Assessing South Australian carbon offset supply and policy for co-beneficial offsets: Shelter belts for lamb mortality reduction

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Executive summary

This research was carried out as part of the Goyder Institute for Water Research project, *Assessing South Australian carbon offset supply and policy for co-beneficial offsets* to provide an understanding of the biophysical potential for carbon sequestration across South Australia as well as the economic constraints to this land use change. This study investigates the physical and economic potential for tree shelter belts along the perimeters of sheep grazing paddocks to reduce lambing mortality and to simultaneously sequester carbon. The research involved estimating relationships between shelter provided by trees and lamb mortality and also provided estimates of the carbon that tree shelter belts can provide. These relationships were estimated across the entire intensive agricultural area of South Australia with differentiation in estimates based on differences in key outcome drivers: wind chill, rainfall and carbon sequestration rates. An economic overlay then estimated the price of carbon credits that would be required for carbon credit value plus economic value of avoided lamb mortality to be sufficient to cover all costs involved.

Results show that significantly higher carbon prices than were available in recent ERF auctions would be required for economic value from shelterbelt carbon and lamb mortality reduction to cover costs of implementation for most of the scenarios and locations considered. The economics of the proposition were found to vary considerably, depending on locational attributes including wind chill and rainfall, as well as assumptions about proportions of twin lambs as opposed to single lamb litters and the impacts of wind chill on mortality. The one exception is in the high rainfall South East, Adelaide and Mount Lofty Ranges regions, where a moderate assumption of 50% twin litter rates in combination with optimistic shelter effectiveness assumptions results in breakeven economics at carbon prices (\$15 to \$16/tCO^2e), which is not far off of recent ERF levels (\$11 to \$12/ tCO^2e). With optimistic assumptions about instances of twins, the economics are estimated to be even more attractive.

The carbon plantings may provide other co-benefits at the same time as the providing tree shelter belts, such as soil conservation, amenity value, water quality improvements, and pollination services. These could conceivably lower the cost of abatement if combined and stacked. However, for this report these benefits were considered singularly in conjunction with carbon benefit. Other co-benefit analyses are presented in Connor *et al.* 2019 and Summers *et al.* 2019.

1 Introduction

1.1 Overview

This report examines the potential for tree shelter belts along the perimeters of sheep grazing paddocks to reduce lambing mortality and to simultaneously sequester carbon in South Australia (SA). The economics of increased returns to a sheep grazing enterprise plus the value of carbon emissions offsets that could be sold on carbon credit markets is estimated. The project was carried out as part of the Goyder Institute for Water Research project, *Assessing South Australian carbon offset supply and policy for co-beneficial offsets*. The Project seeks to understand the biophysical potential for carbon sequestration across SA as well as the economic constraints to this land use change.

The project was motivated by recent South Australian experience in the current Australian Commonwealth economic incentives for carbon sequestration, the Emissions Reduction Fund (ERF). This scheme involves a reverse auction mechanism where least cost per tonne carbon sequestration projects offered by land holders for land use or land management change that produce carbon offset are funded. To date the ERF has provided AUD$2.55 billion to land holders for carbon abatement. Six ERF auctions held since April 2015 have mostly secured offsets through projects involving changes in land cover with an average price of AUD#12.0 tCO_2e (Evans 2018).

Very little carbon has been provided from South Australian projects. A key reason is that previous research has shown that a price in excess of $50 tCO_2e^{-1} would mostly be required before landholders would be better to switch to carbon farming from business as usual agricultural practices.

This is one of three case studies that explore potential for social, economic and ecological co-benefits of revegetation demonstrated in previous research (e.g. Bryan *et al.* 2014; Crossman *et al.* 2011; Paul *et al.* 2013). These case studies explore whether co-benefits may provide sufficient economic incentive to fill gaps between income from carbon and the costs of establishment, maintenance and lost opportunity from agriculture.

1.2 Shelter belt services

One of the potential co-benefits from carbon supply is the strategic planting of trees to provide protection of livestock from extreme weather. Both extreme heat and cold can have a detrimental impact on livestock production systems, through increased mortality (particularly at lambing) and reduced feed conversion and weight gain. Here, our emphasis is on the use of shelter belts to reduce the impact of extreme cold.

In some parts of SA, lambs born during winter and early spring are particularly vulnerable to wind chill. These lambs are most vulnerable for the first 48 hours (King *et al.* 2012) and those with low birth weights are more vulnerable than others (Oldham *et al.* 2011). Because they are more likely to have lower birth weights, twins have much lower survival rates than single births. Under certain (i.e. stressful) conditions, survival rates for twins as low as 40% have been observed (Bird *et al.* 1984; Oldham *et al.* 2011; Watson *et al.* 1968) and rates of 60-70% are not uncommon (Edwards *et al.* 2011). These rates are also affected by the breed of the animal with some cross breeds being much less susceptible (Young *et al.* 2014) (Figure 1).

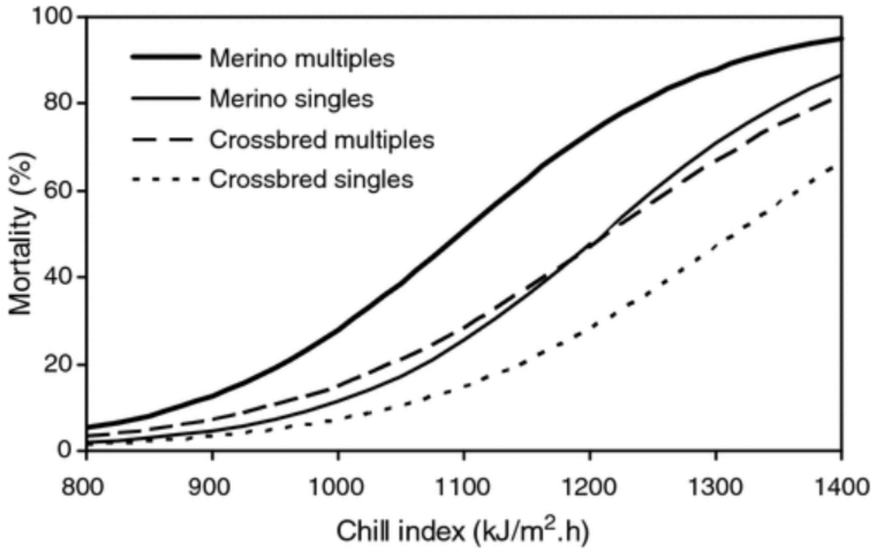

Figure 1: Observed relationship between the mortality rate in single and twin merino and crossbred lambs, and the chill index (Young *et al.* 2014).

High wind chill results from a combination of wet weather, cold temperatures and high winds that essentially strip heat from the lambs at a rate they cannot keep up with. The establishment of appropriate shelter belts can slow wind speed and thereby reduce the chill index. Under the right conditions shelter belts have been shown to reduce mortality of single and twin lambs by up to 13% for singles and 3 % for twins (Broster *et al.* 2012).

There are a number of factors that determine the effectiveness of wind breaks in providing shelter during lambing, including the orientation of the shelter relative to the wind, the height of the shelter and its porosity (Broster *et al.* 2012; Cleugh 2003). Wind speed reductions are typically measured between vegetation stands and leeward distances equivalent to the height of the stands. Reductions in wind speed of up to 82% have been observed over these distances (Bird *et al.* 2007). However, one of the main impediments to the establishment of shelter belts is the high costs involved, both from the upfront costs of establishment and maintenance and the ongoing cost of lost productivity from land that would otherwise have been used for agriculture (Broster *et al.* 2012).

The objective of this study was to assess the economic and spatial realities of planting of trees to provide shelter for lambing as a co-benefit to the income from carbon credits that might be also be available.

Thus, the analysis involved two components: 1) modelling the price of carbon at which carbon credit payments justify the costs of changing sheep grazing land to trees for carbon sequestration; 2) modelling increased returns to a sheep grazing enterprise that carbon plantings in the form of shelterbelts can achieve through reduced lamb mortality.

2 Methods

2.1 Climate data

Rainfall and temperature (daily maximum and daily minimums) were obtained from the Australian Gridded Climate Data (AGGD) (BOM 2018; Table 1). The daily maximum and minimums temperatures were averaged to provide mean daily temperature. For subsequent analysis rainfall data were categorised into different rainfall regions of 0-250 mm, 250-400 mm and greater than 450 mm (Figure 5). Wind speed was obtained from CSIRO near surface wind speed data (McVicar *et al.* 2008).

All climate data were downloaded at daily time steps from 1974 to 2017 and with a spatial resolution of 0.05 decimal degrees. Climate data were spatially subset to SA and the daily wind chill was calculated using equation (1) within Python 3.4 using the Xarray module.

2.2 Wind chill

Daily wind chill across SA (Table 1) was calculated using the formula adopted for the Australian Bureau of Meteorology as part of their sheep graziers alerts (Broster *et al.* 2012; Donnelly 1984; Nixon-Smith 1972). This formula calculates wind chill as potential heat loss (C kj/m^2/h), using mean daily wind velocity (ν m/s), mean daily temperature (T ^{0}C) and daily rainfall (x mm):

$$C = (11.7 + 3.1\nu^{0.5})(40 - \mathrm{T}) + 481 + [418(1 - e^{-0.04x})] \qquad (1)$$

From the daily estimates we calculated average monthly wind chill (Figure 2) and the probability of wind chill exceeding 950 kj/m^2/h in any day on a given month (Figure 3). Wind chill probability zones were calculated as the probability of wind chill exceeding 950 kj/m^2/h in the months of June, July, August and September (Figure 4). These months were chosen because they had the highest likelihood of high wind chill and also because, for many parts of southern Australia, it is the most profitable time for lambing (Warn *et al.* 2006). Four categories of wind chill probability were calculated; 0.0 – 0.4, 0.4 – 0.6, 0.6 – 0.8 and 0.8 – 1.0 (Figure 4).

Table 1: Climate parameters across South Australia.

	MAXIMUM	MINIMUM
Rainfall (mm)	288.8	0.0
Maximum temperature (°C)	53.8	1.4
Minimum temperature (°C)	37.9	-9.4
Wind speed (m/s)	11.1	1.1
Wind chill (kj/m^2/h)	1507.4	452.1

2.3 Carbon supply

Annual carbon supply was calculated using official ERF methods that rely on the carbon accounting software Full Carbon Accounting Model (FullCAM). FullCAM is designed to model carbon sequestration across Australia for a range of species that adhere to ERF project mechanisms and estimate carbon supply that are eligible to earn Australian Carbon Credit Units (ACCUs).

A detailed description of the methods used to develop the carbon supply estimates is available in Settre *et al.* (2019). These estimates were developed on a 0.1 degree grid (approximately 10 km) across SA and provide cumulative carbon sequestration over 100 years. The original carbon supply modelling estimated carbon sequestration for a range of ERF eligible methodologies including environmental plantings, plantation forestry and human induced regeneration. For the shelter belt co-benefit analysis presented here, we only considered environmental plantings.

All carbon supply layers were spatially restricted to ERF eligible areas (Figure 6) based on the original modelling and all spatial analysis was restricted to these areas. In order to match the climate data the carbon supply layers were resampled from 0.1 degrees resolution to 0.05 degrees.

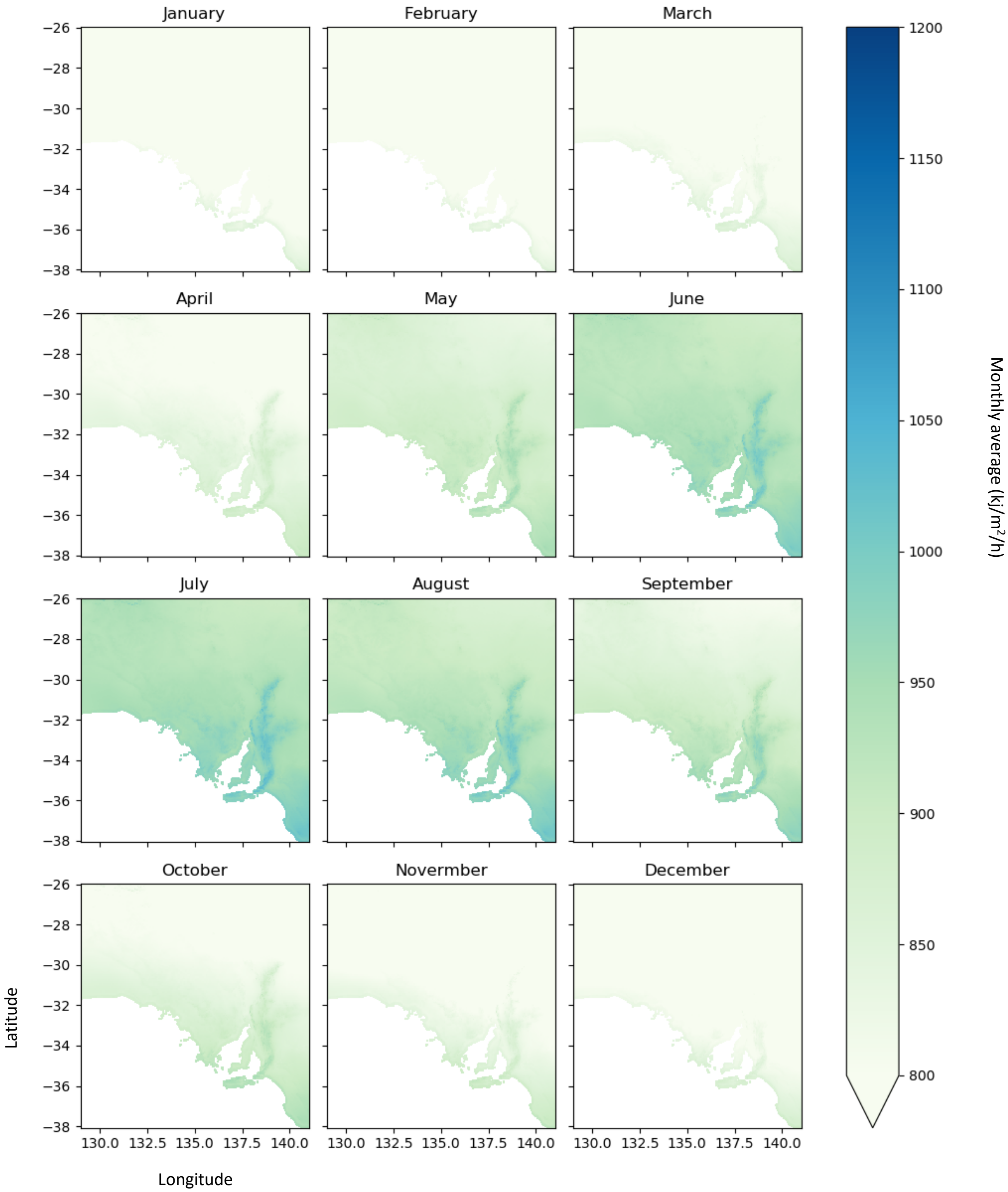

Figure 2. Wind chill monthly averages (kj/m^2/h) across South Australia.

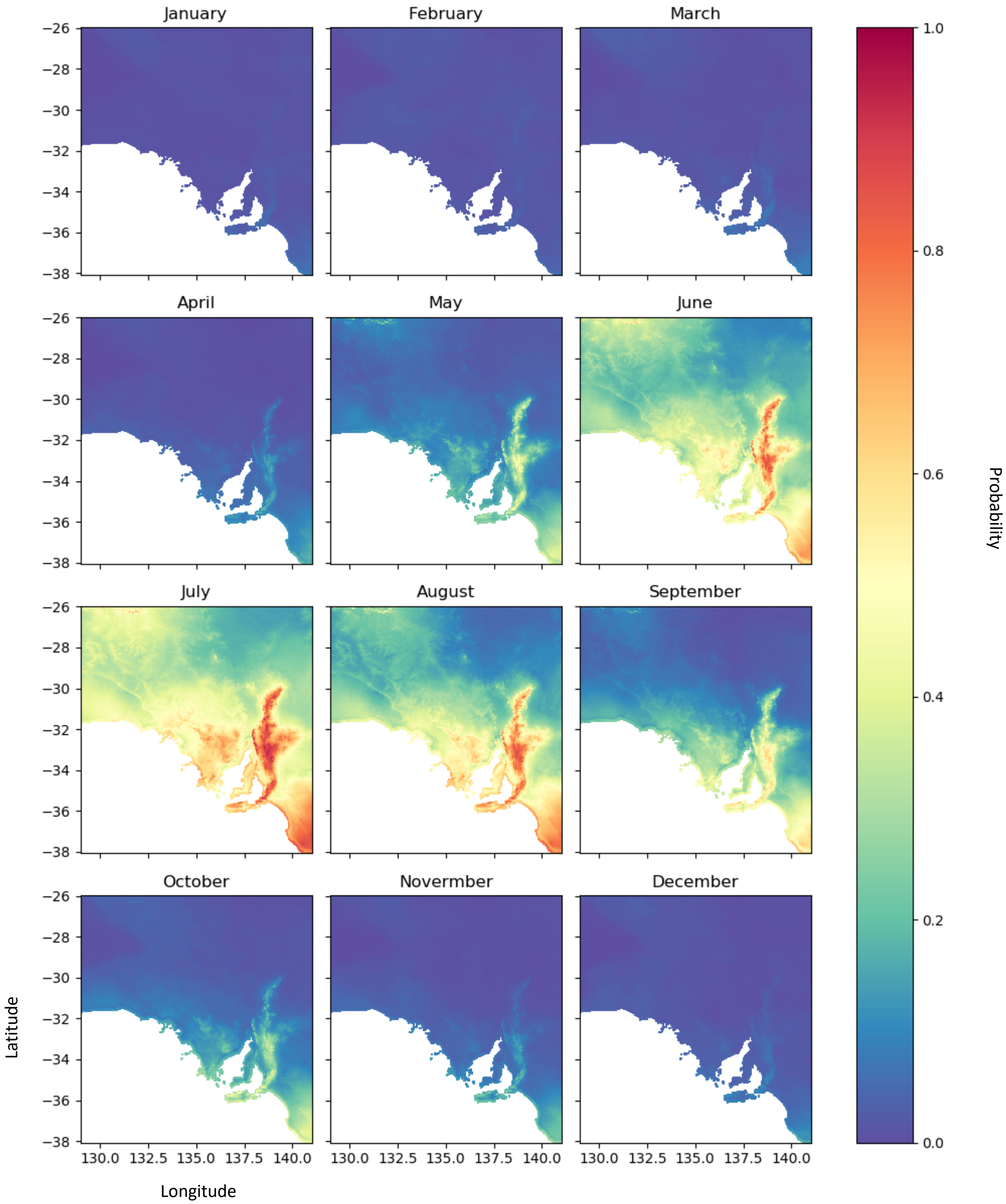

Figure 3. Probability of daily wind chill exceeding 950 kj/m^2/h for given months across South Australia.

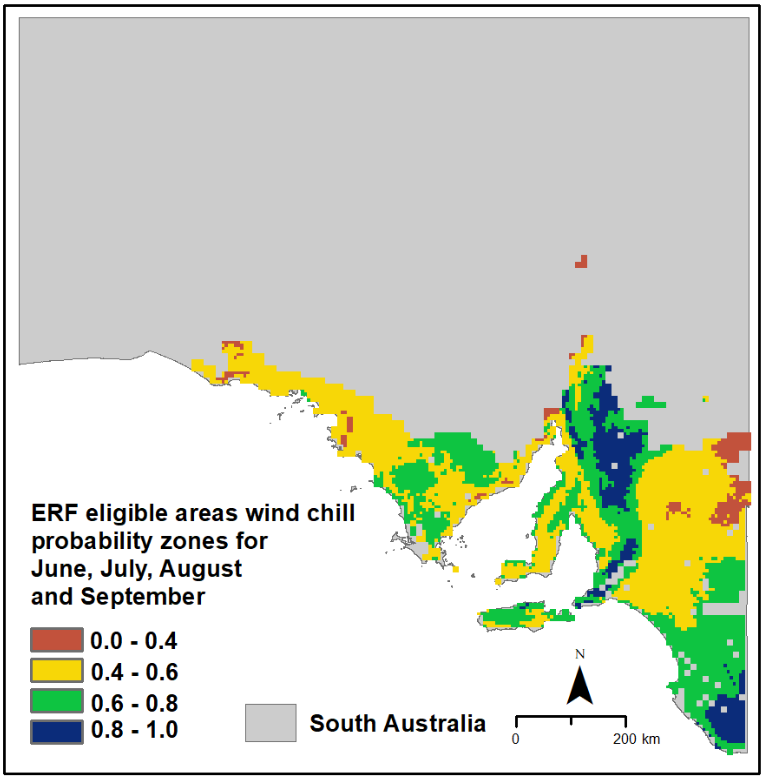

Figure 4: Wind chill probability zones for the Emissions reduction Fund (ERF) eligible zones.

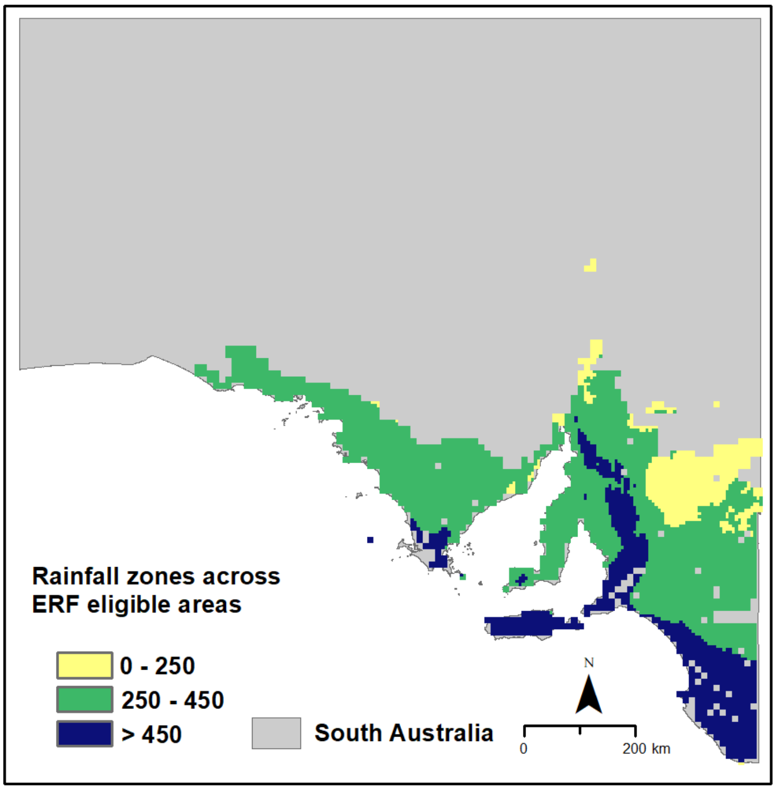

Figure 5: Rainfall zones for the Emissions reduction Fund (ERF) eligible areas

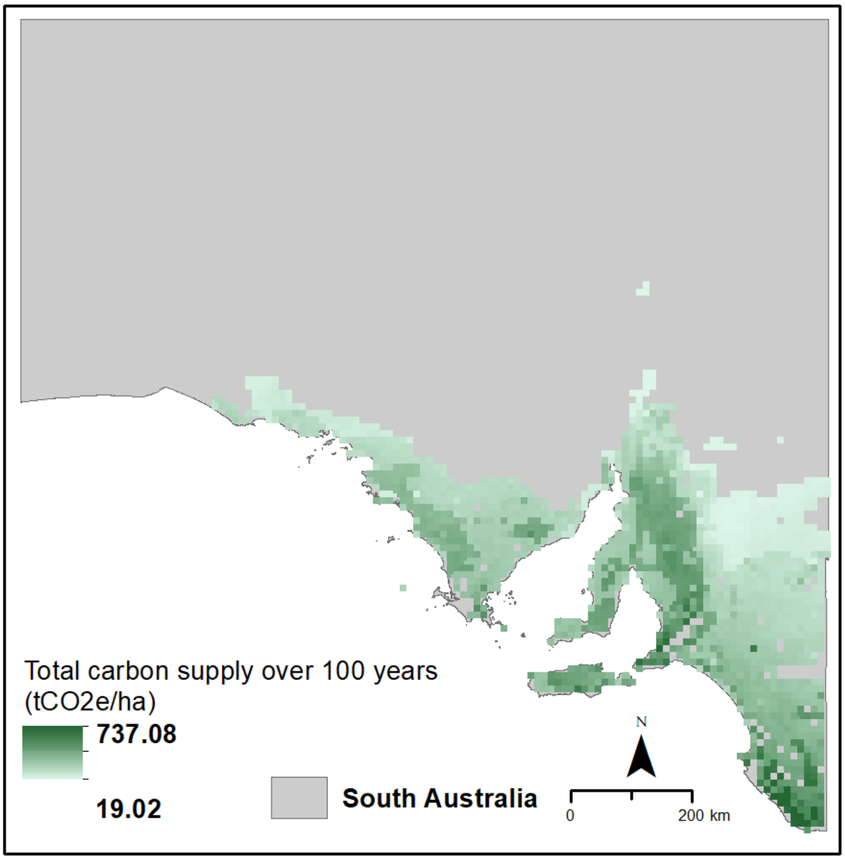

Figure 6: Total carbon supply with environmental plantings in South Australia over 100 years in Emissions reduction Fund (ERF) eligible areas.

2.4 Carbon economics

The methods to assess the price of carbon at which carbon credit payments justify land use change to carbon plantings are described in detail in Regan *et al.* (2019). This involved calculating establishment and maintenance costs for carbon plantings and the cost of forgone agricultural production returns on land no longer available for grazing when it is planted to trees. These costs are compared to returns from carbon credit payments for a range of carbon prices to discover the minimum carbon price where carbon payment returns exceed costs involved. Carbon yields from plantings were estimated with ERF methodologies and their calculation are outlined in detail in Settre *et al.* (2019) and in brief in Section 2.3 Carbon supply above.

Carbon sequestration will become profitable in different areas at different prices. In order to understand this variability, the Net Present Value (NPV) of carbon sequestration was calculated for all areas of the analysis at prices ranging from AUD$2 to AUD$250.

2.5 Shelter belt economics

To assess shelter belt benefits for sheep production we assumed a standard self-replacing merino flock in SA consisting of 1,000 breeding ewes. Key cost and return parameter values associated with production and sale of lambs used in the analysis were based on gross margin budgets (PIRSA 2018; Table 2).

Table 2: Costs associated with production of lambs for sale, pasture opportunity cost and establishment costs associated with a carbon plantation.

Costs ($/Head)			
	High rainfall (above 450 mm)	**Medium rainfall (250-450 mm)**	**Low rainfall (below 250 mm)**
Sale price			
Ewe hoggets	220	220	180
Wether lambs	115	115	110
Marking			
Lamb marking	1.40	1.40	1.40
Pain relief	0.45	0.45	0.45
Ear tag	0.40	0.40	0.40
Animal health			
Drench	0.45	0.45	0.45
Vaccination	0.33	0.33	0.33
Fly strike prevention	1.30	1.30	1.30
Industry levy	1.50	1.50	1.50
Saleyard fees	0.80	0.80	0.80
Transport	4.00	4.00	7.00
Stock agent commission (6%)			
Ewe hoggets	13.20	13.20	10.8
Wether lambs	6.90	6.90	6.60
Total costs of production			
Ewe hoggets	23.83	23.83	24.43
Whether lambs	17.53	17.53	20.23
Costs ($/ha/year)			
Shelter belt costs			
Pasture opportunity cost	503	335	166
Carbon establishment costs ($/ha)	2391	2008	1806
Maintenance costs	825	825	825

2.6 Lamb mortality reduction

The effect of wind chill on the mortality of Merino lambs was adapted from Young *et al.* (2014). From this data we assume that at wind chill index of greater than 950 Kj/m^2/hour, the mortality rate is 2% for twin lambs and 10% for single born lambs. Data for lamb mortality reduction from shelter belt plantings was taken from Sinnett *et al.* (2016). Reducing mortality rate is highly dependent on wind speed reduction provided by the shelter belt. Sinnett *et al.* (2016) present a range of wind reduction distributions of expected mortality rate reductions for a given wind speed reduction. For this analysis, we used the median mortality reduction from the 99, 75 and 60% wind speed reduction distributions presented in their research (Table 3).

Table 3: Wind chill reduction scenarios and associated reduction in lamb mortality used in the economic analysis (from Sinnett *et al.* 2016).

Wind chill reduction scenario	Mortality rate reduction (%)
Optimistic: 99% wind reduction	50
Realistic: 75% wind reduction	32
Pessimistic: 60% wind reduction	24

The economic benefits of shelter belts are predominantly driven by increasing survival of twins (Young *et al.* 2014). As such the analysis is sensitive to the assumed lambing percentages and especially the percentage of twins born. Data relating to average lambing percentages and incidence of twins for SA was difficult to obtain; however, information from unpublished literature suggest that twin percentages can be as high as 50 - 80% (MLA 2006, SCSA). As such, in addition to mortality rate reduction (Table 3), we tested several incidences of twining percentages - 30, 50 and 80%.

2.7 Shelter belt area

In addition to benefits, establishing shelterbelts have a cost, as fraction of grazing land must be sacrificed. Economic analysis requires accounting for this cost and spreading it across the returns to the fraction of land that remains in production.

To this end, the area of shelter belt required to deliver the mortality rate reductions presented in Table 3 was calculated as a proportion of the total lambing area required for a given stocking density, as dry sheep equivalents per hectare (DSE/ha). Stocking rates in general, and for the lambing paddock specifically, are dependent on pasture productivity and are rainfall zone specific. Table 4 outlines the assumed stocking densities for general grazing and of the lambing paddock according to rainfall zones (McCaskill and Beattie 2013; PIRSA 2009, 2018).

Table 4: Stocking rates in dry sheep equivalents (DSE) per ha, size of lambing paddock (ha) and shelter belt area (ha) used in the economic analysis assuming a 1000 breeding ewe self-replacing Merino flock.

	High rainfall	Medium rainfall	Low rainfall
General grazing stocking rate (DSE/ha)	12	6	2
Lambing paddock stocking rate (Ewes/ha)	40	30	20
Lambing paddock stocking rate (DSE/ha)	16	12	8
Area of lambing paddock (ha)	156	208	312.5
Area of shelter belt (ha)	12.1	16.2	24.3

Sources: (McCaskill and Beattie 2013 PIRSA 2009, 2018)

The lambing paddock stocking density used in our analysis was calculated from the *Evergraze shelter for lambing tool* (McCaskill and Beattie 2013). Stocking densities in lambing paddocks are generally higher than under normal grazing situations as supplementary feed is generally provided to heavily pregnant/lactating ewes. The *Evergraze shelter for lambing tool* (McCaskill and Beattie 2013) suggests lambing paddock stocking rates should be between 20 to 40 ewes per ha. The DSE of heavily pregnant and lactating ewes varies between approximately 1.8 and 3.2 DSE/ewe (DPINSW 2018). As such we assumed an average DSE of 2.5/ewe. The stocking density of the lambing paddock (DSE/ha) was therefore calculated as ewes/ha ÷ 2.5 DSE/ewe (Table 4). For example, in the high rainfall area 40 ewes/ha ÷ 2.5 DSE/ewe = 16 DSE/ha.

Assuming a 1,000 breeding ewes (PIRSA 2018) the total DSE needing to be pastured in the lambing area is 1,000 ewes × 2.5 DSE/ewe = 2,500 DSE.

Given the lambing paddock stocking rates (Table 4) the total area needed for lambing can be calculated. For example, in the high rainfall area, 2,500 DSE ÷ 16 DSE/ha = 156 ha required for lambing.

To calculate the area of shelter belt required for the calculated lambing area, we applied a conversion factor from Sinnett *et al.* (2016). Sinnett *et al.* (2016) calculated that 1 ha of *mixed species planting with greater height, but lower density* (analogous to the ERF environmental plantings modelled in FullCAM) would shelter approximately 12.85 ha of pasture. Therefore, for example, in the high rainfall zone a 156 ha lambing paddock requires 12.1 ha of shelter belt (Table 4; calculated as 156 ha ÷ 12.85 ha).

2.8 Calculation of the economic benefit of shelter belts

A partial budget was constructed to assess the effects on farm profit from establishing permanent shelter belts on land currently used for grazing within the sheep enterprise. The additional income, costs and cost savings were calculated from data outlined in Table 2.

The initial step was to calculate the estimated costs associated with lamb mortalities for a given incidence of twins (Table 3) for the business as usual case (i.e. no shelter provided):

$$twins\ born = BE \times IoT \tag{2}$$

where BE is the number of breeding ewes and IoT is the incidence of twins (%).

The mortality rate of twins from exposure is assumed to be 20 percent in areas with a wind chill factor of 950 Kj/m^2/hour (Young *et al.* 2014). Therefore, the number of lambs lost, for any IoT is calculated as:

$$lamb\ losses = twins\ born\ \times 20\% \tag{3}$$

Assuming a probability of 0.5, the number of lamb losses are divided into 50 percent ewe lambs and 50 percent wether lambs. This is important as ewes and wethers receive different prices at sale (Table 2). The value of lost revenue from lamb mortalities can be calculated as:

$$lost\ revenue = lamb\ losses\ \times\ 0.5\ \times SPE\ +\ lamb\ losses\ \times\ 0.5\ \times SPW \tag{4}$$

where SPE is the sale price of ewes and SPW is the sale price of wethers (Table 2).

In addition to lost revenue from lamb mortalities, the production costs not incurred as a result of the death of lambs must also be considered (Table 2), which was calculated as 0.5 in equation below:

$$costs\ saved = \sum PCE\ \times lamb\ losses\ \times\ 0.5 + \sum PCW\ \times lamb\ losses\ \times\ 0.5 \tag{5}$$

where PCE are the production costs associated with ewe lambs and PCW are the production costs associated with wether lambs (Table 2). The difference between the two is largely derived from the stock agent commission, assumed to be 6 percent of revenue from sales (PIRSA 2018).

Therefore, the total annual losses (TAL) incurred from lamb mortality can be calculated as:

$$TAL_{twins} =\ lost\ revenue - costs\ saved \tag{6}$$

In addition to mortalities from twins, mortalities from single born lambs are also considered (TAL_{single}). TAL_{single} is calculated as outlined in eq. 1-5, however the mortality rate for single born lambs is assumed to be 10 percent as opposed to 20 percent for twins (Sinnett *et al.* 2016). TAL_{single} for single born lambs is calculated on the proportion of lambs not born as a twin ($1 - IoT$).

The total annual losses for the sheep enterprise from lamb deaths can then be calculated as:

$$TAL = TAL_{twins} + TAL_{single} \tag{7}$$

To assess the economic impact from the establishment of shelter belts on lamb mortality, the total annual losses with shelter belts (TAL_{sb}) is calculated analogously to TAL (Eq. 1-6). However, in these calculations we consider the mortality reduction provided by the shelter belts (Table 3) and substituted the new mortality rate into Eq. 2 in place of the 20 percent baseline mortality rate.

To calculate the annual net benefit (B_{sb}) of shelter belts, the difference between the losses due to lamb mortality with and without shelter belts can be calculated as:

$$B_{sb} = TAL - TAL_{sb} \tag{8}$$

To fully account for the cost of shelter belt establishment, the annual opportunity costs associated with the lost pasture production (OP) where shelter belts were planted need to be accounted for. In this analysis we have assumed a sown pasture and used annual gross margins for each rainfall zone as outlined in State Government gross margin budgets (PIRSA 2018). The opportunity costs associated with the foregone pasture production are outlined in Table 2. Therefore, considering opportunity cost the total annual benefit of the shelter belts (TBS) can be calculated as:

$$TBS = B_{sb} - OP \tag{9}$$

The Net Present Value (NPV) of shelter belt establishment (NPV_{sb}) over the lifetime of the shelter belt can then be calculated by including the establishment costs (EC) of the shelter belt and ongoing annual maintenance costs (MC) associated with the shelter belt plantation, and can be calculated as:

$$NPV_{sb} = \sum_{t=0}^{T} \frac{TBS_t - MC_t}{(1+r)^t} - EC \tag{10}$$

where T is the time horizon considered, in this instance 100 years to match the ERF permanency requirements, and r is the discount rate, in this instance 5 %.

2.9 Spatial analysis

In order to combine and compare the costs and benefits of shelter belts with carbon supply and the potential for carbon credits we created spatial layers of the NPV of the different shelter belt scenarios. The different shelter belt rainfall scenarios were applied to comparable rainfall zones (below 250 mm, 250 to 450 mm and above 450 mm) developed using the historical averages (1974 to 2017) of the AGGD rainfall layers (BOM 2018; Table 1).

Carbon sequestration potentials vary spatially (Figure 6) even within the same rainfall area. As such the carbon price ($/t CO_2e) that would achieve a positive NPV for the shelter belt project will differ spatially. The prices required from carbon to achieve positive NPV were calculated over the spatial extent of the study area where the chill index was greater than 950 kj/m^2/h. We summarised the different carbon prices at which the co-benefit enterprises surpassed business as usual agriculture by the different wind chill probability regions (0.4, 0.6, 0.8 and 1.0) and rainfall zones.

3 Results

3.1 Shelter belt economics

The results of the NPV analysis can be seen in Table 5. These results show that economic returns to reduced lamb mortality are not sufficient to offset required costs of establishment and forgone earnings on the required land, under all but the most optimistic set of assumptions considered. The results do not, however, account for any carbon credit payments that could be realised by landholders who establish tree planting shelterbelts.

Table 5: The Net Present Value (NPV) of shelter belt establishment considering reduction in lamb mortality, not considering carbon income over a 100 Emissions reduction Fund (ERF) permanency period.

NPV ($)				
	Wind chill reduction scenario	**High rainfall**	**Medium rainfall**	**Low rainfall**
30% instance of twins	Optimistic	-72,842	-76,501	-120,832
	Realistic	-102,741	-106,400	-146,424
	Pessimistic	-116,029	-119,688	-157,798
50% instance of twins	Optimistic	-30,706	-38,852	-89,091
	Realistic	-80,536	-88,682	-130,726
	Pessimistic	-102,683	-110,829	-149,230
80% instance of twins	Optimistic	25,769	17,623	-46,819
	Realistic	-53,960	-62,106	-113,433
	Pessimistic	-89,395	-97,541	-143,040

To understand how carbon payments could alter the results and result in greater economic viability from a farmer's perspective, we performed what economists call a "gap analysis". This involved calculating the income required from the sale of carbon credits from the shelter belt plantation ($/ha/year) for the proposition to be profitable (Table 6).

Table 6: Results of gap analysis showing the added income required from the sale of carbon credits for an Emissions reduction Fund (ERF) compliant shelter belt project to reduce lamb mortalities from exposure to be economically viable.

		Additional income required from carbon credits ($/ha/year)		
	Wind chill reduction scenario	**High rainfall**	**Medium rainfall**	**Low rainfall**
30% instance of twins	Optimistic	302	238	250
	Realistic	426	331	303
	Pessimistic	481	372	327
50% instance of twins	Optimistic	127	121	185
	Realistic	334	276	271
	Pessimistic	425	344	309
80% instance of twins	Optimistic	NPV Positive	NPV Positive	97
	Realistic	224	193	235
	Pessimistic	370	303	296

3.2 Carbon sequestration economics

A summary of the results from the carbon sequestration economics analysis can be seen in Table 7 while Figure 7 shows the spatial distribution. Minimum carbon prices required to achieve positive NPV ranged from zero to AUD $26 /t CO_2e for the different scenarios. Minimum carbon prices declined under all scenarios with more optimistic assumptions. Maximum carbon prices under all scenarios were AUD $250 /t CO_2e, which was the maximum price for carbon that we examined and indicates that under all scenarios there were cells that would require a higher carbon price to achieve positive NPV.

There is a noticeable pattern in Figure 7, with higher carbon prices required to achieve positive NPV in higher rainfall areas such as the South East and the higher altitude areas of the Mount Lofty Ranges and lower carbon prices in the low rainfall areas in the north of the study area. Summarising the results by rainfall zone (Table 8) confirmed this pattern with lower carbon prices required across all scenarios for increasing rainfall.

Table 10 shows the summary of carbon prices by wind chill zone categories. These results indicate that the required carbon price declines with increasing probability of high wind chill across all scenarios.

Table 7: Summary results of carbon price required to achieve positive Net Present Value (NPV) across eligible Emissions reduction Fund (ERF) areas in the analysis.

	Carbon price required to achieve positive NPV across eligible ERF areas ($/t CO_2e)			
	Wind chill reduction scenario	**Minimum**	**Mean**	**Maximum**
30% instance of twins	Optimistic	16	83	250
	Realistic	22	103	250
	Pessimistic	26	111	250
50% instance of twins	Optimistic	8	51	250
	Realistic	18	91	250
	Pessimistic	22	105	250
80% instance of twins	Optimistic	0	13	250
	Realistic	12	66	250
	Pessimistic	20	97	250

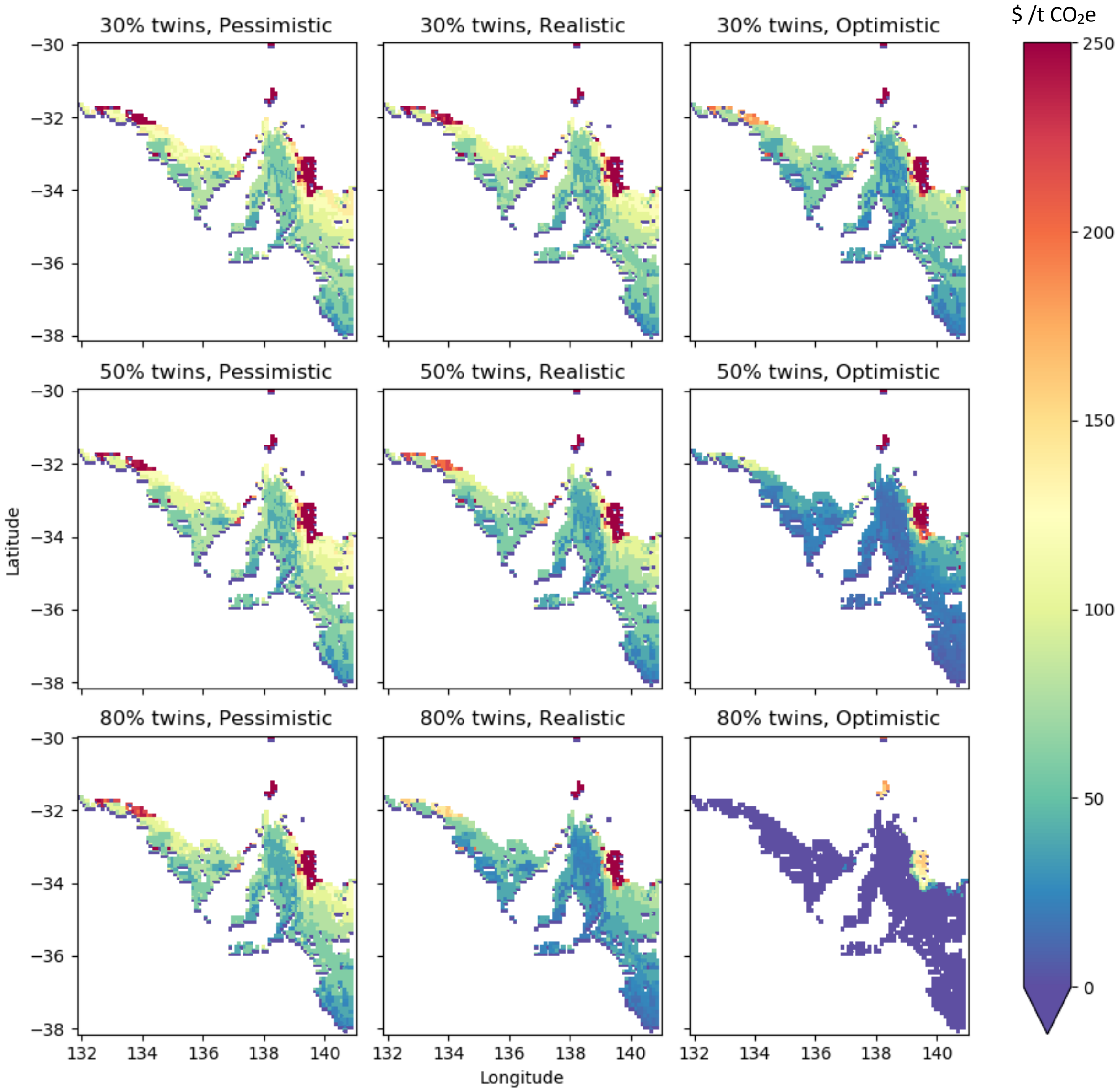

Figure 7: Price required for carbon credits and shelter belt plantations to achieve positive Net Present Value (NPV) across the Emissions reduction Fund (ERF) eligible regions of South Australia ($/t$CO_2$e).

Results show that significantly higher carbon prices than were available in recent ERF auctions would be required for economic value from shelterbelt carbon and lamb mortality reduction to cover costs of implementation for most of the scenarios and locations considered in this analysis. The economics of the proposition, was found to vary considerably depending on locational attributes including wind chill and rainfall, as well as assumptions about proportions of twin lambs as opposed to single lamb litters, and the impacts of wind chill on mortality (Table 8, Table 9 and Table 10).

As would be expected greater lambing mortality reduction benefit expected in windier locations improves the economics of shelter belt considerably. Carbon price required for economic viability were in the range for one half to two thirds less for highest compared to lowest wind chill zones for many of the scenarios considered (Table 10). Average rainfall differences were found to have an even greater effect on economic viability with only 25% to as little as10 % or less of lowest rainfall zone carbon price required for break-even r economics in highest rainfall zones (Table 8).

A consequence of these weather driven differences in shelter belt productivity in combination with higher carbon productivity in higher rainfall areas is that shelter plus carbon benefits justify the costs of shelter belts at lower carbon price in cooler wetter regions including the South East, the Mt Lofty Ranges and Kangaroo

Island (Table 9). In contrast, the economics are more challenging in drier, warmer regions such as SA Arid Lands, the SA MDB and the Eyre Peninsula. Economics are intermediate for the Northern Adelaide Plains and Yorke Peninsula. Regardless of region (Table 9), wind chill (Table 10) and rainfall (Table 8) conditions considered, assumptions regarding proportion of twin versus single lamb litters and effectiveness of shelterbelts at reducing wind chill had large effects on results. Indeed, the results presented in Table 8, Table 9, Table 10 show that combined economic value of shelter plus carbon are only estimated to cover costs of shelterbelts at carbon prices in the range seen in ERF auctions with combined assumptions of very high twin litter proportions (80%) and high (optimistic) effectiveness of shelterbelts at reducing wind chill. The one exception is that in the high rainfall South East and Adelaide and Mount Lofty Ranges regions, with slightly lower (50%) twin litter rates in combination with optimistic shelter effectiveness assumptions resulting in breakeven economics at carbon prices (\$15 to \$16/tCO_2e), not far off of recent ERF levels (\$11 to \$12/ tCO_2e) (Table 8, Table 9).

Table 8: Average price required to achieve positive Net Present Value (NPV) from both carbon sequestration and shelter belts for different rainfall zones (\$/tCO_2e).

	Average carbon price required to achieve positive NPV for different rain fall zones (\$/tCO_2e)			
	Wind chill reduction scenario	**Low Rainfall**	**Medium Rainfall**	**High Rainfall**
30% instance of twins	Optimistic	215.29	72.58	39.68
	Realistic	225.02	95.71	56.12
	Pessimistic	227.34	104.69	63.06
50% instance of twins	Optimistic	188.43	36.64	15.16
	Realistic	219.82	82.30	43.84
	Pessimistic	225.55	98.86	56.10
80% instance of twins	Optimistic	106.99	0.00	0.00
	Realistic	210.68	59.38	27.29
	Pessimistic	224.24	89.50	48.15

Table 9: Average price required to achieve positive Net Present Value (NPV) from both carbon sequestration and shelter belts for different natural resource management regions.

		Average carbon price required to achieve positive NPV for natural resource management zones ($/tCO$_2$e)							
		Natural resource management zones							
	Wind chill reduction scenario	South Australia Arid Lands	Alinytjara Wilurara	South Australian Murray-Darling Basin	Northern and Yorke	Eyre Peninsula	Kangaroo Island	Adelaide and Mount Lofty Ranges	South East
30% instance of twins	Optimistic	187.72	180.00	120.59	61.19	80.22	48.12	34.81	41.16
	Realistic	198.60	230.91	139.83	80.35	105.77	67.62	51.15	56.20
	Pessimistic	202.92	240.00	147.11	88.21	114.79	76.16	57.61	63.42
50% instance of twins	Optimistic	165.22	92.73	85.96	32.56	40.86	18.65	15.05	16.34
	Realistic	191.46	211.82	128.86	67.87	90.91	51.69	41.34	46.98
	Pessimistic	199.06	235.45	142.70	82.25	108.81	67.62	51.64	57.06
80% instance of twins	Optimistic	89.30	0.00	33.78	3.39	0.50	0.00	0.00	0.02
	Realistic	181.46	147.27	109.98	49.46	65.99	33.76	26.17	29.42
	Pessimistic	195.09	220.91	135.31	74.03	99.04	59.13	44.91	50.20

Table 10: Average price required to achieve positive Net Present Value (NPV) from both carbon sequestration and shelter belts for different wind chill probability zones

		Average carbon price required to achieve positive NPV for different wind chill probability zones ($/tCO₂e)			
		Wind chill probability zone			
	Wind chill reduction scenario	0.0 - 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0
30% instance of twins	Optimistic	96.67	78.98	55.94	48.10
	Realistic	117.72	99.09	74.11	66.79
	Pessimistic	125.45	106.89	82.40	75.52
50% instance of twins	Optimistic	61.64	47.14	28.46	23.25
	Realistic	105.31	86.86	62.51	54.47
	Pessimistic	120.14	101.30	76.02	68.87
80% instance of twins	Optimistic	17.69	11.27	2.98	0.00
	Realistic	84.45	67.01	44.71	37.55
	Pessimistic	112.07	92.98	67.70	59.83

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