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Farm-scale analysis of the potential uptake of carbon offset activities

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ABSTRACT

Carbon mitigation through land-use change and forestry has received considerable attention as a low-cost method of addressing climate change. However, spatial and productive heterogeneity is often lost in broader scale analyses frequently used to inform climate mitigation policy. Most research to date does not integrate these analyses with transaction costs; often a significant barrier to implementation. This paper demonstrates a technique for assessing project feasibility while considering both transaction costs and spatial heterogeneity. Ignoring farm heterogeneity was found to significantly overestimate both the market price of carbon and quantity of carbon sequestration required before projects become feasible.

Keywords: carbon markets, transaction costs, project feasibility

1 INTRODUCTION

It is expected that Australia's domestic emissions will be well above its national emission target without the introduction of further policies and incentives to offset emissions from current activities or reduce greenhouse gas (GHG) emitting activities and enterprises (Jotzo, 2012, pp. 12-37). Agricultural landholders have the potential to contribute to these emissions targets in several ways: (a) avoidance of land clearing activities (Henry *et al.*, 2002; Skutsch *et al.*, 2007); (b) provision of carbon offsets through carbon sequestration in biomass and soils (Turner *et al.*, 2005; Eady *et al.*, 2009; Paul *et al.*, 2013); (c) reduction in GHG emitting inputs (Meisterling *et al.*, 2009; Mohammadi *et al.*, 2013); (d) reduction of methane emissions (Hongmin *et al.*, 1996; Shin *et al.*, 1996); and (e) production of biofuels to displace fossil fuels (Fung *et al.*, 2002; Sims *et al.*, 2010).

Kember *et al.* (2013) noted that there is a risk that Australia will rely too heavily on the importation of international permits and thus suggested that domestic mitigation policies need strengthening. Of all the domestic policy options, the sequestration of carbon in forestry biomass has been ranked as the simplest and most cost-effective to implement (Eady *et al.*, 2009). In Australia, previous studies have focused on the forest sequestration potential at the national, state or broad catchment level (Kirschbaum, 2000; Polglase *et al.*, 2008; Eady *et al.*, 2009). Such broad-scale analysis does not allow for local heterogeneity that exists across a region, or even across an individual farm, to be determined. Studies have shown that significant variations occur in farm productivity, management, input and output levels and carbon sequestration potential, even across local regions (Tschakert, 2004; Kwon *et al.*, 2006; Paul *et al.*, 2013). Hence, broad region estimations of costs associated with climate mitigation may not only be inadequate but may provide misleading information to decision makers (Tschakert, 2004). Paul *et al.* (2013) found that the failure to account for local variations in site quality, management and different planting configurations can influence the estimates of sequestration potential by between 15% and 53%.

Planting trees for carbon sequestration purposes may produce additional benefits, known as co-benefits, including enhanced biodiversity conservation, salinity reduction and improved soil and water quality (Plantinga & Wu, 2003; Harper *et al.*, 2007; Shaikh *et al.*, 2007; Mattsson *et al.*, 2009; Townsend *et al.*, 2012). However, paddocks planted to timber plantations for carbon sequestration can potentially impose both positive and negative externalities on adjoining paddocks. In a socio-economic study of returns from farm forestry and agriculture in south-east Australia, Stewart *et al.* (2011) found that an 'edge effect' from timber belts caused a loss in pastures from adjoining paddocks immediately along the paddock edge. This was mainly due to strong competition from tree roots. This impact is dynamic and increases as trees mature. Carberry *et al.* (2007) also found a similar impact on cropping paddocks from adjacent trees. They found that the width of significant decrease due to this edge effect had a linear relationship with tree height. There are, however, also many studies which have shown that outside this immediate 'edge', trees will have a positive impact on pastures and crops in adjoining paddocks (Shelton *et al.*, 1987; Moreno *et al.*, 2007; Gea-Izquierdo *et al.*, 2009; Donaghy *et al.*, 2010; Moustakas *et al.*, 2013).

An Australian carbon offset scheme, the Carbon Farming Initiative (CFI), was introduced in July 2012 with the aim of enticing landholders to reduce GHG emissions through the adoption of approved activities (Macintosh & Waugh, 2012). The CFI has been introduced with the objective of reducing the costs associated with meeting Australia's mitigation targets (Macintosh, 2013) and allows for emissions from four sectors: stationary energy, industrial processes, fugitive emissions from mines and non-legacy waste (Macintosh & Waugh, 2012) to be offset.

While the existence and importance of transaction costs is widely acknowledged in environmental policies (Cacho *et al.*, 2005; McCann *et al.*, 2005; Coggan *et al.*, 2010; McCann, 2013), these are rarely quantified, or where they are included, they are usually presented as a simple static value for all landholders involved in a scheme. Given the complexity of project approval, reporting, crediting and compliance of carbon offset schemes such as the CFI, transaction costs can be inhibiting to individual landholders (Fitchner *et al.*, 2003). Therefore, individual landholders may not be able to directly interact with these schemes. However, it is possible that a project developer can manage a pool of individual landholder contracts to gain economies of scale (Henry *et al.*, 2009; Mattsson *et al.*, 2009; Cacho *et al.*, 2013). This aggregation of a large number of landholders can also help reduce project failure risks.

Welsch *et al.* (2014) posited that the spatial distribution of current farm features is an important factor to consider with policies for ecosystem improvements. Most spatial studies in the Australian context investigate carbon collected at either a cell or per hectare level without regard for the spatial distribution of current farm features. The current paper investigates the impact of farm and landholder heterogeneity while taking into account the actual operating units, individual paddocks and farm level data. In order for the CFI to be successfully adopted, properties with both low opportunity cost and low transaction costs must be identified. Where the net benefits are positive, the inclusion of co-benefits to neighbouring paddocks will also increase the feasibility of the CFI. Therefore, the objectives of this study are to assess the potential economic viability of carbon sequestration through environmental plantings at the property and paddock level, assess the significance of heterogeneous landholder transaction costs, determine the influence of co-benefits on the viability of carbon projects and assess the role of aggregators in obtaining larger pools of landholders. Transaction costs for both individual landholders and project aggregators are quantified using the typology described by Cacho and Lipper (2007) and Cacho (2009). A model based on Cacho *et al.* (2013) was adapted to determine the likelihood of a decision to participate in a CFI project in three case study regions in northern New South Wales, Australia. Project feasibility frontiers based on different market prices of carbon are determined. This paper concludes with a discussion on the feasibility of projects under the current CFI rules and possible improvements to future policy design.

2 MODEL

2.1 Carbon trajectories

The carbon sequestration potential of individual farms from land-use change is mapped both spatially and temporally. This potential is determined as per hectare trajectories [$Cha(t)$] of additional carbon offsets that can be obtained from a land-use change for each eligible paddock. To avoid overestimating additional carbon sequestration potential, the current level of woodiness (i.e. existing carbon storage) in a paddock was taken into account when calculating the carbon sequestration trajectories of each paddock. Adjustments were made using a woodiness index (ξ) and the following equation:

$$C_i(t) = Cha_i(t) \cdot (1-\xi) \cdot a_i \quad (1)$$

where $Cha_i(t)$ is the trajectory of carbon offsets that can be sequestered per hectare on property i if no trees are currently growing within the paddock over the period T of the project ($t = 1,\ldots,T$) and a_i is the area of the i-th paddock in hectares.

2.2 Project feasibility

The project feasibility model of Cacho *et al.* (2013) was adapted to consider the feasibility of carbon sequestration projects using a fixed bundle of heterogeneous farms, modelled down to individual paddock scale. This model considers a single project developer (an aggregator) who will purchase carbon offsets from landholders adopting particular land-use changes. The project developer will purchase these carbon offsets from the individual landholders at a farm-gate price (p_F) and will combine and sell them in carbon markets at price p_C. Obviously, the individual landholders will incur a range of abatement costs, including the opportunity costs of foregone income associated with procuring these offsets. The project developer will also incur costs of designing, acquiring and managing carbon contracts with the individual landholders. A project will only be feasible if both the individual landholders and the project developer perceive their participation to be beneficial. It is assumed that for a project developer to take action, the benefits of selling the carbon offsets in the market must be greater than the abatement and transaction costs of aggregating offsets from individual landholders. For an individual to participate, the benefit of selling carbon offsets to the project developer must be greater than the abatement and transaction costs associated with joining the scheme. These conditions are presented as equations (2) and (3) and both must be satisfied for a project to be feasible.

$$V_C(a, p_C, C(t), \delta_B) \geq V_A(a, p_F, C(t), \delta_B) + V_T(a, n, p_C, C(t), \mathbf{W}, \delta_B) \quad (2)$$

$$v_C(a, p_F, C(t), \delta_S) \geq v_A(a, R(t), \delta_S) + v_T(w, \delta_S) \quad (3)$$

where V_C and v_C are the present values of the revenues received by the project developer from selling carbon in the market and by the landholder from selling to the project developer, respectively; V_A and v_A are the present values of the abatement costs to the project developer and the landholders; V_T and v_T are the present values of the transaction costs for the project developer and the individual landholders; $C(t)$ is the trajectory of carbon offsets which can be produced over the life of the project (t = 1,...,T); a is the total area of land converted; n is the number of individual landholders; W and w are cost vectors containing the different classes of transaction cost for the project developer and the individual landholders; and δ_B and δ_S are the discount rates for the project developer and the landholders.

It has been argued that, when assessing sequestration projects, physical carbon needs to be discounted in the same manner as project costs[1] (Richards, 1997; van Kooten *et al.*, 2004; Boyland, 2006). Not adopting a discount rate implies that no time preference exists between removing carbon from the atmosphere now or at a future point in time. Cost estimates are sensitive to the length of project period. Adding a discount rate on both costs and physical carbon places more importance on carbon sequestration in the near future, allowing cost estimates to account for the timing of the sequestration. Therefore, when determining project feasibility in this study, both these elements are presented in discounted terms.

2.3 The project developer

The discounted sum of payments received by the project developer is derived from collecting carbon offsets from n individual landholders producing carbon offsets in i paddocks, and selling them in the carbon market at price p_C:

$$V_C = \sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{i=1}^{i_n} p_C C_{n,i}(t)(1+\delta_B)^{-t} \quad (4)$$

where i_n is the number of paddocks that landholder n will convert to a carbon-offset-producing land use.

The abatement cost for the project developer is the present value of the farm-gate payments for the carbon offsets paid to the individual landholders:

$$V_A = \sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{i=1}^{i_n} p_F C_{n,i}(t)(1+\delta_B)^{-t} \quad (5)$$

[1] Discount rates assumed for project costs and physical carbon do not necessarily need to be identical.

In addition to the abatement cost payments incurred by paying the landholders in exchange for carbon offsets, the project developer will also incur a range of transaction costs associated with finding appropriate parcels of land, negotiating with eligible landholders and measuring, certifying and monitoring carbon-offset products before they can be sold in the carbon market. Project developer's transaction costs are estimated as:

$$V_T = W_{S1} + W_A + W_{P1} + nW_{S2} + \sum_{t=1}^{T} \left[W_{P2} + W_{M1} + nW_{E2} + \left(W_{M2} + W_{E1} \right) C(t) p_C \right] (1 + \delta_B)^{-t} \quad (6)$$

where the letter and number subscripts of (W) are adapted from the transaction costs notation used in Cacho *et al.* (2013). The letters represent search and negotiation costs (S), approval costs (A), project management costs (P), monitoring (M) and enforcement and insurance costs (E). Number subscripts refer to costs which are measured using different units within each individual transaction cost category. A list of these transaction costs is presented in section 2.4.

2.4 The individual landholder

The present value of the revenue received by an individual landholder for joining the carbon offset scheme is the sum of the discounted farm-gate carbon payments:

$$v_C = \sum_{t=1}^{T} \sum_{i=1}^{i_n} p_F C_i(t) (1 + \delta_S)^{-t} \quad (7)$$

The cost of abatement for the individual landholder is determined using the opportunity cost of switching land use.

$$v_A = \sum_{t=1}^{T} \sum_{i=1}^{i_n} R_i(t) (1 + \delta_S)^{-t} \quad (8)$$

where $R_i(t)$ is the flow of differences between the net revenues of the best alternative land use and the carbon-offset scheme in the i-th paddock. The opportunity cost of each eligible paddock is determined based on the current land-use type. Two broad categories of current land use were estimated; cropping (consisting of both dryland and irrigated cropping) and livestock (consisting of both native and improved pasture) enterprises. The estimation of the opportunity costs for each eligible paddock is described in Moss (2014, pp. 168-171).

The discounted stream of transaction costs for individual landholders joining a carbon offset scheme is:

$$v_T = \left[w_{S1} p_L + w_{S2} d_{\min} p_{trav} + w_A + \sum_{t=1}^{T} \left(w_{P1} p_L + w_{P2} d_{\min} p_{trav} + w_E \right) (1 + \delta_S)^{-t} \right] \quad (9)$$

where p_L is the opportunity cost of the landholder time, $d_{\min}$ is the minimum distance to the nearest town (estimated using the least-cost algorithm described in Moss (2014)), p_{trav} is the cost of travel (\$ km^{-1}), and the letter transcripts for the individual landholder transaction costs (w) are the same as those used in equation (6). The number subscripts are defined in Table 1.

Table 1: Description of transaction costs and the notation adopted in this study (based on Cacho *et al.*, 2013).

Notation	**Description**	**Incurred by**
W_{S1}	Search and negotiation (fixed)	Project developer
W_{S2}	Search and negotiation (variable)	Project developer
W_A	Approval (fixed)	Project developer
W_{P1}	Project management (fixed)	Project developer
W_{P2}	Project management (annual)	Project developer
W_{M1}	Monitoring (annual)	Project developer
W_{M2}	Monitoring (per credit)	Project developer
W_{E1}	Enforcement and insurance (per credit)	Project developer
W_{E2}	Enforcement and insurance (per farm)	Project developer
w_S	Search and negotiation (fixed)	Project developer
w_A	Approval (fixed)	Landholder
w_P	Project management (annual)	Landholder
w_E	Enforcement and insurance (annual)	Landholder
p_{trav}	Travel cost (per km)	Landholder
p_l	Cost of labour (per day)	Landholder

2.5 Project feasibility frontiers

The maximum price that the aggregator would be willing to pay individual landholders, when including their transaction costs can be determined by substituting equations (4) and (5) into equation (2) and rearranging to obtain:

$$p_F \le p_C - \frac{V_T\left(n, a, \mathbf{W}, C(t), \delta_B\right)}{\sum_{t=1}^{T}\sum_{n=1}^{N}\sum_{i=1}^{i_n} C_{n,i}(t)(1+\delta_B)^{-t}} \tag{10}$$

The minimum feasible farm price for an individual landholder depends on the sum of the abatement and transaction costs and can be found by substituting equations (7) and (8) into equation (3) and rearranging to obtain the following equation:

$$p_F \ge \frac{v_T + \sum_{t=1}^{T}\sum_{i=1}^{i_n} R(t)(1+\delta_S)^{-t}}{\sum_{t=1}^{T}\sum_{i=1}^{i_n} C(t)(1+\delta_S)^{-t}} \tag{11}$$

where the numerator is the total cost to the landholder, which includes the transaction and abatement costs and the denominator is the discounted carbon offsets produced.

Project feasibility is determined by the ability of the aggregator to fully cover the cost of the farm-gate carbon payments (p_F) for any given price of carbon in the market (p_C). The minimum project size can be determined by setting equation (10) equal to equation (11). As pointed out by Cacho *et al.* (2013), the ability to cover these costs is dependent on the number of individual farms, the total area of land converted to carbon offsets and the amount of discounted carbon. At each level of p_C the value of n (number of participating landholders), a (total area) or discounted carbon that satisfies the minimum project size condition while keeping all other parameters constant can be solved. Cacho *et al.* (2013) called this the Project Feasibility Frontier (PFF) expressed as:

$$x_{\min}\left(p_C \mid a, w, W, C(t), R(t), \delta_B, \delta_S\right) \quad (12)$$

This function represents the minimum project size ($x_{\min}$) that is feasible as a function of the market price of carbon for the given value of the other parameters. The variable $x_{\min}$ can represent the minimum number of landholders, minimum total area or minimum total discounted carbon. Once heterogeneity is included, an upper bound ($x_{\max}$) is introduced. This can be expressed as:

$$x_{\max}\left(p_C \mid a, w, W, C(t), R(t), \delta_B, \delta_S\right) \quad (13)$$

The area between $x_{\min}$ and $x_{\max}$ represents the feasible project range. This is illustrated graphically in section 4.3.

2.6 Accounting for additional benefits

Additional benefits may be experienced in paddocks adjoining those paddocks which are planted for carbon offset purposes. These additional benefits to agricultural production include increased survival and weaning rates of livestock and protection of crops from prevailing winds. Donaghy *et al.* (2010) divided paddocks into different regions based on adjoining tree height and their relative position to tree plantings when estimating impact on yield. This approach has been adopted in the current study and is graphically depicted in Figure 1.

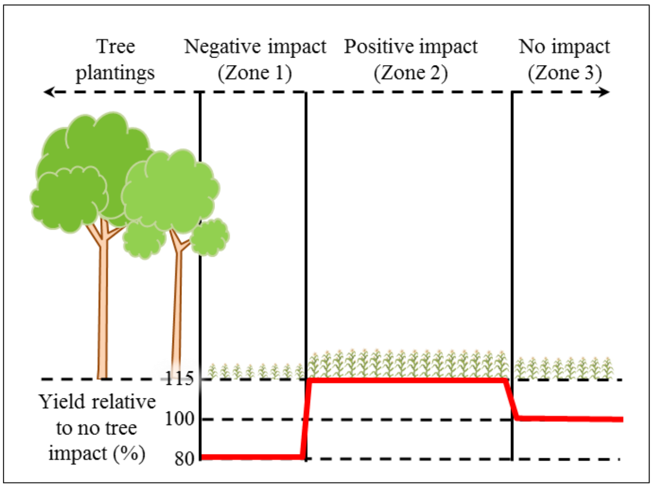

Figure 1: Impact of trees on crop or pasture in adjoining paddocks where width of area for the negative and positive impacts are 1x and 4x the height of trees, respectively (adapted from Donaghy *et al.*, 2010, p. 475). Note, figure not to scale.

Each paddock's yield (be it either crop or pasture gain) was determined with the following equation[2]:

$$Yield_{\text{mod}}(t) = Yield \cdot a_1(t) \cdot \tau_1 + Yield \cdot a_2(t) \cdot \tau_2 + Yield \cdot a_3(t) \cdot \tau_3 \quad (14)$$

[2] Both the positive and negative benefits in terms of increased/decreased agricultural productivity is captured at the localised scale with this equation. While other co-benefits or perverse effects may exist, they were not considered in this study.

where $Yield_{\text{mod}}(t)$ is the modified pasture or crop yield for a paddock influenced by the planting of trees in adjacent paddocks, a_1, a_2 and a_3 are the area of the paddock with reduced, increased and unaffected production in time period t, respectively and τ_i are the yield-modifying parameters. The length of the 'edge' adjacent to any of the neighbouring paddocks is determined to calculate the different paddock regions. Due to the data-intensive nature of dynamic paddock coordinates, a computational restriction is applied where a paddock can only be influenced by a maximum of five neighbouring paddocks. Where more than five adjacent paddocks exist, the five paddocks with the longest interface are selected. In addition, a restriction is applied which requires all paddocks to be at least 10 metres wide to provide any additional benefits. This restriction is included to avoid paddocks providing unrealistic benefits.

When determining the optimal paddocks for conversion to a carbon-offset project, the following algorithm was used:

1. Place all eligible paddocks into a set[3].
2. Systematically consider each paddock in the 'eligible pool' set to determine the cost of capturing carbon while taking into account the influence from paddocks in the 'already planted' set and the paddock under current consideration.
3. Find the lowest-cost paddock and remove this paddock from the 'eligible pool' set.
4. Move the last paddock removed from the 'eligible pool' set into the 'already planted' set.
5. If no paddocks remain in the 'eligible pool' set, move to 6, otherwise return to step 2.
6. The set 'already planted' contains the order in which paddocks should be added to achieve additional carbon capture from the individual landholder.

3 CASE STUDY REGIONS

The Border Rivers-Gwydir catchment covers an area of approximately 5,000,000 hectares. Due to the large scale of the catchment, three case regions were selected based on the results from Moss (2014, pp. 12-37) using the following criteria:

- highest carbon sequestration rate potential per hectare (Case region A);
- lowest mean opportunity cost per hectare (Case region B); and
- lowest positive mean opportunity cost per hectare (Case region C).

An algorithm in MATLAB was run to determine the location of these three regions. Coincidently, all three regions occurred along a border of the catchment (see Figure 1).

[3] 'Eligible paddock' in this sense is a paddock where the current land use can be changed to trees for carbon capture in an offset scheme.

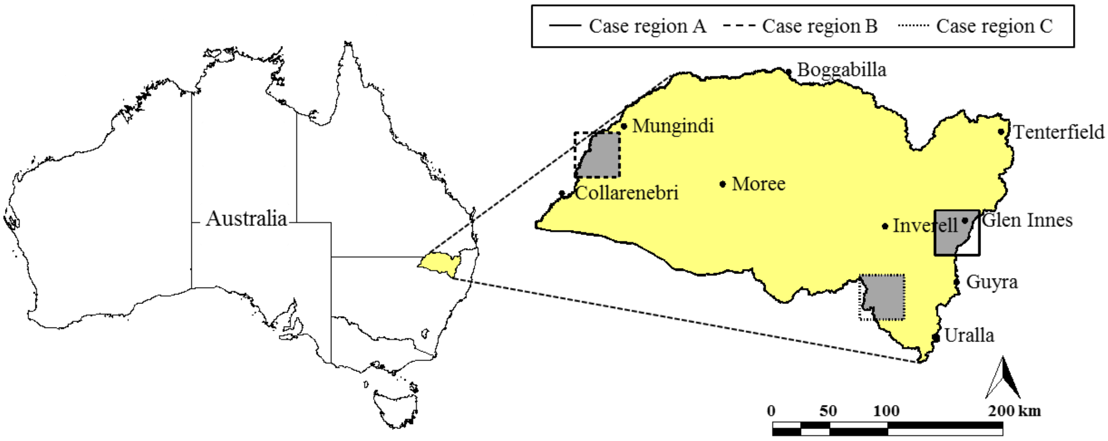

Figure 1: Location of the case regions in the Border Rivers-Gwydir catchment.

The general characteristics of the different case regions are shown in Table 1.

Table 1: General characteristics of the case regions.

	Case study region		
	A	**B**	**C**
Case region size (ha)	128,199	166,446	180,360
Properties (no)	328	46	154
Size of property (ha)#	391 ± 544	3,618 ± 7,186	1,171 ± 1,841
Paddocks per property (no) #	27 ± 27	107 ± 184	51 ± 80
Average size of paddock (ha) #	10 ± 4	45 ± 86	16 ± 5

#Values are in terms of mean ± standard deviation.

Case region A has the highest average additional carbon sequestration potential per hectare (determined by Moss, 2014), but also the smallest average property size (391 ha). This high carbon sequestration potential is partially attributable to the position on the easterly aspect of the catchment and the relatively high average annual rainfall of 856mm. On the other hand, case region B has a larger average property size (3,618 ha) but a lower carbon sequestration potential per hectare. A summary of the current land uses of the case study regions is shown in Table 2.

Carbon sequestration potential is modelled at a paddock level using GIS shapefiles which contain the paddock boundaries, cropping history and level of woodiness for all paddocks in the Border Rivers-Gwydir catchment from summer 1998 to summer 2009 (NSW Government, 2009). Digital cadastral data containing property boundaries in the study regions was obtained from the NSW Government, Land and Property Information (NSW Government, 2011).

Table 2: Current land uses of the case study regions (as a proportion of the total area).

	Case study region		
Current land use	**A**	**B**	**C**
Nature conservation	-	-	1.20%
Other minimal uses	5.71%	1.50%	12.69%
Grazing of native pastures	-	43.64%	-
Forestry	-	0.05%	-
Plantations	0.40%	0.32%	0.19%
Grazing of modified pastures	86.00%	0.12%	76.95%
Cropping	2.88%	43.58%	0.67%
Irrigated pastures and cropping	-	4.15%	0.44%
Urban intensive uses	2.20%	1.13%	0.36%
Water	1.41%	2.01%	1.29%
Unspecified land uses	1.41%	3.51%	6.21%

3.1 Increased carbon storage

Each paddock across the case study regions was assessed for eligibility in the CFI scheme. If a paddock was not currently wooded and was being used for either dryland or irrigated cropping, grazing of native or improved pasture by livestock, or for other minimal agricultural production, the paddock was deemed eligible for conversion to a mixed-species environmental planting. The conversion of current paddocks to environmental plantings assumes that the current fencing infrastructure will allow the exclusion of stock for at least the first three years of a project, ensuring adherence to the approved methodology (DCCEE, 2011). Carbon sequestration trajectories for each eligible paddock across the three case regions were estimated using the CFI-approved methodology for mixed-species environmental plantings (DCCEE 2011). Practically, this was done through the use of the prescribed Reforestation Modelling Tool for a period of 100 years. In keeping with this approved methodology, baseline emissions were set at zero and not recalculated over the course of the project. Fuel emissions from the establishment and management of the environmental plantings were accounted for using the equations outlined in Schedule 1 of the National Greenhouse and Energy Reporting (Measurement) Determination (Australian Government, 2011).

3.2 Parameter and cost assumptions

Permanent environmental plantings must have the potential to attain a height of at least 2 metres and a crown cover of at least 20% of the project area to be eligible under the approved methodology in the Australian CFI (DCCEE, 2011, pp. 4-5). For the study regions, spatial climate, soil and vegetation parameter sets for mixed-species environmental plantings, were derived from DCCEE (2011). As this methodology has been approved for the generation of carbon offsets in Australia, it was assumed that these parameter sets ensured compliance with the height and crown-cover conditions.

Net revenues for the different paddocks were estimated based on a variety of secondary data (ABS, 2008; BRS, 2009; ABARES, 2012; NSW DPI, 2012a, 2012b, 2012c). Supplementary material containing full details are available on the assumptions used are available by contacting the primary author. For the livestock gross margins, individual transportation costs for purchases and sales were determined using the minimum-cost travel distance method described in Moss (2014). Distances were estimated from each of the case study properties to pre-existing saleyards, abattoirs and feedlots (see Figure 2). Landholder and project developer discount rates were assumed to be 9% and 7%, respectively. Assumptions for the different project developer and landholder transaction costs were based on estimates by Cacho *et al.* (2013) and are shown in Table 3.

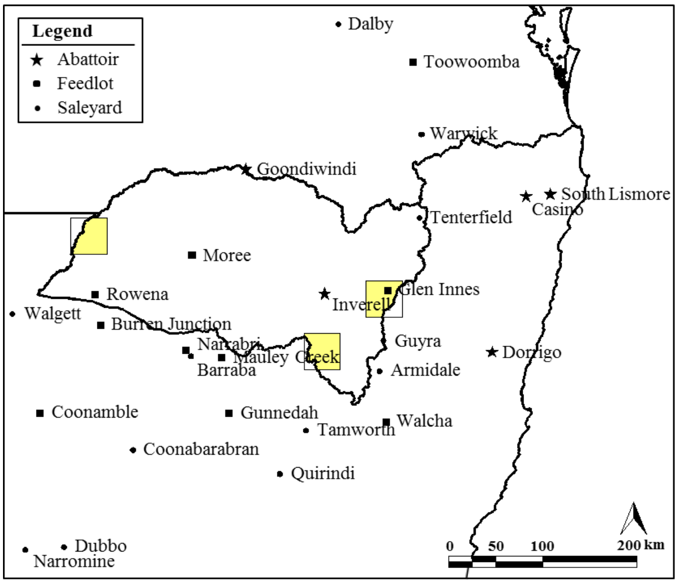

Figure 2: Location of currently existing abattoirs, feedlots and saleyards in proximity to the case study regions.

Table 3: Assumptions used for transaction costs in the case study regions (based on Cacho *et al.*, 2013).

Notation	Description	Units	Value
W_{S1}	Search and negotiation (fixed)	$	43,500
W_{S2}	Search and negotiation (variable)	$ farm^{-1}	2,500
W_A	Approval (fixed)	$	15,000
W_{P1}	Project management (fixed)	$	9,000
W_{P2}	Project management (annual)	$ yr^{-1}	100,000
W_{M1}	Monitoring (annual)	$ yr^{-1}	5,000
W_{M2}	Monitoring (per credit)	credit yr^{-1}	0.02
W_{E1}	Enforcement and insurance (per credit)	credit yr^{-1}	0.05
W_{E2}	Enforcement and insurance (per farm)	$ farm^{-1} yr^{-1}	500
w_S	Search and negotiation (fixed)	days	3
w_A	Approval (fixed)	$	750
w_P	Project management (annual)	$ yr^{-1}	*
w_E	Enforcement and insurance (annual)	credit yr^{-1}	0.05
p_{trav}	Travel cost (per km)	$ km^{-1}	0.55
p_l	Cost of labour (per day)	$ day^{-1}	184

*Landholder project management fees vary based on geographical location and are calculated as one day of labour plus travel costs to the nearest major town for an annual meeting with the project developer.

Parameters used to determine the impact of tree plantings on neighbouring paddocks were based on Donaghy *et al.* (2010) and are shown in Table 4.

Table 4: Parameter values used for determining additional benefits to adjoining paddocks.

Notation	Description	Units	Value
τ_1	Pasture or crop yield, relative to no impact from trees in Zone 1	%	80
τ_2	Pasture or crop yield, relative to no impact from trees in Zone 2	%	115
τ_3	Pasture or crop yield, relative to no impact from trees in Zone 3	%	100
a_1	Area of Zone 1	ha	*
a_2	Area of Zone 2	ha	*
a_3	Area of Zone 3	ha	#

*These parameter values are dynamic in nature and are determined as length of adjoining tree plantations multiplied by 1x and 4x the tree height for a_1 and a_2, respectively. #Area of Zone 3 is calculated as total area of paddock minus the sum of a_1 and a_2.

Planting, follow-up weed control and annual management cost parameters of \$801 ha^{-1}, \$80 ha^{-1} and \$16 ha^{-1}, respectively were applied to the mixed-species plantings based on Polglase *et al.* (2008).

4 RESULTS

4.1 Carbon sequestration potential

The detailed paddock simulations undertaken in this study found the region on the eastern side of the Border Rivers – Gwydir catchment (case region A) to have the highest carbon sequestration potential. Figure 1 illustrates that the highest quantity of annual carbon sequestration occurs within the first eight years of changing land use. The average annual additional carbon sequestration in year eight is 4.89 t C ha^{-1}, 2.14 t C ha^{-1} and 2.37 t C ha^{-1} for regions A, B and C, respectively. There is a substantial variance across each region with additional carbon sequestration in year eight ranging between 2.77 t C ha^{-1} and 6.76 t C ha^{-1}, 1.39 t C ha^{-1} and 2.61 t C ha^{-1} and 1.77 t C ha^{-1} and 3.58 t C ha^{-1} for regions A, B and C, respectively.

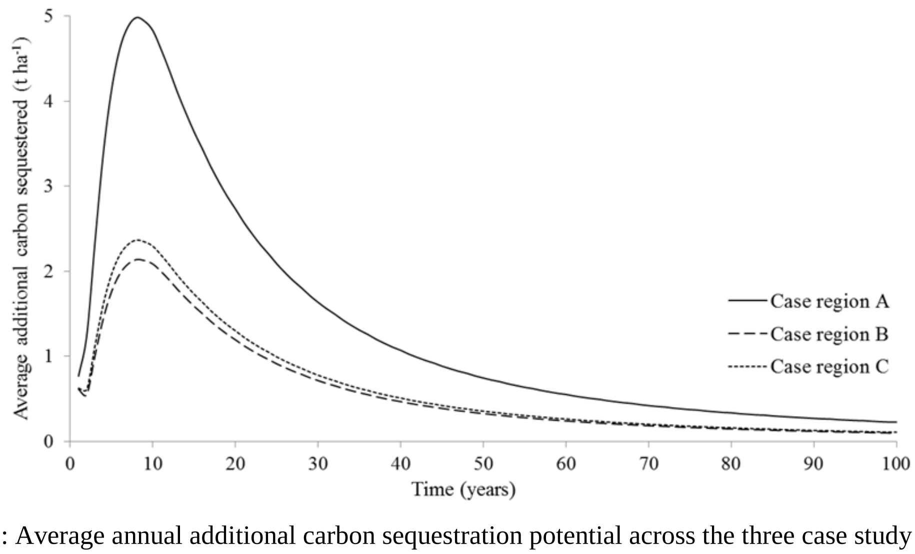

Figure 1: Average annual additional carbon sequestration potential across the three case study regions.

The total average additional carbon which can be expected over the 100 years of the project is 18.27 t C ha^{-1} (range 10.16 t C ha^{-1} – 24.78 t C ha^{-1}) in region A, 7.83 t C ha^{-1} (range 5.10 t C ha^{-1} – 9.57 t C ha^{-1}) in region B and 8.67 t C ha^{-1} (range 6.49 t C ha^{-1} – 13.13 t C ha^{-1}) in region C.

4.2 Feasible price to landholders

The minimum feasible farm-gate price for each landholder (P_S) was determined for landholders in the case regions. A significant variance in the minimum feasible farm-gate price was found with prices ranging from \$8.95 t CO_2-e^{-1} to \$295.99 t CO_2-e^{-1} (Table 1).

Table 1: Minimum feasible farm-gate price to landholders across the case study regions.

	Mean (\$ t CO_2-e^{-1})	**St. dev. (\$ t CO_2-e^{-1})**	**Min (\$ t CO_2-e^{-1})**	**Max (\$ t CO_2-e^{-1})**	**Coefficient of variation (%)**
Case region A	28.06	10.92	8.95	65.30	38.93
Case region B	27.16	8.26	19.07	65.69	30.40
Case region C	52.18	35.73	16.09	295.99	68.48

The average coefficient of variation (CV) for the minimum feasible farm-gate price across the case study regions was 45.94% (determined from the regional CVs in Table 1), with a range from 30.40% to 68.48%. Project developers will need to account for this heterogeneity when assessing project feasibility.

4.3 Feasible project areas

In order for the available technologies and management strategies which can provide climate mitigation products to be adopted, they must be economically feasible to all stakeholders. For a project to be feasible, the price required by landholders (P_S), which is determined through equation (11), must be less than or equal to the maximum amount that the aggregator (the buyer) is willing to pay (P_B); determined with equation (10). This is demonstrated, at a market price of \$23 t CO_2-e^{-1}, for region A, in Figure 2.

When the project developer is only able to aggregate a small number of landholders, sufficient economies of scale have not been reached and the minimum farm-gate price acceptable to the landholders (P_S) is greater than the maximum farm-gate price that the aggregator would be willing to pay. As the aggregator encourages more landholders to enter the project, the maximum farm-gate price that they are willing to pay landholders increases. In Figure 2, it becomes feasible for the project aggregator and some landholders at a farm-gate price of approximately \$10 t CO_2-e^{-1}, on the condition that the aggregator is able to obtain at least 36,000 t CO_2-e^{-1}[4]. This is the first point of intersection between P_S and P_B. At a quantity of approximately 382,000 t $C0_2$-e^{-1}, P_S and P_B again intersect, indicating that no landholders would be willing to add additional paddocks to an offset project as the farm-gate price they would require is greater than the amount the aggregator would be willing to pay (>\$21 t CO_2-e^{-1}). Where x_{min} and x_{max} in equations (12) and (13) are used to represent

[4] This value can be determined from the *x*-axis for the minimum feasible bound in Figure 2.

the viable project size in terms of number of landholders, the feasible range, at this market price for a project is between 16 and 102 landholder contracts.

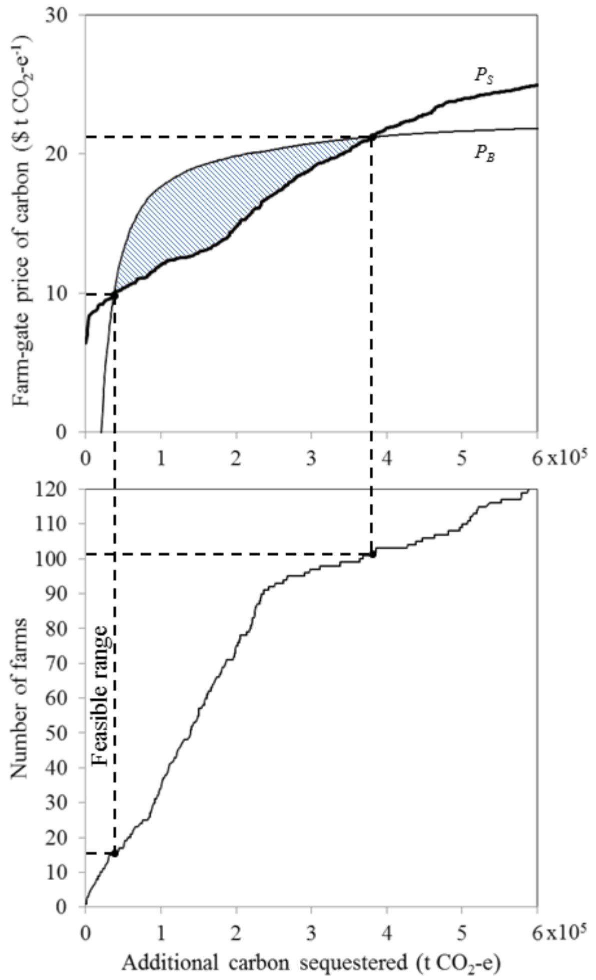

Figure 2: Supply of carbon for individual landholders (P_S), the maximum carbon price for the aggregator (P_B) and the feasible number of farms with a market price of \$23 t CO_2-e^{-1}. The feasible range represents the number of contracts in the project.

The project feasibility frontiers (PFF) represent the feasible quantity of carbon that may be sequestered under a project at different carbon prices. In effect, this provides useful sensitivity analyses on the impact of the market carbon price on a range of project characteristics. Unlike the study by Cacho *et al.* (2013) which assumed an unlimited supply of landholders, the current study considers the actual number of landholders available to a project aggregator and accounts for their heterogeneity. Although this places an arbitrary constraint given by the size of the case study regions chosen for a project, it does demonstrate that an upper limit exists on feasible project size. The feasible project sizes for the three case study regions are shown in Figure 3. Cacho *et al.* (2013) stated that a project is feasible if it falls above or to the right of a PFF curve, but this may not be the case where heterogeneity and availability of suitable land are considered. Ignoring this fact may cause sequestration potential to be overstated.

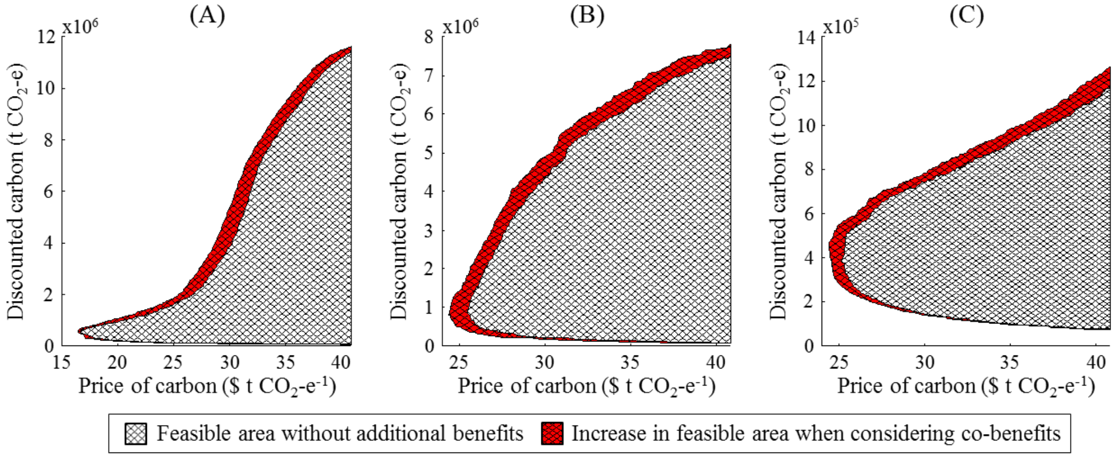

Figure 3: Project feasible areas for the three case study regions, showing the feasible project range both with and without the inclusion of additional benefits from the carbon plantings. Feasible range is plotted as the area between x_{min} and x_{max} at each level of p_C, determined with equations (12) and (13), respectively. Note, different axes scales are used to enhance readability.

As discussed in section 2.2, the discounting of physical carbon, along with the project costs, allows weighting of carbon sequestration through time and comparison between projects. Feasible project areas are therefore presented in terms of discounted carbon in the current section. When projects that do not account for the additional co-benefits on neighbouring paddocks are considered, it can be seen that projects will become feasible in case region A when the market price of carbon is \$16.70 t CO_2-e^{-1} or higher (Figure 3); on the condition that the project aggregator is able to secure enough land to sequester a discounted carbon quantity of at least 563,915 t CO_2-e. On the other hand, for case regions B and C, projects will only become feasible when the market price of carbon is \$25.50 t CO_2-e^{-1} and \$25.16 t CO_2-e^{-1} or higher, respectively. As outlined in section 2.6, planting trees can influence the productivity and profitability of adjoining paddocks. This is discussed in the following section.

4.3.1 Accounting for additional benefits

When accounting for the impact of co-benefits[5], it was found that overall there is an additional benefit of tree plantings on neighbouring paddocks which influences the feasibility of projects in each of the case study regions. This effect is shown in the project feasibility diagrams in Figure 3. When the additional benefits are included, the minimum feasible carbon price decreases by \$0.27 t CO_2-e^{-1} (1.63%), \$1.09 t CO_2-e^{-1} (4.28%) and \$0.75 t CO_2-e^{-1} (2.98%) for case regions A, B and C, respectively. The greater reduction in minimum price in region B compared to the other regions can be attributed to the higher value cropping paddocks in this region, thus resulting in higher dollar benefits from adjoining trees.

Employing a model which accounts for the additional benefits to neighbouring paddocks also increases the amount of area that is feasible at different carbon prices. Across the feasible range of prices up to \$40 t CO_2-e^{-1}, there is an average 23.17%

[5] The term 'co-benefits' may refer to a range of different benefits, including increases in biodiversity, salinity reduction or improved agricultural productivity. In this paper, it is used in the sense of profitability from increased agricultural productivity on neighbouring paddocks.

increase in the area of eligible land that would be feasible for both an aggregator and the individual landholders for region A. Similarly, regions B and C display an average 36.06% and 13.45% increase across the same range of prices.

4.3.2 Alternative PFF inputs

In addition to the range of carbon that must be sequestered to ensure a project is just feasible at any given price, a number of other factors can be plotted as PFFs, making this technique a useful tool for decision making. These include total project size in hectares and total number of farms (contracts).

The number of hectares provides a convenient, readily understood and measureable unit of feasible project size. It should be noted, however, that this needs to be coupled with localised carbon sequestration estimates to determine the quantity of carbon sequestration that could be expected from such an area. The minimum number of hectares that must be secured depending on carbon price for a project in each of the case study regions, to just be feasible is illustrated in Figure 4. This is based on the actual heterogeneous sequestration potential across the properties.

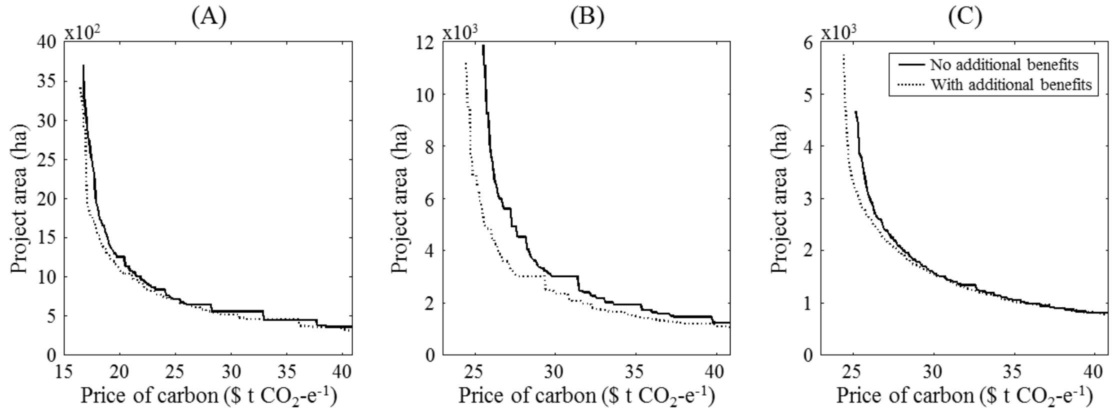

Figure 4: Minimum project size in terms of area for each of the case study regions. Note, different axes scales are used to enhance readability.

The minimum number of farm contracts that are required by an aggregator to just break-even is another useful measure which provides a practical business tool (Figure 5).

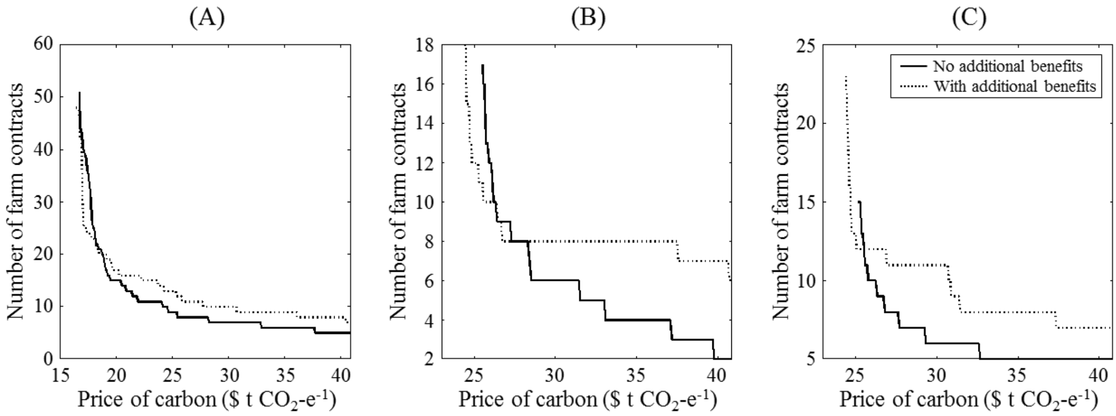

Figure 5: Minimum number of farm contracts required for the carbon sequestration project to be feasible. Note, different axes scales are used to enhance readability.

Interestingly, results show that the number of farm contracts required is generally lower when additional benefits are not included. This can be attributed to the fact that lower opportunity costs occur when the additional benefits are included which results in landholders being willing to enter smaller parcels of land into carbon plantations. Therefore, while more farm contracts are required when including these additional benefits, the actual area required is less than that required when these additional benefits are not included.

4.4 Heterogeneous nature of regions

A wide variance in the carbon sequestration potential across the different regions, as well as across the different paddocks within an individual landholder's property was evident in the current study. Figures 6 – 8 depict the spatial variance in average additional carbon that could be expected in eligible paddocks if they were converted to mixed-species carbon plantations. Case region A has a higher sequestration potential in the south-eastern localities and potential in case region B is highest in the eastern side of the sections. In contrast, case region C displays its highest potential in the western extremities due to their proximity to water courses.

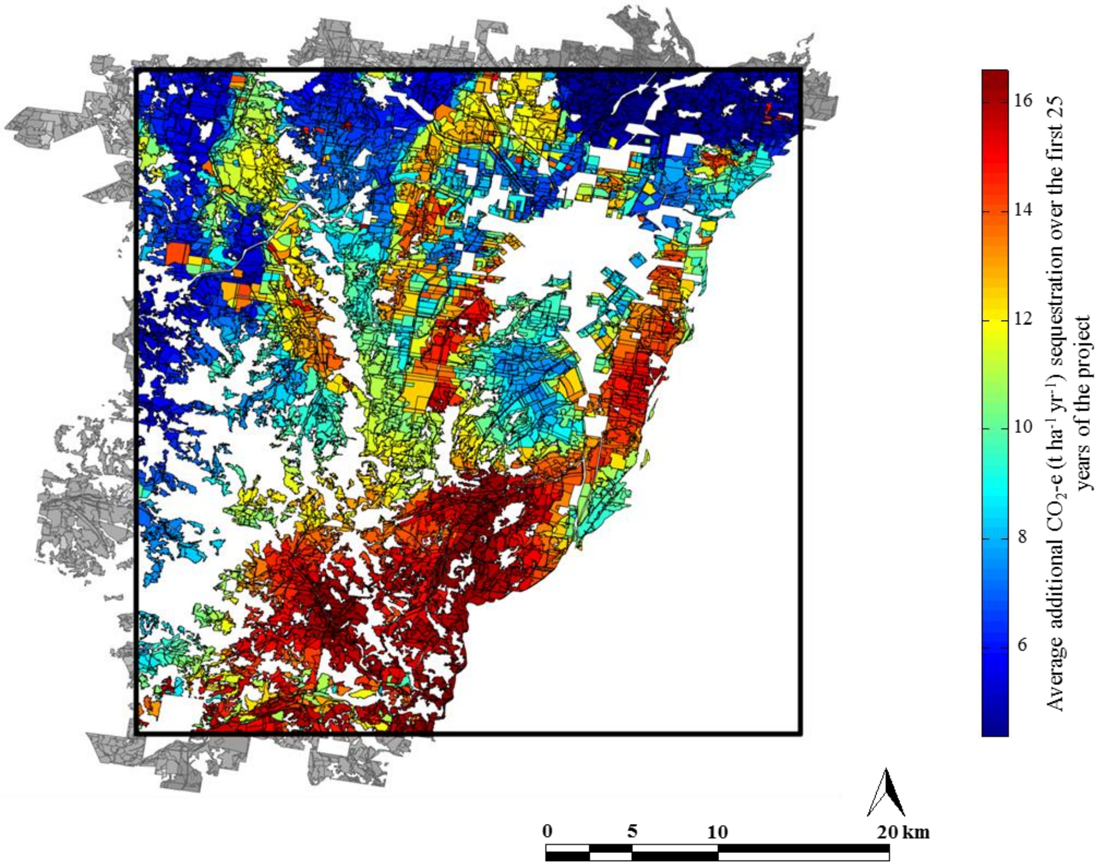

Figure 6: Spatial distribution of average annual carbon sequestration potential for eligible paddocks in case region A.

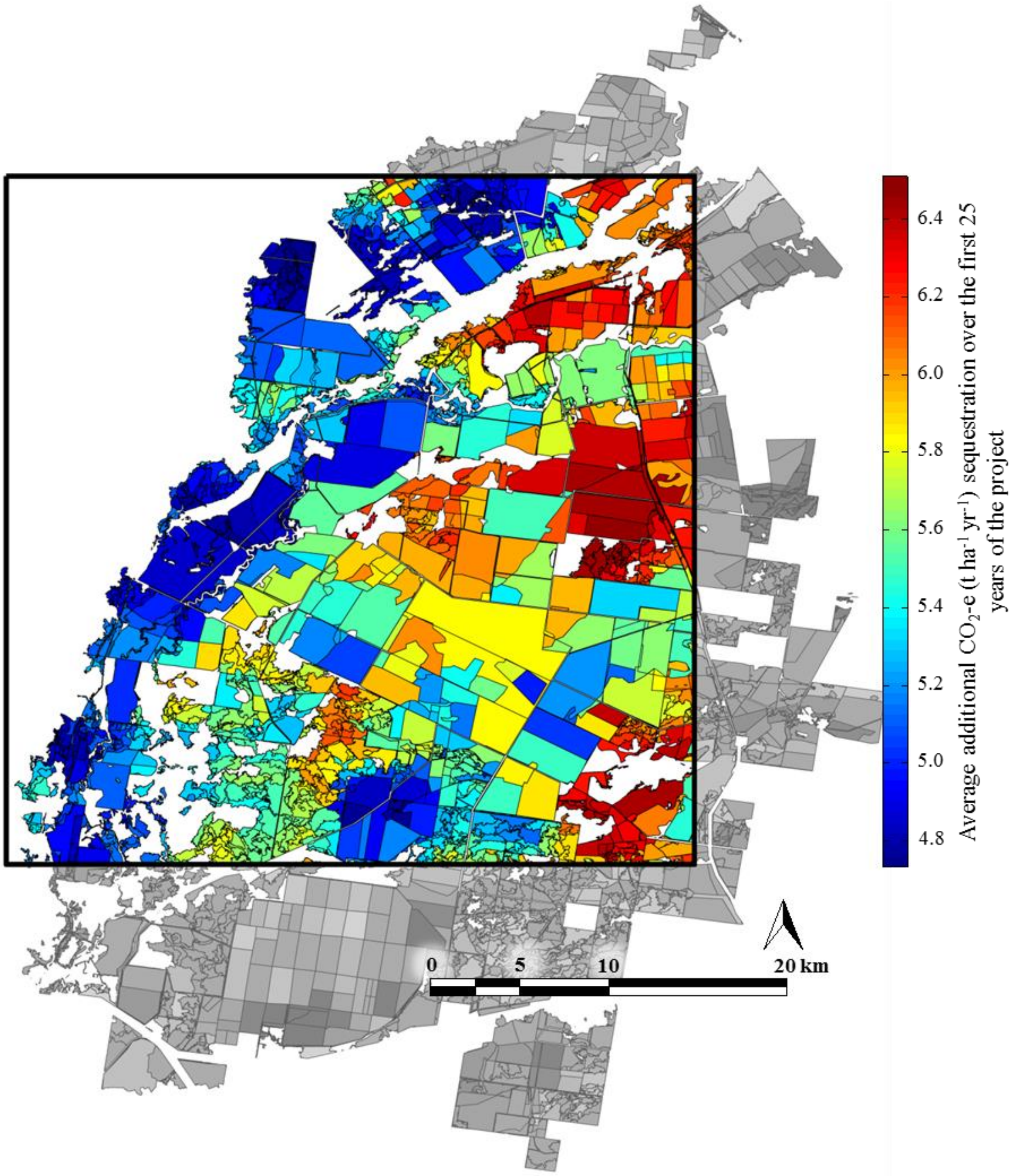

Figure 7: Spatial distribution of average annual carbon sequestration potential for eligible paddocks in case region B**.**

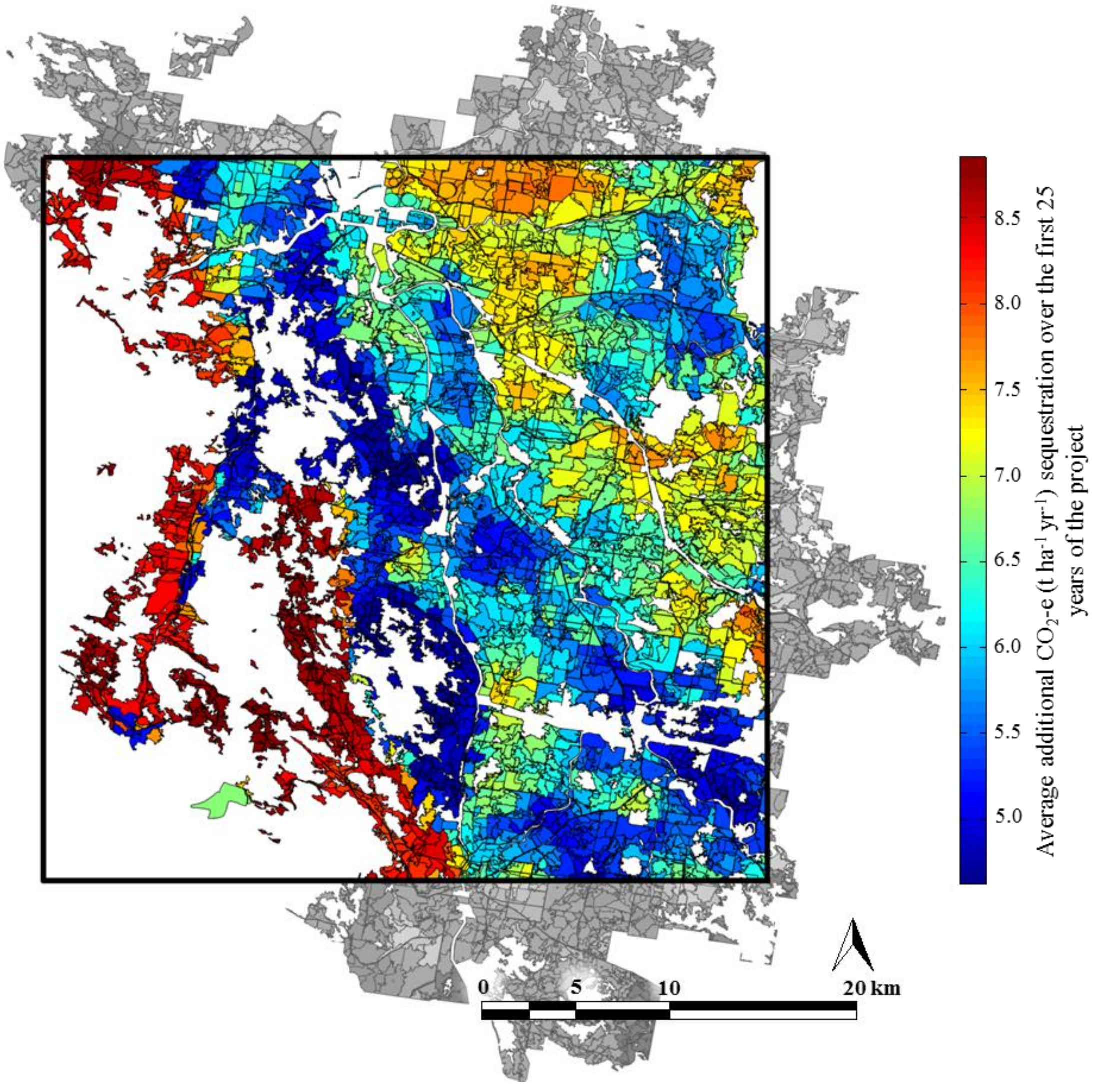

Figure 8: Spatial distribution of average annual carbon sequestration potential for eligible paddocks in case region C.

From a temporal point of view, the variance in sequestration potential becomes more pronounced through time, as shown by the carbon trajectories in Figure 9. The average coefficient of variation (CV) of the additional carbon sequestration potential across each of the three case study regions was 12.67%, with a range between 6.98% and 17.89%. These CV values are lower than those reported by Paul *et al.* (2013) who estimated an average CV of 39% for carbon sequestration potential across their study regions in south-eastern Australia. The smaller variances in the present study may be attributable to the smaller case study regions, the use of a single block planting configuration and a mixed-species carbon plantation strategy with no additional inputs compared to the multiple planting configurations, forestry plantations and the inclusion of nitrogen fertiliser inputs which were included in the Paul *et al.* (2013) study.

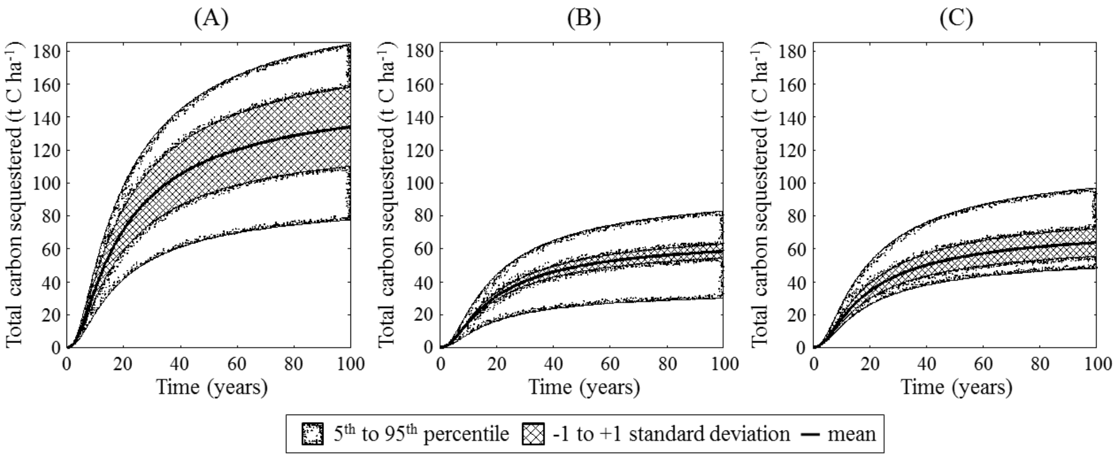

Figure 9: Expected carbon trajectories for the three case region areas.

Assuming that the current management practices and the opportunity costs are homogeneous across a study region is obviously a limiting assumption. Therefore, an additional analysis was undertaken to determine the difference between the actual heterogeneous set of landholders in the case study regions and the assumption regarding a set of homogeneous landholders based on the regional average. For case region A, when assuming a homogeneous group of landholders, it was estimated that no areas would be feasible until the market price reaches \$33.62 t CO_2-e^{-1}. This is a 105% increase in market price required for properties in this case study region to participate compared to the heterogeneous landscape that exists in the region (Table 4.2). For case regions B and C, the assumption of homogeneous regions would see the minimum market price required for any area to be included in a carbon plantation scheme, increase by 20% and 22% respectively.

Not surprisingly, the estimated minimum area that must be contracted by an aggregator for the scheme to just be viable is also affected by the assumption of a homogeneous group of landholders. For case region A the minimum area of land required was between 179% and 669% more than that required when accounting for the heterogeneity across the region. For case region B, the difference was between 47% and 275% and for case region C between 139% and 648% (not shown).

Table 4.2: Increase in minimum feasible starting price when assuming a homogenous landholder set.

	Case region		
	A	**B**	**C**
Homogenous (\$ t CO_2-e^{-1})	34.23	30.68	30.68
Heterogeneous (\$ t CO_2-e^{-1})	16.70	25.50	25.16
Difference (%)	105	20	22

These findings highlight that the failure to account for the heterogeneous nature of the landscape, and the variance in properties across a region, may significantly overestimate both the market price of carbon and the quantity of carbon sequestration required before projects will become feasible.

Antle and Valdivia (2006) described a technique for generating supply curves for ecosystem goods derived from a heterogeneous population of landholders in the US. They derived upward-sloping supply curves by arranging farms in ascending order of opportunity cost. The heterogeneous nature of the landholder populations in the present study allows this technique to be employed. The resulting supply curves, which include transaction costs, are shown in Figure 10.

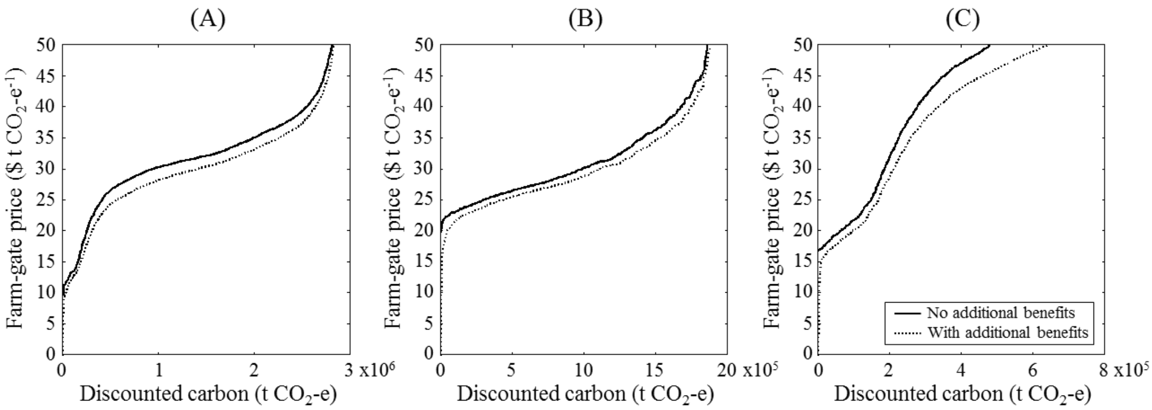

Figure 10: Supply curves for each of the case study regions illustrating cost of carbon offsets both with and without accounting for additional benefits.

An aggregator or policy maker can use these figures to determine the quantity of carbon that may be purchased at different prices from landholders in a region. As discussed earlier, accounting for the influence of carbon plantations on neighbouring paddocks will provide an additional benefit which will move the supply curves down and to the right when these benefits are captured by the landholder[6]. This implies that greater quantities of carbon will be obtained at any price if these additional benefits are taken into account.

4.5 Sensitivity analysis

The PFF diagrams presented in Figures 3 – 5 provide a graphical depiction of the sensitivity of a number of important inputs in relation to a change in the market price of carbon. In addition to this, a sensitivity analysis was undertaken on a range of additional variables. These are presented in Table 3 as elasticities in terms of percentage change in the required minimum project area.

Interestingly, the signs of the elasticities were not consistent for different assumptions across the regions. For example, an increase of one per cent in the cost of agricultural inputs in case region A would see a 0.17% increase in the minimum quantity of area required for a project to become feasible. On the other hand, the same one per cent increase in the cost of agricultural inputs would see a 0.45% and 0.27% decrease in the minimum feasible project area for case regions B and C, respectively[7].

Despite the landholder transaction costs not having a major influence on the minimum feasible project area, the elasticities for case regions A and B suggest that a one per cent increase in these costs will result in a decrease of 0.03% and 0.14% in the minimum area required for a project to be feasible in the region, respectively.

[6] Additional public benefits from carbon plantations, such as the generation of wildlife corridors, are not captured in this model as they will not influence these supply curves.

[7] Due to the heterogeneous but fixed nature of eligible paddock areas, the variance of different parameter assumptions can cause a different set of larger paddocks to be available at a lower cost, resulting in a positive elasticity in some cases where a negative elasticity would be expected.

This reduction in minimum required area in response to higher landholder transaction costs is due to a different set of properties being selected as optimal. When the sensitivity analysis was conducted on the simulation model which ignored the additional benefits, the elasticity ranged between 0.00% and 0.06% (results not shown).

Table 3: Results from the sensitivity analysis on the three case study regions at a market carbon price of \$29 t CO_2-e^{-1}[8]. Values are in terms of elasticies as percentage change in the minimum feasible project area (ha) in response to a one per cent change in the value of each variable/parameter.

	Case region		
	A	**B**	**C**
Aggregator transaction costs	1.28	1.58	1.55
Landholders discount rate	0.45	2.51	1.23
Cost of agricultural inputs	0.17	-0.45	-0.27
Cost of cattle production inputs	0.10	0.01	-0.15
Cost of sheep production inputs	0.10	-0.06	-0.30
Landholder transaction costs	-0.03	-0.14	0.14
Cost of cropping inputs	-0.07	-0.33	0.00
Income from cattle production	-0.10	-0.01	-0.14
Aggregators discount rate	-0.22	-0.26	-0.12
Crop yield	-0.26	0.47	0.00
Income from sheep production	-0.35	0.13	0.37
Agricultural yields and outputs	-0.36	0.66	0.32
Income from livestock production	-0.45	0.11	0.32
Influence of additional benefit	-0.52	-3.46	-1.06

From the elasticities in Table 3, we can see that in addition to the aggregator transaction costs, the additional benefit to neighbouring paddocks and the landholder's discount rate are critical factors. The assumption of the parameter value on the beneficial influence of trees past the initial 'edge' effect (τ_2) is particularly elastic in case region B (elasticity = -3.46). This region has a greater proportion of high value crop paddocks which neighbour eligible carbon plantation paddocks. Therefore, any change to the assumption for the benefit received on these adjacent paddocks will be more pronounced than in case regions A and C, which have lower value enterprises, reflected in elasticities of -0.52 and -1.06, respectively for this parameter.

The landholder's discount rate also had most influence in region B, with an elasticity on the minimum feasible area of 2.51. Again this can be attributed to the influence on the choice of high value crops when they are discounted over a long period of time (100 years). In comparison, the elasticities with respect to landholder discount rate in regions A and B are 0.45 and 1.23. This highlights that the choice of discount rate is an important consideration when modelling carbon sequestration policies. Interestingly, the choice of aggregator discount rate had a significantly lower

[8] A market price of \$29 t CO_2-e^{-1} was assumed to allow feasible areas for each case region to be determined when conducting the sensitivity analysis.

influence on the minimum feasible project area, with elasticities of -0.22, -0.26 and -0.12 on regions A, B and C respectively.

4.6 Proportion of property placed in scheme

Simulations in the current study found that, on average, the minimum proportion of a property required for carbon plantations to be feasible to an individual landholder was 18.35% (± 13.56%) at a market carbon price of \$23 t CO_2-e^{-1}. At this carbon price, there were no feasible projects in either case region B or C. If a market carbon price of \$25 t CO_2-e^{-1} is assumed, the average minimum proportion of a landholder's property required is 18.16% (± 12.52%), 6.52% (± 7.13%) and 9.20% (± 13.50%) for case regions A, B and C, respectively. As the market price of carbon increases, the minimum proportion of a landholder's property requiring conversion to carbon plantations decreases. At a price of \$35 t CO_2-e^{-1} these minimum proportions decrease to 14.38% (± 9.33%), 2.79% (± 2.9%) and 5.72% (± 8.81%) for case regions A, B and C, respectively. While the estimated total proportion of individual landholder's property required to become feasible is higher in case region A, when viewed in terms of actual hectares required, case region A requires an average of only 71 hectares to become feasible, compared to 236 hectares for case region B and 108 hectares for case region C.

5 DISCUSSION

Simulations in the current study have shown that there is significant technical potential to sequester carbon through mixed-species carbon plantations. The results have shown that the minimum feasible price for carbon sequestration projects in northern NSW will vary depending on the location. The lowest market price at which these projects will become feasible is \$16.40 t CO_2-e^{-1} in case region A. For the other two case regions, projects will not become feasible until a market price of approximately \$25 t CO_2-e^{-1} is reached. Given the recent declining global price on carbon (Newell *et al.*, 2013), the findings from this study indicate that the current framework of the CFI may be limiting the potential supply of carbon sequestration from private landholders. Alternative policies and strategies to reduce the cost of this carbon capture, together with methods of encouraging participation by individual landholders, need to be investigated.

5.1 Encouraging landholder participation

Currently, there is a low level of interest in providing long-term carbon plantations in Australia without considerable subsidies or incentives (Hunt, 2008; Patrick *et al.*, 2009). The findings in the current study suggest that, when negotiating terms of contract with an aggregator, encouraging landholders to include additional benefits of planting trees into their opportunity cost estimations may reduce the level of incentives required. It was found that the inclusion of this allowance reduced the minimum feasible price of carbon plantation projects across the case study regions by between 1.63% and 4.28%. The findings show that the area of eligible land available to an aggregator will also increase if landholders are educated on the additional private benefits of planting trees for climate mitigation purposes. Therefore, policy makers should investigate the impact of extension and education programs as a method of reducing the cost of carbon sequestration by private landholders.

Results were found to be highly sensitive to the assumed influence of additional benefits to paddocks adjacent to carbon plantations. There appears to be a lack of rigorous scientific research on the beneficial impacts for adjacent paddocks as a result of planting blocks of trees. Therefore, given the highly elastic nature of this parameter, further scientific research and empirical data will increase the accuracy of estimates.

Given the permanence requirement and the long-term nature of planting native trees for carbon mitigation, farmers may be reluctant to enter large proportions of their property into such schemes. Patrick *et al.* (2009) conducted a study on landholders' willingness to participate in the production of environmental services from a region bordering the current study. They found that 86% of the landholders surveyed did not wish to commit to long-term or perpetuity environmental management agreements. A survey of landholders in central and southern NSW by Schirmer and Bull (2011) reported that a 100-year permanence requirement would be a significant barrier to entry for a carbon offset scheme. Likewise, Markowski-Lindsay *et al.* (2011) found that contract length and concerns over early withdrawal penalties influenced landholders participation in carbon markets. In a study of participation in land diversion schemes in the UK, Brotherton (1989) found that even when presented with economically viable incentives, landholders were only willing to place on average seven per cent of their total landholding into a scheme requiring the conversion of productive agricultural land to woodlands. Raymond and Brown (2011), in an Australian study, found that highly engaged landholders were likely to maintain an average area of 19.54% of their farm to native vegetation and they argued that there is limited scope to expand the areas of conservation with these landholders. They did, however, find that moderately engaged landholders, on average, maintain 12.56% of their property to native vegetation but highlighted that this demographic has the most potential to increase the areas of conservation for environmental purposes.

Therefore, given the evidence that landholders will be likely to commit less than 10% to 20% of their property to trees, the results of this study are not unrealistic. As shown in Table 2, only 1.2% of case region C is currently conserved in ecosystem supply schemes. Thus, given the appropriate incentives and policies, there is significant potential for increasing carbon plantations for the supply of climate mitigation products.

5.2 Heterogeneity and local-scale estimation

Using the local-scale estimation techniques described here, case region A was found to have the highest carbon sequestration potential along with the lowest feasible project costs. This contrasts with the findings in Moss (2014, pp. 12-37) where the highest carbon sequestration potential did not correspond to the area with the lowest estimated costs of sequestration. This suggests that taking into account the individual property characteristics such as existing property infrastructure, tree cover and individual landholder costs, significantly alters the estimated feasible areas and has implications for the areas which should be targeted in policies. It was also found that assuming a homogeneous set of farms and landholders based on a regional average will overestimate the minimum feasible carbon price by a significant amount. This highlights the importance of undertaking a local-scale analysis when developing climate policies to avoid the misrepresentation of costs which occur in broad-scale analyses.

A problem with accounting for heterogeneity across a region and undertaking local scale analyses is the data intensive requirements in regards to the information on individual farm and landholder characteristics required. The procurement of this additional data may incur significant costs and require substantially more work to correctly simulate. Policy makers and aggregators will need to estimate the trade-offs between the extra time, data and modelling requirements required to simulate more accurate supply curves to allow for more informed policy making.

5.3 Reducing project costs

As already mentioned, the results from the simulations in this study suggest that the minimum feasible carbon price of projects under the current CFI framework will impose a barrier to the adoption by landholders in the study region, particularly in case regions B and C. A further sensitivity analysis undertaken on the individual aggregator transaction-cost categories indicated that the aggregator's annual fixed costs were the most influential transaction cost on project feasibility. These findings correspond with those of Cacho *et al.* (2013). This cost category is composed of major project management costs to the aggregator such as the fixed running costs of the local office and staff salaries. Elasticities of this cost category were 0.49 for case region A, 1.53 for case region B and 0.39 for case region C (not shown). The current study assumes that local offices would be set up by private enterprises acting as aggregators in each of the case study regions. The transaction costs of maintaining local offices could be significantly reduced if existing private and government organisations with adequate existing infrastructure were to adopt an aggregator role.

5.4 Choice of discount rate

Studies have found that the choice of discount rate has a marked effect on the cost and feasibility of carbon sequestration projects (for example, Stern, 2007; Hunt, 2008; Torres *et al.*, 2010; Yemshanov *et al.*, 2012). The current study has also found this to be the case, particularly the discount rates assumed for landholders when determining their opportunity costs. In a survey of landholders with private forests in southern USA, it was estimated that landholders required discount rates of 13% for forestry projects lasting 25 years or more (Bullard *et al.*, 2002). This paper highlights that the higher the discount rate of landholders, the less feasible area will be available to project aggregators.

5.5 Policy design of landholder carbon plantations

The current study only considered the land-use change option of converting agricultural land to a mixed-species environmental planting, in accordance with the current CFI rules. A couple of recent studies have found that monoculture farm forestry plantations in south-eastern Australia have the potential to sequester approximately 22% more carbon per year when compared to mixed-species carbon plantations (Crossman *et al.*, 2011; Paul *et al.*, 2013)[9]. Due to this higher sequestration potential, the uptake of monoculture farm-forestry plantations in the CFI scheme could further reduce the cost of carbon sequestration. In addition, if methodologies for the CFI were introduced to allow harvesting of timber strands, in exchange for carbon offset payments, landholders might be willing to accept lower payments per tonne of carbon sequestered as they would have additional economic benefits from the harvesting of timber[10]. This would also encourage a quicker rate of carbon sequestration. As this paper has shown, the highest yearly additional sequestration occurs within the first 25 years of planting. Often the carbon in harvested wood products remains locked-up for several decades (Stockmann *et al.*, 2012) and does not return directly to the atmosphere at the time of harvest. Given the modelling complexities of harvesting and carbon stocks, the current CFIs accounting rules for mixed-species native trees excludes commercial harvest (DCCEE, 2011).

With the current advancements being made in the carbon life-cycle accounting of harvested timber products (Newell & Vos, 2012; Stockmann *et al.*, 2012), it may be possible to more accurately account for a higher rate of permanent/semi-permanent carbon sequestration in harvested wood products. When assessing the life-cycle of wood products, Ingerson (2011) estimated that approximately 14% of carbon captured in timber products across America will remain stored 100 years post-harvest. Currently, there are a handful of voluntary carbon offset markets which have explicitly recognised carbon in long-lived harvested wood products as a forest offset pool (Chicago Climate Exchange, 2009; Winrock International, 2010; Climate Action Reserve, 2012). A shift from short-term to long-term wood products from harvested products will reduce the loss of carbon captured in trees back to the atmosphere. It should be noted that the emissions involved with harvesting, processing and transporting wood products will also need to be included in any accounting policy (Ingerson, 2011).

Finally, the findings of Paul *et al.* (2013) suggested that different planting configurations, such as belt plantings, will be more viable than the simple block plantations which have been assumed in the current paper. Therefore, the influences of different planting configurations on project viability should be assessed in future research.

6 CONCLUSION

The spatial and productive heterogeneity at not only a regional scale, but also across a landholder's property, is often lost in the broader scale analyses which are frequently used by climate mitigation policy makers. This paper has highlighted the vast divergence both between and within the different case study regions. Ignoring this variance may significantly overestimate both the market price of carbon and the quantity of carbon sequestration required before projects will become feasible.

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[9] This may not always be the case. In rainforest regions of north-eastern Australia, it has been found that mixed-species plantations sequestered higher quantities of carbon compared to monoculture plantations (Kanowski & Catterall, 2010).

[10] This paper is set in the policy context of the original CFI rules where no methodologies allowing the harvest of plantations were approved. Given the dynamic nature of the Australian climate regulations, a recent amendment to the legislation now allows farm forestry activities to claim carbon-offset credits (Australian Government, 2013).

Results in this study have shown that the current methodology of planting mixed-species environmental plantings to produce carbon offsets will not be feasible until a carbon price of approximately \$25 t CO_2-e^{-1} in two of the three case study regions. Given the current trend in global carbon markets, this mixed-species, non-harvestable land use may not be a viable option. Planting monoculture plantations may increase the viability of future projects and should therefore be investigated further.

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