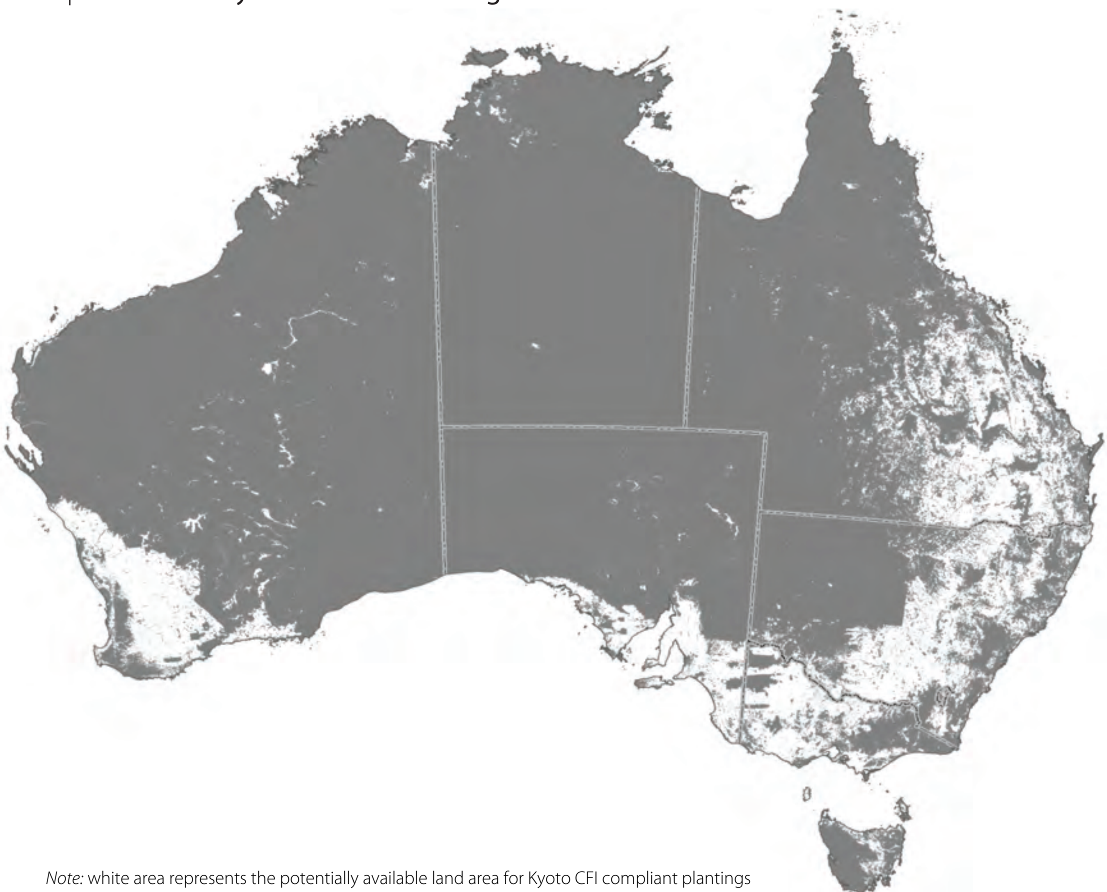
Kyoto CFI compliant land availability and native vegetation restrictions

ABARES has estimated the area of cleared agricultural land in Australia using the following datasets:

- Catchment Scale Land Use mapping for Australia dataset (ABARES 2010b)
- NCAS estimates of forested land in 1989 and 2009 (or 2006 in arid areas where the 2009 update is not available)
- National Vegetation Information System (NVIS) Version 4.1 provided by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC 2011b).

To be eligible for carbon sequestration credits, the land needs to be in an agricultural land use and not covered by woody vegetation in both 1989 and 2009 (or 2006 if 2009 data are not available). Furthermore, areas of intact native vegetation, estimated using the Major Vegetation Groups data provided by DSEWPaC, were excluded from the areas of potential reforestation, as these are likely to have limited development potential under state legislation (Burns et al. 2009). The NVIS data are based on data provided by several state and territory and Australian Government organisations. This analysis was carried out at a 100 m or better resolution and then aggregated to calculate the percentage of each 1 km grid cell potentially available for conversion to reforestation. The resulting potentially available areas are represented by the white areas in map 2.

map **2** Potentially available cleared agricultural land



Note: white area represents the potentially available land area for Kyoto CFI compliant plantings
Sources: ABARES (2010a,b); DSEWPaC (2011b); DCCEE NCAS

As the cleared land data relate to 2009 estimates, these do not include reforestation or deforestation that has occurred between 2009 and the present. ABARES modelling has not assumed any deforestation after the commencement of the analysis period (2012–13) as this analysis does not estimate the potential returns from existing plantations. Accordingly, the estimate of cleared land is assumed not to increase over time as a result of clearing of native forest or of not replanting harvested plantation forests.

Water interception rates and water prices

The Lawson et al. (2008) estimates did not account for any potential water interception implications of significant reforestation in water catchments. While there are currently no catchments in Australia that require investors in reforestation activities to purchase water entitlements, the present study estimates potential water interception on land with more than 600 mm of average annual rainfall (National Water Commission 2008), in order to model the potential impact of water entitlement requirements for reforestation activities. At present, it is difficult to define the policy settings that may be applied to reforestation activities with respect to water interception. Given the considerable uncertainties associated with estimating water interception by reforestation activities, and the fact that there are currently no requirements for forest investors to purchase water entitlements, the analysis presented in this report assumes policy settings that simulate the potential impact of water interception and associated costs on the viability of reforestation investments, but which may not necessarily be equivalent to proposed or actual future government policy. As with the other assumptions presented in this report, it should be noted that the results may be sensitive to changes in these assumed policy settings.

The water costs methodology used in this report is based on Hafi et al. (2010). Water interception is estimated for 1 km grid cells, with interception being defined as the reduction in estimated water yields (estimated as the difference between long-term average rainfall and evapotranspiration). Water costs are assumed not to be imposed on reforestation activities occurring on sites with less than 600 mm average annual rainfall; for land with more than 600 mm average annual rainfall, reforestation costs include the projected price of permanent water entitlements multiplied by the estimated volume of interception. Costs are assumed to be incurred annually by the forest owner, based on an annualised cost of high security or equivalent water entitlements. It is assumed that water interception is negligible for the first five years of a plantation (including the first five years after re-establishment), and that the average annual interception is 70 per cent of the estimated peak interception for the forest. The specific methodology and assumptions relating to the water costs modelling used in this analysis are provided in appendix C.

Data on water costs are available for some irrigation regions in Australia. However, for most areas, the data are either confidential or do not exist because of relatively undeveloped or shallow water markets. Where available, water costs have been incorporated into the calculation of potential net returns for reforestation; for other regions, the cost of water entitlements in neighbouring catchments was used where available, while a zero water price was assumed where this was not possible. Table C1 in appendix C provides the water costs assumed in this analysis, based on the latest publicly available water market prices. ABARES has used the midpoint of the high security—high reliability water pricing entitlements. Where high security water prices were not available, lower security prices were used and adjusted: medium security prices were multiplied by 2 to derive a corresponding high security price, while low security prices were multiplied by 4.

Other key assumptions

The analysis has also considered other potential restrictions on reforestation expansion, such as regional capacity constraints in timber processing. This analysis has assumed that, over the period to 2049–50, the volume of logs harvested from newly established timber plantations identified as viable in this analysis cannot exceed the current log harvest in each state. This assumption is equivalent to assuming that investments in processing capacity to 2049–50 may be sufficient to allow a doubling of log harvest volumes from current levels, or the replacement of some existing log harvest volumes with these newly developed timber plantations. This assumption is intended as a plausible representation of the impact of infrastructure constraints in plantation development. However, it is not based on ABARES analysis, and is not intended to suggest the likelihood of this investment in processing capacity occurring. Placing a timber processing capacity constraint also addresses other issues such as the potential demand that extensive reforestation development will place on other sectors, such as the amount of seedlings required annually and the extent of investment in timber processing capacity required to process harvested timber.

The analysis also included a restriction on the economic haulage distance for logs. ABARES has assumed that cleared agricultural land located more than 250 km from current processing infrastructure would not be considered for timber plantations in the period to 2049–50. This assumption does not apply to carbon plantings.

The carbon accounting provisions of the Kyoto Protocol are assumed to remain unchanged during the course of the analysis period. Any sequestration potential from harvested wood products has not been included in this analysis.

As with the Lawson et al. (2008) analysis, results presented in this report represent the entire area that is economically viable for long rotation hardwood timber plantations or carbon plantings. That is, the results do not reflect any remaining social and other factors that may affect the uptake of CFI compliant reforestation projects.

Scenarios

The Australian Treasury has modelled two global action scenarios—'medium' global action scenario and 'ambitious' global action scenario—corresponding to the stabilisation of atmospheric greenhouse gases at 550 ppm and 450 ppm, respectively, by around 2100. There are two corresponding world carbon price paths projected to achieve these targets.

ABARES has modelled sequestration from reforestation under the CFI for both the medium global action and the ambitious global action scenarios. Generators of Kyoto CFI compliant credits will be able to trade in the global carbon markets at the global carbon price. The carbon prices used in this modelling start at around \$23/ t CO_2-e and \$47/ t CO_2-e in 2012–13 for the medium and ambitious global action scenarios, respectively, with both the starting prices growing at an average rate of about 5 per cent a year to 2049–50. Note that the carbon prices used in this report may differ slightly from the carbon prices in Treasury's final modelling because of the iterative nature of the modelling process. For this analysis, it is necessary to extend the carbon prices out to 2100 and ABARES has assumed an average annual rate of growth in world carbon prices of 4 per cent from 2050–51 to 2099–2100.

4 Results

This section presents ABARES estimates of the economically viable land area for reforestation and the associated potential sequestered carbon for the period 2012–13 to 2049–50 under the two global action scenarios described earlier. Further results are presented in appendix A over a longer period. The modelling results suggest that the ability to sell CFI carbon credits can significantly increase the economic potential of reforestation in Australia, although most of this potential is realised under the ambitious global action scenario. The discussion below also includes some analysis of the potential impacts on agriculture arising from land use change, the robustness of the results to changes in the assumptions, and a comparison of these results with previous modelling.

The medium global action scenario

The ability to sell carbon credits at a global carbon price under the medium global action scenario is projected to increase the area of land economically viable for reforestation in Australia to around 0.35 million hectares by 2049–50, representing about 0.1 per cent of agricultural land (table 4). Of this, 0.19 million hectares are estimated to be long rotation hardwood plantations, and the remaining 0.16 million hectares are projected to be carbon plantings. A large proportion of the long rotation hardwood plantations under this scenario are projected to be planted in southern Australia, particularly Tasmania and South Australia (table 4). This results, in part, from the relatively short rotation lengths and higher average growth rates assumed for long rotation hardwood timber plantations in these regions (table 1). In contrast, carbon plantings are estimated to be most suitable in the north of Australia, particularly New South Wales and Queensland (table 4).

The total amount of carbon dioxide sequestered from the additional reforestation under the medium global action scenario is estimated to be around 72 Mt of carbon dioxide equivalent (CO_2-e) over the period 2012–13 to 2049–50 (table 5). Long rotation hardwood plantations and carbon plantings are each estimated to sequester similar amounts of carbon over the period 2012–13 to 2049–50.

4 Additional areas of reforestation projected under the medium global action scenario, by state and territory, 2012–13 to 2049–50

	2012–13 to 2021–22	2022–23 to 2031–32	2032–33 to 2041–42	2042–43 to 2049–50	2012–13 to 2049–50
	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha
LRHW timber plantations					
NSW	<0.1	<0.1	<0.1	<0.1	<0.1
Vic	<0.1	2.5	4.9	3.6	11
Qld	<0.1	<0.1	<0.1	<0.1	<0.1
SA	0.1	1.9	29.2	22.8	54
WA	<0.1	<0.1	<0.1	<0.1	0.1
Tas	0.6	6.2	66.8	51.5	125.1
NT	<0.1	<0.1	<0.1	<0.1	<0.1
Aus	0.7	10.6	101	77.9	190.2
Carbon plantings					
NSW	4.8	14.6	44.1	35.3	98.8
Vic	<0.1	<0.1	0.1	<0.1	0.1
Qld	5.8	11.5	22.7	18.2	58.1
SA	<0.1	<0.1	<0.1	<0.1	<0.1
WA	<0.1	<0.1	<0.1	<0.1	<0.1
Tas	<0.1	<0.1	<0.1	<0.1	<0.1
NT	<0.1	<0.1	<0.1	<0.1	<0.1
Aus	10.6	26.1	66.9	53.5	157.1

Notes: There are additional 19 450 hectares of softwood and short rotation hardwood plantations projected to be economically viable that do not earn the CFI carbon credits. LRHW = long rotation hardwood plantations.

5 Tonnes of carbon dioxide equivalent sequestered by additional reforestation activities under the medium global action scenario, by state and territory, 2012–13 to 2049–50

	2012–13 to 2021–22	2022–23 to 2031–32	2032–33 to 2041–42	2042–43 to 2049–50	2012–13 to 2049–50
	'000 t	'000 t	'000 t	'000 t	'000 t
LRHW timber plantations					
NSW	<1	<1	<1	<1	<1
Vic	<1	182	696	818	1 696
Qld	<1	<1	<1	<1	<1
SA	15	245	3 438	6 405	10 103
WA	<1	2	8	9	20
Tas	88	946	8 337	14 508	23 879
NT	<1	<1	<1	<1	<1
Aus	104	1 376	12 479	21 740	35 698
Carbon plantings					
NSW	539	2 518	8 160	12 266	23 484
Vic	<1	3	10	16	29
Qld	542	1 977	4 600	6 053	13 172
SA	<1	<1	<1	<1	<1
WA	<1	<1	<1	<1	<1
Tas	<1	1	2	4	7
NT	<1	<1	1	2	4
Aus	1 081	4 499	12 774	18 341	36 695

Notes: Includes only carbon dioxide sequestration in projected CFI eligible reforestation activities. LRHW = long rotation hardwood plantations.

The ambitious global action scenario

The alibility to sell CFI carbon credits at a global carbon price under the ambitious global action scenario is projected to increase the land area economically viable for reforestation in Australia to around 4.9 million hectares over the period 2012–12 to 2049–50 (table 6), representing about 1.3 per cent of agricultural land. Of this, around 1.2 million hectares are estimated to be long rotation hardwood plantations, and 3.7 million hectares are projected to be carbon plantings. As with the medium global action scenario, a large proportion of the long rotation hardwood plantations identified as economically viable in this scenario is projected to occur in southern Australia, particularly Victoria, Tasmania and Western Australia (table 6). In contrast, carbon plantings were estimated to be most suitable in the north of Australia, particularly New South Wales and Queensland.

6 Additional areas of reforestation projected under the ambitious global action scenario, by state and territory, 2012–13 to 2049–50

	2012–13 to 2021–22 '000 ha	2022–23 to 2031–32 '000 ha	2032–33 to 2041–42 '000 ha	2042–43 to 2049–50 '000 ha	2012–13 to 2049–50 '000 ha
LRHW timber plantations					
NSW	0.5	0.5	0.5	0.4	2
Vic	114.1	135.5	109.5	39.8	398.9
Qld	<0.1	<0.1	<0.1	<0.1	<0.1
SA	54.5	74.1	73.5	31.1	233.3
WA	0.9	11.2	140.7	109.1	261.9
Tas	108	109.8	57.6	2.3	277.7
NT	<0.1	<0.1	<0.1	<0.1	<0.1
Aus	278	331.1	381.7	182.8	1 173.7
Carbon plantings					
NSW	334.4	516.9	798.8	639.1	2 289.2
Vic	10.8	14.3	19	15.2	59.4
Qld	146.5	258.5	456.3	365	1 226.3
SA	2.9	10.6	38.7	30.9	83
WA	<0.1	0.5	0.9	0.8	2.2
Tas	0.5	0.9	1.5	1.2	4
NT	8.1	15.7	30.6	24.5	78.9
Aus	503.2	817.3	1 345.8	1 076.7	3 743.0

Notes: There are additional 4072 hectares of softwood and short rotation hardwood plantations projected to be economically viable that do not earn the CFI carbon credits. LRHW = long rotation hardwood plantations.

The total amount of carbon dioxide sequestered from the additional reforestation under the ambitious global action scenario is estimated to be around 865 Mt CO_2-e over the period 2012–13 to 2049–50 (table 7). Most of the sequestered carbon is estimated to occur from the large area of carbon plantings projected to be established between 2012–13 and 2049–50. Also note that additional sequestration is estimated to occur from these carbon plantings after 2049–50; however, this is not presented in this report.

7 Tonnes of carbon dioxide equivalent sequestered by additional reforestation activities under the ambitious global action scenario, by state and territory, 2012–13 to 2049–50

	2012–13 to 2021–22	2022–23 to 2031–32	2032–33 to 2041–42	2042–43 to 2049–50	2012–13 to 2049–50
	'000 t	'000 t	'000 t	'000 t	'000 t
LRHW timber plantations					
NSW	12	33	55	59	160
Vic	13 434	39 927	36 989	10 717	101 068
Qld	<1	<1	<1	<1	<1
SA	6 028	18 779	19 974	8 645	53 426
WA	148	1 629	14 930	26 163	42 870
Tas	11 139	31 562	23 943	720	67 365
NT	<1	<1	<1	<1	<1
Aus	30 761	91 932	95 892	46 304	264 889
Carbon plantings					
NSW	23 888	74 399	139 876	164 449	402 612
Vic	715	2 212	4 123	4 822	11 872
Qld	9 175	30 045	60 444	73 836	173 500
SA	96	490	1 793	2 802	5 181
WA	<1	13	48	71	131
Tas	38	127	267	333	765
NT	271	961	2 161	2 796	6 189
Aus	34 182	108 247	208 711	249 110	600 249

Notes: Includes only carbon dioxide sequestration in projected CFI eligible reforestation activities. LRHW = long rotation hardwood plantations.

Comparing the results under the medium and ambitious global action scenarios, the rate of increase in the area of land economically viable for reforestation would be greater than the rate of increase in the carbon price. This is similar to previous estimates by Lawson et al. (2008) for the two different carbon price scenarios known as CPRS –5 and CPRS –15 (Australian Government 2008), and arises because each area of land has a threshold carbon price, above which reforestation (either long rotation hardwood plantations or carbon plantings) will become economically viable. In other words, this threshold represents the price required to make reforestation competitive against existing land uses for each land area. The results presented above suggest that for a relatively large area of land the threshold returns lie between the carbon price under the medium global action scenario and the higher carbon price under the ambitious global action scenario.

Impact of potential reforestation on current land uses

In general, the economic viability of the projected CFI reforestation appears to be confined to dryland grazing land. Under the medium global action scenario, 94 per cent of land economically viable for reforestation is projected to occur on dryland livestock land (table 8), while the corresponding figure is 86 per cent in the ambitious global action scenario (table 9).

8 Additional areas of reforestation projected under the medium global action scenario, by current agricultural land use and by state and territory, 2012–13 to 2049–50

	livestock – dryland '000 ha	livestock – irrigated '000 ha	cropping – dryland '000 ha	cropping – irrigated '000 ha	sugar '000 ha	total projected reforestation '000 ha	current agricultural land use a '000 ha	projected reforestation as a % of current agricultural land use %
All forests								
NSW	96.8	<0.1	1.8	0.2	<0.1	98.8	51 851	0.2
Vic	10.2	<0.1	0.9	<0.1	<0.1	11.1	11 117	0.1
Qld	42.8	<0.1	14.6	0.2	0.6	58.1	121 801	<0.1
SA	51.9	<0.1	2.1	0.1	<0.1	54	47 255	0.1
WA	0.1	<0.1	<0.1	<0.1	<0.1	0.1	95 591	<0.1
Tas	124.6	<0.1	0.5	0.1	<0.1	125.2	1 052	11.9
NT	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	55 450	<0.1
Aus	326.3	<0.1	19.8	0.6	0.6	347.3	384 118	0.1
% total reforestation	94	<0.1	5.7	0.2	0.2	100		

a Agricultural areas from ABS (2011).
Note: Rounding errors may persist

9 Additional areas of reforestation projected under the ambitious global action scenario, by current agricultural land use and by state and territory, 2012–13 to 2049–50

	livestock – dryland	livestock – irrigated	cropping – dryland	cropping – irrigated	sugar	total projected reforestation	current agricultural land use a	projected reforestation as a % of current agricultural land use
	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	%
All forests								
NSW	1 998.8	1.1	279.4	11.6	0.3	2 291.2	51 851	4.4
Vic	415.3	0.3	40.6	2.2	<0.1	458.3	11 117	4.1
Qld	1 148.0	0.2	74.3	1.4	2.4	1 226.3	121 801	1
SA	234	<0.1	80	2.3	<0.1	316.3	47 255	0.7
WA	112.7	<0.1	151.3	0.1	<0.1	264	95 591	0.3
Tas	240	1.1	36.5	4.1	<0.1	281.7	1 052	26.8
NT	77.9	<0.1	1	<0.1	<0.1	78.9	55 450	0.1
Aus	4 226.7	2.7	662.9	21.7	2.7	4 916.7	384 118	1.3
% total reforestation	86	0.1	13.5	0.4	<0.1	100		

a Agricultural areas from ABS (2011).
Note: Rounding errors may persist

Dryland livestock land generally has a lower land value than other agricultural activities, and where this corresponds to relatively high forest productivity, as measured using the spatial forest productivity index data, the results show that there are many areas where the potential reforestation returns exceed those livestock land values. In contrast, even under the higher carbon prices in the ambitious global action scenario, there is virtually no reforestation on irrigated livestock, irrigated cropping or sugar land. Note that horticulture is excluded from these results as no areas were identified as economically competitive on these land areas.

In aggregate, the potential for reforestation identified in this analysis constitutes, at most, 1.3 per cent of agricultural land in Australia (table 9); the corresponding impact on agricultural returns would be less than this in percentage terms, because the areas identified as economically viable are projected to occur on dryland grazing areas with low returns. For the majority of states, the impact on the agricultural area is projected to be very small (see also maps A1 and A2 in appendix A). However, while the national impact of reforestation is projected to be relatively small, there may be some regions where a significant proportion of the regional agricultural area is identified as economically viable for reforestation. For example, Tasmania has only around 1 million hectares of agricultural land. While the projected land area of economically viable reforestation is smaller in Tasmania than in most other states under the ambitious global action scenario, this represents more than one-quarter of current agricultural land in the state (table 9). While almost all of this is projected to be on dryland livestock land, there are likely to be other constraints, not included in this analysis, which may limit the actual extent of reforestation to below the level estimated in this report.

This highlights some of the limitations of national-scale analyses, such as presented in this report. A national-level analysis cannot include many of the region-specific factors affecting reforestation—such as higher resolution productivity and agricultural land value data, regional resource and skills availability, and local attitudes to land use change. Accordingly, the regional results must be interpreted with caution. Nonetheless, the national results represent robust projections of the overall economic viability of reforestation, while the regional and state results can be used as useful bases for further finer-scale analysis.

Landholders' preferences for land use change to reforestation

The estimates and analysis presented above are based on a framework that identifies when land becomes economically viable for reforestation activities in comparison to current agricultural land uses, based on relative net returns in present value terms across various land uses under selected carbon price paths. In other words, the results presented above assume that land will be converted to reforestation when the net present value of reforestation returns just exceeds the agricultural land value. It neither takes into account the preferences of landholders, nor incorporates the margin by which returns to reforestation must exceed those of agriculture to induce possible land use change. For example, landholders with a preference for traditional agricultural activities, or who are averse to some of the risks associated with changing farm activities, may be less inclined to convert to reforestation activities unless forestry returns exceed those from agriculture by a certain margin.

While unable to take into account landholders' actual preferences, more detailed analysis shows that for a significant proportion of the projected reforestation area, the returns are significantly above the corresponding agricultural land value. The proportion of the projected reforestation area that exceeds agricultural land values by up to 10 per cent, by between 10 and 25 per cent, and by more than 25 per cent was estimated for each scenario. Table 10 shows that, in the medium global action scenario, more than 41 per cent of projected reforestation generated returns that exceeded agricultural returns by more than 25 per cent. In the ambitious global action scenario, around 85 per cent of the projected reforestation area exceeded agricultural returns by more than 25 per cent (table 11).

10 Proportion of total agricultural land that could be converted to reforestation under alternative landholders' decision scenarios: the medium global action scenario, by state and territory, 2012–13 to 2049–50 (%)

	potential forestry returns exceeding agricultural returns by			
	less than 10 per cent	between 10 and 25 per cent	greater than 25 per cent	total
NSW	32.1	28.8	39.1	100
Vic	98.4	0.5	1.1	100
Qld	10.9	13.2	76	100
SA	20.7	20.6	58.7	100
WA	100	<0.1	<0.1	100
Tas	40.3	36	23.7	100
NT	<0.1	<0.1	100	100
Australia	31.9	26.6	41.5	100

Note: Rounding errors may persist

11 Proportion of total agricultural land that could be converted to reforestation under alternative landholders' decision scenarios: the ambitious global action scenario, by state and territory, 2012–13 to 2049–50 (%)

	potential forestry returns exceeding agricultural returns by			
	less than 10 per cent	between 10 and 25 per cent	greater than 25 per cent	total
NSW	3.2	4.1	92.7	100
Vic	19.5	17	63.5	100
Qld	2.2	4.5	93.3	100
SA	9.9	18.1	72	100
WA	50.1	16.8	33	100
Tas	5.8	11	83.2	100
NT	<0.1	<0.1	100	100
Australia	7.5	7.3	85.2	100

Note: Rounding errors may persist

While a more detailed sensitivity analysis would highlight the impact of changes to specific assumptions on the results, the figures presented in tables 10 and 11 suggest that the research finding of a significant proportion of the land area estimated to be economically viable for reforestation would be robust to changes to some assumptions, particularly under the higher carbon price in the ambitious global action scenario.

Comparison with previous modelling

Table 12 presents a comparison of the results from the current study with those from the previous major study by the former ABARE (Lawson et al. 2008), which was provided to the Treasury as part of the Australian Government's *Australia's Low Pollution Future* report (Australian Government 2008). The table indicates that in both scenarios of the previous study, a significant area of agricultural land was projected to be economically viable for reforestation. Under the CPRS –5 scenario, where the carbon price was assumed to start at around \$21/ t CO_2-e in 2010 (in 2005 Australian dollars) and rise by 4 per cent a year, around 5.8 million hectares of land were projected to be economically viable. For the CPRS –15 scenario, where the carbon price was higher, starting at around \$29/ t CO_2-e in 2010 and rising by 4 per cent a year, the area of agricultural land projected to be economically viable for reforestation increased substantially to more than 26 million hectares. As discussed above, consistent with the present study, the economic viability of reforestation was estimated to respond quite significantly to an increase in the carbon price, and most of this increase in reforestation comprised carbon plantings.

As can be seen from table 12, the viability of reforestation has been significantly curtailed in the current study. Despite significantly higher assumed carbon prices in the present ambitious global action scenario compared with both the CPRS –5 and CPRS –15, the land area of projected reforestation is less under the ambitious global action scenario than under the previous CPRS scenarios.

These differences can be attributed to a number of factors, including the policy settings assumed and the data used. In relation to the former, Lawson et al. (2008) examined the potential for reforestation under the CPRS (DCC 2008), under which all timber plantations were assumed to be eligible for carbon credits. As explained above, 'business as usual' timber plantations, such as short rotation hardwoods and softwood plantations, are not assumed to be entitled to these credits under the CFI. While an additional timber plantation has been included in the present analysis, the growth rates and rotation lengths of the long rotation hardwoods regime are significantly different from the traditional timber plantations. The other principal difference in policy assumptions between the two studies is the imposition of water interception charges in the present study, which limited the economic viability of both timber plantations and carbon plantings in areas with more than 600 mm of rainfall.

12 Comparison of economically viable area of reforestation to 2050, current study and Lawson et al. (2008)

	current study		Lawson et al. (2008)	
	medium global action	ambitious global action	CPRS –5	CPRS –15
	'000 ha	'000 ha	'000 ha	'000 ha
Timber plantations a				
NSW	<1	2	293	464
Vic	11	399	491	950
Qld	<1	<1	447	293
SA	54	233	619	1 031
WA	<1	262	546	700
Tas	125	278	651	1 076
NT	<1	<1	<1	<1
Aus	190	1 174	3 047	4 514
Carbon plantings				
NSW	99	2 289	456	7 945
Vic	<1	59	9	84
Qld	58	1 226	1,527	10 591
SA	<1	83	19	481
WA	<1	2	35	1 308
Tas	<1	4	1	1
NT	<1	79	692	1 400
Aus	157	3 743	2 740	21 812

a Long rotation hardwood plantations for current study and short rotation hardwoods and softwood plantations for Lawson et al. (2008); see text for further details.

Other important factors that have constrained the estimated reforestation potential in the current study are the higher costs of establishment for carbon plantings (which were assumed to account for additional costs of compliance and management of these plantings), the restricted land availability in the present study (where land that is likely to be subject to native vegetation restrictions was excluded from the analysis), and the imposition of capacity constraints on the extent of timber plantation expansion in each state, as discussed above. There have also been a number of updates to the price and cost assumptions used in the current analysis.

This comparison reveals, to some extent, the sensitivity of results to changes in key assumptions, and highlights that the results are contingent on the underlaying assumptions and should not be interpreted as forecasts of likely land use change.

5 Conclusion

In projecting carbon sequestration potential from reforestation, this report updates some of the data and assumptions used in Lawson et al. (2008), such as water interception costs for reforestation landholders, the updated Kyoto compliant land and native vegetation restrictions, an additional timber plantation regime and the CFI settings including the risk of reversal buffer. Assumptions relating to the land available to reforestation that could be eligible under the CFI, carbon prices and the costs of undertaking these reforestation activities are important determinants of potential switching from agricultural production to reforestation plantings.

Under the medium global action scenario, the area of agricultural land that is economically viable for reforestation between 2012–13 and 2049–50 is estimated at 0.35 million hectares, representing about 0.1 per cent of agricultural land in Australia. Approximately 45 per cent of this area (0.16 million hectares) is estimated to be carbon plantings. By comparison, under the ambitious global action scenario, the land area economically viable for reforestation between 2012–13 and 2049–50 is projected to be significantly higher, reaching around 4.9 million hectares and representing about 1.3 per cent of Australia's agricultural land. Of this, approximately 76 per cent (3.7 million hectares) is estimated to be carbon plantings.

The methodology used for the estimates neither takes into account the land use preferences of landholders nor incorporates the margin by which returns from reforestation must exceed those from agriculture to induce possible land use change. For example, it is likely that some landholders with a preference for traditional agricultural activities, or who are averse to any risks associated with changing farm activities, will not be inclined to switch to reforestation activities unless reforestation returns exceed those from agriculture by a substantial margin.

To capture such possibilities, for the two global action scenarios, the estimates of economically viable reforestation areas are further analysed for a number of alternative landholders' decision scenarios: reforestation returns exceeding agricultural returns by up to 10 per cent, by betweeen 10 and 25 per cent, and by more than 25 per cent. These cover a range of landholders' risk preferences for potential land use change. The sensitivity analysis suggests that in the medium global action scenario, returns for more than 41 per cent of projected reforestation land exceed agricultural returns by more than 25 per cent. Under the ambitious global action scenario, the comparable estimate is about 85 per cent.

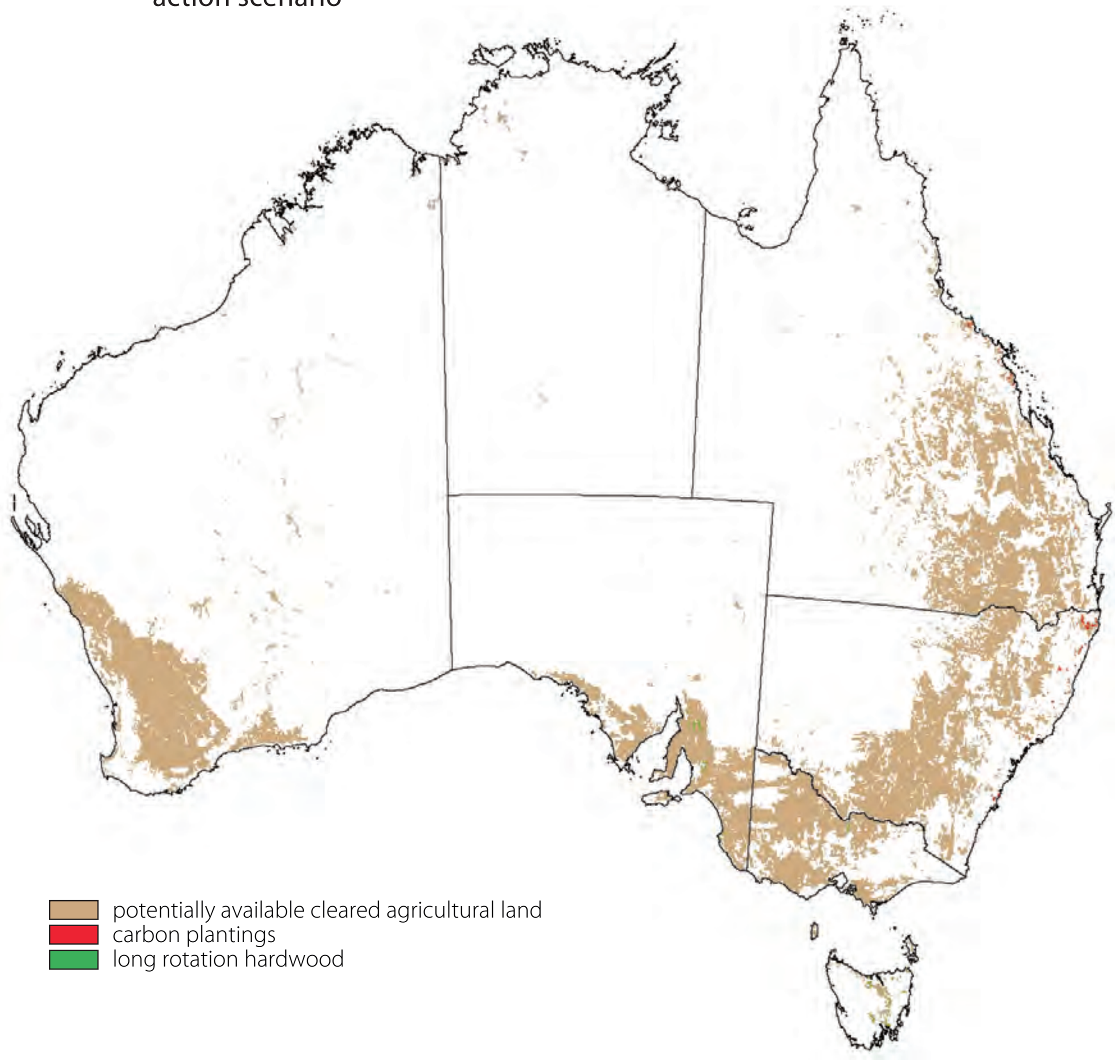
Comparing the results under the two global action scenarios, the rate of increase in the area of land economically viable for reforestation was greater than the rate of increase in the carbon price. This is similar to a previous finding by Lawson et al. (2008) for the CPRS –5 and CPRS –15 scenarios, and arises because each area of land has a threshold carbon price, above which reforestation (either long rotation hardwood plantations or carbon plantings) will become economically viable. That is, the threshold represents the price required to make reforestation competitive against existing agricultural land uses for each land area. The results presented above suggest that for a relatively large area of agricultural land, the threshold returns lie between the carbon price under the medium global action scenario and the higher carbon price under the ambitious global action scenario.

Finally, it must be emphasised that the estimates presented in this report represent the entire land area that is economically viable for long rotation hardwood timber plantations or carbon plantings, and are sensitive, in varying degrees, to the specific assumptions used. In particular, the analysis did not consider uncertainties around reforestation growth rates and future climate change impacts. Nonetheless, the projections in this report are the best estimates given the assumptions listed, suggesting a significantly high carbon price can substantially enhance the economic viability of reforestation activities within Australia.

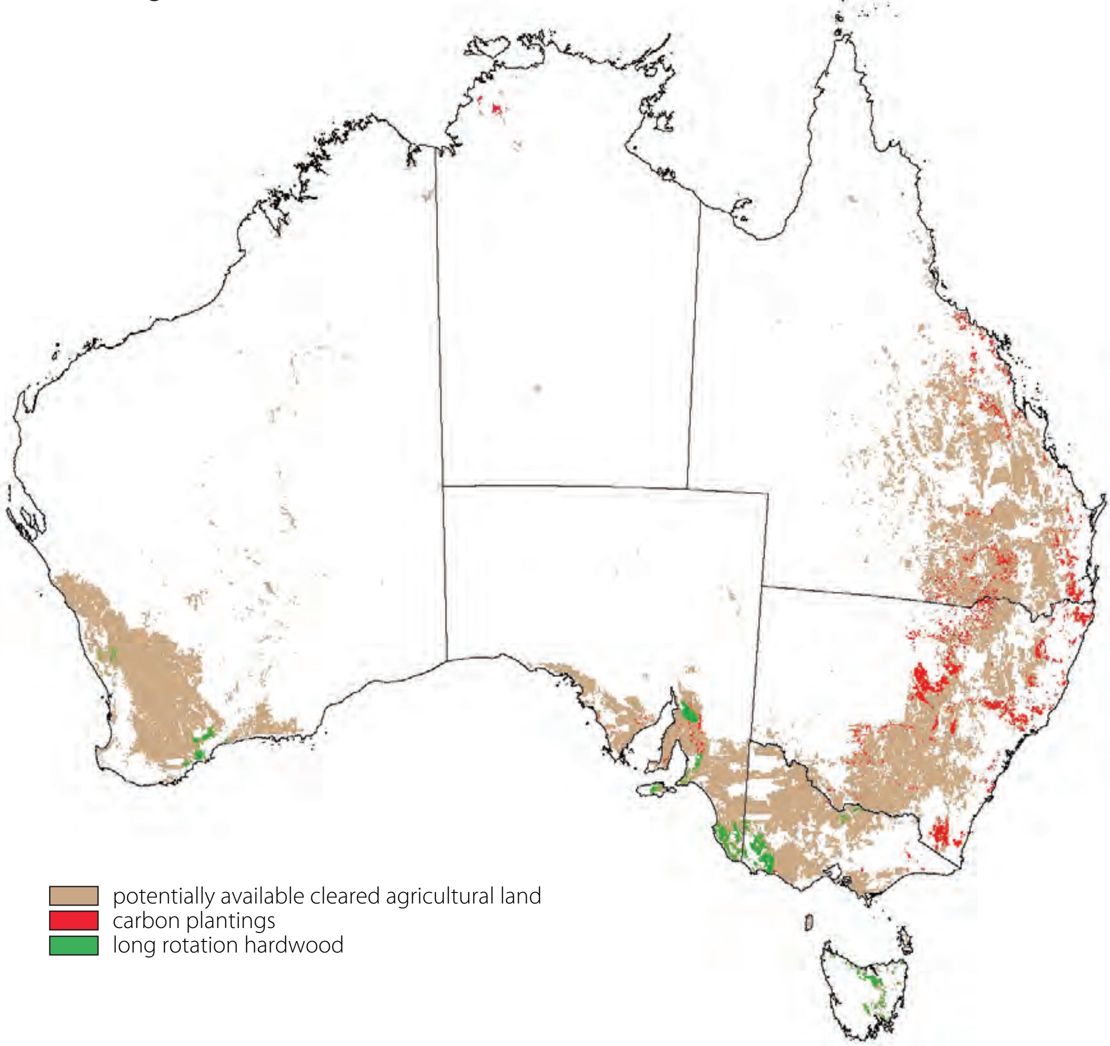
Appendix A
Maps of reforestation potential under the selected carbon prices

This appendix presents maps of the potential land use conversion to reforestation activities under selected carbon price scenarios. These maps of projected land use change represent the projected reforestation under the selected carbon price scenarios to perpetuity and, therefore, depict larger land use change to reforestation than was presented earlier in this report for the period to 2049–50.

map **A1** Potential land use conversion to reforestation under the medium global action scenario



map **A2** Potential land use conversion to reforestation under the ambitious global action scenario



Appendix B
Additional data used in ABARES analysis

B1 Assumed non–CFI compliant plantation species and growth rates by region

hardwoods Region	species	rotation years	MAI a m^3/ha.yr	carbon dioxide sequestration tCO_2-e/ha.yr b
Bombala – East Gippsland	Eucalyptus	15	14	24.9
Central Gippsland	Eucalyptus	25	17	22
Central Victoria	Eucalyptus	15	14	24.9
Green Triangle	*E. globulus*	15	16	28.3
Southern, Central and Northern Tablelands	Eucalypt	15	14	27.3
North Coast NSW and Queensland	Eucalypt	15	14	27.3
Tasmania	*E. nitens*	15	13	22.6
Western Australia	*E. globulus*	10	18	29
South Australia	*E. globulus*	15	14	24.9
Northern Territory	Hardwood	20	14	25.1

softwoods Region		years	m^3/ha.yr	tCO_2-e/ha.yr
Bombala – East Gippsland	*P. radiata*	30	14	13.7
Central Gippsland	*P. radiata*	30	18	19.6
Central Tablelands	*P. radiata*	30	14	13.7
Central Victoria	*P. radiata*	35	14	14.6
Green Triangle	*P. radiata*	30	18	19.7
Murray Valley	*P. radiata*	35	15	16.4
North Coast	Southern pine	30	14	15
Northern Queensland	Southern pine	35	11	12.3
Northern Tablelands	Southern pine	30	14	13.7
Southern Tablelands	*P. radiata*	30	14	13.7
South East Queensland	Southern pine	35	11	12.3
Tasmania	*P. radiata*	35	20	23.4
Western Australia	*P. radiata*	35	17	18
South Australia	*P. radiata*	30	16	17.8

a MAI = mean annual increment, which measures the average annual growth over the entire rotation length, including thinning.
b Carbon dioxide sequestration rate measures tonnes of carbon, expressed in carbon dioxide equivalent sequestered annually, on average, over the entire rotation period, measured prior to final harvest (excluding carbon sequestered then lost during thinning). Note that, for this analysis, the timber plantations presented in this table are not assumed to be CFI compliant, and hence investors do not earn carbon credits.
Source: DCCEE's National Carbon Accounting System (NCAS).

Appendix C
Water interception methodology and assumptions used in ABARES analysis

This appendix lists the specific assumptions used in ABARES water interception analysis by reforestation activities.

- In determining water yield for each catchment, there are assumed to be only two land use types: forest and non-forest (herbaceous vegetation/grassland). Only long-run average water use is modelled.
- Water use by the two land use types is based only on rainfall. Other factors affecting forest productivity, as modelled in the 3–PG model (Landsberg and Waring 1997) or FullCAM in NCAS are not accounted for. Nor does the analysis account for different implications of reforestation species (softwood, hardwood, native, mallee) or silviculture (long/short rotation, thinning, stems per hectare) on water use.
- The analysis is undertaken for 1 km grid cells.
- For rainfall, ANUCLIM mean annual rainfall data for 1976–2005 (CRES 2000) are used.
- The area of non-forest land and forested land is estimated using the most recent (generally 2009) NCAS woody vegetation extent data.
- A simple water balance model developed by Bradford et al. (2001) that links evapotranspiration, precipitation and percent age of land cover under trees is used in this analysis to estimate the effect of reforestation on long-term water yield. The level of evapotranspiration by forests and non-forests (grassland) is estimated using a catchment water balance relationship, where evapotranspiration is a function of rainfall and other parameters (figure C1) as follows:

Equation 1 **Water balance model (Bradford et al. 2001)**

$$ET = P\left\{\frac{1 + w\left(\frac{E_0}{P}\right)}{1 + w\left(\frac{E_0}{P}\right) + (E_0/P)^{-1}}\right\}$$

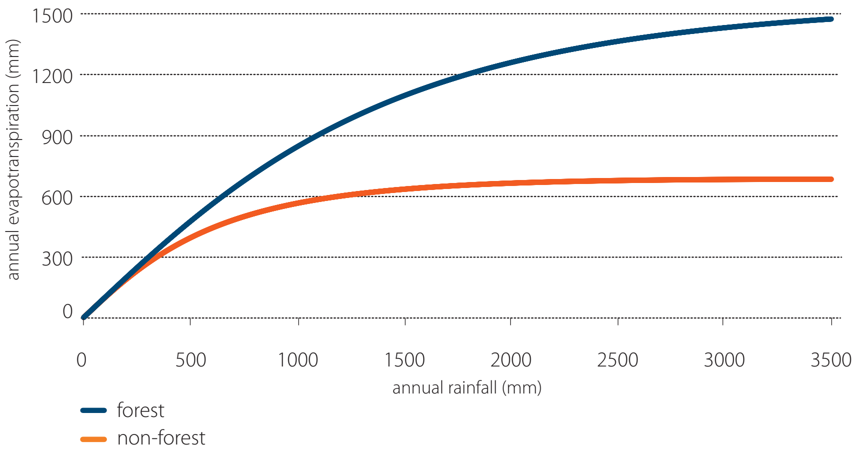
w ~ the plant available water coefficient = 2.0 for forests, 0.5 for non-forests

E_0 ~ potential annual evapotranspiration = 1410 for forests, 1100 for non-forests

ET ~ mean annual evapotranspiration (mm) for each land use, including soil evaporation

P ~ mean annual rainfall (mm)

C1 Relationship between annual evapotranspiration and rainfall



Source: ABARES

- In this analysis, the evapotranspiration for a particular unit (1 km grid cell) of forest or grassland is assumed to be constant over the modelling period. In reality, the amount of evapotranspiration by forest and grassland may fluctuate based on the rainfall in any given year. Because of the lack of specific spatial details, ABARES has assumed no changes to the amount, seasonality and geographic distribution of rainfall across Australia over the projection period.
- The above relationship (equation 1 and figure C1) measures the peak water use by forests. ABARES assumed that over the analysis period, evapotranspiration by reforestation is 70 per cent of this peak, based on Barratt et al. (2007) and work by Pratt Water (2004). According to Barratt et al. (2007), this represents the average proportion of peak water use intercepted by a forest over an entire rotation length. This estimate is conditional on several factors, such as the species, silvicultural management and location of the forest. ABARES has not made any assumptions for the proportion of peak evapotranspiration for non-forest land over the modelling period.
- Water interception by forests is measured as the change in run-off arising from the replacement of grassland with forest. Following the method used in Bradford et al. (2001), it is assumed that the mean annual evapotranspiration from each 1 km grid cell is the sum of the evapotranspiration from grassland and that from forests, weighted linearly according to the proportion of the cell under each land use.
- Usually, run-off is estimated as the balance of water available after rain-based deep drainage and evapotranspiration are subtracted from precipitation, that is R = P – E – D, where R = run-off, P = precipitation, E = total evapotranspiration, and D = deep drainage/recharge (Barratt et al. 2007). Following Bradford et al. (2001), ABARES assumes that the change in catchment water storage over a long period of time is zero; hence, there is negligible change in deep drainage, suggesting R = P – E.
- The increase in interception by forests over non-forests is assumed to be zero in 1 km grid cells with an average annual rainfall less than 600 mm, because the National Water Initiative requires that large-scale reforestation projects be included in water sharing plans.

- Forest interception is assumed to be zero for the first five years after planting (for example, no water costs are imposed for the first five years). Hence, after a timber plantation is harvested, reforestation owners are not liable for water charges until five years after the re-establishment of these plantations.
- The water prices used in the analysis are derived from a variety of sources, including DSEWPaC (2011a), GHD Hassall (2010), the Queensland Government (2011), PSI Delta (2010) and the Victoria Water Register (2011) (table C1).
- From these sources, average water prices for entire catchments are used to estimate the costs of reforestation interception. Reforestation projects are charged the same price for water regardless of their position within the catchment. The catchment boundaries are based on the Australian Water Resources Council river basins data.
- The annualised prices for water interception costs are estimated as the High Security Permanent Water price annualised using a discount rate of 7 per cent. The assumed water prices in this analysis include infrastructure and management costs that are not applicable to forest surface water interception and therefore represent an upper bound of potential water entitlement costs for reforestation projects under the CFI.

C1 Assumed water market prices by catchments

river catchment	basin	state/territory	water price**	source
Pioneer River	GBR catchment	Queensland	625	Qld Govt 2011a
Burnett River	GBR catchment	Queensland	2 524	Qld Govt 2011b
Boyne River	GBR catchment	Queensland	2 554	Qld Govt 2011a
Fitzroy River (Qld)	GBR catchment	Queensland	3 054	Qld Govt 2011a
Daintree River	GBR catchment	Queensland	2 944	Qld Govt 2011b
Mossman River	GBR catchment	Queensland	2 944	Qld Govt 2011b
Barron River	GBR catchment	Queensland	2 944	Qld Govt 2011b
Mulgrave–Russell rivers	GBR catchment	Queensland	2 944	Qld Govt 2011b
Johnstone River	GBR catchment	Queensland	2 944	Qld Govt 2011b
Herbert River	GBR catchment	Queensland	2 944	Qld Govt 2011b
Tully River	GBR catchment	Queensland	2 944	Qld Govt 2011b
Murray River (Qld)	GBR catchment	Queensland	2 944	Qld Govt 2011b
Hinchinbrook Island	GBR catchment	Queensland	2 944	Qld Govt 2011b
Black River	GBR catchment	Queensland	2 944	Qld Govt 2011b
Ross River	GBR catchment	Queensland	2 944	Qld Govt 2011b
Kolan River*	GBR catchment	Queensland	2 524	Qld Govt 2011b
Border Rivers	Murray–Darling	New South Wales	4 552	DSEWPaC 2011a
Condamine–Culgoa rivers*	Murray–Darling	New South Wales	1 800	PSI-Delta
Loddon River	Murray–Darling	New South Wales	2 065	DSEWPaC 2011a
Broken River*	Murray–Darling	New South Wales	2 232	DSEWPaC 2011a
Goulburn River*	Murray–Darling	New South Wales	1 800	GHD Hassall Dec 2010
Lachlan River*	Murray–Darling	New South Wales	1 910	GHD Hassall Dec 2010
Lower Murray River	Murray–Darling	New South Wales	2 335	GHD Hassall Mar 2011
Castlereagh River*	Murray–Darling	New South Wales	1 910	GHD Hassall Dec 2010

continued...

C1 Assumed water market prices by catchments

continued

river catchment	basin	state/territory	water price**	source
Macquarie–Bogan rivers*	Murray–Darling	New South Wales	1 250	GHD Hassall Dec 2010
Murray–Riverina*	Murray–Darling	New South Wales	1 935	GHD Hassall Dec 2010
Lake George*	Murray–Darling	New South Wales	1 910	GHD Hassall Dec 2010
Murrumbidgee River	Murray–Darling	New South Wales	1 910	GHD Hassall Dec 2010
Namoi River	Murray–Darling	New South Wales	4 100	DSEWPaC 2011a
Gwydir River	Murray–Darling	New South Wales	4 478	DSEWPaC 2011a
Upper Murray River	Murray–Darling	New South Wales	2 335	GHD Hassall Mar 2011
Moonie River*	Murray–Darling	Queensland	4 552	DSEWPaC 2011a
Border Rivers	Murray–Darling	Queensland	4 552	DSEWPaC 2011a
Condamine–Culgoa rivers*	Murray–Darling	Queensland	4 552	DSEWPaC 2011a
Warrego River*	Murray–Darling	Queensland	1 800	PSI-Delta
Lower Murray River	Murray–Darling	South Australia	2 242	DSEWPaC 2011a
Mallee*	Murray–Darling	South Australia	2 242	DSEWPaC 2011a
Broken River*	Murray–Darling	Victoria	1 800	GHD Hassall Dec 2010
Campaspe River*	Murray–Darling	Victoria	2 299	DSEWPaC 2011a
Goulburn River	Murray–Darling	Victoria	1 800	GHD Hassall Dec 2010
Loddon River*	Murray–Darling	Victoria	1 800	GHD Hassall Dec 2010
Lower Murray River	Murray–Darling	Victoria	1 775	GHD Hassall Mar 2010
Murray–Riverina*	Murray–Darling	Victoria	2 125	Victorian Water Register
Murrumbidgee River	Murray–Darling	Victoria	2 400	DSEWPaC 2011a
Kiewa River*	Murray–Darling	Victoria	1 800	GHD Hassall Dec 2010
Ovens River*	Murray–Darling	Victoria	1 800	GHD Hassall Dec 2010
Upper Murray River*	Murray–Darling	Victoria	2 125	Victorian Water Register
Wimmera–Avon rivers*	Murray–Darling	Victoria	1 800	GHD Hassall Dec 2010
Burrum River*	North East Coast	Queensland	2 524	Qld Govt 2011b
Millicent Coast*	North East Coast	South Australia	250	Government of Victoria
Glenelg River*	North East Coast	South Australia	250	Government of Victoria
Millicent Coast	North East Coast	Victoria	250	Government of Victoria
Glenelg River	North East Coast	Victoria	250	Government of Victoria
Hopkins River	North East Coast	Victoria	250	Government of Victoria
Barkly*	Western Plateau	Northern Territory	200	PSI-Delta

Notes: ** Water prices are assumed high security prices; where high security prices were not available, lower security prices were used and adjusted (medium security prices were multiplied by 2, while low security prices were multiplied by 4). * Where water price data was not available for the river, the price of the closest river with available data was used as a proxy.

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