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Department of Primary Industries and Regions (PIRSA) Carbon Footprint and Feasibility Assessment

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Department of Primary Industries and Regions SA (PIRSA) Carbon Footprint and Feasibility Assessment

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Executive Summary

This report provides a carbon footprint and emission reduction assessment across two research farms operated by the South Australia Government's Department of Primary Industries and Regions (PIRSA). This assessment was largely undertaken as a fact-finding and upskilling exercise. Staff wanted to better understand how carbon footprints of farming systems are undertaken and what is required in terms of farm data. With the help of Integrity Ag, we then explored how that information can be used to inform opportunities that could help reduce emissions and increase sequestration at the selected locations. Once those opportunities were identified we extended the exercise to work with Integrity Ag to undertake a feasibility of implementation.

Carbon Account and Carbon Footprint

Overall, a carbon account and carbon product footprint have been established for each of the two targeted locations: Loxton Research Centre (Loxton) (a horticultural and viticultural farm) and Turretfield Research Centre (Turretfield and Kingsford) (a sheep and wool farm). Data were gathered across two selected years for each location to provide an annualised estimate of the emissions and potential opportunities. Emissions were reported as per the 3 scopes defined by the Greenhouse Gas Protocol (*Table 1*).

Table 1. Description of GHG emission scopes as per the GHG protocol

Scope 1 emissions	Scope 1 emissions are direct GHG emissions from sources that are owned or controlled by the company (for example, emissions from diesel use in tractors, or livestock enteric methane emissions).
Scope 2 emissions	Scope 2 emissions are the GHG emissions from the generation of purchased electricity consumed on location by the company
Scope 3 emissions	Scope 3 emissions are emissions from sources not owned or controlled by the company (such as the extraction and production of purchased materials such as fertilisers or energy-use associated with irrigation suppliers).

Loxton's overall emission estimates were provided with two different boundaries: firstly, for the overall research centre, and secondly, for the farm-related operations only (excluding operations that relate to running the research centre). Loxton had an overall emission estimate of 68.7 t CO_2-e yr^{-1}, comprising scope 1 emissions of 20.8 t CO_2-e yr^{-1}, scope 2 emissions of 10.9 t CO_2-e yr^{-1} and scope 3 emissions of 37.0 t CO_2-e yr^{-1}. For the farming operation, Loxton had an overall emission estimate of 57.7 t CO_2-e yr^{-1}, comprising scope 1 emissions of 16.5 t CO_2-e yr^{-1}, scope 2 emissions of 4.4 t CO_2-e yr^{-1} and scope 3 emissions of 36.8 t CO_2-e yr^{-1}. The largest emission source was energy use for irrigation water supply (scope 3 emissions), which contributed 54% of emissions for the farm (excluding research facility activities). At the product level, overall emissions intensity was between 158-201 kg CO_2-e t oranges and 239-307 kg CO_2-e t grapes.

Total emissions from Turretfield were 944 t CO_2-e yr^{-1}, comprising scope 1 emissions of 885 t CO_2-e yr^{-1}, scope 2 emissions of 6 t CO_2-e yr^{-1} and scope 3 emissions of 53 t CO_2-e yr^{-1}. Livestock enteric methane emissions were the greatest contributors to farm emissions

(84%). Carbon dioxide (10%) from on-farm fuel and fertiliser use and nitrous oxide (6%) which principally arose from manure also contributed to farm emissions. At the product level, wool from Turretfield had a carbon footprint of 25.8 kg CO_2-e.kg greasy, and the product carbon footprint was 9.6 kg CO_2-e.kg liveweight^{-1} for sheep meat and lamb.

Opportunities for Reducing Emissions

A range of options were identified for reducing emissions across the farm operations. At Loxton, emissions reduction options centred around on-site energy and fuel efficiencies and off-site energy emission reduction. These improvements included:

- on-site renewable energy (e.g. solar);
- optimisation of irrigation water application;
- fuel efficiency improvements through vehicle upgrades;
- utilising green initiatives through electricity retailers.

At Turretfield, the emissions reduction options were focused on methane reduction and mitigation. These options included:

- improving productivity through increased lambing and marking rates, allowing a reduction in overall ewe numbers;
- improving feeding regime for wether lambs to increase average daily gain (ADG) and reduce time on farm;
- introducing feed supplement additives such as a species of the *Asparagopsis* genus (red seaweed) and/or 3-NOP (3-nitrooxypropanol);
- increasing legume content and introducing anti-methanogenic pastures;
- introducing perennial pastures to extend the growing season and reduce summer feed gaps;
- introducing livestock with improved genetics to improve productivity and emission intensity.

At both sites, options were also examined to increase carbon sequestration in vegetation and soil to offset emissions. This focused on native varieties, such as mallee and mixed environmental plantings.

Emissions Scenario Modelling

Based on the carbon footprint across each location, multiple scenarios were developed to indicate the potential mitigation of emissions to 2030. The vegetation plantings required to sequester carbon and reach net zero emissions by 2030 and maintain this to 2040 were also modelled for each scenario.

At Loxton, three emission mitigation scenarios were developed: low, medium and high. The mitigation scenarios incorporated on-site changes across vehicle fuel efficiency, renewable energy (e.g. solar power), and pre-farm emission improvements (e.g. fertiliser emissions). Emission reductions associated with improvements in the South Australian electricity grid were also incorporated into these scenarios, reflecting the South Australian Government’s shift towards renewable energy for the state grid.

The low mitigation scenario reflected "no action" with respect to the management of the farm. Improvements were achieved as a result of changes to the SA electricity grid and a small (20%) improvement in vehicle fuel efficiency due to fleet vehicle upgrades, which resulted in approximately 45% reduction in farm emissions. The medium mitigation scenario assumed the same SA electricity grid improvements, increased fuel efficiency improvements (50%), and solar panels to reduce grid electricity consumption, which resulted in approximately 55% reduction in farm emissions. The high mitigation scenario includes a more optimistic estimation of grid electricity emissions factor improvements, implementation of solar power and battery storage, a strong shift to renewable vehicle utilisation, and small efficiency improvements in purchased input application. This resulted in an overall reduction in emissions of 73%.

Emission offsets associated with vegetation were a minimum of 15.7 - 31.8 t CO_2-e yr^{-1} from 2030, assuming four tree plantings of 2.1 – 4.7 ha total. With this included, the three mitigation scenarios were found to be carbon neutral from 2030 through to 2040. Due to difficulties in quantifying small areas and low soil carbon sequestration rates at this location, as well as economic considerations involved in measuring and monitoring soil carbon levels, soil carbon sequestration was not included in the emissions pathway scenarios.

At Turretfield, four scenarios were developed, including business as usual (BAU), low, medium, and high mitigation. The mitigation scenarios incorporated changes across flock numbers and efficiency improvements, implementation of anti-methanogenic pastures, and the utilisation of anti-methanogenic feed additives (such as red seaweed). An allowance for grid electricity emission improvements was included; however, it provided minimal overall benefit.

The BAU scenario reflected "no action" with respect to the management of the farm, with only minimal improvement from the emissions profile of the grid electricity (0.5%). The low mitigation scenario reflected flock optimisation improvements such as improved lambing % allowing for a reduction in ewes and rams, increased average daily gain and sale weight turnoff of wether lambs, which resulted in approximately 17% reduction in overall emissions with higher liveweight turnoff, but lower wool production because of the reduction in adult sheep numbers. The medium mitigation scenario included the same flock optimisation outputs, alongside inclusion of an anti-methanogenic feed additive (red seaweed) for 6 months of the year when supplementary feeding is occurring, which resulted in approximately 39% reduction in overall emissions. The high mitigation scenario included the same flock optimisation outputs, with anti-methanogenic pastures utilised until feed additives are available, and inclusion of an anti-methanogenic feed additive (red seaweed) for 12 months of the year, which resulted in approximately 56% reduction in overall emissions.

Emission offsets associated with vegetation resulted in 60 - 573 t CO_2-e yr^{-1} of offsets, assuming four tree plantings of 8 – 50 ha total. Emission offsets for soil were estimated to be 308 t CO_2-e.yr^{-1} based on a moderate assumption scenario across 400 ha. With this included, the four mitigation scenarios were found to be carbon neutral from 2030 through to 2040, with the lower mitigation scenarios requiring much larger areas of tree planting.

For both sites, carbon offsets, via soil carbon sequestration and/or vegetation carbon sequestration, could enable carbon neutrality within the next decade. This could be achieved with fairly modest areas of the farm being planted to trees and would be supported by modest improvements in soil carbon. However, because of the very small farm areas, it is likely to be difficult to establish a cost-effective ERF project, which is a problem faced by many commercial operations. Further, it is difficult to determine cost-effectiveness because of the significant unknowns around projected soil carbon sequestration rate. The assumptions made in this report should be understood in the context of the high uncertainty around soil carbon sequestration: the range in outcomes could be from zero (or even carbon loss) to even higher sequestration rates than assessed here over 25 years.

The key implications of this is that the financial incentives of the ERF are not available to small producers. Additionally, it is difficult to quantify ‘low carbon' or ‘carbon neutrality' with the very high compliance costs. One avenue that could overcome this in the future is use of voluntary offset methods. We have identified some promising options that could be more flexible and potentially more cost effective than ERF methods in this region. Further investigation in this space is warranted.

Based on the findings in this report, a range of recommendations have been provided for consideration (page 65).

Table of Contents

List of figures

List of tables

1 Introduction

This report has been prepared for the Department of Primary Industries and Regions (PIRSA). It is an assessment of two research centre locations to determine the current carbon footprint and opportunities to integrate demonstrable emission reduction strategies to lift knowledge and capability amongst key relevant regional industries.

1.1 Background

As part of the South Australian Government's commitment to the continued research and development of sustainable and productive farming practices, PIRSA identified two research centre farming locations to assess the operations' carbon footprint and investigate practical and demonstrable opportunities to reduce carbon emissions and sequester carbon. This assessment took place at:

1. Loxton Research Centre (Loxton), a 32 ha horticultural and viticultural farm, and
2. Turretfield Research Centre, consisting of two livestock and pasture farms (Turretfield at 508 arable ha and Kingsford at 370 arable ha).

This report, in the form of a carbon footprint and an assessment of emissions reduction feasibility options for the respective locations, further enables the development of knowledge and practical improvement solutions to relevant regional primary producers. The opportunity to utilise these PIRSA-administered locations as demonstration sites in the future may provide an opportunity to broaden carbon emission management knowledge within South Australia. It may also assist in identifying new collaboration opportunities with Research Development Corporations and industry and encourage new and expanded research investment strategies for South Australia.

1.2 Project Objectives

The project included a carbon footprint and emission reduction assessment.

Specific objectives for the carbon footprint included:

1. Conduct a carbon footprint assessment of the Loxton location, taking into account horticultural and viticultural management.
2. Conduct a carbon footprint assessment of the Turretfield location, taking into account livestock and pasture management.
3. Understand the baseline average carbon footprint across two representative years.

Specific objectives for the emissions reduction opportunities include:

1. Investigate and detail practical options for carbon emission improvement for the Loxton location, including emission reduction and sequestration activities.

2. Investigate and detail practical options for carbon emissions improvement for the Turretfield location, including emission reduction and sequestration activities.
3. Assessment of potential eligibility options for Emissions Reduction Fund (ERF) or other voluntary market-based farming practices, farming system trials and other potential funding opportunities nationally.
4. Assessment of proposed costs and requirements in setting up emission reduction actions.

1.3 Description of the PIRSA Research Facilities

The Department of Primary Industries and Regions is a key economic development agency in the Government of South Australia, with a purpose to grow primary industries and drive regional development. To help facilitate research and provide support to primary industry, several research centres and demonstration farms are managed and utilised by the Department. The research centres studied here are described in the following sections.

1.3.1 Loxton

Loxton Research Centre is located on the north-eastern edge of Loxton in the Riverland region of South Australia. It is primarily responsible for supporting the Riverland and Murraylands production systems through horticultural and viticultural farming and research initiatives.

The vision for the Loxton Research Centre is for it to build on its legacy as a regional hub for collaboration, bringing together industry, research, education, and government to drive sustainable innovation for the continued benefit of agricultural communities in this region, across Australia and internationally.

The farm is 32 ha in size, with a variety of crops under irrigated cultivation (particularly tree and grape crops). Soils are predominantly shallow sand over limestone and sands over clay.

This report focused on the primary crops currently under cultivation as follows:

- 2.56 ha Navel Citrus
- 1.27 ha Valencia Citrus
- 1.90 ha Chardonnay Grapes
- 1.54 ha Shiraz Grapes
- 0.74 ha Cabernet Sauvignon Grapes

Additionally, the farm has 1.25 ha of Apricots, but these are not managed commercially. Loxton has 11 PIRSA staff based at the centre, who support the management of the farm and conduct ongoing soil, horticultural and viticultural research.

1.3.2 Turretfield

Turretfield Research Centre is located at Rosedale in the Barossa Valley region of South Australia, and is primarily responsible for conducting research that benefits the state's primary livestock industries, in particular, sheep and wool production, sheep reproductive biology and field crop research.

The centre consists of a primary property "Turretfield" at Rosedale of 651 ha, with a secondary property "Kingsford" of 370 ha located 4 km west of the primary research centre (combined properties referred to as Turretfield in this report).

Turretfield Research Centre consists of 878 ha of arable, flat to undulating land with contour banking enabling cropping on the slopes. Soils are predominantly loamy red-brown, slightly acidic to neutral, with smaller areas of sandy red-brown earth and patches of dark-brown alkaline cracking clays over limestone.

Crop and pasture rotations are managed across multiple paddocks, with crop research also undertaken through this process. Six paddocks of 100 hectares each are rotated between barley and oaten hay when cropped, and pasture in the alternate years. Remaining arable land is either irregularly cropped or left as pasture.

Turretfield has 15 staff, four farm staff and 11 research and technical staff, who support the management of the farm, with a predominant focus on sheep reproduction research.

2 Materials and Methods

2.1 Goal and Scope

This study aimed to complete a carbon account and carbon footprint assessment of the two PIRSA research centres and the primary products produced at each site, to determine impacts, identify hotspots in current practices and guide emissions reduction opportunity development. The products included citrus and viticultural crops at the Loxton Research Centre, and sheep and wool at the Turretfield Research Centre. The system boundary utilised was the farm gate.

As multi-functional systems, the reference flows for Loxton included ‘one kilogram of oranges measured as fresh weight’ and ‘one kilogram of grapes measured as fresh weight’. The reference flows for Turretfield included ‘one kilogram of greasy wool’ and ‘one kilogram of sheep meat measured as liveweight’. Emissions related to non-farm activities such as research centre management were identified separately to enable the ‘total facility’ emissions and ‘farm’ emissions to be reported separately.

The assessment was completed utilising methods that were consistent with international LCA (life-cycle assessment) guidelines and the Australian National Inventory Report (NIR) (Commonwealth of Australia 2021). Facility emissions were reported according to scope 1, scope 2 and scope 3 emission sources following the GHG Protocol (Greenhouse Gas Protocol 2014) (*Table 2*).

Table 2. Description of GHG emission scopes as per the GHG protocol

Scope 1 emissions	Scope 1 emissions are direct GHG emissions from sources that are owned or controlled by the company (for example, emissions from diesel use in tractors, or livestock enteric methane emissions).
Scope 2 emissions	Scope 2 emissions are the GHG emissions from the generation of purchased electricity consumed on location by the company
Scope 3 emissions	Scope 3 emissions are emissions from sources not owned or controlled by the company (such as the extraction and production of purchased materials such as fertilisers).

Emission estimates were determined using the International Panel on Climate Change (IPCC)global warming potential characterisation factors (GWP_{100}) from Assessment Report 5 (AR5) (Myhre *et al.* 2013) (*Table 3*). Emissions are reported as carbon dioxide equivalents (CO_2-e).

Table 3. Global warming potential (GWP100) value relative to CO2 (Myhre *et al.* 2013)

Greenhouse gas	Chemical formula	Fifth Assessment Report (AR5)
Carbon Dioxide	CO_2	1
Methane	CH_4	28
Nitrous Oxide	N_2O	265

2.2 Data Collection

Data provided from the respective farm management systems were used as the basis for flock and crop modelling. As these sites are research centres that undertake non-farm activities as a portion of the operations, data were disaggregated to enable reporting of total facility emissions (inclusive of research activities) and "farm" emissions, reflective of the operations required to run the farm. The latter were more reflective of comparative commercial operations. Research facility activities that were not attributable to the farm included additional offices and additional vehicles used by research staff.

For both locations, two appropriate years were obtained and averaged to provide a 'representative' year as a baseline for each site. For Loxton, this included a "strong" performing year (FY18) and a "poor" performing year (FY16). For Turretfield, the two most recent years (FY19 and FY20) were provided as being reasonably representative of average performance.

2.3 Loxton (Citrus and Viticulture)

Table 4 shows the major crops grown at the site and typical yields, representing the average of the two chosen years. In addition to these crops, 1.25 ha of Apricots were grown, but these are not commercially managed. Consequently, results were not reported for this crop separately, but emissions were included in the farm and facility level assessment.

Table 4. Land propagated (ha) and annual yield achieved (t/ha) by crop type (average of FY 16 and FY 18)

Yield by crop type	Land propagated (ha)	Yield (t/ha)
Orange Navel	2.56	31.98
Orange Valencia	1.27	41.22
Grape Chardonnay	1.9	25.00
Grape Shiraz	1.54	26.00
Grape Cabernet Sauvignon	0.74	20.00

2.3.1 Purchased Inputs

Purchased inputs were derived from the farm management system and validated against the purchase records by the Farm Manager. Fertiliser applications for each crop type were determined and allocated accordingly, and nitrogen values were calculated from the application rate and analysis of each fertiliser. Values for phosphorus, potassium, calcium and trace element application were recorded for each crop (*Table 5*).

Herbicide and pesticide utilisation was recorded at the crop level. Given the current practices and proximity to local insectaries, herbicide and pesticide spraying is typically minimised at Loxton.

Table 5. Annual fertiliser and herbicide/pesticide purchased inputs by crop type (average of FY 16 and FY 18)

	Orange Navel	Orange Valencia	Grape Chardonnay	Grape Shiraz	Grape Cab Sav	Apricot
Fertiliser (kg/ha)						
Urea	120	120	0	0	0	0
Easy N	0	0	140	140	140	0
MAP	75	75	75	75	75	6
Calcium Nitrate	200	200	100	100	100	38
Potassium Nitrate	200	200	100	100	100	0
Total N Content/ha	121	121	99	99	99	6.6
Herbicide/pesticide (L)						
Glyphosate	27.3	10.9	0	0	0	0
Glufosinate	0	0	6.4	5.7	4.2	25.9
Oil Sprays	185.7	136.9	0	0	0	0

On-farm energy consumption comprised fossil fuel sources, specifically diesel, petrol, and grid electricity. As these included inputs for farming activities and research centre activities. The percentage of these allocated to on-farm operations were estimated by the Farm Manager (*Table 6*).

Table 6. Annual purchased energy input values and the allocation of these to farm activity (average of FY 16 and FY 18)

Energy Utilisation	Total (annual)	% allocated to farm activity	Total farm allocation
Diesel (L)	4303	70%	3012
Petrol (L)	1078	70%	755
Electricity (kWh)	21030	40%	8412

Loxton purchases irrigation from a local water network and utilised 170 ML yr^{-1}. Energy required for pumping water to the farm was 352 kWh per ML (obtained from the Central Irrigation Trust for the irrigation region of the property).

Emissions associated with grid electricity were determined from the Australian Government National Greenhouse Accounts, which apply a scope 2 emissions factor to South Australia of 0.43 kg CO_2-e.kWh^{-1} and a scope 3 emission factor of 0.09 kg CO_2-e kwh^{-1}. Emissions associated with supply of irrigation water included both scope 2 and scope 3 emission factors.

Emissions associated with transport of purchased inputs to the farm was determined based on a transportation distance of 7 km from the service centre to the farm.

2.3.2 Field Emissions

Field emissions were determined using methods consistent with the most recent NIR (Commonwealth of Australia 2021). The specific prediction methods are outlined in the sections below.

Field emissions were determined by detailed inorganic fertiliser application records for each crop (see *Table 5*). Direct N_2O emissions from fertiliser, and indirect N_2O emissions associated with leaching and runoff were reported (*Table 7*).

Direct N_2O emissions were calculated using the formula:

- E = (M x EF x Cg), where:
    - M is the mass of fertiliser N applied
    - EF is the emissions factor of 0.0085 and,
    - Cg is the factor to convert elemental mass of N_2O to molecular mass (44/28)

- M was calculated as M = TM x FN, where:
    - TM is the total mass of fertiliser
    - FN is the fraction of N applied to the production system

Leaching and runoff was calculated using a FracWet value of 1 (irrigated land) and a FracLEACH factor of 0.24. The EF was 0.011. All factors were derived for irrigated crops from the NIR (Commonwealth of Australia 2021).

Indirect N_2O arising from volatilisation and redeposition of ammonia (NH_3-N) would typically be calculated when following the NIR, but at Loxton all N fertiliser is applied via fertigation, with pre and post irrigation, which minimises volatilisation losses. In the present analysis, we have therefore excluded this emission source.

Emissions related to the return of crop residues were included in the assessment, though specific assumptions were not available in the NIR. These were estimated by comparing tree crop biological factors to existing NIR values for other crop types to determine an estimated emissions value.

Direct carbon dioxide emissions from urea (including Easy N) were determined using an emissions factor of 0.2 (20% carbon by mass) which was then converted to CO_2.

Table 7. Field emissions reported by emission source and crop type (average of FY 16 and FY 18)

Emission type	Orange Navel	Orange Valencia	Grape Chardonnay	Grape Shiraz	Grape Cab Sav	Apricot
N_2O emission – fertiliser ($t\ CO_2$-e)	1.1	0.5	0.7	0.5	0.3	0.03
N_2O emission – Crop Residues ($t\ CO_2$-e)	0.6	0.4	0.3	0.3	0.1	0.1
N_2O emission – Leaching and runoff ($t\ CO_2$-e)	0.5	0.3	0.3	0.2	0.1	0.03
CO_2 from urea ($t\ CO_2$-e)	0.2	0.1	0.0	0.0	0.0	0.00
Total emissions ($t\ CO_2$-e)	2.4	1.3	1.3	1.1	0.5	0.12
Emissions per ha ($t\ CO_2$-$e.ha^{-1}$)	0.93	1.01	0.68	0.69	0.64	0.10

2.3.3 Vegetation and Tree Crop Carbon

Loxton Research Centre is a smaller horticultural operation with minimal variation in the environment as it relates to land and vegetation diversity (*Figure 1*). The predominant non-crop vegetation system consists largely of mixed native species plantings, specifically river gum, black box, casuarina, and saltbush species. The trees were planted by Landcare during the 1990s, therefore the average age is estimated at 25 years.

Figure 1. Loxton Research Centre satellite image

Remnant and planted vegetation was estimated from satellite imagery and verified by field staff. This covered approximately 6% of the property (2 hectares in total). Some small tree lines and plantings are dispersed around the property, with most of the vegetation being along the western side of the property adjacent to the main roadway. A generalised mapping exercise was undertaken through remote satellite imagery to obtain a rapid assessment of carbon stocks in relation to vegetative growth on the property. FullCAM data for the region was used to determine annual carbon sequestration rates.

Tree crops located at the facility were mature and were not expected to be sequestering carbon. Consequently, these were not included in sequestration estimates.

2.4 Turretfield (Sheep)

2.4.1 Emission Estimation for Sheep Production

The emission profile for mixed farming production systems that include ruminant livestock is generally dominated by emissions from livestock processes (Wiedemann, Ledgard, *et al.* 2015; Wiedemann, McGahan, *et al.* 2015; Wiedemann *et al.* 2016). Therefore, particular attention must be given to the specific methods used to calculate these impacts from sheep meat and wool.

In this study, livestock and manure emissions were determined using methods consistent with the most recent NIR (Commonwealth of Australia 2021). The specific prediction methods are outlined in section 2.4.2 below.

As recommended by ISO/TS 14067 (ISO 2013) emissions arising from land use (LU), including changes to soil and vegetation carbon stocks were reported separately.

Modelling of GHG emissions from energy use and other purchased inputs was based on the inventory of purchased goods, services, and transport distances and impacts assessed using data from Aust LCI (AusLCI 2020). Published research has shown that purchased services (e.g. accounting services, veterinary services) contributed negligible amounts to the study (Wiedemann, Ledgard, *et al.* 2015; Wiedemann, McGahan, *et al.* 2015) and were therefore excluded.

2.4.2 Livestock Feed Intake and Livestock Emission Sources

Feed intake was modelled using the Agricultural and Food Research Council (UK AFRC 1990) feed intake model as applied by the NIR (Commonwealth of Australia 2021), which determines intake from liveweight and feed availability for each livestock class. Total feed intake was modelled from the sheep flock data.

The dominant livestock emission sources were enteric methane, manure nitrous oxide, manure methane, indirect nitrous oxide emissions arising from volatilised ammonia or nitrogen lost via leaching and runoff.

2.4.3 Purchased Inputs

Purchased inputs were derived from the farm management system and validated against the purchase records supplied by the Farm Manager.

On-farm energy consumption comprised fossil fuel sources such as diesel, petrol and grid electricity. As these include both on-farm utilisation and overall research centre utilisation, the percentage of these allocated to on-farm operations were estimated by the Farm Manager (*Table 8*). The inputs included sheep that were purchased or transferred onto the farm. As a largely self-replacing flock, purchased sheep numbers were minimal and limited to a small number of rams. These emissions were classified as pre-farm/upstream emissions.

Herbicide, pesticide, and fertiliser application volumes were recorded. Fertiliser application was limited to Single Superphosphate (SSP) in FY19 and Diammonium Phosphate (DAP) in FY20.

Table 8. Annual energy and purchased input values and the allocation of these to farm activity (average of FY 19 and FY 20)

	Annual	% allocated to farm activity	Total farm allocation
Diesel (L)	17216	79%	13601
Petrol (L)	524	79%	414
Electricity (kWh)	165000	8.5%	14025
Herbicide/pesticide (L)	920	100%	920
SSP/DAP (t)	22.3	100%	22.3
Peas (feed) (t)	55	100%	55

2.4.4 Livestock Data

The Turretfield and Kingsford centres combined have a carrying capacity of:

- 4,500 dry sheep equivalent (DSE) or 4.5 DSE per hectare, equating to approximately:
    - 7.5 DSE per arable pasture hectare
    - 2.5 DSE per non-arable hectare
    - 1.0 DSE per cropped hectare (stubble grazing)

Average livestock numbers for Turretfield Research Centre based on two financial years data (FY19 and FY20) were determined (*Table 9*).

Table 9. Average livestock numbers for Turretfield based on two financial years (average of FY 19 and FY 20)

Average	Rams	Wethers	Maiden breeding ewes	Breeding ewes	Ewe lambs	Wether lambs
Q1	55	85	148	2,356	855	460
Q2	54	85	223	2,580	581	403
Q3	55	84	223	2,473	512	186
Q4	52	126	249	2,336	482	142
Annual Average	**54**	**95**	**211**	**2,436**	**607**	**298**

Production data for the sheep flock was derived from the farm management system and subsequent discussions with the Farm Manager. Sheep flock data was provided for FY19 and FY20, showing monthly opening and closing numbers by class, weaning numbers, deaths, sales, and purchases (*Table 10*). Estimated or actual sheep sale weights and ages were used to determine growth rates in young sheep. The weight of adult sheep was estimated by the manager and cross referenced with sale weights where available.

Table 10. Average and annualised sheep numbers, weight gain and sales/purchases at Turretfield (average of FY 19 and FY 20)

Class	Head	LWG (kg/day)	Sales (head)	Sales (LW/hd kg)	Purchases
Rams	54	0.02	0	0	5
Wethers	95	0.13	8	65	0
Maiden breeding ewes	211	0.02	0	0	0
Breeding ewes	2,436	0.08[1]	298	65	0
Ewe lambs	625	0.15	21	25	0
Wether lambs	316	0.15	413	38	0

[1] Ewe weight accounts for weight gain during pregnancy

Total greasy wool sales and total number of sheep shorn were reported by the farm, with lamb wool reported separately disaggregated for lambs (*Table 11*). From these data, wool cut per sheep shorn was calculated (see *Table 11*).

Table 11. Outputs of greasy wool, bales sold, and number of sheep shorn (average of FY 19 and FY 20)

Annualised	Head shorn	Greasy kg	kg/head avg
Total	3502	22397	6.40
Lamb wool	1020	360	0.35
Rest of flock	2482	22037	8.88

Livestock feed intake consisted entirely of a mix of grazing and barley and oaten hay produced on-farm, with peas purchased for supplementary feeding with the barley. *Table 12* lists the harvested barley and oaten hay yield, and the purchased peas, per year for livestock consumption.

Table 12. Harvested barley and oaten hay yield, and purchased peas per year for livestock consumption (average of FY 19 and FY 20)

	Ha	Yield (t)	t/Ha
Barley	126.5	429.5	3.42
Oaten hay	96.5	518.5	5.47

2.4.5 Vegetation Carbon

Turretfield Research Centre locations are predominately dominated by arable, flat to undulating land with contour banking permitting cropping on the slopes (*Figure 2*). The predominant tree plantings consist largely of mixed native species.

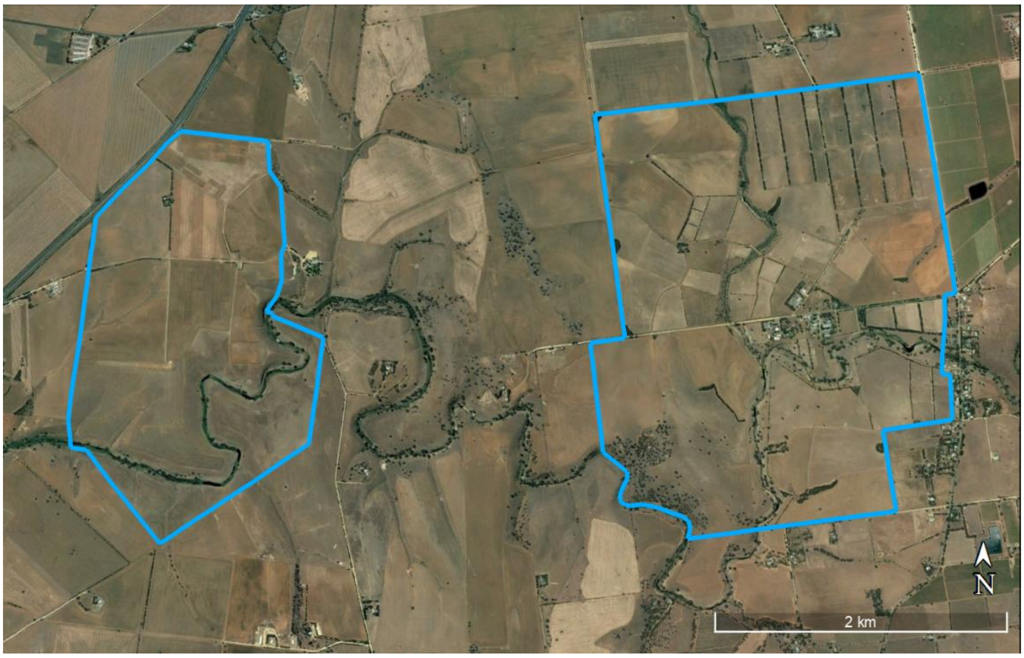

Figure 2. Satellite image of Turretfield Research Centre comprising farms Turretfield (right) and Kingsford (left)

Planted and potentially sequestering vegetation was calculated as covering approximately 8% of the properties combined, at 71 ha total. The coverage can be found dispersed around the farm in small strips and along drainage lines. There is sparse vegetation along the riparian area at Kingsford. A generalised mapping exercise was undertaken through remote satellite imagery to obtain a rapid assessment of carbon stocks in relation to vegetative growth on the property. FullCAM data for the region was used to determine annual carbon sequestration rates. Areas of long-term established native vegetation have not been assessed. As coverage was sparse in areas, sequestration rates were reduced by approximately 55% overall in comparison to expected native density sequestration rates.

2.5 Emission Reduction Opportunities

To identify and focus on the most relevant mitigation and sequestration options, a screening process was used to assess mitigation and sequestration potential and to identify technical barriers to application at Loxton and Turretfield.

The screening process assessed each option using the following criteria for both locations:

- The portion of the emission profile where this option is applicable;
- Technical mitigation and/or sequestration potential (percentage reduction in emissions realistically possible, with sequestration rate in t CO_2-e);
- The amount of each property where this option could be applied (e.g. hectares of land for tree planting);
- The percentage adoption across the fraction of the operation where this is applicable (e.g. anti-methanogenic feed additives may realistically be possible to distribute to only a portion of the flock).

Example mitigation scenarios were created from the identified mitigation opportunities and forecast through to 2030. These scenarios were combined with forecast sequestration from soil carbon and for relevant tree types to determine the plantings required to offset residual emissions at each location through to 2040 to provide a carbon neutral scenario. Results are presented in section 4 of the report.

3 Results & Discussion

3.1 Carbon Footprint Loxton

Total emissions (excluding soil and vegetation sequestration) on an annualised basis for the Loxton Research Centre were 68.7 t CO_2-e, and emissions attributed to the farming operation only were lower at 57.7 t CO_2-e (*Table 13*). The higher emissions for the facility were associated with research staff facilities and vehicles, and all additional emissions were associated with electricity and fuel use. For the purpose of the discussion, most attention has been directed to the 'farm level' results, which would be more comparable to a commercial farm (*Figure 3*).

Table 13. Facility and farm level gross emissions by source and scope

	Facility level	Farm Level	Unit
Gross emissions by source			
Field Emissions	6.6	6.6	t CO_2-e
Electricity	10.9	4.4	t CO_2-e
On-Farm Fuel Usage	14.9	10.5	t CO_2-e
Pre-Farm - fertiliser, pesticides, and other purchases	5.1	5.1	t CO_2-e
Pre-Farm Water Pumping	31.1	31.1	t CO_2-e
Gross emissions by scope			
Emissions – Scope 1	20.8	16.5	t CO_2-e
Emissions – Scope 2	10.9	4.4	t CO_2-e
Emissions – Scope 3	37.0	36.8	t CO_2-e
Total emissions	68.7	57.7	**t CO_2-e**

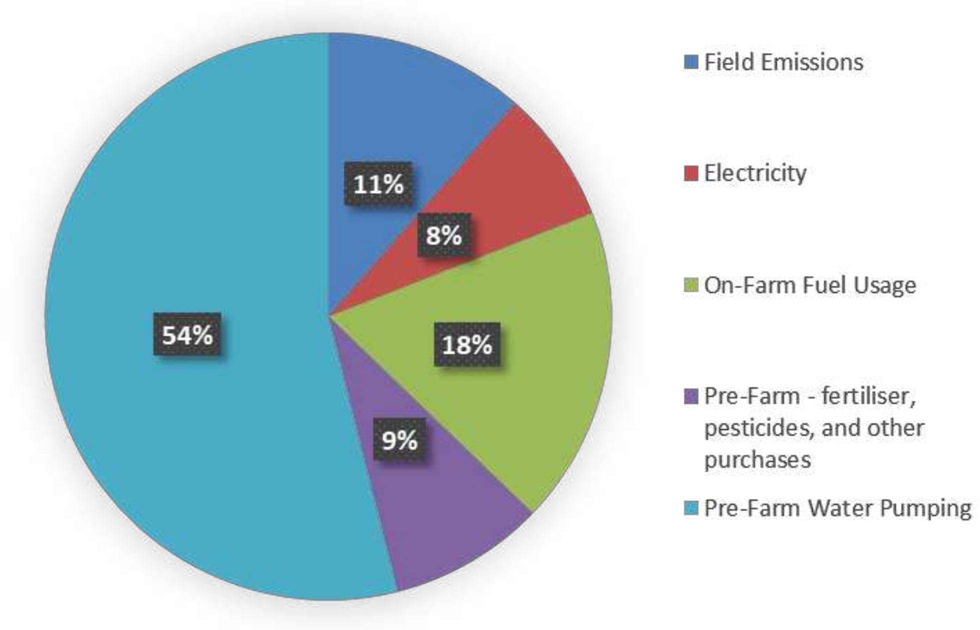

Figure 3. Farm operation emissions

The emissions profile for the Loxton farming operation was dominated by fossil fuel energy utilisation. Energy required for pumping irrigation water in the pressurised irrigation system that supplies Loxton contributed the greatest share of emissions, followed by on-farm fuel use and field emissions. Because fertiliser contributed via field emissions and pre-farm emissions, when combined this was almost as substantial as on-farm fuel use.

3.1.1 Vegetation Carbon

Native vegetation (excluding all horticultural and viticultural crops) at Loxton was estimated to sequester 4.1 t CO_2-e yr^{-1}.

Higher sequestration rates can be expected for different plantings and ages of trees (in particular prior to reaching maturity) and these factors are explored in the emissions reduction opportunity section of this report.

Net emissions including vegetation carbon sequestration were 53.6 t CO_2-e, which was 7% less than gross emissions.

3.1.2 Tree Crop and Viticultural Operation – Product Carbon Footprint

The product carbon footprint (including all on-farm and pre-farm sources) for the farming aspect of the Loxton operation was 158 - 201 kg CO_2-e.t oranges and 239 - 307 kg CO_2-e.t grapes, excluding carbon sequestration (*Table 14*). If offsets from vegetation were attributed to these crops, emission intensities would decline by approximately 7%.

Table 14. Carbon footprint for each crop/field at Loxton research farm

Carbon footprint for each crop/field	Oranges Navels	Oranges Valencia	Grape Chardonnay	Grape Shiraz	Grape Cab Sav
Crop emissions t CO_2-e	16.5	8.3	11.8	9.6	4.6
Crop emissions kg CO_2-e/t yield^{-1}	201	158	248	239	307

Differences in functional units, methodology choices and temporal and regional differences can make direct comparisons of studies in horticulture challenging (Clune *et al.* 2017). However, the below have been included to provide broad context for the results for crops grown at Loxton.

Bell and Horvath (2020) found that the production phase of oranges in US markets resulted in emissions of 200 kg CO_2-e.t $^{-1}$. A cradle-to-farmgate study in Iran by Alishah *et al.* (2019) found emissions were 379 kg CO_2-e.t^{-1} on average in years two to seven of the life of orange trees (year one was excluded due to the initial planting of the trees producing emissions significantly higher than those of subsequent years). Further, a study by Ribal *et al.* (2019) in Spain reported 278 kg CO_2-e.t^{-1} to the farmgate. Large variabilities were observed between studies relating to yield, purchased inputs, water and fuel application and system boundaries, highlighting the significant difference in management practices for differing varieties and regions. A meta-analysis by Clune *et al.* (2017) reported a mean of 350 kg CO_2-e.t^{-1} for oranges based on nine studies. However, this meta-analysis had different system boundaries to those in the Loxton analysis, including packaging and transport to the regional distribution centre or wholesale market rather than finishing at the farmgate.
We speculate that the slightly higher reported impacts in the literature compared to Loxton relate to higher nitrous oxide emissions in these overseas examples, and potentially lower production efficiency combined with inclusion of packing and transport.

No comparison was found to Australian orange production, but Maraseni *et al.* (2010) identified in the study of irrigated vegetables in Australia, that on-farm emissions related to energy used for irrigated water pumping were 54%, nitrogen emissions from fertiliser and from soils after fertiliser inputs were 27%, and on-farm fuel use was 8%. These results showed some similarities to Loxton in emission contribution from pumping, though fertiliser related impacts were higher for field crops.

A challenge with finding comparable literature in viticulture is that the most commonly used functional unit is a 0.75 L bottle of wine. The grapegrowing part of the wine supply chain is typically a smaller contributor to overall LCA impacts, with Abbott *et al.* (2016) reporting 17% of emissions were contributed from grapegrowing, with the remainder from transport, winemaking, and packaging in Australian wine production systems (Abbott *et al.* 2016). Similar to Loxton, the largest contributors to grapegrowing were from electricity used for irrigation, electricity used onsite, and fuel for machinery, though the contribution from energy for irrigation was lower than Loxton, possibly because other regions don't have water supplied from a pressurised water supply system. A study by Marras *et al.* (2015) found that the carbon footprint of a mature vineyard in Italy with a system boundary of cradle-to-farmgate was 390 kg CO_2-e.t^{-1} produced. Furthmore, Steenwerth *et al.* (2015), in their study of Californian grapes, reported emissions from two separate regions were 203 kg CO_2-e.t yield^{-1} to 456 kg CO_2-e.t^{-1}, with the differences attributed to the higher emissions intensity region utilising hand-harvesting and lower yielding but higher quality and value grapes, in comparison to mechanical harvesting and higher yielding grapes at the lower emissions intensity region. This highlighted the importance of yield when understanding the impact on emissions intensity.

Likewise, a study by Litskas *et al.* (2017) in Cyprus found differences between grape varieties and regions grown, reporting 283 kg CO_2-e.t^{-1} for Xynisteri, 556 kg CO_2-e.t^{-1} for Cabernet Sauvignon, and 846 kg CO_2-e.t^{-1} for Soultanina grapes. In comparison, grapes grown at Loxton had emissions at the lower end of reported impacts, partly because of the high yield and relatively low fertiliser inputs compared to the studies reported.

We note that, as Loxton is in a low rainfall region with irrigation water provided by a centralised distribution system, results may differ to wine grapes in other parts of Australia. Therefore, any comparisons and relevance from the results should closely consider environmental, crop type and management practices and how these may differ.

3.2 Carbon Footprint Turretfield

Total emissions on an annualised basis for the Turretfield Research Centre were 944 t CO_2-e, excluding soil and vegetation change and sequestration.

The emissions profile for the Turretfield farming operation of 944 t CO_2-e was dominated by methane emissions (84%) from enteric and manure sources, followed by carbon dioxide (10%) from on-farm and pre-farm farm fuel and electricity use and pre-farm fertiliser use, and nitrous oxide (6%) predominantly from urine and dung (*Table 15*). On-farm scope 1 emissions were 94% of total emissions due to the dominant role of livestock emissions.

Table 15. Emissions profile for the Turretfield farming operation

Gross Emissions		
Emissions – Scope 1	t CO_2-e	885
Emissions – Scope 2	t CO_2-e	6
Emissions – Scope 3	t CO_2-e	53
Total Emissions	**t CO_2-e**	**944**
Methane emissions	t CO_2-e	799
N_2O emissions	t CO_2-e	54
CO_2 emissions	t CO_2-e	91

Enteric methane was the most significant contributor to overall emissions, with carbon dioxide from purchased inputs and manure emissions (urine and dung) contributing the next highest volumes (*Figure 4* and *Table 16*).

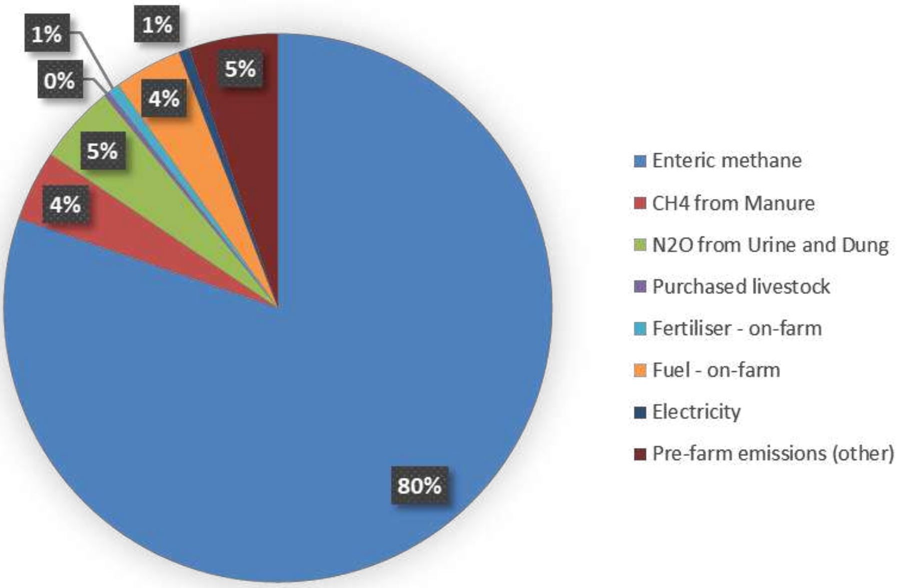

Figure 4. Hotspot analysis of Turretfield emissions

Table 16. Emissions sources at Turretfield

Emission Source	t CO_2-e
Enteric methane	758
CH_4 from Manure	39
N_2O from Urine and Dung	44
Purchased livestock	3
Fertiliser - on-farm	7
Fuel - on-farm	38
Electricity	6
Pre-farm emissions (other)	50
Total	**944**

3.2.1 Vegetation Carbon

Vegetation at Turretfield and Kingsford was estimated to sequester 48 t CO_2-e yr^{-1} (*Table 17*). These values are an estimate, and the accuracy of the assessment was limited by the difficulty in quantifying sequestration rates from tree lines and plantings around the property, some of which had variable tree survival rates. This, and the relative age of plantings (mean assumed to be 30 years) resulted in very low sequestration rates.

Higher sequestration rates can be expected for different plantings, climates, and ages of trees (in particular prior to reaching maturity), as is explored in the emissions reduction opportunity section of this report.

Table 17. Carbon sequestration in trees at Turretfield and Kingsford

Carbon sequestration in trees	
Current land (ha)	71
Age of trees (years average)	30
Carbon sequestered (t CO_2-e annually)	48

3.2.2 Livestock Operation – Product Carbon Footprint

The product carbon footprint (including all on-farm and pre-farm emissions sources) for Turretfield was 25.8 kg CO_2-e.kg wool^{-1} and 9.6 kg CO_2-e.kg LW^{-1}, excluding soil and vegetation sequestration. When including soil and vegetation change and sequestration, the net product carbon footprints were 24.5 kg CO_2-e.kg wool^{-1} and 9.1 kg CO_2-e.kg LW^{-1} (*Figure 5*).

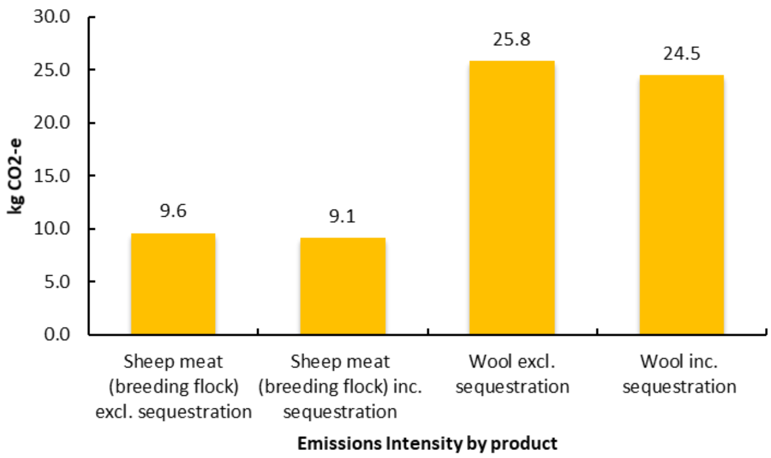

Figure 5. GHG emissions for Turretfield and Kingsford, including and excluding sequestration

The results for wool were marginally lower for low rainfall systems than those reported by Wiedemann *et al*. (2016) when the latter was corrected with AR5 GWP_{100} values and updated allocation factors. This study found a carbon footprint of 26.1 kg CO_2-e.kg greasy wool^{-1} for a regional average of the South Australian Southern Pastoral Zone. Lamb results were higher than the average merino systems reported in the same study and were higher than cross-bred lamb production in NSW reported in a separate study by Wiedemann *et al.* (2016) when the latter was corrected with AR5 GWP_{100} values, which was largely attributed to inefficiencies in flock production due to ongoing research activities. We also noted that the clean wool yield was relatively low at Turretfield, which resulted in relatively higher greasy wool yield but lower clean wool yield than the comparison studies. As a consequence, impacts for wool from Turretfield would increase substantially later in the supply chain after wool scouring.

4 Emission Reduction and Sequestration Opportunities

4.1 Loxton Research Centre

4.1.1 Emissions reduction

Options were screened for reducing emissions at the Loxton farm (*Table 18*). Broadly, they focus on a shift to renewable energy options (either on-site, through external renewable energy changes such as at state grid level, or through external schemes) and a continued focus on maximising the efficient application of inputs such as fertiliser and water. Options were included that may not be directly relevant to Loxton, but were none-the-less likely to be relevant to commercial farms and were therefore included here.

Table 18. Mitigation options for reducing Loxton farm emissions

Strategy	How	Positives	Negatives
Improve mix of renewable energy through green energy retailer programs	Engage energy retailer to offset grid purchased electricity through renewable energy purchase costs eg. Greenpower	On-site power use can be attributed to partial or full renewable generation; volume to be offset expected to reduce as South Australia increases renewable generation	May not be possible through energy retailer; expense required
Installation of renewable energy on-site	Installation of solar panels and potentially battery storage to reduce grid electricity use	Minimise grid electricity use	Expense requires cost benefits analysis against other options
Decreased water use through increased application efficiency	Improved irrigation timing; scheduling and use of soil moisture sensors; timing of irrigation	Specific and targeted water availability to crops; reduced water use	Farm already operating at close to optimal so only small changes are possible. Requires technological inputs and management time; minimal benefit expected
More fuel-efficient vehicles and machinery	Upgrade existing and older machinery and vehicles to more efficient versions or use electric vehicles and renewable electricity.	Minimise fuel usage; state government has committed to a renewable energy fleet by 2030	Capital cost; may be limited practical options for some machinery types
Enhanced Efficiency Fertilisers	Nitrification inhibitors reduce nitrification, nitrate leaching and nitrous oxide production	Reduced emissions per N applied; reduced product losses to emissions; more efficient use	Extra cost per unit; varied research on effectiveness on emissions

4.1.1.1 Reducing fossil fuel utilisation

For the Loxton farm operation, 80% of emissions are attributed to fuel and energy utilisation (54% from pre-farm irrigation pumping, 8% from on-farm electricity usage, and 18% from on-farm fuel usage). Therefore, the greatest opportunity to mitigate emissions is through water usage efficiency, energy mix improvements for electricity (for example increased renewable energy utilisation), fuel efficiency improvements, and exploration of alternative energy providers and energy provider schemes.

Grid Electricity Emission Improvements – Renewable Energy

As pre-farm irrigation pumping emissions contribute 54% of overall emissions, improvement in the emissions profile of the upstream electricity generation is the greatest opportunity to improve both irrigation emissions, and the overall emissions profile of Loxton. Currently, the water supply network that supplies water to Loxton uses 352 kWh ML^{-1} for pumping. With a total of 170 ML yr^{-1} of water delivered for irrigation, the associated electricity use is 59840 kWh on an annual basis.

South Australia currently has an emissions factor of 0.52 kg CO_2-e.kWh^{-1} for state-wide electricity generation when scope 2 and scope 3 are combined (Commonwealth of Australia 2020; DISER 2020a). This is based on a 3-year rolling average for all state electricity generation and imports. In 2020, the renewable energy generation mix of South Australia's energy generation was 59.7% (60.1% as a proportion of consumption) (Clean Energy Council 2021).

The South Australian State Government has committed to 100% net renewable energy generation by 2030 (Parkinson 2020), with some reports indicating this could be on track to be achieved by 2025 (Bowyer and Kuiper 2021; Matich 2021). As a result, the emissions factor for South Australia is likely to significantly improve throughout the decade and beyond, leading to a large reduction in the emissions profile at Loxton. As a comparative example, in 2020 Tasmania achieved 99.2% renewable energy generation (100.6% of energy consumption), with the current scope 2 and scope 3 National Greenhouse Account emissions factor for Tasmania is 0.17 kg CO_2-e.kWh^{-1} (Commonwealth of Australia 2020). While state electricity factors are complex and cannot be directly compared, they do provide an indicative comparison. As an example of potential improvements, if SA achieved a similar emissions factor as Tasmania (0.17 kg CO_2-e.kWh^{-1}) this would result in irrigation pumping emissions reducing by 20.9 t CO_2-e, from 31.1 t CO_2-e to 10.2 t CO_2-e, which equates to a 36% reduction in the overall emission profile at the Loxton farm. Further emissions reductions through increasing renewable mixes and reducing fossil fuel supplementation, and the implementation of energy storage via centralised and distributed battery storage, are forecast to drive improvements beyond this estimate over time. The same relative improvement would apply for any grid electricity utilisation, such as on-farm electricity use.

Irrigation Efficiency

Improvements in water efficiency to reduce water utilisation could assist with emission reductions. From discussions with Loxton staff, irrigation practices are efficient and largely employ the latest technologies and efficiency measures. Therefore, the potential to reduce irrigation water application is likely to be minimal without impacts to crop productivity. However, as irrigation contributes a high proportion of emissions, smaller gains may still provide an impact to any emission reduction plans. As a result, an ongoing exploration of water use efficiency may enable incremental improvements in water use efficiency and reduced GHG. The potential to further utilise, schedule and automate the timing of water application to reduce wastage and losses, and further leverage soil monitoring tools (such as gypsum block probes and tensiometers) could be beneficial. As an indication of the potential from incremental improvements, reduction in water application of 10% (17 ML) would result in an emissions reduction of 3.11 t CO_2-e under current emissions factors.

Energy providers

To supplement the improvements expected from the state grid, alternative short-term options to deliver a reduction in emissions for electricity could be explored further. An option for the mitigation of emissions associated with electricity usage is to consider energy providers that may source their energy from renewable energy sources rather than fossil fuels.

No energy provider in Australia can claim to only sell renewable power. All retailers sell electricity from an energy grid made up of energy that is a mix of renewable energy and energy generated from the mining of fossil fuels (Wrigley 2021). However, there are options such as GreenPower and carbon offsetting that are available through some providers.

GreenPower is a government-led initiative where retailers agree to offset some or all of a customers' power usage by purchasing electricity through accredited renewable generators. When GreenPower is purchased, it is not received straight from a renewable generator, but comes from the grid. Customers can elect to have a portion or all of their electricity bills offset with GreenPower, which comes at an additional cost of approximately five to 10 cents more per kWh depending on the retailer (Gudova 2021). For average Loxton scope 2 farm use, this example would incur an expense of an additional $420-$840 annually. To offset scope 3 irrigation electricity usage, this example may incur an expense of approximately $3000-$6000 annually.

As an example of an energy provider that offers carbon offsetting, Powershop is an electricity provider that offsets 100% of their customer's energy usage with no additional fee. Powershop is accredited under the Australian Government's Climate Active Carbon Neutral Standard as a carbon neutral business. Further research would be required to confirm availability for the operation, and to establish any ongoing costs or other impacts that may be incurred.

Renewable energy infrastructure

It may be practical to install solar panels at Loxton to reduce reliance and utilisation of grid electricity. One option is the partial use of renewable energy from solar panels while still maintaining a connection to the grid for times when energy cannot be generated by solar panels. A second option is going "off-grid" by installing batteries with the solar panels to store and provide electricity in times of demand. Both options would require a cost-benefit analysis that includes a payback period.

Reducing diesel and petrol usage

Fuel use contributed 18% of the emissions for the Loxton farming operation. Replacing older, inefficient machinery and vehicles with newer, modern equipment that has increased fuel efficiency will reduce diesel and petrol usage. A cost-benefit analysis would be required, as this is typically a high capital cost and there are limited options for electric farm vehicles at present, making this a less feasible option.

Similar to the renewable energy commitments listed earlier, the South Australian Government has committed to government fleet vehicles being 100% renewably powered by 2030 (Government of South Australia 2020). This may provide benefits to the Loxton location through improved emissions factors for fleet vehicles. As a demonstration centre, Loxton may be well positioned to explore renewable energy powered agricultural vehicles and machinery over the coming years. This would require further investigation to determine opportunities. As an example, a 50% reduction in diesel and petrol utilisation at Loxton would reduce emissions by 5.3 t CO_2-e or around 9% of current emissions.

4.1.1.2 Fertiliser, pest and weed purchased inputs

Field emissions and pre-farm emissions for purchased inputs were 11% and 9% of the farm emissions. Discussion with Loxton staff indicates that current practices around the use of nitrogen fertiliser, herbicides and pesticides are efficient, including the utilisation of best practice techniques and application approaches such as fertigation. Therefore, there is likely minimal short-term scope to improve nitrogen, herbicide and pesticide application efficiencies whilst still maintaining optimal yield and plant health outcomes.

One option to potentially reduce N fertiliser requirements is via legume plantings within the inter-row. Cover cropping with legumes in a Mediterranean olive orchard showed an increase in the N nutritional status of olive trees with legume cover cropping when compared with natural vegetation cropping after two years (Rodrigues *et al.* 2015). Likewise, comparing soil-protecting orchard management practices (cover cropping, no tillage, compost application and mulching of pruning residues) with local orchard management practices (soil tillage, removing of residues and mineral fertilisation) in Mediterranean kiwifruit and apricot orchards showed positive results on yield and soil carbon inputs however did not display a significant effect on SOC over a four year time period (Montanaro *et al.* 2010). Similarly, green manure legume crops in coppiced tree cropping systems in Australia showed the potential to reduce N fertiliser applications, however further research was recommended to understand the impact of legumes on weed control systems, the release of N from decaying legume residues, and to understand the impact of competition and growth across water and nutrients (Rose *et al.* 2019). While the findings show potential, further research is warranted to understand and quantify the benefits and costs in specific production systems in specific environments and this has not been included in the strategy pending further research.

In the future, emissions from fertiliser production (pre-farm) may be reduced if more efficient fertilisers can be produced, or if renewable energy can be used in fertiliser production. This is particularly relevant for N fertilisers. An example is the research being undertaken to develop an improved Haber Bosch process to enable reduced emissions and energy inputs in urea creation, with one investigation reporting a potential energy efficiency gain in the synthesis loop of 50% (Smith *et al.* 2020). Further research is underway by Grains Research Development Corporation, Orica and CSIRO in Australia to enable the production of ammonia with the only inputs being water, air and solar PV energy (Commonwealth Scientific and Industrial Research Organisation 2020).

Whilst there is likely minimal scope for improvement in fertiliser application volumes and management approaches, due to the extension aspects of the Loxton Research Centre, options for the industry more broadly are listed in *Appendix 1*.

4.1.2 Carbon Sequestration

4.1.2.1 Carbon sequestration in tree and viticulture crops

Beyond maturity, tree crops such as oranges and grapes sequester immaterial amounts of carbon. According to the NIR (Commonwealth of Australia 2021), sequestration is included up to maturity but no allowance is made post-maturity. Due to the crops at Loxton being beyond the maturity ages provided within the NIR, no tree crop sequestration has been included in the sequestration profile at Loxton.

4.1.2.2 Carbon sequestration in native trees

The limitation of space at Loxton reduces the potential for sequestration through tree plantings. Small areas of wind breaks and block plantings have been considered. Preferred planting types identified by the project working group are targeted at biodiversity and pollination benefits to support other initiatives. Mixed environmental varieties are the preferred approach to consider given these biodiversity benefits,and include mixes of native species such as *Casuarina* genus (particularly as windbreaks), *Acacia pycnantha*, *Mallee* eucalypts (e.g. *Eucalyptus kochii), Bursaria spinosa*, *Melaleuca* genus, and *Callistemon* genus.

Forecast carbon sequestration on an annual basis was determined through FullCAM modelling. FullCAM is not sensitive to different sequestration rates across the mixed varieties at this location. As a result, FullCAM results were identical for the above species with the exception of mallee eucalypts, which were higher. For this reason, results are shown for mixed environmental plantings and mallee eucalyptus only (*Figure 6*).

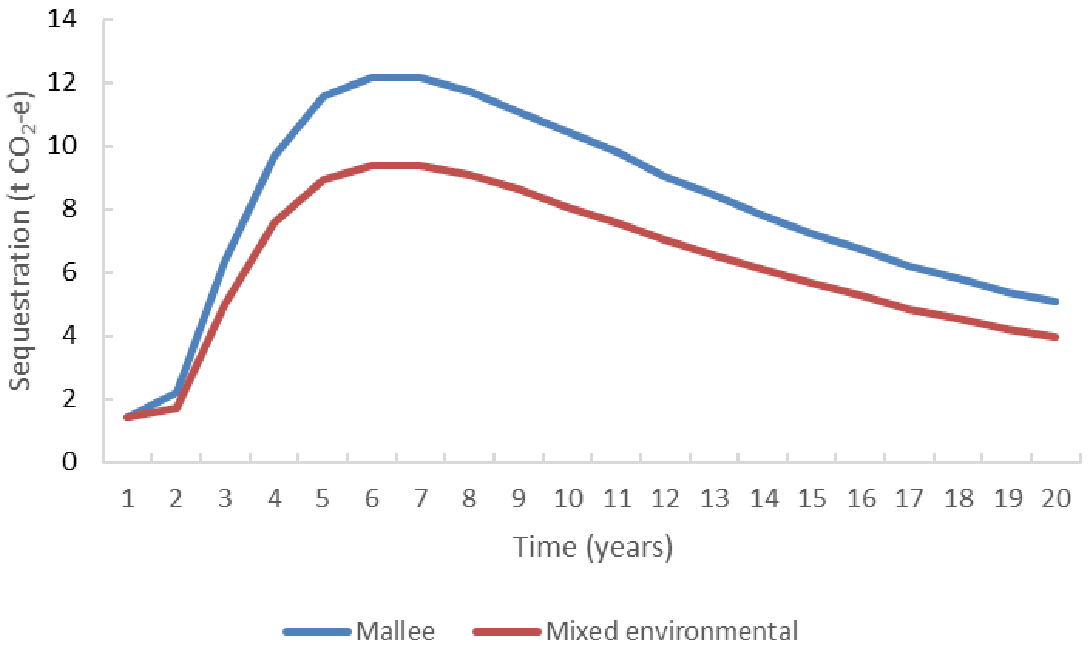

Figure 6. Annual sequestration potential (per ha) of mallee and mixed environmental plantings over 20 years (t CO_2-e) at Loxton

Forecast tree plantings required to achieve a variety of emission pathway scenarios are shown in section 5.

4.1.2.3 Carbon Sequestration in Soil

4.1.2.3.1 Site Evaluation

Soil carbon in Australian soils is typically constrained by limited nutrients, poor soil structure, poor water retention and low rainfall. There is greater potential for carbon sequestration in readily degraded soils than a soil that has been under best management practices for a number of years, because there is an expectation that the difference between the current soil organic carbon (SOC) levels and the carbon saturation level or upper limit (Stewart *et al.* 2008) will be greater in degraded soils. This may provide an opportunity to increase soil carbon levels for Loxton, depending on previous management over the last 50+ years.

Carbon sequestration is also strongly influenced by soil texture, and heavy-textured clay soils typically have a greater capacity to store carbon than sandy soils (Sanderman *et al.* 2010). Organic matter adsorbs to clay surfaces, physically protecting the carbon from decomposition by microorganisms. While microorganisms are critical to decomposition processes, they also play an important role in the stabilisation of organic matter. Climate also influences the attainable carbon storage levels, primarily by influencing plant biomass production. Areas of high rainfall and irrigation areas have a greater capacity to store carbon due to expected higher plant biomass. High temperatures are generally negatively correlated with soil carbon (Sanderman *et al.* 2010), and are expected to accelerate biological activity and decomposition of organic carbon.

To develop an indication of potential carbon sequestration rates, we have investigated soil carbon levels from background soil surveys and carbon levels observed at the site from a survey undertaken by PIRSA staff as part of this project.

According to the districts used in the Soil Carbon in South Australia Volume 4 – Benchmarks and Data Analysis for the Agricultural Zone 1990 – 2007 (Schapel *et al.* 2021), Loxton is in the Northern Murray Mallee agricultural district. Values within this cited report are in organic carbon (OC) assessed using the Walkley-Black method, which has been shown to underestimate carbon in SA soils (A Schapel *pers. comm.*). These were subsequently revised using a factor of 1.12 to account for this. According to this report, soils in the Northern Murray Mallee have an average ETOC of 0.67% in the topsoil (0-10 cm), and the general trend over time is that OC concentration is relatively stable, with a small increase in OC of 0.014% per year. Assuming an average bulk density of 1.3 g cm^{-3}, this is a stock of 8.7 t C ha^{-1}, and a change of 0.17 t C ha^{-1} yr^{-1} (0.64 t CO_2-e ha^{-1} yr^{-1}). If the 0-10cm carbon change was assumed to be half of the 0-30cm carbon change, the carbon stock may be in the order of 17.5 t C ha^{-1} and change may be 0.34 t C ha^{-1} yr^{-1} (equivalent to 1.2 t CO_2-e ha^{-1} yr^{-1}) (*Table 19*).

Soil samples were collected from six sites at Loxton, in the planting-row and adjacent mid-row area of one citrus and two grapevine blocks. A total of 10 samples were collected for each site, from five panels along the row. The results show a range of 0.71 to 2.67% dOC, with an average of 1.61% ETOC (0-10cm). This amounts to a range of 10.89 to 29.57 t C ha^{-1}, with an average of 20.85 t C ha^{-1} (0-10cm). The midrow soil ETOC stocks for the grape plantations showed a higher ETOC stock than the planting rows, ranging from 1.40 to 1.80% ETOC and 0.71 to 1.10% OC respectively. In contrast, the midrow ETOC stocks for the citrus blocks showed a lower soil ETOC than the plantings rows at 1.97 and 2.67% ETOC respectively. These carbon stocks appear considerably higher than regional averages according to the benchmarking report, which may be the result of increased carbon inputs to the site, supported by irrigated cropping. Noting the potentially elevated carbon stocks, it is not clear whether further improvements are possible. Scenarios investigating soil carbon sequestration are examined in the following section.

4.1.2.3.2 Carbon Sequestration Potential

Four scenarios for two different rates of soil carbon sequestration over two different areas were run to ascertain what impact soil carbon sequestration could have as an emissions offset (*Table 19*). These small changes in soil carbon would be difficult to detect with current sampling methodologies unless a very long time frame was used to detect change over time and were therefore not included in the scenarios for this farm.

Table 19. Soil carbon sequestration scenarios for Loxton

	Scenario 1 – Lower sequestration, small area	Scenario 2 – Lower sequestration, larger area	Scenario 3 – Higher sequestration, small area	Scenario 4 - Higher sequestration, larger area
Land area (ha)	8 (25%)	16 (50%)	8 (25%)	16 (50%)
Stock change ($t\ CO_2$-e $ha^{-1}\ yr^{-1}$)	0.37	0.37	1.2	1.2
Total soil carbon Sequestration (-$t\ CO_2$-e yr^{-1})	3	6	10	20
Net Carbon balance ($t\ CO_2$-e yr^{-1})	55	52	48	38
% reduction to farm emissions from soil carbon	5	10	17	35

4.2 Reducing Turretfield Research Centre Emissions

4.2.1 Emissions reduction

Livestock emissions (enteric methane, manure, and urine and dung) contributed 90% of farm operating emissions at Turretfield and are therefore the primary focus of mitigation options. There are two primary areas to address in terms of emissions reductions from livestock at Turretfield. These are:

1. Increasing flock efficiency and optimising flock size.
2. Reducing enteric methane fermentation.

The following mitigation options have been considered for the Turretfield location (*Table 20*).

Table 20. Mitigation options for reducing Turretfield farm emissions

Options	How	Positives	Negatives
Reduce total sheep numbers by improving lambing and marking %; improved shearing and health management practices	Improve lambing % and weaning % through revision of mating approaches; pregnancy scanning to reduce dry sheep flock	Improved flock efficiency; reduced ewes required to maintain productivity	To be balanced against research centre priorities
Increase average daily weight gain for wether lambs	Improve feed regimes	Reduced time on farm; improved productivity	Potential costs and management required to implement
Introducing feed supplement additives	Implement feed supplement additive program as feed supplements and distribution practices become available	Potential for large reduction in enteric methane; improved feed and weight characteristics	Not yet widely available; requires leap in feed delivery technology and further research is required on impacts to animal growth, reproduction, health and product quality.
Introducing anti-methanogenic pastures and legumes eg. biserulla	Sowing of regionally suitable anti-methanogenic legumes where land can be made available	Reduction in enteric methane; improved feed efficiency productivity	Land availability and sowing expense; additional management required; enteric methane mitigation can be variable
Implementing genetic lines that have reduced emissions	Introducing sheep with low emissions over an ongoing breeding program	Genetic reduction in emissions and feed conversion efficiency	Unlikely to result in a low methane flock within the next ten years; production characteristics of low-methane sheep to be considered against current flock wool and meat productivity

4.2.1.1 Increasing flock efficiency

Lambing Rate

The average weaning rate at Turretfield was 55% during FY19 and FY20. This represents a substantial inefficiency in comparison to industry standards, which is largely attributed to the research aspects of the farm (such as artificial insemination research).

Flock management can be used to reduce emission intensity by producing more wool and liveweight from the same number of sheep (i.e. more output, same size flock), or can be used to reduce gross emissions by optimising animal numbers and maintaining similar flock outputs (i.e. same output, smaller flock). Cruickshank *et al.* (2009) modelled the impact of various management changes on emissions, including: ewe liveweight, ewe growth rate, ewe death and culling, ewe cull year, ewe mortality, dry ewe scanning percentage and hogget lambing. The top three strategies were:

1) hogget lambing (13.6% reduction in methane emissions intensity),
2) scanning percentage[1] increase by 10% (7.8% reduction in methane emissions intensity) and,
3) decreasing ewe LW by 10% without altering productivity (3.9% reduction in methane emissions intensity).

In combination, the top three management strategies had a mitigation potential of up to 21% reduction in methane per lamb sold.

Harrison *et al.* (2014) analysed the effect of ewe fecundity on enterprise-level productivity, GHG emissions and emissions intensity. Emissions intensity was reported on a clean fleece weight (CFW) and LW basis. The results from the study showed that increased fecundity had little effect on net emissions but decreased emissions intensity, because stocking rate was maintained at a similar level across the simulations. An increase in the number of lambs per ewe from 0.94 to 1.53 was modelled, resulting in a reduction of emissions from 9.3 to 7.3 kg CO_2-e kg $CFW+LW^{-1}$. This is in contrast to the results of Cottle, Harrison and Ghahramani (2016), who found no change in emissions intensity effect from conception. However, their study showed that animal breeding options reduced emissions intensity more than feed base interventions, where breeding ewes with greater body size or genotypes with higher fleece weight reduced emissions intensity by 11% and 9%, respectively.

Alcock *et al*. (2015) modelled the effects of manipulating flock management or animal genotype on whole-farm production, enteric methane emission and wool emissions intensity for sheep enterprises in southern Australia. Various influences were examined for annual wool production, methane emissions and wool emissions intensity which included:

1. lambing time,
2. joining maiden ewes at 7 months instead of 19 months of age,
3. increasing lamb weaning rates or,
4. using genotypes with:
    a. improvement in fleece weight,
    b. feed efficiency and/or
    c. methane yield.

The results indicated that lambing time had little effect on total methane emissions, as stocking rates were adjusted for sustainable pasture utilisation. The joining of maiden ewes at seven months eliminated a cohort of unjoined ewes, which resulted in 4–5% lower weaning rates but saw an overall increase in the total number and total sale weight of young sheep. While total emissions remained the same, joining maiden ewes earlier resulted in reduced emissions intensity by 4%. Increasing ewe fecundity also reduced emissions intensity by 7–8% even though methane emissions remained relatively constant.

As expected, the combination of a superior genotype with 10% improved fleece weight, feed efficiency and methane yield resulted in the largest profit and reduced emissions intensity, indicating that a shift in superior genotypes could be a profitable long-term goal.

[1] Changing scanning percentage alters the number of multiples, which affect lamb growth rates and survival.

Reduction in emissions via genetics typically occurs by generating less methane production per unit of feed intake, or less methane due to lower feed intake at the same rate of growth (Black *et al.* 2021). Utilising genetic strategies can deliver incremental improvements in methane reduction per animal, while productivity and emissions intensity improvements can be used to reduce emissions via flock restructure, reducing the flock size while maintaining production levels.

4.2.1.2 Reducing enteric methane fermentation

Enteric methane emissions contribute 80% of farm operating emissions at Turretfield. Various options exist to reduce enteric methane fermentation, such as use of anti-methanogenic feed additives, anti-methanogenic pasture species, and breeding low-methane sheep.

Methane-Mitigating Feed Additives

The introduction of methane-mitigating additives – for example, *red seaweed* – into feed has shown significant potential to reduce methane emissions from ruminant animals. The *Asparagopsis* species of seaweed produces a bioactive compound (bromoform) which prevents the formation of methane by inhibiting a specific enzyme in the gut during the digestion of the feed. This is currently in the development stage, with further work on delivery mechanisms and mitigation potential to be completed in sheep flocks. Further research is also required on the short- and long-term impacts on sheep health, feed efficiency, reproduction, growth rate and product quality (meat and wool). *Asparagopsis* has been found to reduce enteric methane emissions by up to 80% in sheep when offered to animals at 3% of their ration (Li *et al.* 2018). Likewise, 3-NOP has been found to be effective in mitigating enteric methane emissions without compromising the productive performance of sheep (Jayanegara *et al.* 2018). However, trial work to date has been done in a controlled environment as it is less clear what the mitigation potential may be when feeding is done in a grazing environment. The key challenges for feeding supplements in a grazing environment is ensuring sheep receive the right rate of supplement every day (or even multiple times per day) to ensure efficacy.. Supplementary feeding occurs at Turretfield from summer to winter, with additional management required to feed across a full year. Currently there are also no methane-mitigating feed products suitable for paddock feeding. These and other challenges suggest that the mitigation potential should be moderated to account for lower efficacy or the inability to feed all sheep classes at all times of the year.

Having noted these challenges, the methane mitigating potential of these additives is still significant. As an example at the higher end of potential mitigation, *Asparagopsis* with 60% in-field efficacy, fed to 80% of the flock year round, may achieve a reduction in enteric methane of 364 t CO_2-e.yr^{-1} from a total enteric methane value of 758 t CO_2-e.yr^{-1} at Turretfield.

Anti-methanogenic pastures

Examples of anti-methanogenic legumes and pastures include *Biserrula pelecinus* (Biserulla), *Eremophila* spp., *Lotus corniculatus* (Birdsfoot trefoil) and forage rape. Whilst enteric methane mitigation estimates vary across pasture and legume types (for example, 16% mitigation potential for Biserulla when compared with subterranean clover in southern

Australian grazing systems) (Banik *et al.* 2019), the in-field efficacy and proportion of the flock that can be grazed on these pastures across the year reduces these values quite considerably. As an example, 5% mitigation potential may be more realistic once variables are considered. If this was grazed by the entire flock for 6 months of the year, this may lead to a reduction in enteric methane of 19 t CO_2-e.yr^{-1} at Turretfield.

Genetics
An alternative flock management practice that could be implemented is selecting for sheep that have reduced emissions. The repeatability and heritability of reduced methane emissions in sheep has been examined by Goopy *et al.* (2016) who identified high (n = 103) and low (n = 104) methane emitting mature ewes. The results showed that methane emissions were always higher (31 %) in the high emitting sheep compared to the low emitting sheep. Repeatability of this trait was moderate (0.43) with heritability low (0.13), when adjusted for LW. Heritability was influenced by ewe sires (0.13) as well as the genotype and environment interactions. This study provides an initial understanding of the relationship between methane output and individual animals in less controlled conditions such as a respiration chamber. While this displays potential, genetic selection for methane reduction needs to be considered against other flock traits such as reproduction and growth characteristics (Black *et al.* 2021). Focusing on genotypes with improved growth and productivity characteristics, such as those which consume less feed per unit of production (high net feed efficiency), may lead to reduced methane emissions through improved feed utilisation and associated growth (Cottle *et al.* 2011). While this may be one possible long-term option, the potential for feed additives to significantly reduce emissions appears to be a more viable short-term option, and genetics have not been examined further.

4.2.2 Carbon Sequestration

4.2.2.1 Carbon sequestration in native trees

As an open grazing system with riparian and tree-suitable areas, a number of planting types were considered. Native planting types which are anticipated to support biodiversity were prioritised. Mallee tree plantings were considered for block and supplementary plantings, as were general mixed environmental plantings.

FullCAM was utilised to model the forecast carbon sequestration potential of these planting types. Mallee eucalypt plantings achieved a 29% higher sequestration rate than mixed environmental plantings (see *Figure 7*).

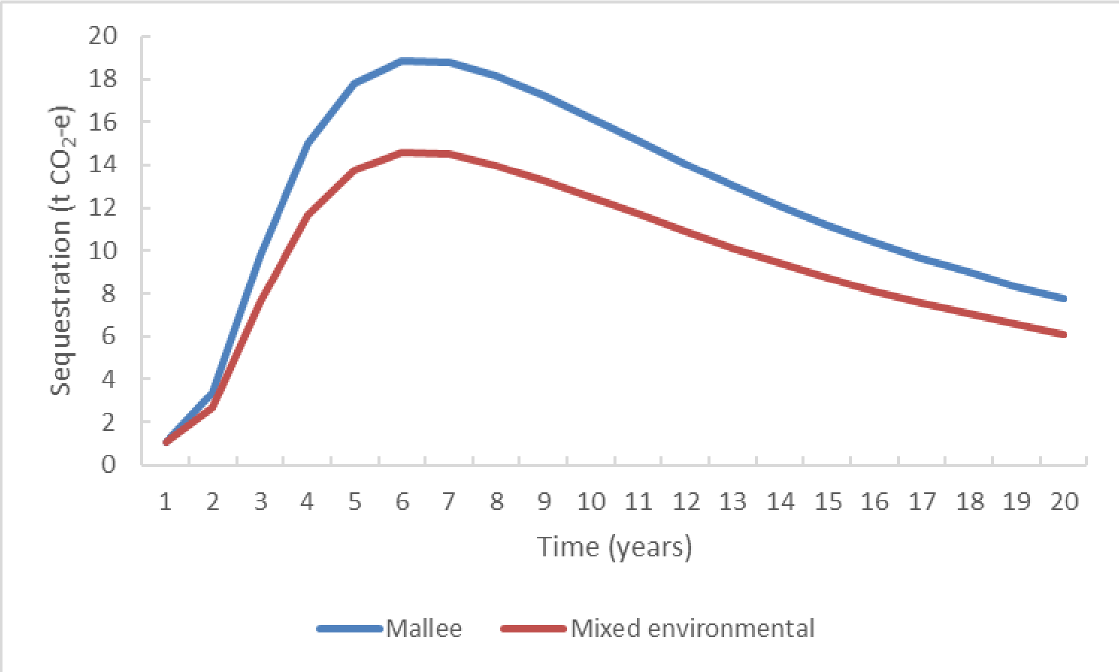

Figure 7. Annual sequestration potential (per ha) of mallee and mixed environmental plantings over 20 years (t CO2-e) at Turretfield

4.2.2.2 Carbon sequestration in soil

To develop an indication of potential carbon sequestration rates, we have investigated soil carbon levels from background soil surveys and carbon levels observed at the site from a survey undertaken by PIRSA staff as part of this project.

According to the districts used in the Soil Carbon in South Australia Volume 4 – Benchmarks and Data Analysis for the Agricultural Zone 1990 – 2007 (Schapel *et al.* 2021), Turretfield is in the Lower North agricultural district of South Australia. According to this report, soils in the Lower North have an average estimated total organic carbon (ETOC) of 1.48% in the topsoil (0-10 cm), and the general trend over time is an increase in ETOC of 0.012% per year. Assuming an average bulk density of 1.3 g cm^{-3}, this is a carbon stock of 19.3 t C ha^{-1} yr^{-1}, and a change of 0.16 t C ha^{-1} yr^{-1} (equivalent to 0.56 t CO_2-e ha^{-1} yr^{-1}) (0-10 cm). This dataset did not provide comparison results for 0-30cm, but if the 0-10cm carbon change was assumed to be half of the 0-30cm carbon change (based on the carbon stock ratios tested at the Turretfield site), the carbon stock may be in the order of 38.6 t C ha^{-1} yr^{-1} and change may be 0.31 t C ha^{-1} yr^{-1} (equivalent to 1.1 t CO_2-e ha^{-1} yr^{-1}).

Soil samples were collected at four sites at Turretfield. Ten samples were collected within a 25 m x 25 m area for each sampling site, with one bulk density sample collected from the southwest corner. The results show a range of 1.19 to 2.16% ETOC, with an average of 1.70% TOC (0-10 cm). This amounts to a range of 15.64 to 28.88 t C ha^{-1}, with an average of 22.64 t C ha^{-1} (0-10 cm). The average carbon stock of the soil at Turretfield is higher than the regional average.

4.2.2.2.1 Carbon Sequestration Potential

Four scenarios for two different rates of soil carbon sequestration over two different areas were run to ascertain what impact soil carbon sequestration could have as an emissions offset (*Table 21* and *Table 19*). These are extremely small changes in soil carbon, and they would be impossible to detect with current sampling methodologies.

Table 21. Soil carbon sequestration scenarios for emissions reduction at Turretfield

	Scenario 1 – Lower sequestration, smaller area	Scenario 2 – Lower sequestration, larger area	Scenario 3 – Higher sequestration, smaller area	Scenario 4 - Higher sequestration, larger area
Land area (ha)	50 (10%)	200 (39%)	50 (10%)	200 (39%)
Stock change (t CO_2-e ha^{-1} yr^{-1})	1.03	1.03	1.83	1.83
Sequestration (-t CO_2-e yr^{-1})	51	205	92	367
Net carbon balance (t CO_2-e yr^{-1})	882	728	841	566
% reduction to farm emissions from soil carbon	6	22	10%	39%

5 Emissions Pathway Scenarios

Scenarios were created to show potential emissions pathways across the next ten years (from business as usual to high mitigation). Whilst it is not a current target or commitment for the South Australian Government, we also investigated an end-point of carbon neutral at 2030 as a scenario for each property to examine the requirement for on-farm carbon offsets to achieve this outcome. This was then extended through to 2040 to show what was required to maintain this target over the following decade.

5.1 Loxton Research Centre

Three scenarios were modelled to 2030 (*Table 22* and *Figure 8*). These display a combination of potential mitigation and sequestration options to reduce emissions to zero by 2030 and to maintain this for the following decade to 2040. The scenarios were based on different projections for renewable energy across both grid and on-site energy utilisation, changes in the renewable energy profile for vehicles, and minor adjustments to on-farm input emission factors.

Various factors were taken into consideration to forecast an estimate of how the emissions factor for South Australia's grid electricity may change over the following decade, and therefore impact upon Loxton's emissions profile. This included identifying committed and non-committed renewable energy projects, the impact of increasing energy storage technology (e.g. distributed and centralised battery storage), and the implementation of the interlink to New South Wales helping to drive an improved market appetite for renewable energy projects. Estimated emissions factor changes were modelled to determine potential emissions impacts over the decade, including a potential scenario where South Australia exceeds renewable energy targets of 100% net renewable energy at mid-decade (2025-2026). Fleet and machinery fuel efficiency improvements from renewable and battery integration were estimated, as were modest reduction in emissions from purchase input utilisation.

Table 22. Emissions mitigation scenarios for the Loxton farm

Strategy	Description
Scenario 1 - low emission reduction	SA grid electricity to achieve 100% net renewable generation from 2030; no onsite solar generation; 20% fuel efficiency improvement; fertiliser and input emissions maintained at current levels.
Scenario 2 - mid emission reduction	SA grid electricity to achieve 100% net renewable generation from 2030; onsite solar installed to reduce scope 2 by 75%; progression to fuel efficient vehicles for 50% fuel reduction from 2025 to 2030; fertiliser and input emissions maintained at current levels.
Scenario 3 - high emission reduction	SA grid electricity to achieve 100% net renewable generation from 2025/26 (continuing past 100% to 2030); onsite solar panels and battery storage installed for 100% off-grid from 2023; 80% fuel efficiency improvement by 2030; fertiliser and purchased input emissions improve 15% (through Enhanced Efficiency Fertilisers, reduced manufacturing emissions, and reduced scope 3 upstream and transport emission reductions).

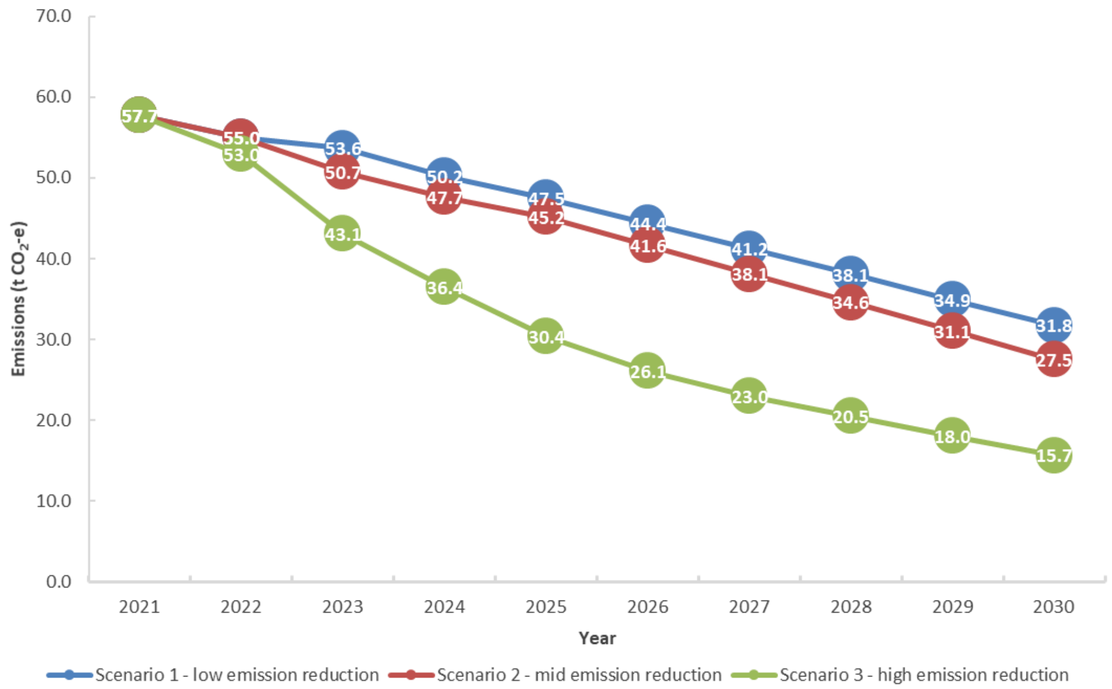

Figure 8. Predicted emissions at Loxton to 2030 for three mitigation scenarios

To determine the sequestration required to achieve carbon neutrality in 2030 and maintain to 2040, tree planting types, land area and timings were plotted. Tree plantings were assumed to be mixed environmental plantings, which reach their highest annual sequestration rate at 6 years post-planting and then gradually reduce thereafter, as provided by FullCAM data (DISER 2020b). Consequently, the area of ongoing plantings required to fully offset emissions over the following decade were determined (see *Table 23* and *Figure 9*). Further emissions mitigation post-2030 has not been modelled, however any further reductions will reduce the ongoing planting volumes accordingly. The total plantings over this period vary from 2.1 ha to 4.7 ha, with a starting land area of 1.4 ha to 3.0 ha in 2025, depending on the mitigation scenario.

Aligning to the ERF assessment, soil was not included in the emissions pathways for Loxton, due to the challenges in measuring reportable change and economic viability of assessing change.

Table 23. Vegetation plantings (mixed environmental type) required to achieve carbon neutral at 2030 and maintain until 2040 (ha)

Vegetation Plantings (ha)					
	2025	**2029**	**2033**	**2037**	**Total**
Scenario 1 – low emission reduction	3.0	0.4	0.8	0.5	4.7
Scenario 2 – mid emission reduction	2.6	0.3	0.7	0.4	4.0
Scenario 3 – high emission reduction	1.4	0.2	0.2	0.3	2.1

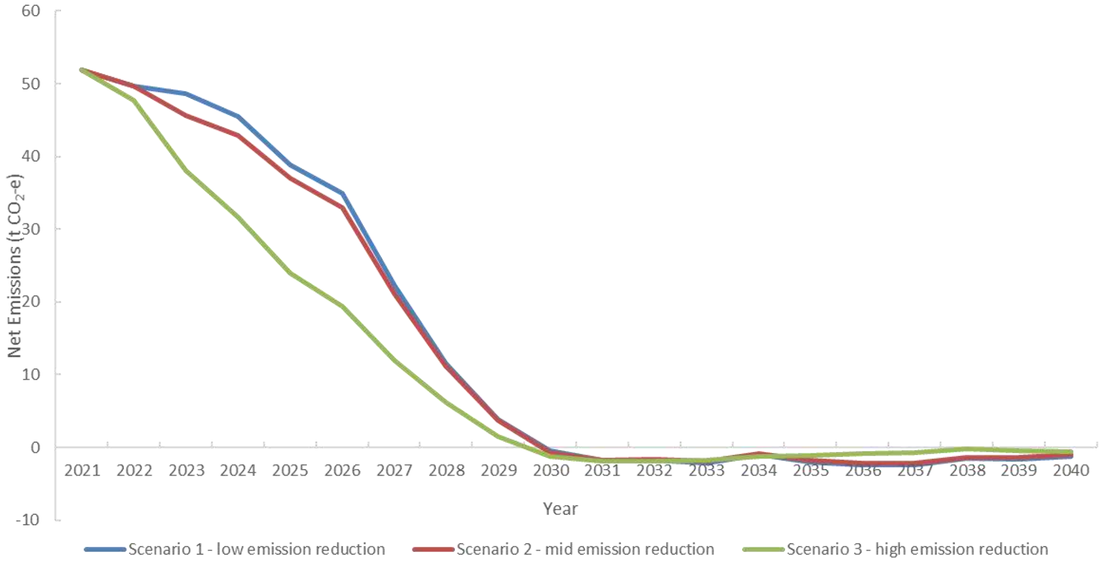

Figure 9. Forecast net emissions profile for the Loxton farm to 2040 for each scenario, considering mitigation actions and vegetation sequestration

Area sizes were mapped for the different emission pathway scenarios (*Figure 10*).

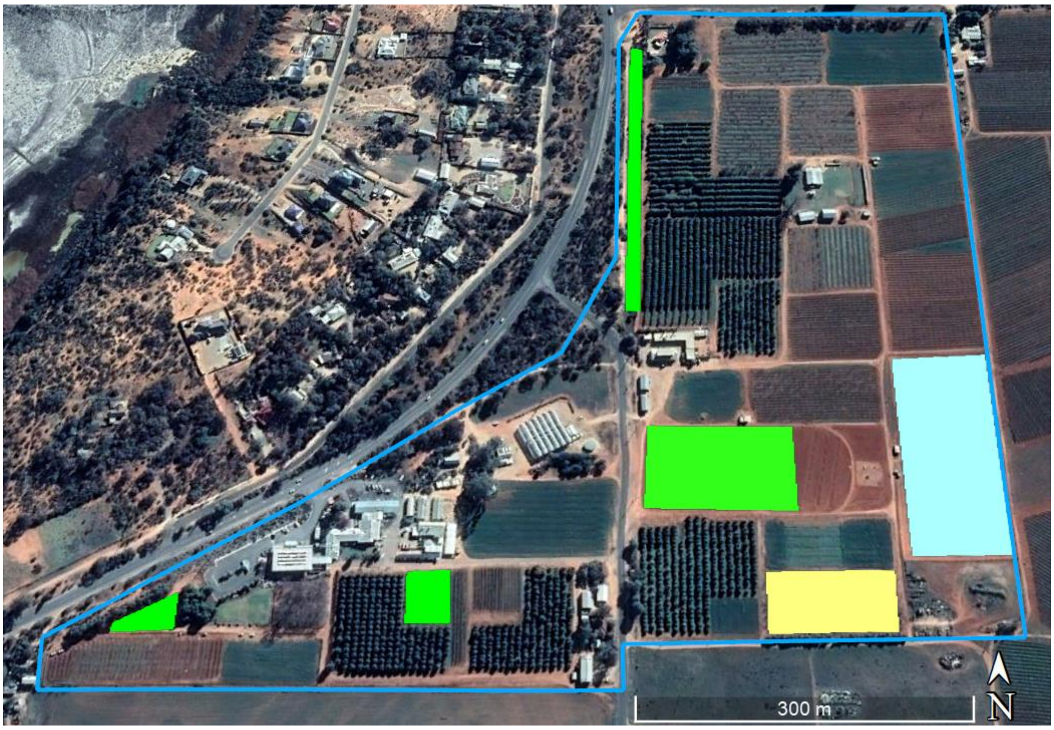

Figure 10. Area available for planting for carbon sequestration in native vegetation at Loxton. Green indicates total plantings required for the high mitigation scenario, green and blue for the mid mitigation scenario, and green, blue and yellow for the low mitigation scenario (areas are cumulative)

5.2 Turretfield Research Centre

Four scenarios were modelled for Turretfield (*Table 24* and *Figure 12*). These display a combination of potential mitigation and sequestration options to reduce emissions to zero by 2030 and to maintain this for the following decade to 2040. Due to enteric methane dominating the on-farm emissions profile, the scenarios were focused on different projections for flock optimisation, feed additive development and incorporation, and anti-methanogenic pasture implementation to address enteric methane generation. A minor reduction in scope 2 electricity utilisation has been considered in line with estimated emissions factor reductions for South Australian grid electricity.

Table 24 Emissions mitigation scenarios for the Turretfield farm

Strategy	Description
Scenario 1 - BAU	No change in current management or sheep numbers; SA grid electricity to achieve 100% net renewable generation by 2030.
Scenario 2 - low emission mitigation	Flock optimisation actions; no feed additive incorporation; no anti-methanogenic pastures; SA grid electricity to achieve 100% net renewable by 2030.
Scenario 3 - mid emission mitigation	Flock optimisation actions; half year emission mitigant feed additive (red seaweed) increasing through to 2025, nil anti-methanogenic pastures; SA grid electricity to achieve 100% net renewable by 2030.
Scenario 4 - high emission mitigation	Flock optimisation actions; full-year mitigant feed additive (red seaweed) increasing through decade to full flock from 2027, anti-methanogenic pastures used when feed additives not available (2023-2026); SA grid electricity to achieve 100% net renewable by 2030.

Flock structure was modelled to reflect optimisation projections (*Table 25*) and was included in scenarios 2, 3 and 4. Approximately 21% of the sheep in the Turretfield Research Centre flock are classified as PC2 sheep and are therefore subject to regulations imposed by the Office of the Gene Technology Regulator (OGTR), as they are involved in research projects that are large animal models of human disease. As such, the sheep are run under strict conditions where data is already being collected in relation to disease progression and was excluded from the emission reduction and mitigation options undertaken, although the emissions were counted as part of the farm's overall emission footprint.

The projected flock numbers (once adjusted for the PC2 sheep where no adjustment was made) included an overall increase in lambing % of approximately 20%, a reduction in ewes and rams of 20%, an increase in average daily gain of 10% for wether lambs, and associated adjustments for sale weight and time on farm. Adjustments were also made to wool cuts to account for the flock structure changes.

Table 25. Annualised sheep flock projection

Annualised Sheep Data				
Class	**Annualised Average**	**LWG kg/day**	**Sales**	**Purchases**
Rams	45	0.02	0	5
Maiden Breeding ewes	400	0.04	0	0
Breeding ewes	2,008	0.03	299	0
Ewe lambs	527	0.15	254	0
Wether Lambs	654	0.17	654	0

The optimised flock projections obtained improved results across both total emissions and emissions intensity when modelled (*Table 26*, *Figure 11* and *Table 27*). Total emissions reduced from 944 t CO_2-e to 799 t CO_2-e for the farm operation. Emissions intensity reduced from 25.8 kg CO_2-e.kg wool^{-1} and 9.6 kg CO_2-e.kg LW^{-1}, to 22.2 kg CO_2-e.kg wool^{-1} and 7.1 kg CO_2-e.kg LW^{-1}.

Table 26. Flock optimisation projected emissions.

Gross Emissions		
Emissions – Scope 1	t CO_2-e	741
Emissions – Scope 2	t CO_2-e	6
Emissions – Scope 3	t CO_2-e	53
Total Emissions	**t CO_2-e**	**799**
Methane emissions	t CO_2-e	661
N_2O emissions	t CO_2-e	47
CO_2 emissions	t CO_2-e	91

Figure 11. Flock optimisation projected emissions intensity

Table 27. Flock optimisation projections for product volumes

Sale Volumes	Unit	Original	Projected
Greasy wool sold (annual)	kg	22,397	19,759
LW Sold (annual)	kg	42,095	50,435

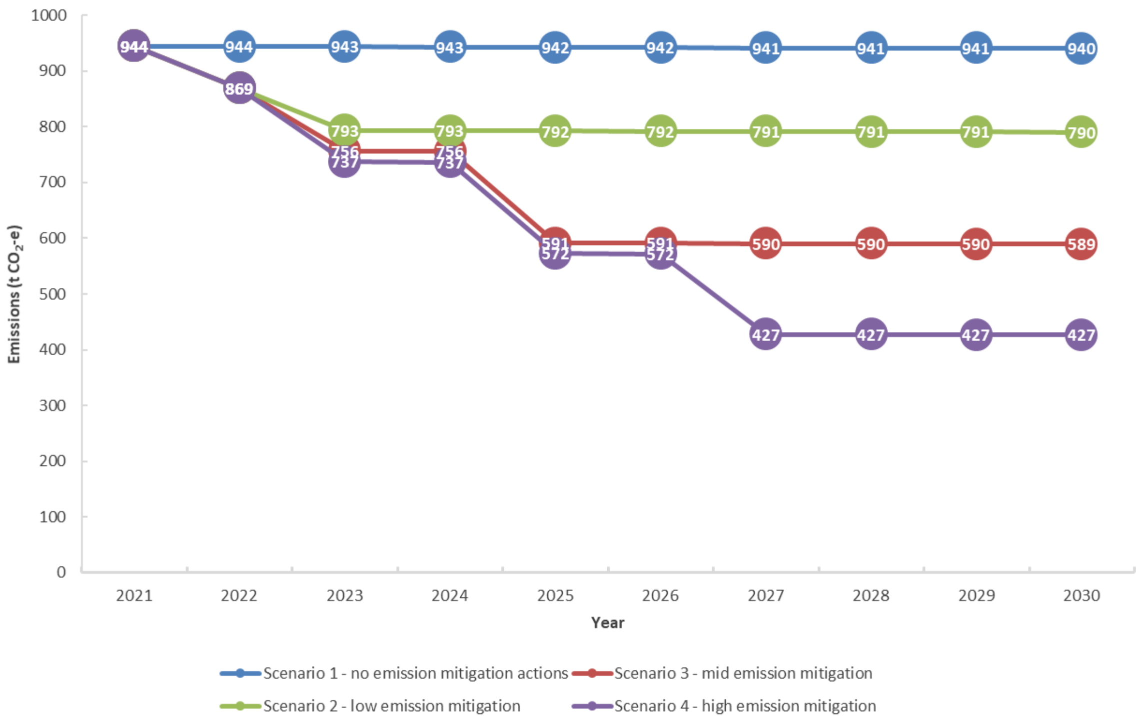

Figure 12. Predicted emissions reductions at Turretfield to 2030 for four mitigation scenarios (t CO_2-e)

To determine the sequestration required to achieve carbon neutrality in 2030, soil and vegetation sequestration were plotted against emissions. A moderate soil sequestration assumption of 308 t CO2-e.yr^{-1} over 400 ha was included which aligned to the values used in the ERF assessment (0.28 t C.ha^{-1}.yr^{-2} equating to an annual sequestration of 308 t CO_2-e.yr^{-1} (after discounts). Planting types, land area and timings were plotted for vegetation to account for any residual emissions. Tree plantings were assumed to be mallee plantings, which reach their highest annual sequestration rate at 6 years post-planting and then gradually reduce thereafter, as provided by FullCAM data (DISER 2020c). Reported FullCAM sequestration rates were reduced by 30% to ensure conservative values were utlised as per requirements for the ERF. Mixed environmental plantings are another recommended option due to suitability and biodiversity benefits, requiring approximately 27% higher land area to achieve the same sequestration rate. Consequently, the area of ongoing plantings required to fully offset emissions over the following decade were determined (*Table 28* and *Figure 13*). Further emissions mitigation post-2030 has not been modelled, however any further reductions will reduce the ongoing planting volumes accordingly. The total plantings over this period vary from 8 ha to 50 ha, with a starting land area of 4 ha to 30 ha in 2025, depending on the mitigation scenario. Mixed environmental plantings would required from 10 ha to 65 ha to achieve a similar sequestration outcome to mallee plantings.

Table 28. Vegetation plantings (mallee eucalypt type) required to achieve carbon neutral at 2030 and maintain until 2040 (ha)

Vegetation Plantings (ha)					
	2025	**2029**	**2033**	**2037**	**Total**
Scenario 1 – BAU	30	6	8	6	50
Scenario 2 – low emission mitigation	23	4	6	5	38
Scenario 3 -mid emission mitigation	12	3	3	3	21
Scenario 4 – high emission mitigation	4	2	1	1	8

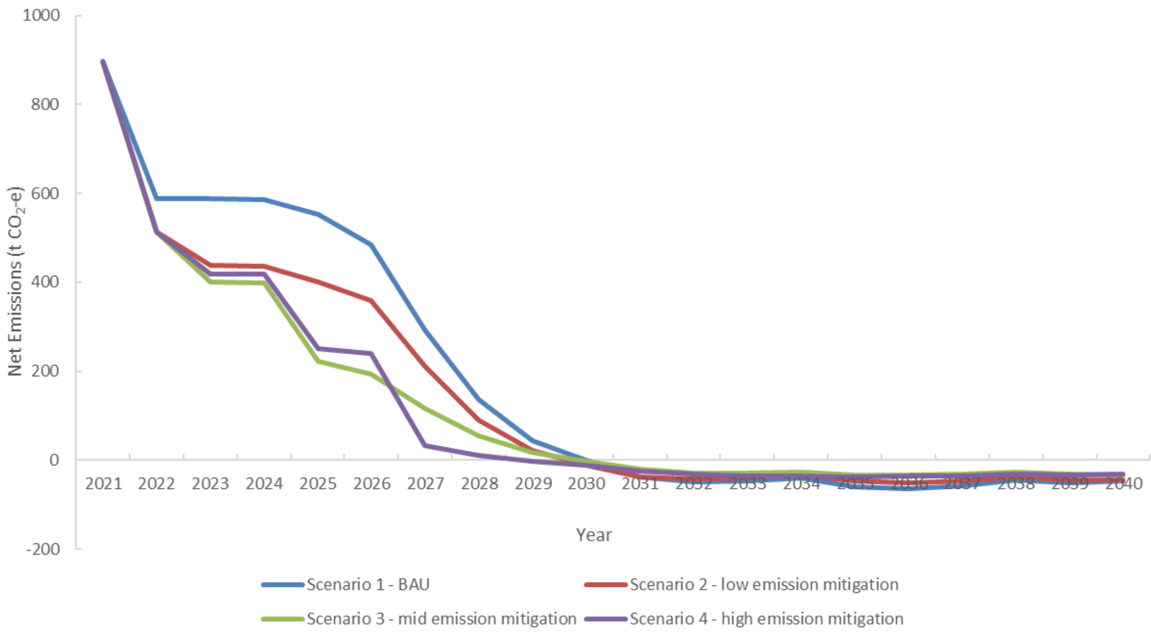

Figure 13. Forecast net emissions profile for the Turretfield farm to 2040 (t CO_2-e) for each scenario, considering mitigation actions and vegetation sequestration

Area sizes were mapped for the different emission pathway scenarios (*Figure 14*). These areas are block plantings, based on the assumption that a single Mallee species is planted. If riparian areas were to be planted with a mixed species environmental planting, a 29% greater area would need to be used to achieve a similar sequestration rate.

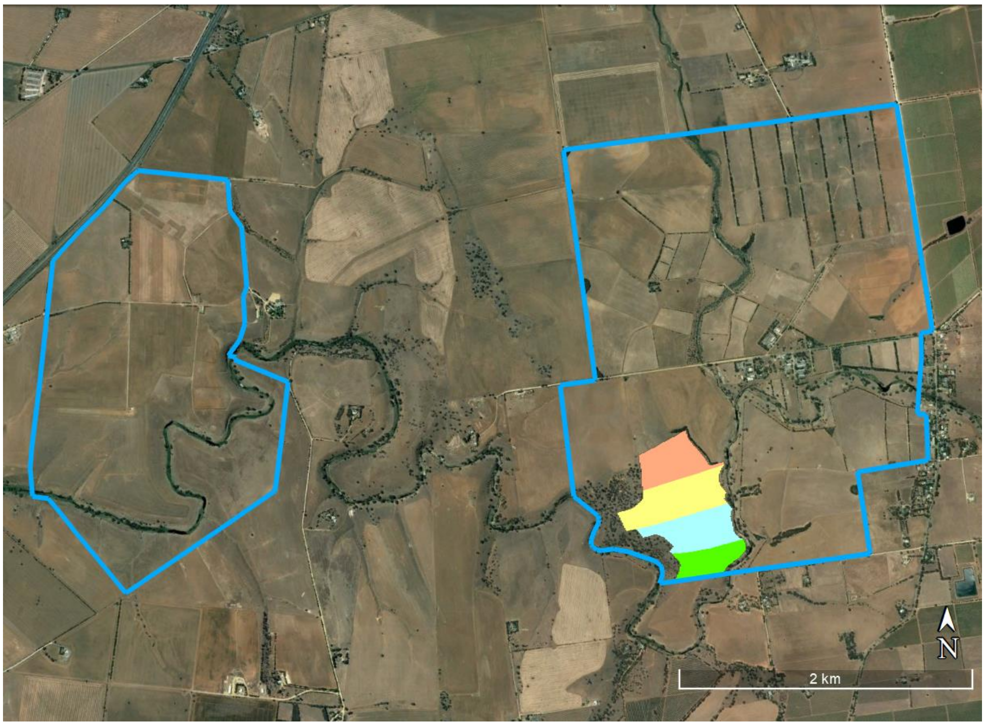

Figure 14: Area available for planting for carbon sequestration in native vegetation at Turretfield. Green represents the high mitigation scenario, green and blue represent the medium mitigation scenario, green, blue and yellow represent the low mitigation scenario, and all the colours together represent the BAU scenario (areas are accumulative).

6 Emissions Reduction Fund Feasibility

The below sections outline the potential Emissions Reduction Fund (ERF) methods that could be implemented at Loxton and Turretfield. The ERF is a voluntary scheme where eligible activities can earn Australian Carbon Credit Units (ACCUs). One ACCU is earned for each t CO_2-e either stored or avoided, after penalties for semi-permanence of these changes have been subtracted.

Based on the spatial scale of the operations, Turretfield was selected as the main property to investigate. The approach and concepts outlined in the Turretfield example would be applicable to Loxton, but the scale of that operation would make it non-viable.

To confirm eligibility with the ERF, a questionnaire was completed for the site and the findings are shown in Appendix 2 (*Table 36*). The following considerations need to be taken into account when considering any ERF project.

6.1.1 Permanence Obligation

Sequestration projects are subject to a 'permanence obligation', meaning that the stored carbon or vegetation must be maintained 'permanently'. Landowners may nominate a period of either 100 or 25 years. We have assumed that a 25-year permanence period would be most suitable, but this can be revised if 100 years is more appropriate.

6.1.2 Land Tenure Requirements

The permanence obligation highlights an issue regarding ongoing land tenure. While it is **not a requirement** that an ERF project is listed on the title of the property, there is a general obligation that landholders with a registered sequestration project should inform prospective buyers and property agents of any permanence obligations associated with the land when selling their property. Prospective buyers are able to view the public ERF project register to identify land that is subject to a permanence obligation. Parties are able to negotiate prior to completing the sale about whether to continue or withdraw the project. Additionally, proponents must have consent from eligible interest holders before lodging a project, including mortgage holders and owners. While these considerations are less important for a state government, they are highly relevant to commercial producers who may view this as a demonstration site.

6.1.3 Carbon Estimation Areas (CEAs)

Carbon Estimation Areas (CEAs) are the area defined for inclusion in an Emissions Reduction Fund Project. The new project management activities prescribed for the selected method will be implemented in the CEAs to sequester carbon and generate Australian Carbon Credit Units (ACCUs). CEAs will generally be uniform, exclude all non-eligible land like dwellings and roads, and may or may not be one area or a group of areas. Currently, only one method can be applied in any CEA. Selection of CEAs would require mapping and site evaluation, and this was not completed in the present feasibility study.

6.2 Potential methods

There is a large number of potential methods that could be applied at Turretfield, though only a limited number are feasible. We screened methods to narrow the list of appliable methods, focusing on soil and vegetation.

There are two potentially applicable ERF methodologies for storing carbon in the soil. These are:

1. *Carbon Credits (Carbon Farming Initiative - Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination 2015* (Australian Government 2015)
2. *Carbon Credits (Carbon Farming Initiative - Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018* (Australian Government 2018)

The *Estimating Sequestration of Carbon in Soil Using Default Values* method has heavy compliance obligations with low sequestration rates for most of Australia, making it cost prohibitive and therefore not recommended.

Therefore, the method selected for the feasibility assessment was the *Carbon Credits (Carbon Farming Initiative - Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018* (Australian Government 2018) which is referred to from this point as the Measured Soil Carbon Method.

Multiple methods for carbon storage in vegetation are potentially applicable for Turretfield. The methods for storing carbon in vegetation available in the ERF involve different approaches to measuring the carbon stored for various land management and vegetation management activities including reforestation, revegetation or protecting native forest or vegetation that is at risk of clearing. Methods for storing carbon in vegetation under the Clean Energy Regulator as an ERF project have been assessed for feasibility at the Turretfield and Kingsford properties (*Table 29*), with the assistance of relevant methodologies and the Sequestration Decision Tree (*Figure 15*).

The methods that use FullCAM to determine abatement are far more user-friendly than those based on allometric methods. Allometric methods require destruction of trees, which is expensive and time consuming. Therefore, all allometric methods have been deemed unfeasible.

Other methods involved regeneration of forest without the planting of any seeds or tubestock, required harvest of forest products, or were based around avoiding clearing of native regrowth or avoiding deforestation and were therefore excluded.

It has been established by a process of elimination that the most appropriate method to use is the Reforestation by Environmental or Mallee Plantings-FullCAM method (*Table 29*). We note that 41 projects have been registered applying this method, with a total of 500,355 ACCUs issued thus far (Clean Energy Regulator 2021).

Table 29. Screening of ERF methods for storage of carbon in vegetation

ERF method	Reason for dismissal
Human-Induced Regeneration of a Permanent Even-Aged Native Forest 1.1	This method does not allow any planting of trees or direct seeding.
Reforestation by Environmental or Mallee Plantings - FullCAM	This has been selected as the method to use for the feasibility assessment.
Plantation Forestry	This method requires harvest of forest products to occur periodically and was not considered for Turretfield as the rainfall and operation focus was not seen as favourable for a forestry project.
Quantifying Carbon Sequestration by Permanent Environmental Plantings of Native Species using the CFI Reforestation Modelling Tool	This method is no longer in force.
Measurement based methods for new farm forestry plantations	This method requires destructive tests on mature trees which is considered cost prohibitive.
Reforestation and Afforestation	This method requires destructive tests on mature trees which is considered cost prohibitive.
Avoided clearing of native regrowth	Not relevant – no suitable vegetation.
Native forest from managed regrowth	Not relevant – no suitable vegetation.
Avoided deforestation 1.1	Not relevant – no suitable vegetaion.

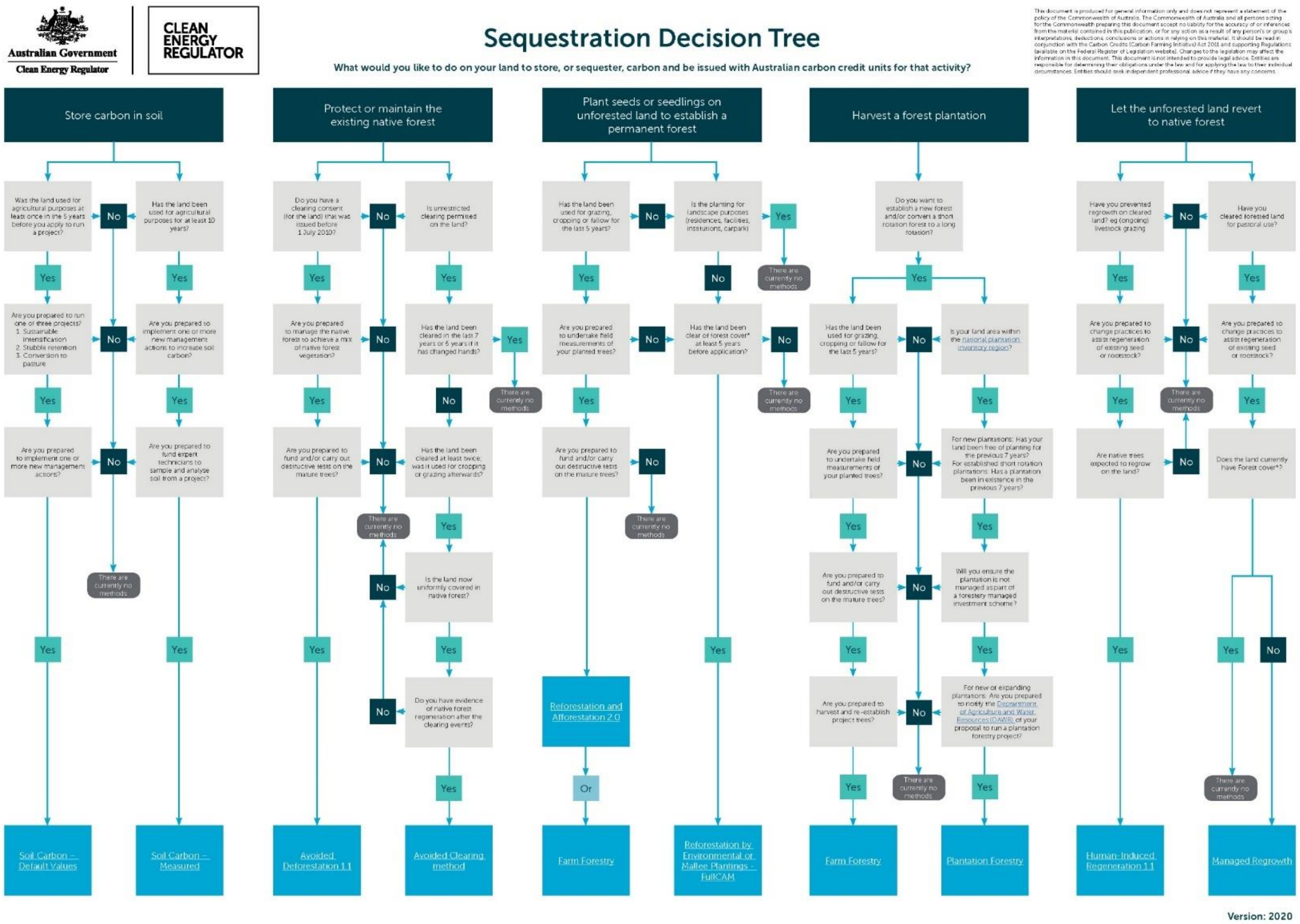

Figure 15. ERF sequestration decision tree

6.2.1 Soil Method

6.2.2 Project Activities and Potential Sequestration Rates

A list of eligible management activities is found in the determination. The project proponent must, in all areas of land included in a CEA, carry out or maintain at least one eligible management activity until the end of the permanence obligation period for the project. Eligible activities are found in Part 2, division 7, subdivision 2 of the Determination.

Upon discussion with Amanda Schapel from PIRSA, the following eligible management activities may be applicable:

- applying nutrients to the land in the form of a synthetic or non-synthetic fertiliser to address a material deficiency;
- applying lime to remediate acid soils (for some Turretfield paddocks);
- applying gypsum to remediate sodic or magnesic soils;
- re-establishing or rejuvenating a pasture by seeding;
- altering the stocking rate, duration or intensity of grazing.

For a more detailed information on key project activities, see *Appendix 2* (*Table 37*). For potential sequestration rates, refer to section 4.2.2.2.1.

Upon discussion with Amanda Schapel from PIRSA, it was identified that the only sampling point with potential for "moderate increases in soil carbon stocks" was site 7 (13B, mid-slope). This area represents approximately 50 ha of the property, and the current stock from 0-30 cm is 124.76 t CO_2-e ha^{-1}. However, this land area is insufficient for a feasibility assessment. For illustrative purposes, the feasibility investigated 400 ha and 880 ha.

6.2.3 Estimated ERF Abatement, Costs and Returns

For the Measured Soil Carbon Method, we have provided hypothetical rates for soil carbon sequestration to generate an estimate for the potential abatement that may be expected if the eligible management activity "re-establishing or rejuvenating a pasture by seeding" was implemented. Costings only include the marginal cost of running a soil carbon project (testing and compliance) and therefore assume that all management costs are covered by planned farm expenditure. Projects are not likely to be cost effective unless this is the case.

Soil carbon sequestration can vary with seasonal rainfall (drought), which cannot be predicted ahead of time. This is the largest uncontrolled environmental factor risking carbon sequestration. Drying soils decrease microbial activity, limiting the decomposition of organic matter that is returned to the soil. Additionally, limited rainfall reduces plant available water which limits plant biomass production.

A sequestration estimate of 0.28 t C ha^{-1} yr^{-1} was selected to correspond reasonably with benchmark data for SA, while a rate of 0.5 t C ha^{-1} yr^{-1} was selected as a more optimistic rate to examine the impact on feasibility and profitability. We note that detecting these modest changes would require long sampling intervals and sampling in the first 5 years may not reveal a small change in soil carbon.

Project ACCU yield was determined after removing project emissions from carbon sequestration. Project emissions are likely to include (but are not limited to) increased fuel use for sowing improved pasture and increased livestock emissions from higher stocking rates on improved pastures. Of these, livestock emissions are expected to be the largest source and for the purpose of the feasibility assessment, we have estimated potential emissions from this source using a simplified method that extrapolates the increased DSE required to consume the extra dry matter produced.

The sequestration prediction and soil sampling cost estimates were based on measurements taken from 0 to 30cm, as this is the minimum depth required for sampling for an ERF project. Increasing sampling depth increases sampling costs substantially. The sequestration rates were assumed to occur as an average over 25 years, and that the higher soil carbon stocks were maintained for the permanence period (an additional 25 years). There is also a possibility that no carbon is sequestered, due to the limitations placed upon soil carbon sequestration from external factors mentioned above, such as climatic factors and soil type. Additionally, these factors mean that there is the possibility that soil carbon stocks can be lost.

Table 30. Estimated carbon sequestration rates and potential abatement

Project Activities		**Re-establishment or rejuvenating a pasture by seeding**		
Forward Abatement Estimate	**Units/other**	**Medium sequestration**	**High sequestration**	**High sequestration, large area**
Hectares	ha	400	400	880
Estimated gross C sequestration	t C/ha/yr	0.28	0.50	0.50
Est. gross sequestration potential (t C/ ha) after 25 years	t C/ha/ 25 yrs	7.0	12.5	12.5
Current soil carbon level (0-30cm) (%)	%	0.74	0.74	0.74
Potential soil organic carbon level (%) at end of project period	%	0.90	1.02	1.02
% ∆ in SOC (per year)	%	0.006	0.011	0.011
% ∆ in SOC over project period	%	0.15	0.27	0.27
Current soil organic carbon stock	t C/ha	34	34	34.
Potential soil organic carbon stock	t C/ha	41.3	46.8	46.8
Annual est. sequestration potential (no deductions) – ha	t CO_2-e/ha/yr	1.03	1.84	1.84
Annual est. sequestration potential (no deductions) – whole project	t CO_2-e / yr	411	734	1615
Est. total sequestration potential after deductions for 25 yr permanence & risk reversal buffer (25 years)	t CO_2-e / yr	308	551	1211
Est. sequestration potential after discount for additional livestock *	t CO_2-e / yr	233	438	964
Est. total sequestration potential for the project	**t CO_2-e project**	**5832**	**10950**	**24090**
Potential return from sales of ACCUs		$ 106,726	$ 200,385	$ 440,847

** To be refined. The method requires that changes in emissions from livestock and field inputs to be deduced from the sequestration estimate. Livestock emissions were estimated assuming an increase in DSE/ha of 0.75 (medium) and 1.1 (high). We have only accounted for the discount of livestock emissions as this is the largest emission source.*

Estimated carbon sequestration and project costs and revenue were calculated and reported in *Table 31*.

Table 31. Estimated carbon sequestration project costs and revenue

	Medium sequestration rate (400 ha)	High sequestration rate (400 ha)	High sequestration rate (880 ha)
Forward Abatement Estimate	$5,832	$10,950	$24,090
Revenue (abatement $18.30/ACCU price)	$ 106,726	$ 200,385	$ 440,847
Compliance costs			
Project establishment fees	$20,000	$20,000	$20,000
Soil sampling	$63,580	$63,580	$95,370
Ongoing project management and reporting	$60,000	$60,000	$60,000
Audit costs (minimum of 3 scheduled audits across the project period)	$60,000	$60,000	$60,000
Contingency	$15,000	$15,000	$15,000
Subtotal costs	$218,580	$218,580	$250,370
Net return	-$111,854	-$18,195	$190,477

It is difficult to determine cost-effectiveness for soil ERF projects because of the significant unknowns around projected soil carbon sequestration rate.

Given the high cost of ERF project implementation, a project would only be cost effective if the cost of implementation is fully covered by farm investment and management expenditure and reflects the direction the owner wants to progress in.

The assumptions made in this report should be understood in the context of the high uncertainty around soil carbon sequestration: the range in carbon sequestration outcomes could be from zero (or even carbon loss) to even higher sequestration rates than assessed here over 25 years. Thus, results must be treated with caution. Given the high cost of project implementation, and the probable low returns, an ERF soil carbon project at Turretfield would only be feasible with reasonably high sequestration rates, over a large portion of the farm and would be considered high-risk considering the low rainfall environment.

6.3 Vegetation Methods

6.3.1 Project Activities and Potential Sequestration

A summary of project activities and assessment of the eligibility of the project is listed in ***Error! Reference source not found.***. *Appendix 2* contains relevant sections of the Determination and further detail of eligibility requirements.

Table 32. Key project activities and assessment of the eligibility of suitable lands for the reforestation by environmental or mallee plantings FullCAM method.

Reference	Criteria	Comment
Carbon Farming Initiative Act, Part 3, Division 1, Section 27, Subsection (4A) & (4C)	The project must be new (new tree planting).	Existing plantings could not be used to generate ACCUs.
Carbon Farming Initiative Regulations, Part 3, Division 3.12, Regulation 3.36	The project must ensure that the project is not an excluded offsets project.	See regulations for excluded offset projects. Expected to comply.
Determination, Part 2, Section 2.2	The project must involve planting a mixed-species environmental planting or a mallee planting.	Expected to comply
Average annual rainfall	Where project proponents establish Mallee the land must receive long-term average rainfall of 600 mm or less.	Turretfield received less than 600 mm average annual rainfall.
Determination, Part 2, Section 2.3, Subsections (3), (4) & (5).	The land must not contain woody biomass or an invasive native scrub species that need to be cleared in order for planting to occur, other than known weed species required or authorised by law to be cleared. For at least 5 years before the date of the application, the project area must have been clear of forest cover. Project trees must have the potential to attain a height of 2 metres or more and a crown cover of at least 20% over the total area of the stratum.	The project areas do not require clearing. The project area has been clear of forest cover for at least 5 years. Species selection and plant spacing will need to be tailored to meet these requirements.
Determination, Part 3, Division 3.8, Section 3.45 – Restricted activities	Biomass must not be removed from a carbon estimation area unless in accordance with this Division.	Up to 10% of fallen timber may be removed for personal use (meaning that the timber is not sold or used for other commercial purposes).

Sequestration rate has been generated using the Mallee plantation function in FullCAM using default regimes and include carbon mass in trees and debris (*Table 33*).

Table 33. Estimated potential sequestration from FullCAM for a Mallee plantation

Parameter	Unit	
Potentially eligible area	ha	30
Annual estimated sequestration potential	t CO_2-e ha^{-1} yr^{-1}	13
Annual estimated sequestration potential	t CO_2-e yr^{-1}	390
Total estimated sequestration (25 years)	t CO_2-e	11703
Total estimated sequestration less permanence deductions and project emission deductions	t CO_2-e	8192

6.3.2 Estimated ERF Abatement, Costs and Returns

Professional service expenses were estimated to be $82,500 (with a range from $74,250 to $107,250). The project implementation costs for tree planting, based on a rate of $1500 per hectare, are $45,000.

Indicative income less project expenses (excluding the cost of planting trees) is predicted to be $67,414 (*Table 34*) for a 30 ha project. A project size of 30 ha has been used as this is relatively reflective of what needs to be planted in 2025 to offset all emissions by 2030 (in the absence of any other emissions mitigation strategies). This income is based on an ACCU value of $18.30, includes the 25% discount required for projects with a 25-year permanence obligation, and has not been adjusted for inflation. As the professional services expenses would not vary significantly for a project of a larger spatial area, the return from increasing the number of hectares would be higher.

Table 34. Indicative income for an ERF project using the Reforestation by Environmental or Mallee Plantings Method

	Unit	Parameters
Project area	ha	30
Estimated sequestration potential (total t CO_2e over 25 years)	t CO_2-e over 25 years	8192
ACCU value (as at May 2021)	$	18.3
Gross Income	$	149,914
Income less project expenses (excluding tree planting costs)	$	67,414
Income less project expenses (including tree planting costs)	$	22,414

Considering the modest returns, a vegetation project would be difficult to justify, particularly considering the uncertainties around tree survival rates in low rainfall regions such as Turretfield. None-the-less, it does demonstrate the capacity of relatively modest areas of trees to offset livestock emissions, and futher work to reduce compliance costs would be beneficial to enable producers to demonstrate carbon neutrality.

7 Other voluntary market-based farming practices

A number of methodologies for voluntary market-based farming practices for storing carbon in vegetation and soil were reviewed and screened for eligibility at Turretfield. There are two major global standards with methodologies that are applicable to Australia. They are Verra, also known as Verified Carbon Standard (Verra 2021), and Gold Standard (Gold Standard 2021).

Global standards are most relevant where they can overcome limitations in the ERF methods, either with respect to the scope of the method, or the cost effectiveness of applying it.

Key limitations for the *Reforestation by Environmental or Mallee Plantings-FullCAM* methodology are:

- The method is limited to environmental or Mallee plantings. Higher growth rate tree species are not eligible.
- Professional service costs (baseline analysis, reporting, auditing) are relatively high because of method complexity, particularly for small land holdings.

Key limitations for the *Measurement of Soil Carbon Sequestration in Agricultural Systems* methodology are:

- Lack of ability to detect small changes in soil carbon with current sampling methodologies.
- Costs and required frequency of soil sampling that adheres to the requirements as well as has the statistical power to detect changes in soil carbon stocks.

Both limitations could be addressed with a modelled method, however the *Estimating sequestration of carbon in soil using default values* method has heavy compliance costs with low sequestration rates for most of Australia, making it cost-prohibitive. Therefore, the objective of investigating other carbon markets is to ascertain if other methodologies could potentially help overcome the key limitations in the ERF (*Table 35*).

Table 35. Potential feasibility methodologies from other voluntary market-based farming practices.

Method	Regulatory Body	Benefit in comparison to equivalent ERF method
Vegetation method - Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology (Gold Standard 2017)	Gold Standard	This method is similar to the Reforestation by Environmental or Mallee plantings method, with the key benefit that there are fewer elements of compliance around types of trees that can be planted, with no species restrictions based around long-term average rainfall. This could provide benefit in terms of targeting a high growth monoculture that is suitable for the area that would not be subject to the generic calibration feature on FullCAM, which provides a lower sequestration rate. Further investigation into potential species with high sequestration rates that will grow at Turretfield and modelling of these potential species using the techniques specified in the methodology is required to ascertain whether this method will provide benefit when compared to an ERF project. Additionally,

		this methodology allows grazing (without restrictions) to occur in the project area.
Soil carbon method - VM0042 Methodology for Improved Agricultural Land Management (Shoch and Swails 2020)	Verra (Verified Carbon Standard)	This method allows a measured, modelled, or remote sensing approach. A modelled or remote sensing approach has the key benefit of a substantial cost reduction because soil sampling is not required. Additionally, a modelled or remote sensing approach does not restrict sequestration to pre-determined low default values. Further investigation is required into whether the modelled approach and/or remoting sensing approaches are applicable to the Turretfield region, and whether these approaches are able to detect small enough changes in soil carbon stocks.

The other two potential methodologies were the *VM0017 Adoption of Sustainable Agricultural Land Management* (Verra 2011) and the *VM0026 Methodology for Sustainable Grassland Management* (Verra 2014). Further investigation is required to establish whether the models that are required to be used can be demonstrated to be applicable in the project region. In the former of these two methodologies, the Roth-C model is the only measurement method. In the latter, where the models cannot be demonstrated to be applicable in the project regions, direct measurement is required.

Further investigation through a detailed feasibility assessment is required to establish whether these alternative methodologies overcome the key limitations of the investigated ERF methodologies.

8 Conclusions and Recommendations

This study provided key insights into the emission profile and reduction opportunities for Loxton and Turretfield research stations, and can provide early insights, more broadly, for related commercial farming operations.

Impacts for Loxton revealed the key role of irrigation water supply and the dominance of energy related emissions in the emission profile for the farm and for each production system. A key finding was that targets set by the South Australian Government to decarbonise the energy grid will provide significant emission reductions for the facility: by 2030 emissions will have declined 45% without direct action required from management. Options to further reduce emissions focused on energy efficiency both for on-site electricity and potentially machinery operations. Reducing impacts from machinery is important, but is still a ‘blue sky’ option with limited machinery available to achieve this at present.

Impacts from Turretfield confirmed the very high contribution of livestock emissions (predominantly enteric methane) and showed a strong contrast to Loxton. In the BAU scenario, reductions in energy emissions associated with improvements in the South Australian grid were negligible. This highlights that state-wide government initiatives will contribute positively for some sectors of agriculture, such as horticulture, but will leave other sectors such as livestock behind. Livestock agriculture will require specific investment to provide the mitigation options needed to decarbonise this sector. Options for Turretfield centre on flock optimisation, which could be actioned rapidly, and uptake of novel feed additives, which requires further research that is not yet funded. Investment is required in this space to ensure the emission reduction options postulated here could be realised between now and 2030.

For both sites, carbon offsets, via soil carbon sequestration and/or vegetation carbon sequestration, could enable carbon neutrality within the next decade. This could be achieved with fairly modest areas of the farm being planted to trees and would be supported by modest improvements in soil carbon. However, because of the very small farm areas, it is likely to be difficult to establish a cost-effective ERF project, which is a problem faced by many commercial operations. Further, it is difficult to determine cost-effectiveness because of the significant unknowns around projected soil carbon sequestration rate. The assumptions made in this report should be understood in the context of the high uncertainty around soil carbon sequestration: the range in outcomes could be from zero (or even carbon loss) to even higher sequestration rates than assessed here over 25 years.

The key implications of this is that the financial incentives of the ERF are not available to small producers, and it is also difficult to quantify ‘low carbon’ or ‘carbon neutrality’ with the very high compliance costs. One avenue that could overcome this in the future is use of voluntary offset methods, and we identified some promising options that could be more flexible and potentially more cost effective than ERF methods in this region. Further investigation in this space is warranted.

The role of research centres such as Loxton and Turretfield in investigating and demonstrating opportunities to reduce costs and increase productivity will be increasingly important as industries and governments move towards carbon neutrality. Research and development is required to realise the potential identified here, particularly in demonstrating integrated options to reduce emissions and store carbon in the farm context, and to achieve outcomes such as carbon neutrality. This will be strategically important for enabling producers to map a path towards these goals through practical, implementable action on their farms.

The following recommendations are provided to progress from the results presented here:

1. Develop a target for emission reduction at each site. Without a target, it is difficult to focus priorities. With industry setting aspirational targets such as carbon neutrality by 2030, there is an acute need for demonstration sites that can show how this can be done. Both Loxton and Turretfield could assist here by setting tangible emission reduction or carbon neutral targets, with a clear plan and investment to achieve it.
2. Develop an action plan for each site to reach the target, and provide an investment plan. This would benefit from a cost-benefit analysis of key options.
3. Consider expanding the program to other research sites and developing a multi-site target and plan.
4. Invest to address specific research gaps, such as the development of field ready feed additives to feed anti-methanogenic supplements to sheep. This will avoid the risk that these industries will be ‘left behind’ in the state-wide decarbonisation plan.
5. Explore opportunities for collaboration and co-investment with industry partners and research development corporations to prioritise emission reduction actions that could assist in addressing research gaps.
6. Given the high cost of ERF project implementation, large land areas and reasonably high sequestration rates would be required for a project to be cost effective, and this is only the case where the cost of implementation is effectively covered by farm investment and management expenditure. As a research station, examining specific strategies that could lead to soil carbon sequestration of the quantum reported here, over large areas, would provide very useful information for commercial operators that wish to understand the cost and benefit of the ERF.
7. Investigate voluntary carbon methods that may reduce compliance costs and provide more flexibility for developing carbon credits from tree planting or soil carbon. This could be advanced via a feasibility project looking at 2-4 of the most prospective method options, and looking at the actual on-farm requirements for launching a project at Turretfield.
8. Develop data collection, reporting and monitoring program to track progress to the plan. This could involve updating the carbon account every year, or every second year.

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Appendix 1

Increasing Nitrogen Use Efficiency

This appendix has been included for extension purposes.

Emissions associated with nitrogen fertiliser can be improved by increasing nitrogen fertiliser use efficiency using "4Rs" principal (Armstrong *et al.* 2021), as well as increasing soil organic matter content.

The "4Rs"

1. **Use the right type of nitrogen fertiliser.**
   a. Enhanced efficiency fertilisers (EEFs), which include nitrification inhibitors (urea-3,4-dimethylpyrazole phosphate (DMPP)-coated urea), urease inhibitors (a.k.a. "Green Urea"), and controlled-release fertilisers (e.g. polymer-coated urea) (Rowlings *et al.* 2016; Antille and Moody 2021) can help reduce nitrogen losses. However, these products should be treated with caution, as they incur a price premium and have varying rates of effectiveness, which are thought to be due to a lack of understanding of the interaction of these chemicals with soil and environmental variables. For example, some EEFs may reduce losses in very cold climatic conditions, but be less effective in warmer conditions (Chen *et al.* 2008).
   b. Liquid fertilisers allow nutrients to be dissolved in water so that they can be applied as liquids, with application through fertigation as an option.
2. **Apply nitrogen fertiliser at the right rate.**
   a. Applying nitrogen fertiliser so that the volume of nitrogen is matched to plant needs helps reduce wastage, and therefore increases nitrogen use efficiency.
   b. Split applications (applying lower rates of nitrogen fertiliser more frequently) have been shown to improve nitrogen use efficiency as well as increasing residual fertiliser nitrogen in the soil (Wu *et al.* 2019). However, in other cases, split applications have not consistently improved nitrogen use efficiency (Congreves and Van Eerd 2015). Split applications will also increase the number of passes with machinery that utilise fossil fuels, so the impact of this on the carbon footprint must be considered.
3. **Apply nitrogen fertiliser at the right time.**
   a. Applying nitrogen fertiliser when the plant is going to use the nitrogen helps reduce wastage, and therefore increases nitrogen use efficiency.
   b. In an irrigated system (in the absence of fertigation), apply nitrogen and follow with an irrigation event.

4. **Apply nitrogen fertiliser in the right place.**
    a. Broadcasting is considered a less efficient method for nitrogen fertiliser application and is associated with leaching, denitrification, and volatilization of nitrogen. Broadcasting can be implemented in two ways:
        i. Topdressing (left on the soil surface).
        ii. Incorporation (by discing or ploughing).
    b. Granular nitrogen fertiliser can deep banded or deep placed in the soil to help reduce losses through volatilization.
    c. Liquid nitrogen can be injected into the soil to help reduce volatilization.
    d. Foliar application of liquid fertilisers allows plant nutrients to be absorbed through leaves. The nutrients are more readily available for plant use than if they are ground applied, but availability is short lived and not continuous for the rest of the growing season (Isleib 2016).
    e. Fertigation is the process of supplying dissolved fertiliser to crops through an irrigation system. This can work for drip, furrow, or sprinkler irrigation systems (Bryla 2011). Fertigation can reduce the necessary nitrogen application rates and reduce the risk of losses. Additionally, fertigation can provide constant nutrient availability to the plant, and enables application of the fertiliser directly where it is required for plant uptake. Nutrient loss is nearly eliminated and in the case of urea, there are no losses via volatilisation (Harvey *et al.* 2016).

The Impact of Soil Organic Matter on Nitrogen Use Efficiency

Another factor that impacts nitrogen use efficiency is organic matter in the soil. Increasing soil organic matter helps provide a native supply of nitrogen, while also helping to improve soil structure. This soil structure helps increase drainage, which will reduce the amount of time soils are saturated after irrigation or rainfall events, which in turn reduces the time soils are prone to nitrogen losses (Rowlings *et al.* 2016).

Appendix 2

Eligibility Requirements for the Emissions Reduction Fund

If PIRSA were to pursue an ERF project, the project and entity are required to meet all the eligibility requirements listed in Table 36.

Table 36: Proponent and project eligibility requirements for the Emissions Reduction Fund (all projects).

Reference	Proponent and Project Preliminary eligibility requirements[1]	Assessment
	Will the project activities be carried out in Australia?	yes
Newness requirement	Does the project meet the newness requirement? (i.e. activities have not started before project is registered, including signing a contract to undertake project activities, acquiring, or leasing equipment, construction or making final investment decisions)	yes
Regulatory additionality	Emissions Reduction Fund projects will not be registered to participate in the Emissions Reduction Fund if they are required to be carried out by Commonwealth, state, or territory law unless a method specifies otherwise. For example, some tree planting and landfill gas capture is mandatory and so cannot be credited under the Fund. You will need to consider the work health and safety laws associated with your project as part of your preparation and implementation. Contact the relevant authority in your state or territory before you undertake your project. **Is the proponent required to carry out the proposed activities by law? If yes, DO NOT proceed**	no
Fit and proper person requirements	Do you believe you have the appropriate character and skills to successfully run an Emissions Reduction Fund project? This includes demonstrating your capability, competence, integrity, business practices and good character aspects. Is/are the proponents **'Fit and Proper Person(s)'** and have a legal right to the property/conduct project? This requirement will include confirming your identity, checking past compliance with the law, insolvency etc.	yes
Support for ERF project finance	Will you rely on the income from Australian carbon credit units (ACCUs) to finance the start of your project? **If yes, DO NOT proceed**	no
Legal right	Do you have the **legal right** to conduct project activities on the sites or assets where the project will be conducted, and do you have the exclusive right to claim ACCUs for abatement achieved by the project?	yes
Support for Emissions Reduction Fund Project Finance	It is a requirement that projects do not receive funding, rebates, or other financial incentives from other government programs, e.g. 20 Million Trees program. Does/will your project receive funding, including financial incentives or rebates, from any government program or under the legislation and regulations? **If yes, DO NOT proceed**	no
Eligible interest holder	You must seek the consent of any persons or organisations holding an eligible interest for the land on which area-based emissions avoidance projects or sequestration projects that store carbon in soil or plants as they grow. **If applicable, will you be able to acquire all eligible interest holder consent?**	yes
Permanence obligations	Can/will you commit to maintain the carbon stores throughout the **permanence period** for sequestration projects (**nominated by the project owner as 25 year or 100 years**)?	25 years

[1] *Source:* (Clean Energy Regulator 2020)

Table 37. Key project activities and eligibility requirements (measured soil carbon method)

Reference	Criteria[1]	Comment
Determination, Part 3, Section 9	During the baseline period eligible land was used for pasture, cropping or fallow	Yes (verification required)
Determination, Part 3, Section 9	During the baseline period, the land was not forested land, included dwellings or structures, or featured drained wetlands	The land was not forested land.
Determination, Part 3, Section 7	There must be a reasonable expectation that the proposed land management activities will result in a carbon abatement	If PIRSA is to pursue an ERF soil carbon project, a land management strategy must be selected from Part 3 of the Determination (below), that can be reasonably expected to result in carbon abatement.
Determination, Part 3, Section 7 ***Determination, Part 3, Section 13***	To be eligible under this method, project must introduce one or more of the following activities: (i) applying nutrients to the land in the form of a synthetic or non-synthetic fertiliser to address a material deficiency, (ii) applying lime to remediate acid soils, (iii) applying gypsum to remediate sodic or magnesic soils, (iv) undertaking new irrigation, (v) re-establishing or rejuvenating a pasture by seeding, (vi) establishing and permanently maintaining a pasture where there was previously no pasture, such as on cropland or bare fallow, (vii) altering the stocking rate, duration, or intensity of grazing, (viii) retaining stubble after a crop is harvested, (ix) converting from intensive tillage practices to reduced or no tillage practices, (x) modifying landscape or landform features to remediate land, (xi) and using mechanical means to add or redistribute soil through the soil profile.	Activities have not been identified yet. The land management strategy must be supported by an assessment by an independent person with knowledge of agronomy and plant nutrition, and good understanding of agricultural management on soil carbon, and no financial interest in the project.
Determination, Part 3, Section 7	At least one of the eligible land management activities must be new or materially different from activities during the baseline period	This must be taken into consideration when selecting a land management strategy.
Determination, Part 3, Section 9	It is possible to sample soil on the land consistently with the requirements of this determination.	This may need further investigation, as some parts of the property are steep. If they are unable to be sampled, these areas may need to be excluded.

Determination, Part 3, Section 10	At least one eligible activity must be carried out throughout each CEA until the end of the permanence obligation period. These activities may change over time.	Yes, the activity will be maintained.
Determination, Part 3, Section 10	The first eligible activity in each CEA must occur after the project is declared eligible and before the first round of sampling and reporting.	To be verified
Determination, Part 3, Section 11	Ineligible non-synthetic fertilisers cannot be applied. Eligible non-synthetic fertilisers include any biologically-derived solid or liquid that supplies nutrients to enhance plant growth and soil fertility – it does not include non-biodegradable substances such as plastic or rubber, or biochar.	Ineligible material will not be applied.
Determination, Part 3, Section 11	Coal and pyrolysed material other than biochar cannot be applied	Coal and pyrolyzed material other than biochar will not be applied.

[1] *Source:* (Australian Government 2018)

Additionally, some key land management requirements for this method are listed below (Table 38) to be considered if this method were to be pursued.

Table 38. Land management requirements (measured soil carbon method)

Reference	Criteria[1]	Assessment
Determination, Part 3, Section 12	Woody vegetation cannot be cleared unless: - it was permitted by the relevant government body before the project - it is to manage invasive woody weeds, manage pasture or forage crops - it is a regular part of horticultural pruning activities	Woody vegetation does not need to be cleared
Determination, Part 3, Section 12	Non-synthetic fertilisers (such as manure) cannot be applied at times they would make it impossible to comply with sampling round requirements.	Noted
Supplement, Part C	It is a requirement that all sampling rounds occur at least 24 months after the application of non-synthetic fertiliser.	Noted. For example, manure must be applied no later than year 3 in the reporting cycle.
Determination, Part 3, Section 12	If soil is added or redistributed by mechanical means, sampling must occur below any effected soil	Noted.

Table 39. Important aspects of soil carbon ERF project costings for professional service expenses

Crediting period for an offsets project is 25 years. A project cannot have more than one crediting period (Australian Government 2020).
Reporting period for an eligible offsets project means a period that is expressed, in an offsets report about the project, to be a reporting period for the project. A reporting period for a sequestration offsets project must be between six months and five years and must begin immediately after the end of the previous reporting period for the project (Australian Government 2020).
Permanence period for a project is 25 or 100 years. A 25-year permanence period is recommended, however this means that ACCUs are subject to a 25% discount (Australian Government 2020).
It is a requirement that there is a minimum of one year and a maximum of five years between sampling rounds (The Department of Industry, Science 2020).
After the end of the crediting period, the land management strategy must be reviewed, and if necessary, revised, by an independent person, at least every 10 years until the end of the permanence period for the project (Australian Government 2018).
The Regulator may require audits of one or more aspects of a person's compliance with this Act and the associated provisions to be carried out. An estimate of these costs has been included.