Economic methods for assessing carbon offset supply cost

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1 Introduction

This is one of a series of reports prepared for the Goyder Institute for Water Research project, *Assessing South Australian carbon offset supply and policy for co-beneficial offsets*. One report in the series (Regan *et al.*, 2019) examines the potential supply of carbon offsets from land use change and land management change across South Australia's agricultural land base including assessment of how much supply would be viable economically at what price of carbon credits. Three additional reports examine case studies where the value of carbon credits from land use change could also generate co-benefit outcomes (Connor *et al.*, 2019; Summers *et al.*, 2019a; Summers *et al.*, 2019b). This report is one of two methods reports that support all of the project reports. The other methods report (Settre *et al.*, 2019) describes how spatially differentiated carbon sequestration yields were estimated for a set of land use and land management changes agreed for evaluation with the project advisory committee.

The objective of this report is to outline economic methods that are applied to assess prices for carbon credits where change from current agricultural to a new carbon sequestering land uses would be economically viable. This information is the basis of developing carbon offset supply curves representing total tonnes of supply that could be expected from land use change and land management based offset projects at different carbon credit price points. The data and formulas that are described in this report are used in analysis for all other reports to model decisions to supply carbon offsets by changing from current agricultural land use to carbon sequestration land uses to earn carbon credit payments for the resulting carbon sequestration.

1.1 Organisation of the report

The next section outlines the scope of economic analysis carried out for this project. It includes a description of types of land use change evaluated with economics methods and the spatial extent of the study area considered. The following section provides an overview of the conceptual model used to calculate net economic returns from changing to a carbon land use from an agricultural land use. Section 4 discusses how opportunity costs associated with the current land uses were calculated as current agricultural land use profitability. Section 5 outlines the calculation of establishment costs and ongoing maintenance costs associated with carbon forestry. Section 6 outlines the analyses to test the sensitivity of results to key parameters, including discount rates used in analysis, and assumptions about how agricultural profitability and climate change may evolve in the future.

2 Scope of economic analysis

2.1 Spatial coverage

Broadly, the study area for this research is the non-continuous 98,424,000 ha of land in the State of South Australia (SA; l Figure 1). More specifically this study focuses on the reforestation of areas of SA predominantly used for intensive agriculture (i.e. areas cleared for broad acre cropping/grazing) which encompass approximately 11 percent of SA's area. Agricultural production across the state is carried out on land interspersed by areas of remnant revegetation and urban land uses. Agricultural production is dominated by cereal cropping, beef and sheep grazing with isolated areas of high-value irrigated horticulture and agriculture (Bryan *et al.*, 2014). In 2015/2016 the gross value of agriculture production from SA was $6.2 billion and the most important commodities, based on gross value, were wheat, cattle, sheep and lambs and wine (ABARES, 2017).

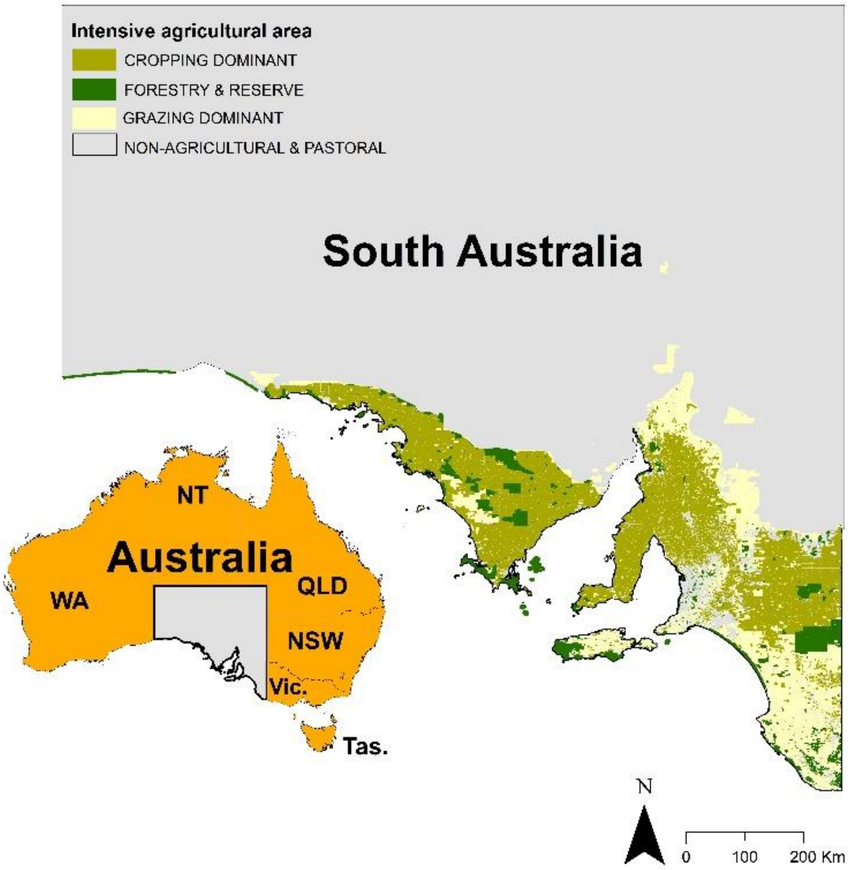

Figure 1: South Australian study area and current land use categories.

2.2 Carbon supply methods considered

The economics of carbon supply was assessed for three types of land use change that are currently admissible in large parts of SA under the Commonwealth Emissions Reduction Fund (ERF) rules (methods), and three land use changes that can also sequester carbon but do not presently qualify for ERF credits (non-ERF methods). The ERF methods considered in economic analysis as well as the areas over which they were evaluated for the project are shown in Figure 2 and the non-ERF methods and areas where they were considered are shown in Figure 3.

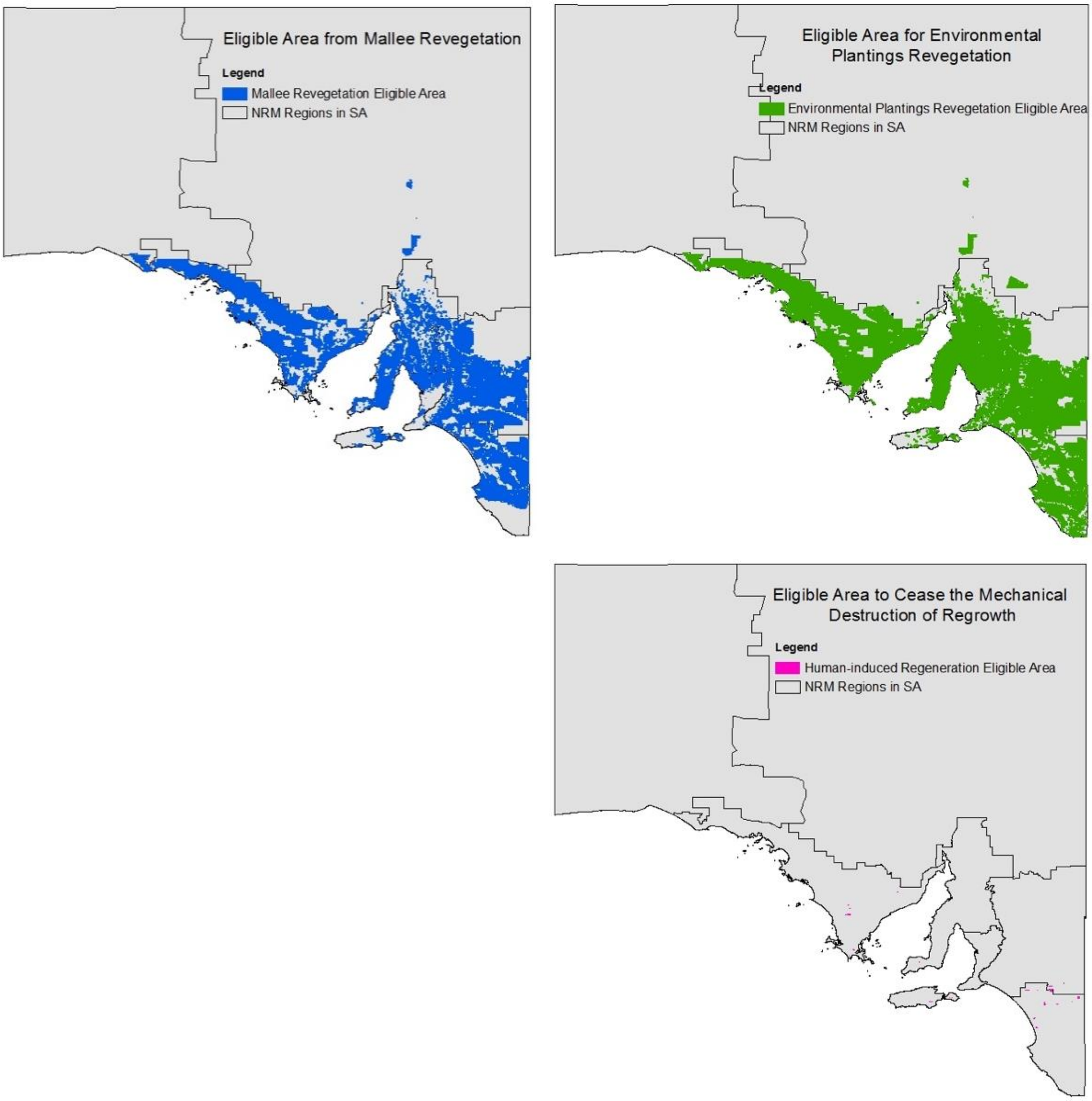

Figure 2: Geographic extent of the eligible areas for each ERF methodology included in the economic analysis.

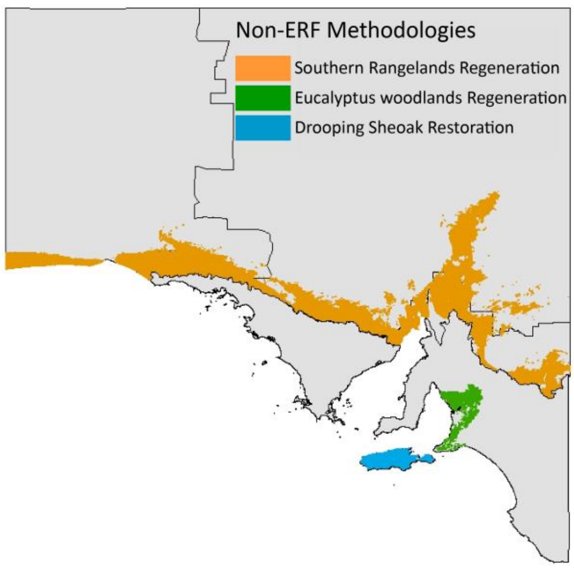

Figure 3: Geographic extent of the eligible areas each non-ERF method included in the economic analysis.

3 Conceptual model of economic viability of land used change for supply carbon credits

The conceptual model of economic decision making applied is based on the perspective of a landholder who considers the potential stream of income from carbon credits that switching land use would generate. As well, they consider two costs: a) the cost of establishing and maintaining the new land use (e.g. the cost of establishing and maintaining a new carbon forest), and b) the cost forgone from no longer using the land in the current agricultural use (i.e. the value of returns net of cost from current cropping or grazing that will no longer be possible once land is converted to carbon forest).

Most establishment costs occur in the first year. Returns from carbon credit supply and agricultural opportunity costs must be considered for all years in 100 year permanency requirement for credits supplied into the ERF. To account for the time-value of the investment decisions over such long timeframes, discounted cash flow analysis was applied to sum all benefits (carbon payments) and costs into a single net present value metric.

Functionally, the NPV_{fp} of changing from current agricultural land use to carbon land use f at carbon credit price p can be expressed as

$$NPV_{fp} = PVR_{fp} - PVC_f \qquad (1)$$

In equation 1, PVR_{fp} is the present value of returns to carbon land use f at carbon credit price p and is calculated as:

$$PVR_{fp} = \sum_{t=0}^{T} \frac{P * Cseq_{ft}}{(1+r)^t} \qquad (2)$$

Where *P* is the price of per tonne of CO_2e carbon credits and $Cseq_{ft}$ describes sequestered carbon[1] in each year t. Spatially differentiated estimates of $Cseq_{ft}$ annual incremental and cumulative values over a one hundred year horizon were estimated across relevant areas for each ERF and non-ERF practice considered primarily with the ERF FullCAM model. The details of estimation methods and results are explained in detail in (Settre *et al.*, 2019).

The term r is the discount rate applied in discounting future costs and returns and T is the time horizon in our case 100 years representing the 100 year permanency requirement for the ERF.

The term PVC_f in equation 1 is the present value of all costs for carbon land use f. It is calculated as:

$$PVC_f = EC_f + \sum_{t=0}^{T} \frac{MC_t + PFE_t}{(1+r)^t} \qquad (3)$$

[1] $Cseq_{ft}$ relates the physical carbon sequestration in tonnes of carbon dioxide equivalents in each year. It was not seen as appropriate to discount a bio-physical process. Instead risk posed to carbon accumulation is accounted for in the economic calculations through the application of higher discount rates.

Three elements of cost are considered in equation 3: EC_f is the initial establishment cost for carbon land use f. This value is not discounted as it occurs in at project initiation. MC_t represents the maintenance costs that occur in each year *t* over the investment horizon. As described below these costs are assumed to be relevant in years t_{1-10}. The final term considered in calculating net present value of all relevant costs is opportunity cost of forgoing previous agricultural land use returns. This is expressed as the profit at full equity PFE (agricultural returns net of all costs of agricultural production).

The overall objective of economic analysis was to produce estimates of the increasing level of supply (t CO_2e) that would become viable with increases in the level of carbon credit payment ($/t CO_2e). To this end, the NPV model (equation 1) was solved iteratively at all points in the grid representing unique supply and economic conditions for a range of carbon prices P ranging from $13/t CO_2e to $800/t CO_2e, in increments of $4/t CO_2e. At the first price that was sufficiently high to produce a positive (or zero) NPV for any sample point, carbon supply for the area associated with the point was added to cumulative supply. Note that for each scenario, once a price that produced a positive NPV was reached, prices were considered constant over 100 years.

4 Opportunity cost

As described in the conceptual model of carbon offset supply economics above, agricultural profitability was calculated using the concept of profit at full equity (PFE). PFE is a measure of profit which is calculated as the revenue from the sale of agricultural commodities minus all fixed and variable costs. Because forgoing current agricultural land use would involve forgoing income from the use but also not require incurring the costs, it is an appropriate measure of opportunity cost. To properly account for how land ownership costs would be incurred regardless of land use, this concept is based on the assumption that the land is fully owned.

PFE is a function of the gross revenue ($/ha/year) less the production cost ($/ha/year). PFE also captures multiple commodities as primary and secondary products (e.g. sheep wool, sheep meat), variable costs such as area dependent costs (i.e. seeding, fertiliser) quantity dependent costs (i.e. harvest, storage) and fixed costs such as insurance, maintenance and others.

To estimate PFE and how it varies across the study area we updated the spatially explicit national agricultural profitability (PFE) layer produced by Marinoni *et al.* (2012) for relevant parts of SA. Marinoni *et al.* (2012) collated data from Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) national land use map 2005/2006 (ABARES, 2010), Australian Bureau of Statistics (ABS) Agricultural Survey 2005/2006 (ABS, 2006) and various Department of Agriculture gross margin budgets. This information allowed producing a raster dataset of agricultural profitability across Australia for the year 2005/06 at a 1.1 km resolution.

We updated PFE/ha calculated following Marinoni *et al.* (2012) as:

$$PFE = \big((P1 \ \times Q1 \ \times TRN) + (P2 \ \times Q2 \ \times Q1)\big) - ((QC \ \times Q1 + AC) + (WR + WP) + (FOC + FDC + FLC) \quad (4)$$

where $P1$ is the Farm Gate Price ($/ha or $/DSE), $Q1$ the Yield or Stocking Rate ($/ha or $/DSE), TRN is the Turn-off Rate (Ratio; portion of livestock herd sold per year, set to 1 for non-livestock commodities), $P2$ is the Price of Secondary Product ($/kg or $/l), $Q2$ the Yield of Secondary Product (kg/DSE or l/DSE), QC is the Quantity Dependant Variable Costs ($/t or $/DSE), AC is the Area Dependant Variable Costs ($/ha), WR is the Water Requirement of Land Use (ML/ha), WP is the Water Price ($/ML), FOC is the Fixed Operating Costs ($/ha), FDC is the Fixed Depreciation Costs ($/ha) and FLC is the Fixed Labour Costs ($/ha).

To create the updated agricultural profitability dataset for 2017, fixed and variable costs were revised with price indices from The ABS. For example, FOC, FDC, QC, AC, were updated using the Consumer Price Index (CPI) as follows:

$$\Delta CPI = \left(\frac{Average\ of\ CPI\ level\ in\ Dec\ 2016, Mar\ 2017, Jun\ 2017, Sept\ 2017}{Average\ of\ CPI\ level\ in\ Dec\ 2006, Mar\ 2006, Jun\ 2006, Sept\ 2006} - 1\right) \times 100\% \quad (5)$$

The corresponding inflation for the period 2006 - 2017 was 25 percent. Similarly, the ABS *Wage Price Index: total hourly rates of pay excluding bonuses for South Australia* was used to calculate changes in FLC for the same period. This index was chosen based on advice from the ABS as no wage price information is collected by the ABS on agricultural wages specifically. Wage increases equated to a 33 percent increase over the period 2006 – 2017.

It was also necessary to update yields from the original PFE dataset because Australian agriculture has seen modest, but continuous improvement in productivity over time. For example, improvements in broad acre agriculture and grains yields specifically, has averaged approximately one percent per year (Fischer, 2009;

Kirkegaard and Hunt, 2010; Robertson *et al.*, 2016). Granular agricultural yield data is largely non-existent at a broad spatial scale. The original PFE dataset applied production data from the ABS agricultural survey 2005/2006 at a Statistical Area 2 (SA2) resolution (Figure 4) and yields were allocated spatially using a sophisticated algorithm determined using ABARES (2010) Normalised Difference Vegetation Index (NDVI) based land use data. These data were updated with yield data from the ABS Agricultural Census 2015/16 at SA2 resolution.

The result, an updated agricultural profitability layer is presented in Figure 5.

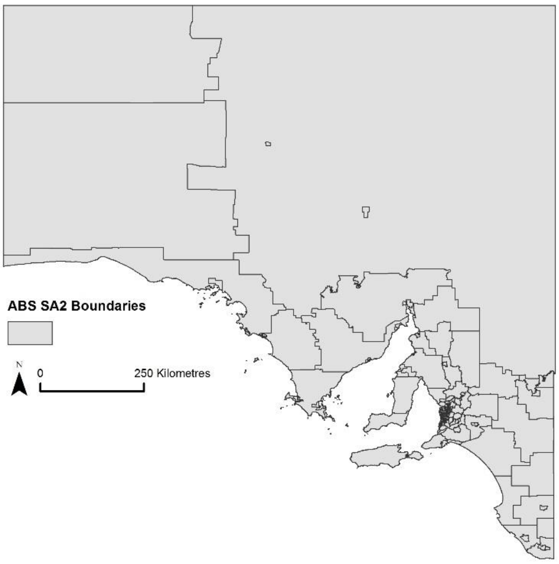

Figure 4: ABS SA2 boundaries

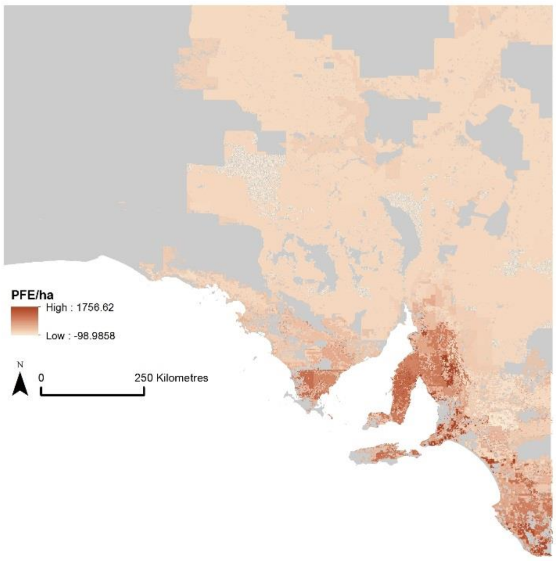

Figure 5: Agricultural profit at full equity (PFE) 2017.

5 Establishment costs

Previous studies on the economics of carbon forestry have shown that establishment costs can play a significant role in the viability of carbon plantings (Paterson and Bryan, 2012; Summers *et al.*, 2015). Reforestation costs for plantations in Australia vary significantly from $740/ha (Bryan *et al.*, 2008) to over $9000/ha (Townsend *et al.*, 2012). The variation in prices can be attributed to several factors including planting method (direct seed, tube stock planting), price of seed/tube stock, labour cost and plantation configuration (mixed plantings vs monocultures) with more expensive methods generally required in higher slope areas. Calculation of establishment costs for carbon sequestration projects is problematic for several reasons. There is substantial variability in the reported costs of inputs in the literature. Several planting methodologies exist with no clear guidance on which is appropriate in what situation and scant information exists regarding consistently applied planting densities and how these vary across the landscape. The following section outlines the development of establishment costs for this study. Experts from SA Water and the Department for Environment and Water (DEW) were consulted on the validity of our estimates and costs were tested in scenario analysis.

5.1 Planting methodologies

Three seeding methodologies were considered following Summers *et al.* (2015): *direct seeding* (DS), *manual tube stock* (mantube) and *mechanical tube stock* (mechtube). Direct seeding is a common way to reforest land for purposes other than timber production (Summers *et al.*, 2015; Salt and Freudenberger, 2009). This technique involves seeding machines, towed by vehicles, placing seed directly into the soil at intervals. The advantage of direct seeding is that a range of species can be sown as mixed seeds with little labour required. Direct seeding is the cheapest form of active reforestation (Cole *et al.*, 2011). The disadvantage of direct seeding is that germination can be inconsistent. Factors known to affect the rate of germination include seed stock age, low rainfall and high soil clay content (Vesk and Dorrough, 2006; Summers *et al.*, 2015).

Planting seedlings in the form of tube stock is the most common form of revegetation, particularly for establishment of monoculture plantations. The planting procedure can be either mechanical or manual, however both require similar preparatory steps including chemical weed control and soil preparation in the form of deep ripping, discing or moulding (Preece *et al.*, 2013; Summers *et al.*, 2015). These methods are labour intensive and represent higher revegetation costs when compared to direct seeding methods.

Geographical considerations such as soil type and slope often determine the applicability of planting methodologies. For example, *DS* and *mechtube* is unsuitable in areas on steep slopes due to the need for machinery access, in these areas *mantube* methods are more suitable. To attribute the most suitable planting method across the landscape a decision algorithm (Figure 6) developed by Summers *et al.* (2015) was employed.

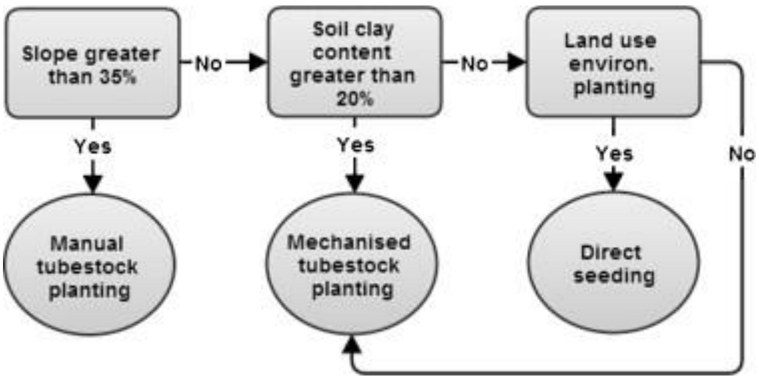

Figure 6: Planting method allocation algorithm (Summers *et al.*, 2015).

Within the algorithm the three different planting options exist. *DS* was only allocated where soil texture was suitable to promote germination and ease of machine use and the slope of the terrain is suitable for machinery operation. Mechtube establishment was allocated where the slope would not affect machinery operation and soil texture is unsuitable for *DS*. Mantube establishment is allocated to areas where the slope of the terrain makes it unsuitable for machine. The decision algorithm was applied spatially using a GIS.

5.2 Planting costs

Estimates of costs for various inputs into reforestation activities were sourced from NRM Review and Price Guide for Significant Environmental Benefits (DEWNR, 2016). This enabled cost estimation using South Australian data from local revegetation activities. The costs associated with plantation establishment are presented in Table 1.

Table 1: Costs associated with establishment of carbon forestry plantation

Activity	Cost ($)	Unit
Spot spray (SS)	100	ha
Boom spay (BS)	10	ha
Vermin control (VC)	300	ha
Seed (SC)	435	ha
Direct seeding (SA)	100	ha
Machine seeding	150	ha
Soil preparation (SP)	100	ha
Ripping (SP_{mech})	190	ha
Tube cost (TC)	1.00	per tube
Planting tube (TP)	1.00	per tube
Tree Guard (G)	0.40	per guard
Initial planning (P)	396	ha

5.3 Planting density

Information pertaining to planting density for reforestation activities was somewhat problematic. As outlined in Settre *et al.* (2019), the FullCAM model sets stocking density as between 500-1500 stems per ha with no indication of how stocking density is assigned or varies over the landscape. The implication of this is that based on outputs from FullCAM, establishment costs cannot be differentiated between highly productive sites in high rainfall areas and low productivity, low rainfall areas.

To overcome this issue, data from observed planting densities from across South Australia was taken from Hobbs *et al.* (2013) and used to estimate appropriate planting densities. This data set provides information on observed plant densities for South Australian NRM regions, local government areas and by rainfall zone. In order to apply varying establishment costs spatially, SA was divided into four regions based on average annual rainfall (Table 2). Based on these data, and the FullCAM configuration of 500-1500 stems per ha, the following planting densities by rainfall zone were assumed (Table 2).

Table 2: Planting density by rainfall zone

Rainfall Zone	Stems per ha
<300	725
300-400	850
400-600	1200
>600	1500

5.4 Establishment cost calculation

The calculation of establishment costs (EC) for the three seeding methodologies was implemented following Summers *et al.* (2015) and consisted of three individually parameterised models (Eq. 6 – 8, as described below).

5.4.1 MANUAL TUBE STOCK PLANTING

The manual tube stock planting method consists of three applications of chemical weed control using a spot spray system (SS) costed on a per hectare basis. Manual soil preparation (SP), purchasing tube stock (TC), manually planting tube stock (TP) and applying tree guards (G) were costed on a quantity basis of stems per ha (SPH). The cost of manual tube stock planting (*Cmantube*) was calculated as:

$$Cmantube = SS \times 3 + (SP + TC + TP + G) \times SPH + V + P \quad (6)$$

5.4.2 MECHANICAL TUBE STOCK PLANTING

The mechanical tube stock planting method consisted of three applications of chemical weed control; two with a boom spray (BS) and one with a spot spray, each costed on an area basis. Mechanical site preparation (SP_{mech}), typically deep ripping, was also costed on a per hectare basis. Purchasing tube stock, mechanically planting tube stock (TP) and plant guards were costed on a quantity basis (SPH). The cost of manual tube stock planting (*Cmantube*) was calculated as:

$$Cmechtube = (BS \times 2) + SS + \mathrm{SPmech} + (\mathrm{TC} + \mathrm{TP} + \mathrm{G}) \times \mathrm{SPH} + \mathrm{V} + \mathrm{P} \quad (7)$$

5.4.3 DIRECT SEEDING

The direct seeding method consisted of two boom spray and one spot spray application of chemical weed control. Soil preparation (SP), purchasing seed (SC) and sowing seed (SA) were each carried out once. The areal costs of soil preparation and sowing seed were adjusted by the ratio of planted SPH to costed SPH. The cost of manual tube stock planting (*Cmantube*) was calculated as:

$$Cdirectseed = (BS \times 2) + SS + \left(SP \times \frac{SPHplant}{SPHcost}\right) + \left(SC \ \times \frac{SPHplant}{SPHcost}\right) + SA + V + P \quad (8)$$

The establishment costs developed for the economic modelling for each planting methodology and rainfall zone are presented in Table 3.

Table 3: Plantation establishment costs by planting method and rainfall zone with comparison against Summers *et al.* (2015).

Rainfall zone	Mantube ($/ha)	Mechtube ($/ha)	Direct seed ($/ha)
<300	2597	2481	1806
300-400	2843	2726	2008
400-600	3526	3409	2391
>600	4306	3994	2760
Data from Summers *et al.* (2015)			
Min	2682	1763	1703
Max	6396	5747	4229
Mean	4745	3529	2474

In order to test the sensitivity of results to establishment costs, economic valuation was conducted with establishment costs at ± 25 percent of calculated establishment costs.

5.4.4 MAINTENANCE COSTS

In addition to upfront establishment costs, maintenance costs were also considered (Table 4). Maintenance costs were adapted from revegetation case studies presented in DEWNR (2016). Maintenance costs were assumed to accrue for the first 10 years of the plantation, except for water which applied from year 1- 5 (establishment occurring in time t = 0).

Table 4: Annual maintenance costs associated with carbon plantation (present value presented in the table was calculated with a 5 % discount rate. This is adjusted appropriately in sensitivity analysis).

Maintenance activity	Cost ($/ha/year)	Present value ($/ha)
Vermin control	150	1158
Weed control	100	772
Water	500	2164
Monitoring	75	579
Total (t= 1-10)		***4674***

6 Sensitivity analysis

Offset economics are sensitive to a number of factors including:

- Discount rates (Bryan *et al.*, 2008, Connor *et al.*, 2015).
- Establishments costs (Paterson and Bryan, 2012).
- Agricultural opportunity cost (Bryan *et al.*, 2014).
- Effects of potential future climate change (Nelson *et al.*, 2014).

These factors are discussed in further detail below.

6.1 Discount rate

The selection of discount rate can vary according to many factors including the cost of capital, risk preferences/perceptions, time horizon of the investment and economic knowledge (Koppenberg and Spiegel, 2017). The level of discount rate used in the literature varies substantially from very low social discount rates (1-2%; Stern, 2008) used to determine the benefits of social projects to high hurdles rates associated with private investment decisions. Generally experience, economic theory and empirical studies show higher rates of return than predicted by net present value computation are required before land use changes from agriculture to forests (Musshoff, 2012). Globally, areas of marginal agricultural land persist despite NPV analysis suggesting greater profitability under alternative land uses (Hauer *et al.*, 2017). This underestimation can be partially explained by the discount rates used in the NPV calculations. Often calculations use commercial discount rates. i.e. the cost of credit for agricultural activities or returns from government bonds to discount future cash flows. However, enterprises such as forestry present a unique set of risks and challenges such as the potential for large sunk costs, loss of flexibility in land use, expensive reversibility, long timeframes and therefore high levels of uncertainty over future returns (Isik and Yang, 2004). Landholders have been seen to require higher financial yields from these enterprises to compensate for some of the aforementioned risks (Prestemon and Wear, 2000). Additionally, econometric models incorporating different sources of risk have shown landholders require returns from forestry to be 2-5 times higher than returns to conventional agriculture (Schatzki, 2003; Wolbert-Haverkamp and Musshoff, 2014; Regan *et al.*, 2017). To address this, we have tested the effect of several discount rates found in the literature on the supply of carbon sequestration (Table 5).

Table 5: Discount rates applied in sensitivity analysis and rationale for use

Scenario	Rate	Rationale
Base case	5%	Represents low discount rate and is in the vicinity of long term bond rates Australian 2 year government bonds
Scenario 1	10%	Represents average cost of credit to Australian agriculture over past 30 years (Connor *et al.*, 2015)
Scenario 2	15%	Has been quantified in United States' studies on conversion from agriculture long rotation forestry (Murray-Rust *et al.*, 2013, Prestemon and Wear, 2000)

6.2 Expected future agricultural opportunity cost

Determining future agricultural opportunity costs is complicated and future agricultural profitability will be determined by multiple interacting factors including future and changing consumer demand, market access, scale of productivity improvements and competition for land from non-agricultural sources (Hatfield-Dodds *et al.*, 2015). Recent trends in several of the aforementioned factors appear consistent with potential future increases in agricultural commodity prices, most notably changes in consumer preferences and increased demand. Global trends show a dramatic shift of diets (Asian in particular), away from traditional staples and towards westernised diets including increased consumption of wheat, livestock and dairy products, vegetables and fruit, and fats and oils (Pingali, 2007). In addition to changing diets, food demand as a result of growing population is forecast to increase by anywhere from 20-30 percent (Tilman *et al.*, 2011) to potentially 50-98 by 2050 (Valin *et al.*, 2014).

Considering these multiple factors, the Australian National Outlook 2015 (Hatfield-Dodds *et al.*, 2015) forecasts agricultural productivity to increase at trend rate of 1.5% per annum to 2050 and forecasts agricultural commodity prices increasing into the future, largely driven by growing demand from an increasingly affluent global population. Under a scenario of increasing agricultural profitability, the assumption of static temporal opportunity costs would potentially result in inaccurate estimates of supply.

In order to test agricultural opportunity cost impacts on carbon offset supply economics, a similar framework as presented by Bryan *et al.* (2014) was adopted (Table 6). The estimates used by Bryan *et al.* (2014) were developed from forecasts presented in the Australian National Outlook 2015 (Hatfield-Dodds *et al.*, 2015). In the “Current” scenario opportunity cost was calculated as profit at full equity (PFE) from current agricultural land use as detailed above. In “Trend” and “Optimistic” scenarios current PFE was increased at a rates of 1.5% and 3% each year over the 100 year investment horizon.

Table 6: Increase in agricultural profitability used in sensitivity analysis

Productivity scenario	Productivity increase
Current	0% per annum
Trend	1.5% per annum
Optimistic	3.0% per annum

6.3 Climate change

Changes in carbon abatement potential due to climatic changes have potential to significantly reduce carbon sequestration yield from forests (Hobbs *et al.*, 2016, Hatfield-Dodds *et al.*, 2015) and the effects are expected to be spatially heterogeneous. Furthermore, such changes have been shown to significantly affect the economics of supplying of carbon abatement (Bryan *et al.*, 2011, Bryan *et al.*, 2014). It is important to note that while future climate change may negatively affect sequestration potential, it may conversely have positive effects on associated co-benefits (shade, shelter, amenity) produced by tree plantations. Quantifying changing value in the full spectrum of co-benefits under climate changed futures was beyond the scope of this study. As such the economic analysis assesses carbon prices required to compensate for changed carbon yields as a result changed bio-physical processes as a result of climate change.

The FullCAM model currently has no mechanism to account for the potential impact of climate change on key variables that influence carbon sequestration, namely temperature, rainfall volume and variability. Consequently, climate change impact on carbon offset supply cannot be assessed directly using ERF methodology estimates of carbon yields.

To investigate the effects of climate change we sourced data from an alternative model of carbon sequestration developed by Hobbs *et al.* (2016). This model is an allometric model derived from direct measurements of biomass from plantations in SA. This model was run for the sample point previously modelled in FullCAM across SA over several climate change scenarios adapted from Bryan *et al.* (2011) as outlined in Table 7, describing assumed changes in temperature, rainfall and evaporation to the year 2070.

Table 7: Climate change scenarios used in sensitivity analysis

Climate Change Scenario	Temperature	Potential evaporation	Rainfall
S0 Baseline	Historic	Historic	Historic
S1 Mild warming & drying	+1°C	+3%	-5%
S2 Moderate warming & drying	+2°C	+6%	-15%
S3 Severe warming and Drying	+4°C	+8%	-25%

The Hobbs *et al.* (2016) model does not provide a dynamic carbon sequestration curve like the FullCAM model. It instead provides and estimation of total carbon accumulation over 65 years. The total carbon accumulation for 65 years for climate scenarios S1-S3 were compared to the baseline (S0) climate scenario model output for all sample points (1,184) across South Australia. The percentage change in total carbon accumulation between climate scenario S1-S3 and S0 was calculated for each sample point as the percentage change in carbon productivity (Figure 7).The percentage change for each sample point was used as a scaler for the original FullCAM model data and was applied to the FullCAM data as follows:

$$C_{t\,1-50} = FC_{t\,1-50} \times \frac{t}{50} \times CC\% \qquad (9)$$

where $C_{t\,1-50}$ is the climate changed annual carbon sequestration rate for years 1 to 50, $FC_{t\,1-50}$ is the FullCAM modelled annual carbon sequestration rate for years 1 to 50, and $CC\%$ is the percentage yield reduction for calculated for each location under each climate scenario.

The effect of climate change was modelled to increase linearly over the 50 year period 2020-2070, after which (year 51 to 101) the full yield reduction was applied

The climate change scenarios had the greatest effect on environmental plantings due a higher proportion of shrubs and smaller, shallower rooted plants that are potentially more susceptible to dryer, hotter conditions than larger tree species.

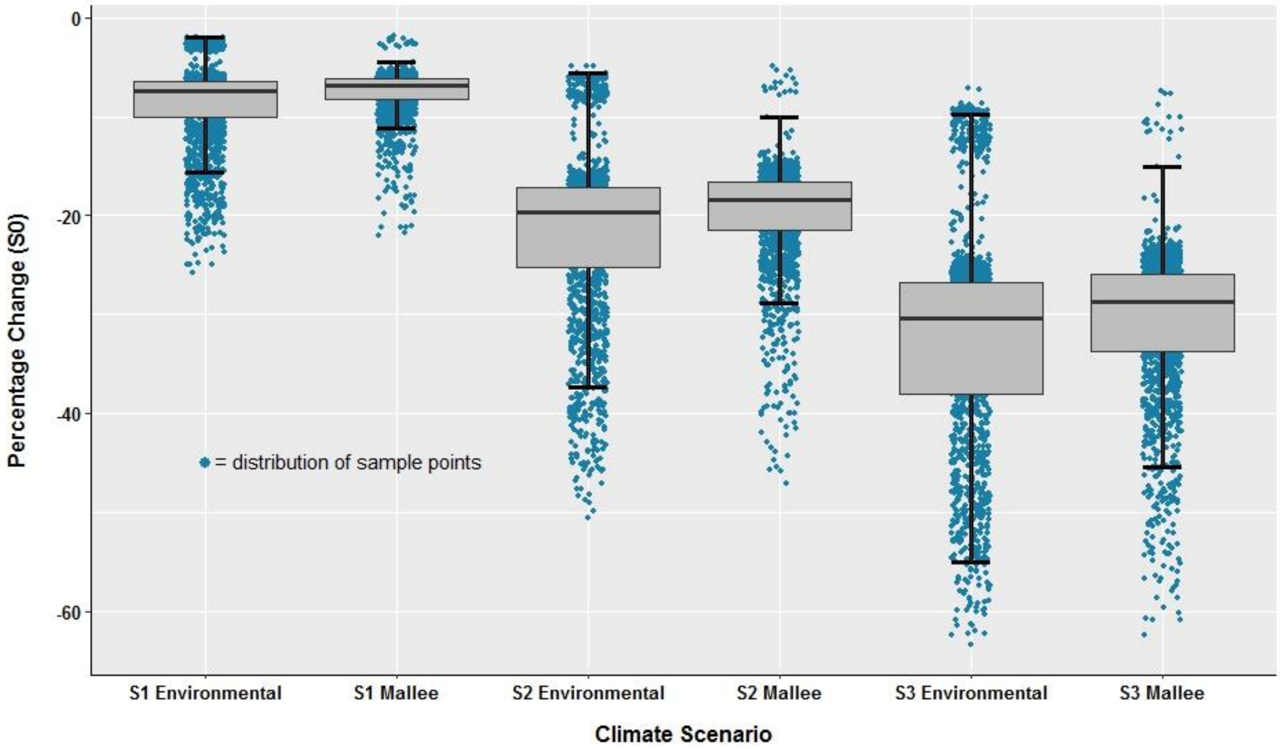

Figure 7: Percentage change in sequestration rates for three climate change scenarios for all sample points in the study area.

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