Final report

CSP – Maximising co-benefits of trees on farm

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Abstract

This research aims to quantify the productivity and carbon sequestration benefits of integrating trees into livestock systems in southeast Australia, assist graziers in incorporating information into planting decisions and ease the implementation process. These aims address current research gaps and challenges identified by farmers that increase uncertainty and hinder tree planting. This project used literature review, farmer interviews, and case study modelling approach to address the aims. The results provide a better understanding of the benefits and risks associated with integrating trees into farm enterprises. In high productivity systems (14-18 DSE/ha) in Victoria, tree planting scenarios covering 4.8%, 5.2% and 11.6% of the case study farms' area reduced net farm emissions by 20%, 23%, and 33%, respectively, over 30 years. In one scenario, planting 6.1% of a case study farm more than offset on-farm emissions (Scope 1 & 2) from 2029 to 2031. Farmers can customise tree planting configurations based on their objectives, with return on investment influenced by factors like frequency and severity of extreme conditions, effectiveness of shelter, quality of pasture replaced, and carbon auditing costs. The decision framework provides easier access to relevant and reliable information and a process to incorporate information into decision making process. The results and outputs from this project support improvements in farm profitability, resilience and sustainability while contributing to the Australian Red Meat Industry's goal of being carbon neutral by 2030.

Executive summary

Background

This research aims to quantify the productivity and carbon sequestration benefits of integrating trees into livestock systems in southeast Australia, assist graziers in incorporating this and other information into planting decisions and ease the implementation process. These aims address current research gaps and challenges identified by farmers that increase uncertainty and discourage graziers from planting trees. The results and outputs from this project support improvements in farm profitability, resilience and sustainability while reducing carbon emissions in the red meat industry.

Objectives

The objectives of this project have been achieved. The original objectives in the project agreement were to:

1) *Design and implement a survey and farmer interviews to assess the effects of trees on livestock production in south-eastern Australia*
2) *Incorporate survey results into a database developed under Phase 1 project: Trees on Farms : a tool for decision making*
3) *Assess the costs and benefits associated with different tree planting designs in a range of livestock production systems and environments in south-eastern Australia*
4) *Develop improved models to determine tree planting designs to optimise benefits for different production systems and environments and*
5) *Communicate the results of the project on costs and potential benefits of tree planting, and appropriate planting designs to farmers and advisors.*

Methodology

This project used a literature review, farmer interviews, and a case study modelling approach to address the aims. The literature review was needed to ensure available science could be communicated and research gaps could be identified. The farmer interviews provided a broad range of relevant information to inform case study analysis and the co-design of the decision framework. The case study approach is a well-established method of investigating farm economics and was used to evaluate the impacts of incorporating trees into the farming system.

Results/key findings

Planting trees on 5-12% of the high-productivity case study farms was estimated to reduce total emissions from farm by 20% to 33% over the 30-year analysis period. Farmers can tailor tree planting configurations based on their specific goals to achieve multiple objectives. The return on investment in tree planting varies depending on factors such as exposure to cold conditions, the impact of shelter on conditions experienced by animals, the quality of the pasture replaced by trees, and the costs associated with independent auditing of carbon accounts. Achieving a 10% annual return seemed possible on two of the case study farms. On the 3rd farm rates of return were between 2.6% and 6.8% depending on wind reduction, value of replaced pasture, and auditing costs.

Benefits to industry

The case study results provide a better understanding of the benefits and risks associated with integrating trees into farm enterprises. The decision framework provides easier access to relevant and reliable information and a mechanism to incorporate information into decision making processes. Tree planting on farms can significantly reduce greenhouse gas emissions and contribute to the Australian Red Meat Industry's CN30 goal of being carbon neutral by 2030.

Future research and recommendations

Better quantification of the ability of trees to mitigate reductions in weight gain due to hot or cold temperatures would reduce uncertainty in the value of trees as well as inform management to maintain productivity and improve animal welfare in a changing climate. Several recognised co-benefits were not included in this analysis due to a lack of available data, including availability of scientifically sound metrics that can be used on farm. These issues need to be addressed to get a more comprehensive understanding of the value of trees to the farm enterprise, address biodiversity and other environmental goals, and to support the development of inclusion of such factors into whole-farm modelling.

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1. Background

Integrating trees into farm operations is an integral component in the livestock industry's pathway to achieving net zero emissions by 2030 and the NFF target of net zero emissions from agriculture by 2050 (Davis et al., 2023; Meyer et al., 2020). Growing trees on farms is potentially the most feasible short-term pathway for livestock producers to achieve carbon neutrality (Doran-Browne et al., 2017). Carbon sequestration from tree plantings is only one of many benefits that trees can provide farm businesses. Providing better information about on-farm benefits will support decisions on how to best incorporate trees for carbon sequestration.

A significant body of research has been undertaken on the benefits of trees on farm. Research on the benefits of windbreaks on Australian farms began in the 1980s (Lynch and Donnelly, 1980) with identified benefits including: reductions in wind erosion (Bird et al., 1992a), benefits to pasture growth (Baker, In Prep.; Bird et al., 1992a; Reid and Bird, 1990) and benefits to livestock due to shelter from cold winds and shade. Trees and shrubs can supplement intake from pasture (Hall et al., 1972; Revell et al., 2013), enhance productivity of sheep and cattle systems (Bird, 1998), improve milk production by reducing heat stress (Mayer et al., 1999), improve fertility (Reid and Bird, 1990), and improve lamb survival, growth and wool production (Bird et al., 1984; Broster et al., 2012). There is also potential for diversification of income through sale of timber or non-timber products (Neufeldt et al. 2009) which may reduce farm financial risks in changing climates and markets. The available information includes anecdotal evidence through to scientific experimental data.

While the general benefits of trees on farms have been understood for some time, research gaps remain. Data from specific experiments and demonstration sites point to potential benefits, but these are often difficult to extrapolate to other farm systems or different conditions. Additionally, the information quantifying these benefits is not easily accessible and is challenging to incorporate into farm decisions. These decisions require consideration of costs, financial and non-financial benefits, and risks, as well as farmer priorities and risk profile.

Consequently, a lack of understanding of the on-farm co-benefits of incorporating trees is a known barrier to implementation (Kragt et al. 2017; Evans 2018). Other barriers include policy uncertainty (Harper et al. 2017; Evans 2018), the opportunity cost of taking land out of production (Greiner and Gregg, 2011; Kragt et al., 2017) and risks associated with establishing trees such as tree death caused by insects or fires (Evans 2018). These barriers as well as a lack of good metrics on which to assess the value proposition for growing trees is limiting establishment of trees on Australian farms. Providing unambiguous recommendations (Sherren et al., 2010) and credible information on economic returns (Schirmer et al., 2000) to graziers are concrete steps to address these obstacles.

Our research aimed to equip graziers with knowledge and tools to make better decisions about tree planting and management to improve the profitability, resilience, and sustainability of their farming businesses. To achieve this aim, we used a social research and case study modelling approach. Interviewing farmers who currently have trees on their property provided a comprehensive and relevant set of data to inform case study modelling. Additionally, information from the interviews in conjunction with the feedback from events allowed for co-design of a decision framework to ensure the outputs of the project are applicable, useful, and clear.

Using responses from in-depth interviews with farmers, information on co-benefits from the published literature, and a case study approach we quantified the costs and benefits of differing tree planting designs and determine ways to maximize benefits and minimize risks of planting trees on farm. Case studies also addressed how plantings can be designed to achieve specific co-benefits while reducing risks of establishing trees on farms. Case studies also provide data on what situations justify the investment based on benefits to their farm operation as well as for carbon sequestration.

Project outputs provide the red meat industry with readily available knowledge and examples of demonstrated benefits of trees for farm operations that gives producers greater confidence to grow trees to meet their objectives while reducing net emissions. Providing the best available science in easy-to-access formats can provide a stronger basis for graziers to incorporate trees into farm planning and reduce uncertainties associated with establishing trees. This will lead to greater incorporation of trees into farming systems, lower net farm carbon emissions and improved farm resilience.

2. Objectives

The objectives of this project were to:

1. *Design and implement a survey and farmer interviews to assess the effects of trees on livestock production in south-eastern Australia*
2. *Incorporate survey results into a database developed under Phase 1 project: Trees on Farms : a tool for decision making*
3. *Access the costs and benefits associated with different tree planting designs in the range of livestock production systems and environments in south-eastern Australia*
4. *Develop improved models to determine tree planting designs to optimise benefits for different production systems and environments and*
5. *Communicate the results of the project on costs and potential benefits of tree planting, and appropriate planting designs to farmers and advisors.*

All objectives have been met, with some minor changes agreed with MLA. A wider survey was not undertaken but more interviews were done. The interview methods are in section 3.1 and the interview results are in section 4.1. Objective 2 was updated, due to the database being hard to operate and interpret. Results from the database were incorporated into factsheets that included results and quotes from the interviews. The results from the 3 case studies in western (section 4.2.1), eastern (section 4.2.2), and northern (section 4.2.3) Victoria directly address objective 3. The analyses performed for these cases studies addresses different planting configurations in different climates and production systems. In the course of the project, it was decided to limit the scope to the direct productivity impacts of shade and shelter. This was due to the shorter timeframe of the project (2 years), difficulty assessing changes retrospectively on the case study farms, and the lack of data to robustly connect co-benefits such as biodiversity to productivity outcomes. The case study analysis informs the outputs relevant to objective 4 and all analyses have been incorporated into the communications and outputs that address objective 5. Although better described as a framework, than a model (objective 4), these outputs are informed by, and include content from the interviews and other efforts to incorporate farmer and consultant input on mechanisms to ease planting decisions and implementation. Details of the outputs that address objectives 4 and 5 are described in the decision framework section (4.3) and include:

- *factsheets that also address objective 2.*
- *the Index of Resources - an easy-to-use catalogue of information sources that assists farmers access “how to” information relevant to their circumstance.*
- *the step-by-step guide to provide context, assistance with planning and timing, and advice informed by farmers with expertise in integrating trees into the farming system.*
- *examples of using the decision matrix to address tree planting decisions that was provided as part of Phase 1 of this project.*

3. Methodology

3.1 Interviews

3.1.1 Approach

Forty-three semi-structured interviews were conducted with livestock farmers whose farms were located in NSW, Tasmania and Victoria. Interviewees were identified through both purposive sampling and chain referral (Bryman, 2016; Sarantakos, 1998). Purposive sampling was employed to ensure that a range of production systems were represented from the five regions that are part of this research (Table 1). Across these interviews, a total of 44 farms were discussed (one farmer discussed two farms) and at six of these interviews two interviewees were present, discussing the same farm. During the interviews, interviewees were asked about: their enterprise, including ownership arrangements and income; the extent and nature of woody vegetation on the farm; the benefits and impacts of trees on livestock production and other aspects of the farm; the changes planned for the farm over the next five years; any factors or resources that influenced the planting decisions; interest in timber production; and their views on trees as a carbon offset (see Appendix 1). The interviews were conducted online via Zoom (39 interviews), in person at the farm (three interviews) or telephone interviews (one interview) between July 2021 and September 2022.

Most farms had only one production system present (57%), but many farms were mixed farming systems, with two (36%) or three systems (7%) present. Farmers varied from relatively new entrants to those who had farmed for most of their lives, in farm size, the proportion of woody vegetation on their farms (Table 2), and their associated income. Most interviewees (63%) reported gross farm income of less than $1M in the 2021 financial year and half reported a net farm income of less than $250,000 (Table 3). The proportion of woody vegetation were farmer estimates. Although many of these would be quite accurate based on farm mapping, many were highly uncertain and thus further analysis with this figure was not considered.

Interviewees predominantly fell into the 'winding down' (48.8%) and 'driving growth' (39.9%) segments of the MLA farmer segmentation (Table 4). There were no farmers considered 'planning for succession' and only one farmer categorised as 'living the life'. Our criteria were developed to exclude hobby farmers, so this lack of representation is expected. The high proportion of 'winding down' was unanticipated, considering 93% of farmers agreed that they actively seek information to improve their operations and 88.4% disagreed with the idea that there was no need to change farming operations since they already know what works. 72.1% of participants agreed that farming is a business like any other and 67.4% adjust their management to market conditions. There was an even split on the interest in borrowing heavily to increase the size of the farm and only 25.6% were interested in borrowing heavily to diversify. It is hypothesized this lower appetite for risk may be influencing the number of farmers categorised as 'winding down'.

Table 1: Location and primary income source of interviewees' farms.

Region	Beef	Prime lamb	Wool	Dairy	Total
TAS-High Rainfall	2	1		0	3
VIC-Southwest	1	5	2	1	9
VIC-Gippsland	1	3	2	3	9
VIC-Central	8	4	4	0	16
NSW	3	2	1	1	7
Total	15	15	9	5	

3.1.2 Data analysis

Sections of the interviews related to the effects of trees on production, other impacts of trees and factors affecting planting decisions were transcribed and imported to QSR NVivo 20 software. An initial coding list was based on a literature review of the benefits and risks of trees on farms with livestock systems (project objective 2), which divided those benefits and risks into five themes: productivity co-benefits; other co-benefits; risks and challenges; financial considerations; and social and logistical considerations. During analysis of interview transcripts, additional impacts of trees were identified and added to this list. Thematic analysis of interview data (Braun and Clarke, 2006) was conducted to identify any benefits, effects, risks, challenges or other considerations that interviewees reported in association with the trees or planting trees on their farm. Information and funding sources used by interviewees were also recorded. Interviewees are identified by the production systems present on their farm and their region to protect their anonymity. This research was approved by the Human Research Ethics Committee of the University of Melbourne (Project ID 21594).

Table 2: Interviewees' time in farming, farm size and estimated proportion of farm with woody vegetation.

Attribute	Median	Min value	Max value
Time in farming (years)	25	3	61
Farm size (ha)	460	50	11,500
Proportion of farm with woody vegetation (%)	15	2.5	67

Table 3: Number of farms reporting gross and net farm income for FY 2021, where reported.

Gross farm income (FY 2021, $M)	Number of farms	Net farm income (FY 2021, $M)	Number of farms
0-0.25	9	0-0.25	13
0.26-0.5	5	0.26-0.5	5
0.51-0.75	3	0.51-0.75	3
0.76-1.0	7	0.76-1.0	2
1.01-1.25	2	1.01-1.25	1
1.26-1.5	3	1.26-1.5	0
1.51-1.75	3	1.51-1.75	0
1.76-2.0	0	1.76-2.0	0
>2.0	6	>2.0	2

Table 4: Proportion of interviewees allocated to each MLA farmer segment.

	MLA farmer segment				
	Winding down	Holding steady	Planning for succession	Living the life	Driving growth
Proportion of interviewees (%)	48.8	9.3	0.0	2.3	39.5

3.2 Case study analysis

The case study approach is a well-established method of investigating farm economics (Crosthwaite et al., 1997; Sinnett et al., 2016) and was used to evaluate the impacts of incorporating trees into the farming system. The rationale for the case study approach in farm economic research includes:

- *Farm economics is about the whole of the farm in its natural, economic, and social settings.*
- *The case study approach suits research into alternative actions for managers of farm businesses.*
- *The case study method encompasses the many and different variables in a farm system that arise given that each farmer and farm business are unique.*

A framework used in previous case study analysis (Malcolm et al., 2012; Sinnett et al., 2019), was adapted to our analysis. By carefully selecting case studies hypotheses can be tested by comparing findings of alternative cases (Sinnett et al., 2019; Yin, 2018) Key elements of this approach include:

- *Consulting with industry experts to define the research questions.*
- *Adopting a multiple case study approach (rather than a single case study) to improve the robustness of the results.*
- *Selecting farms that were well-managed businesses with detailed information about the farming system.*
- *Conducting semi-structured interviews (with open-ended questions) with the farmer to understand, in-depth, the production system.*
- *With each case, the selection criteria included such things as region, livestock operation, potential for (additional) planting, and data availability.*

Two case study farms were selected for the research addressing sheep and shelter and a third case study farm addressed shade and shelter in a beef operation. The farms were identified through the farmer interviews being conducted under the first two objectives of the project (from October 2021 to approximately May 2022), and from the NEXUS project that has seven farm case studies from Tasmania to north Queensland. Details of the case studies used in this project and the assumptions associated with each one are outlined in the results section.*

3.2.2 Carbon accounting

The SB-GAF tool provided by the Primary Industries Climate Challenges Centre at the University of Melbourne was used to estimate case study farm emissions. This tool is consistent with the Australian government accounting approach and the MLA CN30 program. The data required for the SB-GAF tool was collected from Dunkeld Pastoral as part of the IMS project and from Tambo Crossing as part of the Nexus project. Data was obtained from the Rosewhite Case study as part of this project. Tree carbon sequestration options in SB-GAF were not used. The methodology for tree carbon sequestration is outlined below.

For consistency, the sequestration associated with the proposed tree plantings is displayed as a percentage of on-farm (Scope 1 & 2 emissions) and total emissions (Scope 1-3), both at peak sequestration and using an annual average over the 30-year timeframe for all case studies. Although general principles were followed, it should be noted that the methods used here do not follow a specific insetting or carbon removals accounting standard.

A landowner can manage their carbon asset in several ways:

- *Choose to maintain their carbon for their own accounting and reporting. This can be used to support claims for producing climate-friendly agricultural products (e.g., lamb certified as climate neutral by*

* The NEXUS project explored the connections between profitability, productivity, greenhouse gas mitigation, carbon sequestration and consumer perceptions of livestock businesses in an increasingly variable climate. With funding from Meat & Livestock Australia's Donor Company, University of Melbourne, University of Tasmania and CSIRO, the NEXUS project will run from March 2020 – June 2023. https://www.piccc.org.au/research/project/NEXUS.html.

Climate Active), or to maintain a carbon sink on the farm in the expectation that the value of the carbon will be capitalised into the land value.

- *Sell carbon to a third party as Australian Carbon Credit Units (ACCUs). In this case, the carbon stored in trees cannot be used to offset farm emissions.*

In the case where plantings since 1990 comprised a significant portion of sequestration (Dunkeld) this was also included as it aligns with the draft Climate Active insetting guideline. However, to meet the draft guidelines a discount factor would need to be applied (likely 25%). The sequestration associated with the timber planting as described in Appendix 4, generally following the FullCAM plantation guidelines, was included in the timber planting scenario. Although including removals associated with trees grown for harvest may not be possible with some standards, agroforestry can be used to meet Science Based Targets in the Forest Land and Agriculture (FLAG) sector pathway.

Soil carbon was not addressed in these analyses. It was assumed that over the course of the simulation period, soil carbon lost at tree establishment would be recovered by the end of the 30-year period. This assumption is supported by trends in soil carbon following tree planting (Paul et al., 2002). The focus of this research was to investigate the impact of tree carbon sequestration on net farm emissions. Thus, modelling of impacts of management change outside of planting trees or future climate on soil carbon on these properties over the next 30 years was outside the scope of our research objectives.

Sequestration estimates: *The carbon sequestered with the differing tree planting scenarios was estimated using FullCAM (the Full Carbon Accounting Model used in Australia's National Greenhouse Gas Accounts for modelling Australia's greenhouse gas emissions from the land sector). FullCAM predicts the amount of carbon in trees (aboveground and belowground components) and debris, expressed as tonnes of carbon per hectare. We converted these results to tonnes of carbon dioxide equivalent per hectare using a multiplication factor of 44/12.*

Modelling of carbon stocks in woody vegetation using FullCAM is carried out in carbon estimation areas (CEAs) that are areas that have uniform site characteristics, are planted with the same combination of plant species, and are established and managed under the same land management regime (Australian Government, 2018). The key data required for a CEA are the area and date of planting†. These were determined for each individual case study farm.

We estimated carbon stocks (i.e., sequestration) in existing planted trees and proposed plantings using the predictions from the FullCAM model (2020 Public release version). The standard calibration was used for environmental plantings. All existing plantings were modelled with a start date of 1 July in the year we estimated the plantings were established. All proposed plantings were modelled with a start date of 1 July. For example, if the proposed planting year was 2025 the modelled sequestration start date was 1 July 2025. The model for each CEA was run from the planting date for 30 years.

Under the Methodology Determination we followed, a 'belt' planting means a planting that is established in a belt configuration, follows landscape contours or is arranged in a straight line, and is no more than 40 m wide. Plantings that do not meet these requirements are 'block' plantings. FullCAM has different calibrations for belt and block configurations and has calibrations for belt plantings with <1500 stems per ha and belt plantings with >1500 stems per ha. There are further calibrations for different establishment methods (the use of weed control and application of fertiliser). For all three case studies, we used the following environmental planting calibrations:

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† Carbon Credits (Carbon Farming Initiative) (Reforestation by Environmental or Mallee Plantings—FullCAM) Methodology Determination 2014, Compilation No. 2, 2018, Authorised Version F2018C00118 registered 26/02/2018.

- *Environmental Planting calibration, Block configuration; and*
- *Environmental Planting calibration, Belt configuration, <1500 stem per ha.*

In applying the calibration for the belt configuration, we applied the test for 'material competition' from adjacent trees specified in the Methodology Determination and adjusted where necessary the length of the belt to which we could apply the calibration.

A Tambo Crossing scenario included a native timber plantation. FullCAM had calibrations for three eucalypt plantation species but not for species native to the locality. We consulted with a FullCAM expert[‡] and devised an approach to model abatement in the proposed eucalypt plantation. The details of this method are outlined in Appendix 4.

3.2.3 Biophysical modelling

Changes in sheep production associated with shade and shelter were estimated by modelling the relevant case study farm systems in GrassGro. The baseline farms were modelled ensuring appropriate estimation of livestock numbers, lamb per ewe in the month of lambing, and proportions of singles, twins and, in the case of Dunkeld, triplets. Both farms were modelled using the Corriedale sheep calibration to reflect the dual-purpose nature of both systems and to ensure that comparisons between case studies were focused on factors related to wind and shelter and not differences in animals.

GrassGro can be used to assess the effect of wind on lamb mortality through a chill factor. This function is comprehensive and includes several factors including surface area, the impact of rainfall, fleece depth and body condition. The minimum critical temperature for a sheep with 8 cm of fleece is 0° C. This allows for the impact of reduced wind speeds on lamb productivity to be estimated by comparing the number of lambs produced in the baseline farm scenario with the number produced in the reduced wind speed scenario.

One of the primary functions of shelterbelts is to reduce wind speeds. The area that wind speed is reduced due to shelter depends on the height of the trees with some reduction in wind occurring out to about 20 tree heights distance from the shelterbelt (Bird et al., 1992b; Burke, 1991; Cleugh et al., 2002). The extent of the wind speed reduction in this area depends on several factors, primarily the orientation of the planting compared to predominant wind direction and the porosity of the windbreak (Cleugh et al., 2002). Porosity directly impacts on the extent to which wind speed will be reduced. A general guide is that the wind speed reduction is similar to the shelterbelt density (e.g. porosity of 30%, or density of 70%, leads to a wind being reduced 70% at the most sheltered location) (Cleugh et al., 2002). Winds that hit the windbreak at oblique angles increase the wind reduction near the windbreak, similar to a reduction in porosity (Cleugh and Hughes, 2002). Two reductions in wind cover were investigated for both sheep case studies. These windspeed reductions and baseline case selection were determined with input from the farmers and are therefore not the same on both case studies.

Aside from lost area of production due to conversion from pasture to trees, changes in pasture were not addressed in this analysis. This was done for several reasons. GrassGro was not used to estimate the change in pasture production since pasture production in GrassGro is not sensitive to change in windspeed. A trial using microclimate data at varying heights from the tree line resulted in a 1% increase in pasture production in the sheltered paddock. Given this level of climate data was not available for the case study farms, GrassGro could not be used to estimate this production change for the case study farms. Based on a meta-analysis of pasture responses to tree plantings (Baker, In Prep.), no net change in paddock productivity was assumed. This meta-analysis found that in paddocks over 5 tree heights wide, the slight increase in production in the sheltered zone typically offset the losses in the competition zone. This was most likely in drier sites and years and in winder locations. There were situations in which shelter did not offset losses in

[‡] Geoff Roberts, Mullion Group, 5 August 2022.

the competition zone. These cases were uncommon and net reductions were small. In contrast, in most cases there was a small increase in pasture production and occasionally there were substantial increases in overall pasture production.

3.2.4 Economic analysis

The economic analysis answered the following question for each case study farm: 'what is the likely risk and return from an investment in growing trees on parts of the case study farm?' To answer this question discounted net cash flow analysis was used (Malcolm et al., 2005). As part of this analysis, all extra costs and extra benefits were identified and, where possible, values placed on the extra benefits and extra costs and extra risks of the change. The same approach was applied in a study of the carbon credits and economic returns of environmental plantings on a sheep (prime lamb) enterprise in south-west Victoria (Sinnett et al., 2016)

To assess the economic merits of an investment in growing trees, the internal rate of return was used. The IRR is the annual compound rate of return on capital in real terms.

Trees provide a benefit to the farm system through sequestering carbon. The carbon sequestered has a value to the farm system as it could off-set GHG emissions on farm or it could be sold to another emitter of GHG to off-set their emissions. The value of this carbon is based on the social cost of carbon. The social cost of carbon is the cost of the damages created by one extra tonne of carbon emissions. Thus, if trees offset the damages created by one extra tonne of carbon, then the benefit of the trees is this cost avoided. To estimate the social cost of carbon is difficult – the cost of the damages the carbon does to the economy and human welfare is estimated in integrated assessment models. There is some debate on the social cost of carbon, as it depends on the actions governments take to correct this market failure, on the assumptions in the modelling and on the discount rate used in the analysis. The project team decided that in the first year of the analysis the price of carbon was \$35/tCO_2e (current market price), which was assumed to increase at 5% each year until it reached a value of \$80/tCO_2e (a value to reflect the social cost of carbon). Stern and Stiglitz (2021) estimate that the social cost of carbon is between \$US60 and \$US100/ t CO_2e.

The outputs from the Grassgro modelling provided an estimate of the number of extra lambs likely to survive as a result of trees reducing wind chill as well as a probability distribution of number of extra lambs sold. In both sheep case studies two scenarios of wind reduction were investigated, giving benefits associated with an average and a highly effective design and use of shelter. In all case studies it was assumed that the shelter benefit began 7 years after planting and continued throughout the simulation (year 30). It was assumed that additional lambs had an average net margin of \$45 with a standard Deviation of \$24.35 to reflect varying market conditions (see Fig. 1). This net margin is the benefit of an extra lamb sold less the extra costs of each lamb (extra costs for crutching, animal health, commission on sales, possibly a price on emissions, extra labour, extra pasture maintenance) The estimate of the net margin per extra lamb was derived using the Ag Price Guide, Gross Margin Budgets from the Department of Primary Industries NSW and the GRDC gross margin guide, as well as feed budgets.

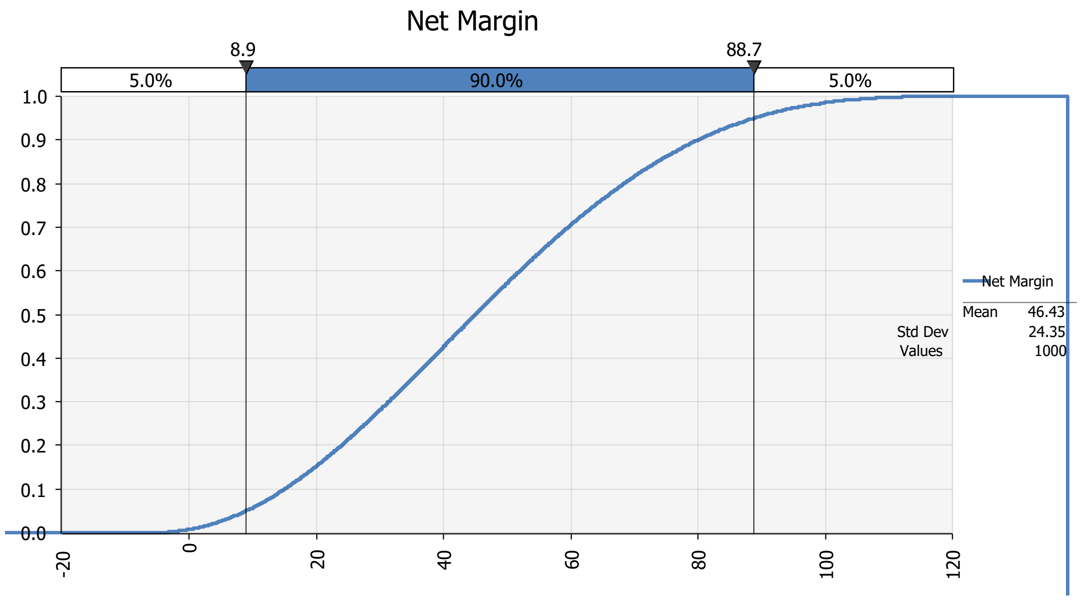
An additional analysis was conducted for all three case studies, whereby instead of defining the benefits from the trees, threshold analysis was used to answer the following questions:

- *For this investment in extra trees on the case study farm to earn on average 10% p.a. real return, what is the value of the co-benefits required every year from year 7 to year 30?*
- *If there are no co-benefits to the farm system from the trees, what price needs to be received for the carbon sequestered for this change to earn on average 10% p.a. real return?*

Threshold analysis is a form of sensitivity analysis whereby the breakeven level of a critical variable is identified whilst all other variables are held constant. This was the only economic analysis performed for the Rosewhite case study, as it is a beef system.

If the trees are harvested, then another benefit of the trees is the income from timber[§]. At Tambo Crossing it was assumed that some of the trees were planted for timber revenue. It was assumed there would be a semi-commercial thin in year 12; the first commercial thin at year 20; and the final harvest in year 30. The projected volumes used were 1,420 m^3 for the semi-commercial thin, 2,556 m^3 for the first commercial thin, and 8,804 m^3 at final harvest.

Figure 1: The distribution of the net margin for each additional lamb, with 90% worth between $8.9 and $88.70 per head.



The costs of planting and growing extra trees on each case study farm include both capital and ongoing costs. Capital costs varied based on case study and planting type (see Table 5). Fencing cost data is from

Table 5: Tree establishment costs by case study and planting type

	Fencing costs $/ha	*Length of fence (km)*	*Tree establishment cost – year 1 ($/ha)*	*Tree establishment cost – year 2 ($/ha)*	*Annual cost (labour, insurance, etc) ($/ha)*
Dunkeld environmental planting (over 8 years)	*13,000*	*24*	*3,460*	*120*	*50*
Tambo shelterbelt	*14,000*	*7.0*	*4,500*	*400*	*75*
Tambo environmental planting	*13.500*	*2.7*	*4,500*	*400*	*50*
Tambo plantation	*13,500*	*0*	*4000*	*400*	*See note below[**]*
Rosewhite (planted over 4 years	*13,500*	*4.5*	*4,500*	*400*	*50*

[§] To reflect the shorter life of the trees grown for timber a 25% discount was applied on the carbon sequestered.
[**] Only the Tambo Eucalypt plantation had additional maintenance costs above those annual costs reported for all other case studies and tree plantings. It was assumed: pruning occurred three times at a cost of $1000/ha; a non-commercial and a semi-commercial thinning cost $750/ha; and one application of micronutrients cost $400/ha. This gives the total cost of maintaining the Tambo plantation of $129,220.

industry sources with an allowance for scale and topography. The establishment cost data used for Tambo is from industry sources whereas for Dunkeld data from recent plantings was used. The costs in year one includes two chemical weed control applications before planting, ripping, mounding, and rotary hoeing and supplying seedlings with milk carton guard with two bamboo stakes and the labour to plant and guard trees.

The extra ongoing costs from investing in growing trees to sequester carbon (and possibly other co-benefits to the farm system) include the cost of maintaining the trees (Table 5), the cost for auditing, and the benefit foregone (pasture area replaced). For auditing and the 'quality of the replaced pasture' two scenarios were investigated for each case study farms. The cost of auditing was either 10% of the value of the carbon or 30% of the value of the carbon. The two values for the quality of the pasture replaced was 9 DSE/ha and 18 DSE/ha for the two sheep systems, and 0 DSE/ha and 3 DSE/ha at Rosewhite to reflect that proposed plantings are occurring on unproductive and low productivity areas. This provides an important contrast to the other case studies as it is more common for low productivity land to be targeted for planting.

It was assumed that planting trees to sequester carbon would replace pasture that was used to feed livestock and that this pasture that was 'lost' to the farm system would add an extra cost. The assumed cost ranged between \$25/DSE (low probability), \$35/DSE (most likely) and \$60/DSE (low probability) (a pert distribution was fitted to these estimates).

The combination of scenarios from the carbon audit costs, the quality of the replaced pasture, and the effectiveness of the shelter leads to 8 scenarios for the sheep systems (Box 1), with each cost and benefit scenario performed for both levels of productivity of replaced pasture (9 DSE/ha and 18 DSE/ha). For Rosewhite the cost of carbon auditing of 10% and 30% of the value of the carbon was investigated at the 2 values of quality of replaced pasture of 0 DSE/ha and 3 DSE/ha for the threshold analysis.

Other assumptions applied to all three case studies:

- *If the trees provide co-benefits to the farm system it is assumed these benefits will begin from year 7 year and will continue to year 30.*
- *Assumed that trees will remain on the property for 100 years (except for the timber plantation)*
- *To be conservative the salvage value of the trees at the end of 30 years is assumed to be zero*
- *The budget is in real terms (effects of inflation have been excluded from the analysis)*
- *The analysis is done before tax;*
- *The discount rate (opportunity cost of capital) was real 10% p.a. real before tax;*
- *Each project analysed had a 30-year planning horizon (the trees will remain for 100 year to ensure that the carbon stocks in sequestration projects be retained for 100 years)*

Box 1: Summary of scenarios analysed as part of the economic analysis for sheep case studies.

Low cost & high benefit scenario	*Cost of auditing the carbon sequestered: 10% of the value of carbon.* *Dunkeld: Plantings reduce wind speeds experienced by the herd an average of 60%* *Tambo Crossing: Plantings reduce wind speeds experienced by the herd an average of 50%*
High cost & high benefit scenario	*Cost of auditing the carbon sequestered: 30% of the value of carbon.* *Dunkeld: Plantings reduce wind speeds experienced by the herd an average of 60%.* *Tambo Crossing: Plantings reduce wind speeds experienced by the herd an average of 50%.*
Low cost & low benefit scenario	*Cost of auditing the carbon sequestered: 10% of the value of carbon.* *Dunkeld: Plantings reduce wind speeds experienced by the herd an average of 30%* *Tambo Crossing: Plantings reduce wind speeds experienced by the herd an average of 15%*
High cost & low benefit scenario	*Cost of auditing the carbon sequestered: 30% of the value of carbon.* *Dunkeld: Plantings reduce wind speeds experienced by the herd an average of 30%.* *Tambo Crossing: Plantings reduce wind speeds experienced by the herd an average of 15%.*

4 Results

4.1 Interview results and discussion

4.1.1 Animal production impacts

Several different impacts to animal production, providing benefits to each production system, were described by interviewees (Table 6). All five dairy producers reported increased milk yield associated with the presence of trees on their farm, often explained by cattle being more willing to eat more in sheltered paddocks or being less stressed where shade is available.

> I think when the cows aren't stressed you do get better flow. And if they're stressed and they've got heat problems all day long, they've got nowhere to really relax, you definitely can see that. On the really extreme hot days, they're still out in the sun, they're not always under the treeline, you do get a drop in their milk production. It's definitely there. (Dairy producer, NSW)

Table 6: Proportion of farms with a beef, dairy, prime lamb or wool production system present where an impact of trees was reported by the interviewee. Empty cells indicate where data is not applicable.

Impact	Production system present on farm			
	Beef (%, n = 29)	Dairy (%, n = 5)	Prime lamb (%, n = 17)	Wool (%, n = 15)
Benefits				
Increased beef liveweight	14			
Decreased beef mortality	0			
Increased cattle carrying capacity	7	0		
Increased dairy milk yield		100		
Decreased lamb or offshear mortality			59	53
Sheep carrying capacity			6	7
Increased sheep liveweight			0	0
Increased lamb liveweight			6	0
Increased wool growth			0	7
Increased productivity (general and livestock)	10	0	18	13
Risks and challenges				
Reduced livestock production	14	0	6	0

A majority of farms where a prime lamb (59%) or wool production system (53%) was present reported decreased lamb or offshear mortality associated with trees on the farm: "the biggest impact of providing shelter on productivity is lamb survival rate." (Prime lamb producer, central Vic). Interviewees explained this increased survival as being due to trees providing conditions including protection from wind and rain as well as privacy. One interviewee was able to quantify the benefit of paddocks with trees in both lamb marking rates and financial benefit.

> The little bit of data that I've collected here over the years, it's roughly a 4% increase in marking rates in paddocks that are offered shelter to paddocks that aren't. So, it adds up. I think it's about $85 a hectare for me, the increase. (Beef and prime lamb producer, Tas)

Yet, the shelter provided by trees was often described as only one of several factors influencing lamb survival, along with other factors including feed available, mob size and condition score.

Many interviewees discussed the difficulty in being able to distinguish the impacts of trees in terms of production benefits from other factors or changes they had made on their farm.

> In terms of being able to quantify more than just saying it's a benefit is somewhat challenging. We haven't got any numbers to be able to sit there and say, "I've saved this many more lambs by having them in this paddock or that paddock." There's so many other variables that influence an outcome in any given paddock (Prime lamb and beef producer, NSW)

> I guess because we bought the farm that was underdeveloped – that increase in milk production has been happening at the same time I've been doing trees. So there's a lot of factors. But as I said before, I see it as positive. (Dairy producer, Gippsland, Vic)

Four interviewees also described trees as decreasing livestock production because trees made land unavailable for livestock or livestock were excluded from young plantings. However, these impacts were counterbalanced by other on-farm improvements in some cases

4.1.2 Pasture and crop impacts

Almost a third of interviewees reported increased pasture production and one interviewee reported increased crop production (Table 7). Trees were associated with the provision of shelter for pasture, reducing cold or retaining warmth in the soil, providing shade, improved soil moisture retention or improved soil biology, all of which could increase pasture or crop growth rate according to interviewees.

> And when we talk about shelter, it's not only shelter for the livestock, it's also shelter for the pasture, especially on a change of season. You can see what country moves first, and it's usually country that's protected from prevailing winds by tree lines and such. (Wool producer, central Vic)

As with the livestock production benefits, these impacts of trees were typically based on farmers' observations rather than being quantified or specifically measured.

> It's just simply damper for longer over summer, and certainly down next to the regenerating box, the same thing, but it's pretty amateur observational stuff – we don't measure that with soil probes or anything like that a lot of the time. (Beef producer, central Vic)

Trees were also providing feed for the livestock of four interviewees, who reported this benefit from tree lucerne (or tagasaste, Cytisus proliferus) or fruit trees they had planted.

Fewer interviewees reported reduced pasture or crop production, or pasture production being unaffected by trees. Negative impacts of trees were described due to reduced pasture abundance alongside tree plantings, canopies shading the ground in plantations, planting trees on land suitable for pasture or stock camping next to trees. Neutral impacts were typically explained as being due to the negative impacts of trees on pasture production that were counteracted by any benefits to production. Two interviewees explained that some of the negative impacts of trees on pasture production were due to attributes of particular tree species, such as canopy size and canopy density, as well as the spacing of trees.

4.1.3 Other on farm impacts

Additional benefits for livestock

Animal welfare benefits associated with trees were described by interviewees for all but three farms (Table 8). While interviewees described benefits for animal health, their livestock's ability to regulate their temperature and unspecified animal welfare benefits, the provision of shelter and shade were the most commonly reported of any benefits from trees. The shelter provided by trees was reported to provide

Table 7: Proportion of farms with production system present where an impact of trees on pasture or crop production was reported by the interviewee.

Impact	Production system present on farm			
	Beef (%, n = 29)	Dairy (%, n = 5)	Prime lamb (%, n = 17)	Wool (%, n = 15)
Benefits				
Increased pasture or crop production	21	80	35	27
Provision of feed for livestock (e.g. Tagasaste)	10	0	12	13
Risks and challenges				
Reduced pasture or crop production	24	0	18	7
Neutral impacts				
General farm productivity impact	3	20	6	7
Pasture production	14	0	6	7

Table 8: Proportion of farms where the interviewee reported an impact of trees.

Impact	Production system present on farm (%)			
	Beef (n=29)	Dairy (n=5)	Prime lamb (n=17)	Wool (n=15)
Benefits				
Animal welfare (all)	90	100	94	93
Animal health	0	20	6	0
Animal welfare (general)	3	20	6	7
Livestock temperature regulation	3	20	0	0
Shade for livestock	55	100	65	67
Shelter for livestock	76	80	82	87
Biodiversity increase	59	100	65	60
Services from biodiversity	34	20	29	40
Improved aesthetics	48	40	59	53
Biosecurity	10	0	6	13
Erosion control, stabilisation	34	20	18	20
Landscape contributions	21	0	29	27
Improved working/living conditions	10	40	24	27
Carbon sequestration	21	0	24	27
Increased water quality	3	60	6	13
Fencing, subdivision, security & management	7	20	12	0
Water table management	3	20	6	0
Increased water efficiency or availability	7	0	0	0
Privacy	3	0	6	13
Utilise areas unsuitable for farming for timber	3	0	6	0
Soil carbon	3	0	0	0

Risks, challenges				
Carbon market and sequestration (various)	76	80	82	73
Pest animals	45	60	35	40
Timber	38	20	53	40
Climatic risks	17	40	18	7
Damage to fences, roads, powerlines	17	0	18	27
Livestock damaging trees	10	20	0	7
Weeds	7	0	12	7
Increased runoff	3	0	0	7
Neutral impacts				
Shade	7	0	12	7
Shelter	7	0	6	7
Carbon sequestration	3	0	0	7
Erosion	3	0	0	0

benefits for both cattle and sheep on over three quarters of farms across all production systems. Sheltering benefits were predominantly protection from wind and wind chill, but also protection from rain and providing more moderate temperatures in areas planted with trees, while also contributing to the lower lamb and off-shear mortality previously outlined.

> The difference in lambing down ewes over the years in a sheltered paddock compared to being out in the open with the elements and sleety rain and wind and stuff like that is incredible. She'll always go in behind a log or tree or something like that, anything she can find to lamb in a more sheltered place and that makes perfect sense. (Wool and beef producer, central Vic)

> These benefits were also reported for cattle: "you do see the cattle using the paddocks differently. There are less days when they're hiding from the wind than what they were previously." (Beef producer, SW Vic). Some connected these shelter benefits to improved production: "So keeping our cows comfortable for two reasons, one, to maximise their production and animal welfare reasons, a comfortable cow will produce more milk and have a longer happier life." (Dairy producer, Gippsland, Vic).

Shade was reported as a benefit associated with trees by most farms, including for all dairy farms.

> Shade is huge, huge, especially when you've – so we shear in August and in February – so in the month of January you could have 40-degree days and you've got sheep with 11 ½ months of wool on them, they are sweltering, and so they need to be under shade. And they'll start – and even the cattle, they will start to move under those shady trees, they'll start to move there from as early as seven thirty or eight o'clock in the morning in the summer. (Wool and beef producer, central Vic)

As with many of the impacts of trees described, most interviewees could not quantify the shelter or shade benefits of trees.

> If they've got shelter, they're in the shelter when the weather is at extreme points. There's got to be benefits there. How you actually put a dollar on that or something, I don't know. (Prime lamb producer, SW Vic)

> I think it's probably a bit harder to measure any direct benefit from cattle, but cattle always love shade, you always see them sitting under trees if they can get at them along the edge of the fence lines and things. Whether there's any productivity benefit out of giving them shade when they want it, I don't know about that. (Wool, prime lamb and beef producer, Gippsland, Vic)

Provision of shade and shelter were specifically linked to animal welfare by respondents because it provided animals with the opportunity to avoid unpleasant conditions and was associated with improved lamb and offshear survival.

> I can drive out and I see animals sitting in the shade or seeking shelter all the time, and you're going "They've got to be happier by doing that.", and that's gotta spin off on production. (Wool and beef producer, SW Vic)

Environmental impacts

Most farms also reported an increase in biodiversity associated with trees on their farm. This biodiversity increased was most often in bird species, but also included insects, other plants, and soil microbes.

> But it also can be that nice, little sanctuary that can link up with other plantations and provide that small bird, diversity of birdlife, I suppose. Even the water birds. Swans and – It's always good to have a few sets of swans on your dams and things like that. (Prime lamb producer, SW Vic)

> I think the great thing that we saw was in those gullies that we fenced off. As soon as we fenced them off, the reeds and the rushes and the small herbaceous things would just come up, we didn't have to sow any seeds. And this is talking about 50 years prior where there was nothing, the cows were walking through, a real bog. (Dairy producer NSW)

Many interviewees also described additional benefits from the increase in biodiversity, most commonly pest control.

> You certainly get a lot of biodiversity and that in the system, which helps from an insect management point of view and that sort of stuff, all the birds and insects and that prey on other insects, help the system stay a lot stronger. (Prime lamb producer, SW Vic)

Three of the five dairy producers reported water quality benefits associated with trees, though few other producers described this benefit.

> We're very mindful of nutrient sediment runoff, and it's a concern of ours. So, by having those buffer strips, I know that's not 100%, but by having careful rotational management of pastures, number one, trying to avoid pugging through use of a feed pad, and then the vegetation buffers along our waterways that's how we aim to manage the water quality. (Dairy producer, Gippsland, Vic)

> The quality of the water has improved quite a lot since not only – well we fenced and treed that some 10 or 12 years ago, 15 years ago. But in the last 5 or 6 years the neighbours have as well. So there's definitely clearer water. (Dairy producer, Gippsland, Vic)

Improvement to farm aesthetics due to tree plantings were also commonly reported across all production systems.

> it was all just open grassland and now we've got lots of trees plantations and it's aesthetically much nicer and it does provide windbreak and shade for the animals. It makes us humans feel better. (Prime lamb and beef producer, Central Vic)

In some cases, interviewees associated this with improving the farm environment for the people living and working there, as seen in the quote above and as one interviewee commented:

> [tree planting] improves the aesthetics of the of the property, and also it's much more pleasant to be in with the trees here."(Prime lamb and wool producer, SW Vic).

Risks and costs

The most reported risks and challenges were those risks and uncertainties associated with carbon markets and sequestration. Interviewees described various issues with utilising or relying on carbon sequestered by trees, but most interviewees were concerned with the potential for reduced sequestration benefits over time and work already completed on both trees and soil not being accounted for.

> I'm again worried about the situation where you're only doing the right thing if you're increasing [soil carbon] from today and forgetting about people that have increased from 50 or 100 years ago. ... you don't want people that have cleared every single tree off their farm to get a competitive advantage in a carbon market, to put them back, compared to somebody that's already been planting them over the last few years, (Beef producer, Tas).

Other issues described by interviewees included the challenge required to understand carbon sequestration and the market, scepticism related to measurements as well as markets and the difficulty of the auditing process.

Almost half of all interviewees described costs associated with tree plantings and the presence of pest animals, both mammal and insect pests. Most of the interviewees reporting costs associated with pests explained this issue as being a concern because pest animals damaged trees on their farm: "So we've got rabbits and hares that have literally decimated areas that we've popped tube stock into, which is quite devastating. In some years, we don't have a problem" (Beef producer, NSW). The remaining issues with pests were because the trees provided a habitat for the pest animals, therefore encouraging their presence in the area: "And the kangaroos have become a problem in our paddocks, and our plantings are a hideout for them basically" (Prime lamb and wool producer, central Vic).

Over a third of interviewees described risks or challenges associated with timber plantations they had planted, or had considered planting. The most commonly described risks were associated with timber markets being unstable or risky: "no one seems to want it [timber] because it's not economical viable because the sawmills are all too far away" (Wool producer, NSW). This also included higher risk or relatively lower income relative to livestock: "I've only done some very rough numbers on the payback from it and thought that dairy's probably still a better option" (Dairy, SW Vic). The risks and challenges associated with growing particular tree species was another common concern with timber plantings. These issues were due to the management requirements of particular species or were issues associated with growing certain species in their region.

> climate shift has actually affected species choice, and that's why I think long term wise, to answer your question a backwards sort of way, whether they like blue gums and pine, I don't think will be the significant question. My point will be is, 'Will I be able to grow those trees where they've grown them before?' So, they may be forced to actually change species choice. (Prime lamb, wool and beef producer, SW Vic)

> What I'd do differently is I wouldn't plant any southern mahogany. They are a difficult species to grow because they are a really aggressive growing tree, and pruning these massive side branches that are two inches in diameter at two years of age is a serious amount of work. So they're a handful to manage, (Prime lamb and beef producer, NSW)

Other risks and challenges associated with timber were: timber plantations being a monoculture, which was undesirable because it did not provide benefits associated with a more diverse planting; the damage to land and restoration needed following harvest of timber plantations; farms having too small of an area to plant for timber to be commercially viable and the long time frame until harvest of timber.

4.1.4 Financial impacts

A belief that trees are likely increasing the farm resale value was expressed by the majority of farms with wool, dairy and beef enterprises (Table 9). Trees were described as contributing to increasing the value of the farm predominantly because of the aesthetic improvement, but also because the property appears more productive and because tree plantings are often associated with other on-farm improvements.

> They certainly have a positive impact on land values, there's no doubt about that, if you've got a treed property. That's in my opinion, maybe it's different in the marketplace. But certainly a property that

has trees and older trees would be much more valuable than a property without trees. (Beef producer, central Vic)

Interviewer: what's your take on the impact of trees on your property value?

Interviewee: It's only positive and like you just mentioned, we're very fortunate in the area that we farm and if the property was to be sold, it would be more likely that it would be split into smaller lots I would think and sold as lifestyle type – or it's highly probable that it would be sold for viticulture or something like that, so the trees only add value in that situation. (Beef producer, Tas)

Although some interviewees believed that the trees were unlikely to be improving their farm value, none were confident in a decrease in farm value arising from the trees. Ten interviewees suggested that any potential influence of trees on farm value depended on the plans of potential buyers.

Interviewees also reported their current use of, or plan to use, trees to improve their market access or for their marketing as a financial benefit of trees on their farm.

Table 9: Proportion of farms with production system present where a financial impact of trees was reported by the interviewee.

Impact	Production system present on farm			
	Beef (%, n = 29)	Dairy (%, n = 5)	Prime lamb (%, n = 17)	Wool (%, n = 15)
Benefits				
Believe trees are likely increasing farm value	52	60	47	67
Market access, marketing				
Trees currently used or intend to use trees for market access, marketing	31	0	41	43
Trees not currently used in marketing, market access	3	0	24	20
Timber benefits and opportunities				
Financial benefit from timber	14	0	29	7
Financial benefit in the long-term, security	10	0	24	7
Markets available, good prices currently	10	0	24	7
Risks and challenges				
Maintenance of trees (all)	31	0	35	20
Maintenance of timber plantations	17	0	24	13
Managing weeds and pests	14	0	12	7
Labour assistance	7	0	6	7
Believe trees are likely not affecting farm value	17	0	12	13

The climate change and the carbon argument has almost vindicated, to some extent, our position and our tree planting. And now, for the very first time, I'm actually using it – Well, in the last couple of years, I've been using it in our promotions, whereas before, it was something that you almost just keep quiet about. (Beef producer, NSW)

Several different costs were also reported to come from tree plantings, including maintenance of trees (thinning and pruning), costs of employing someone to carry out this work, as well as weed and pest management.

4.1.5 Other considerations for tree planting

A small number of interviewees discussed other considerations that may be important when planning planting (Table 10). Interviewees' relationships with their neighbours were described as potentially influencing their tree planting to avoid conflict or tensions with neighbours who were concerned about trees affecting cropping or fire risk. However, neighbours that were also interesting in planting trees could provide mutual support: "We were an island together, so they were big into land-care works as well. And so, we were kindred spirits and very supportive of one another," (Beef producer, NSW). The presence of trees was suggested to benefit the social license associated with beef production by balancing carbon emissions and improving environmental responsibility.

Table 10: Proportion of farms with production system where consideration was reported by the interviewee.

Consideration	Production system present on farm			
	Beef (%, n = 29)	Dairy (%, n = 5)	Prime lamb (%, n = 17)	Wool (%, n = 15)
Relationship with neighbours	17	0	12	20
Supportive, also planting trees	7	0	6	7
Different priorities, trees are a potential source of tension	10	0	6	13
Social license	7	0	0	7
Productivity of the land to be planted	10	0	6	7

A total of 11 named or types of individuals and 39 organisations or types of organisations were listed as sources of information and advice for interviewees. The most commonly reported information sources were: Landcare groups or networks and their staff; nurseries; Catchment Management Authorities; other groups and networks; other farmers; and family members (Table 11*). These individuals and organisations provided information on topics including tree species selection, plans for planting, maintenance of trees and previous or current research.*

Table 11: Number of interviewees reporting using listed individuals or organisations as a source of advice or information about trees, tree planting and carbon emissions/sequestration.

Information source	Number reporting	Information source	Number reporting
Organisations and their staff		**Individuals**	
Landcare group or network	23	Other farmers	7
Nursery	12	Partner, family, relatives	7
Catchment Management Authority	11	Other people living in the area	5
Other networks and groups	7	Farm and business consultants	5
Agriculture Victoria	5	**Other sources**	
MLA, Local Land Services	4	Participating in research or trials	5
Council, CSIRO, Melbourne Water	3	Reading: media sources	7
Council	3	Reading: existing research	6
CSIRO	3	Own experience and property	5
Melbourne Water	3		

Six types of tools or resources were listed as being used to plan or in relation to tree planting, most commonly carbon calculators such as those using the Greenhouse Accounting Framework (GAF, Table 12). Fifteen funding sources were named by interviewees, with Landcare the most common source or means of identifying funding (Table 13).

Table 12: Proportion (%) of farms with production system reporting using resources to assist with planning of tree planting.

Tools and resources used	Production system present on farm			
	Beef (%, n = 29)	Dairy (%, n = 5)	Prime lamb (%, n = 17)	Wool (%, n = 15)
Carbon calculators	7	20	18	7
Mapping (photos, software)	0	20	12	0
Farm management software	0	20	6	0
Farm Tree	3	0	0	0
Forestry software	3	0	6	0
Don’t use online tools	3	0	6	0

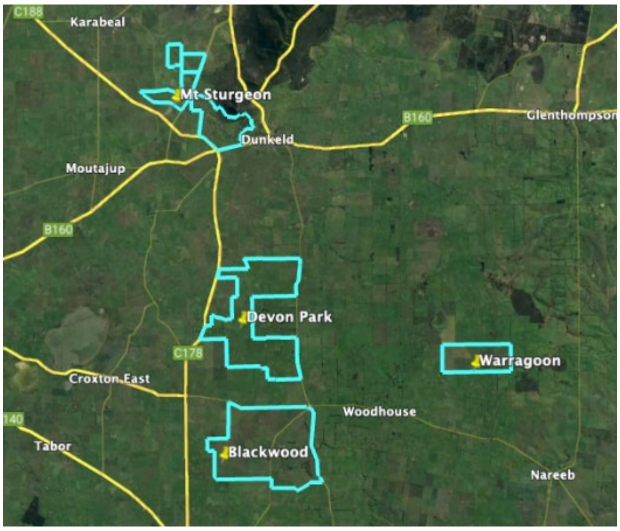
Table 13: Proportion of farms with production system reporting using organisation as a source of funding to plant trees.

Funding sources	Production system present on farm			
	Beef (%, n = 29)	Dairy (%, n = 5)	Prime lamb (%, n = 17)	Wool (%, n = 15)
Landcare (including funding sourced via Landcare)	14	0	18	7
CMA	3	0	12	7
Local council	7	20	12	0
Melbourne Water	7	0	12	0

4.2 Case study analysis

4.2.1 Dunkeld Pastoral Co. Pty Ltd

Figure 2. Locations of the four properties assessed in the Dunkeld Pastoral case study.



Description

Sheep (prime lamb) enterprise (also an IMS case study)

<u>Location</u>: Four properties of Dunkeld Pastoral in Southwest Victoria: Blackwood, Devon Park, Mt Sturgeon, and Warragoon (Fig. 2).

<u>Agro-ecological region</u>: Temperate cool-season wet. Annual rainfall of 690 mm.

<u>Property size</u>: Two properties will be used in the case study. First, the 'Blackwood' property of 2,460 ha of which 46 ha (2%) is woody vegetation. A whole farm plan has been drawn up with proposals to plant 378 ha over several years to lift the proportion of woody vegetation on the property to 17%. Second, the 'Warragoon' property of 650 ha of which 109 ha (17%) is woody vegetation. There are plans to establish a further 31 ha of trees, bringing the proportion of woody vegetation on the property to 22%.

<u>Livestock</u>: The two properties are part of consolidated holdings of 11,500 ha in the region that run 30,000 composite ewes, 3,500 Merino ewes and wethers, and 3,000 Angus cattle. Marking rate over all breeding composite ewes is 1.24%.

<u>Ownership structure</u>: Family owned, family board of directors.

<u>Farming experience of current operators</u>: Principal person has 20 years of experience.

Existing vegetation and proposed plantings

Table 14 summarises the area of each property included in the Dunkeld Pastoral case study, and the area of existing planted woody vegetation and proposed environmental plantings. Fig. 3 is an image of a recent planting from the Dunkeld property. The planting timeline with areas per year at the 4 properties is outlined in Table 15. Appendix 2 includes maps of the existing and proposed plantings at the Blackwood, Devon Park, Mt Sturgeon and Warragoon properties.

Table 14: Dunkeld Pastoral statistics for property areas planted or proposed to be planted with trees

Property	Property area (ha)	Stocked tree area (ha)	Proportion of property	Proportion of treed area
Blackwood	*2460*			
Existing trees		49	2.0%	12%
Proposed planting from 2022		366	14.9%	88%
Total		415	16.9%	100%
Devon Park	*2130*			
Existing trees		83	3.9%	20%
Proposed planting from 2022		329	15.5%	80%
Total		412	19.4%	100%
Mount Sturgeon	*1216*			
Bush Brokerage		180	14.8%	51%
Other existing trees		151	12.4%	42%
Proposed planting from 2022		25	2.1%	7%
Total		356	29.3%	100%
Warragoon	*650*			
Existing trees		98	15.1%	76%
Proposed planting from 2022		31	4.8%	24%
Total		130	19.9%	100%
Total	*6456*			
Existing trees		561	8.7%	43%
Proposed planting from 2022		752	11.6%	57%
Total		1313	20.3%	100%

Notes

1. Property boundaries taken from Dunkeld Pastoral maps for Blackwood and Warragoon, from the shapefile for Devon Park, and from information provided by Dunkeld Pastoral for Mt Sturgeon.
2. The areas of existing vegetation and proposed planting are those areas that are forest (i.e., plantings have the potential to reach 2 metres or more in height and provide crown cover of at least 20% of the land) and have a stocked area of at least 0.2 ha, or have forest potential.
3. Proposed shelterbelts are typically 30 m wide.
4. Remnant paddock trees are not included in the statistics.

Table 15: Proposed establishment of environmental plantings on the four properties in the Dunkeld

Property	Proposed planting (ha)									Total
	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Blackwood	98.6	36.5	5.3	37.4	23	81.1	84.2			366.1
Devon Park	15.8	6.8	37.9	38.9	47.7	45.8	49.5	48.6	38.3	329.3
Mount Sturgeon		5.0	5.0	5.0	5.0	5.0				25
Warragoon		31.2								31.2
Total	114.4	79.5	48.2	81.3	75.7	131.9	133.7	48.6	38.3	751.6

Pastoral case study over the period 2022 to 2030.

As, in terms of carbon with all the case studies we *used the following calibrations from the FullCAM guidelines (details in Methods section 3.2.2):*

- *Environmental Planting calibration, Block configuration; and*
- *Environmental Planting calibration, Belt configuration, <1500 stem per ha.*

Figure 3: Recent shelterbelt planting at Dunkeld

On examining the spatial imagery at Dunkeld, some of the existing plantings qualified for a belt planting calibration. However, we were conscious that the age of existing plantings had been estimated and hence the modelling commencement date we used may not have been accurate. To be conservative, all existing plantings in the CEAs were modelled using the mixed species environmental planting block calibration.

At Dunkeld there were small areas of conifers, mostly Radiata Pine (Pinus radiata), estimated to be more than 50 years of age at the Blackwood property (2.8 ha) and the Devon Park property (9.8 ha). The carbon stocks in these plantings were modelled with a user defined FullCAM calibration for Radiata Pine. At Warragoon there were 23.5 ha of Spotted Gum (Corymbia maculata) planted from 2008-2009. There was no calibration in FullCAM for this species, so we used the calibration for Sugar Gum (Eucalyptus cladocalyx), a species with similar growth habits to Spotted Gum.

Mapping of vegetation and modelling of sequestration

Updates to maps of existing vegetation on Dunkeld pastoral properties was required. We completed the mapping of the existing planted woody vegetation in Google Earth, for all areas that were forest (>=20% canopy cover and >=2 m height) and had a stocked area of at least 0.2 ha (Australian Government, 2018). To assist in estimating ages of existing plantings, Dunkeld pastoral provided photographs of the 35 areas added in the course of updating the maps.

Using these photographs, and viewing the imagery on Google Earth, we estimated the age of each planting in the following age classes: 0-5, 5-10, 10-20, 20-30, 30-50, and >50 years. Species groups were differentiated based on the shape and colour of the tree crowns – compared to eucalypts, conifers had larger, rounded crowns that were darker green in colour.

Once the age classes were assigned to the shapefiles, the spatial distribution of each age class was examined. This was done to determine which shapefiles of the same age class and species group could be combined to form a single carbon estimation area (CEA) according to the rules in the mapping guidelines issued by the Clean Energy Regulator (Australian Government, 2018). Implementation of these standards led to the creation of 9 CEAs at Blackwood, 11 at Devon Park, 28 at Mt Sturgeon, and 8 at Warragoon.

Dunkeld Pastoral provided maps of areas of proposed plantings for the period of 2022-2030. We created shapefiles and CEAs for these plantings with a minimum area specified of 0.2 ha and estimated the width of plantings established as a linear belt. The proposed plantings were distributed evenly over the entire planting period. The proposed plantings were mapped in 96 CEAS as follows: Blackwood 44 CEAs, Devon Park 37 CEAs, Mt Sturgeon one CEA, Warragoon 14 CEAs.

Carbon Sequestration

The long-term carbon sequestration, expressed as tonnes of carbon dioxide equivalent per year (t CO_2e/year), by existing trees and proposed planting during 2022 to 2030 at four properties at Dunkeld Pastoral is shown at Figs. *4 and 5. Sequestration varies over time driven by the large areas proposed to be planted during 2022-2030 and the pattern of tree growth that peaks at an early age and then slows as the trees fully occupy the site. The peak sequestration by existing trees of 4,187 t CO_2e/year occurred in 2023, whereas the peak sequestration by the proposed plantings was predicted to be 16,180 t CO_2e/year in 2033. Combined, the peak carbon sequestration by existing and proposed plantings on the four properties at*

Figure 4. Long-term carbon sequestration by existing trees and proposed planting during 2022 to 2030 at four properties at Dunkeld Pastoral

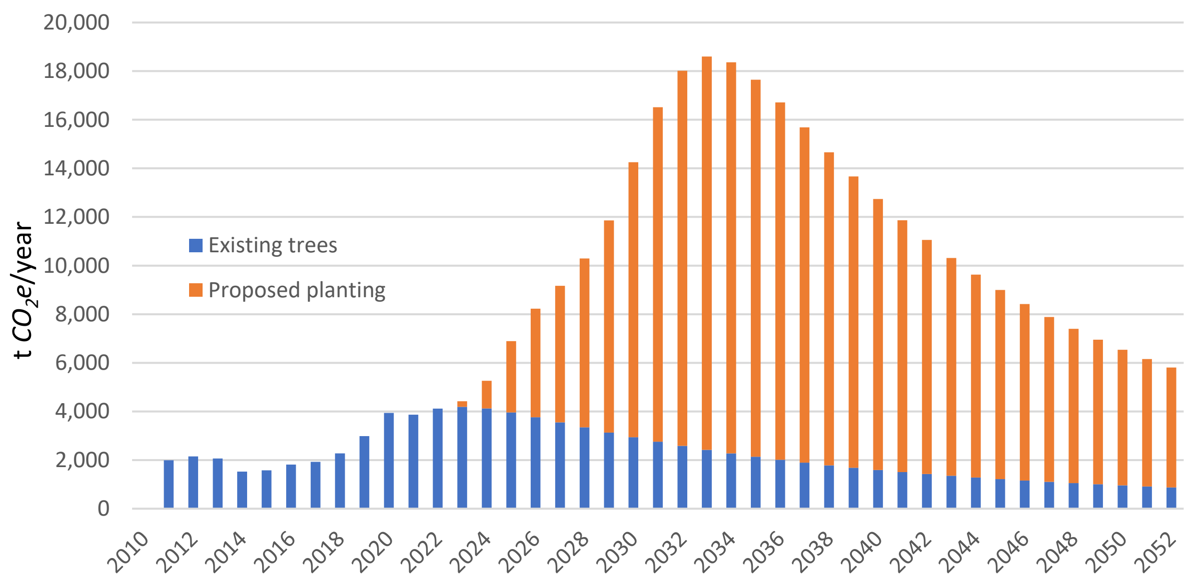
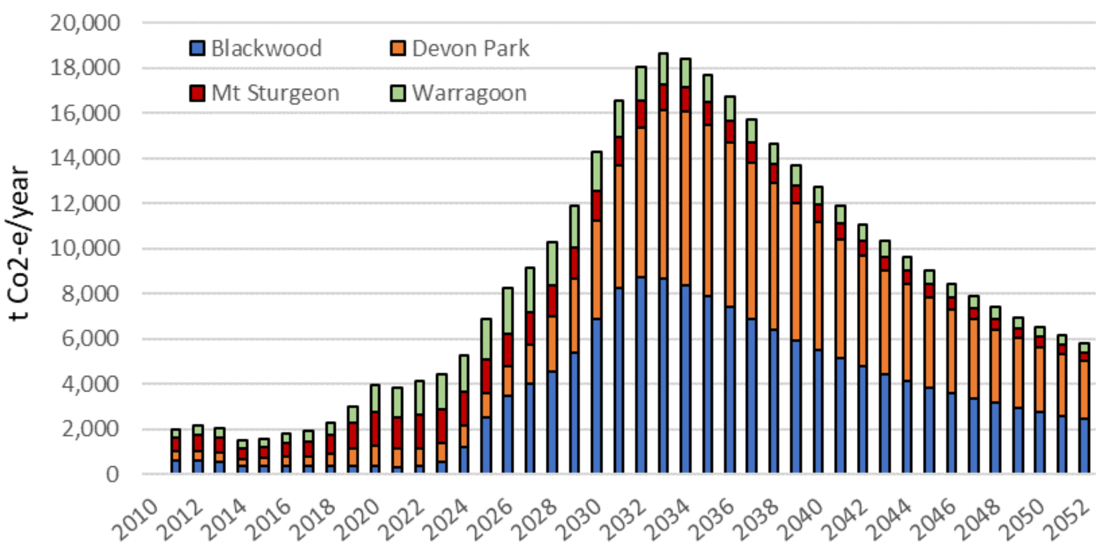


Figure 5. Long-term carbon sequestration by existing trees and proposed planting combined for each property at Dunkeld Pastoral.



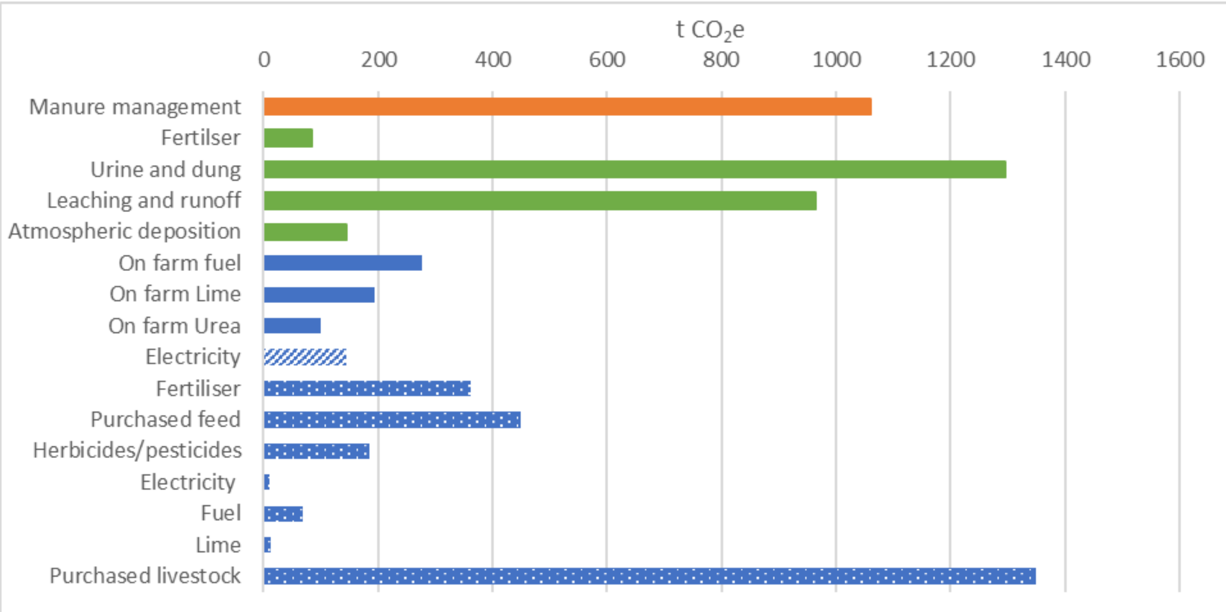
Dunkeld Pastoral of 18,600 t CO_2e/year was predicted to occur in 2033. With no further planting, the annual rate of sequestration for existing trees and proposed planting was predicted to fall to 5,805 t CO_2e/year by 2052.

At the end of the modelling period in 2052, the cumulative sequestration was predicted to be 136,200 t CO_2e for existing trees and 270,000 t CO_2e for proposed plantings, giving a combined total of 406,200 t CO_2e across the four properties. Using this estimate for new plantings gives an average sequestration rate over the modelling period of 12.0 tonnes CO_2e/ha/year across proposed plantings.

Emissions

The total emissions from Dunkeld including Scope 3 emissions from inputs into the farm system (e.g. purchased livestock, fertiliser, herbicides, etc) was 27,024 *t CO_2e. As is the case of livestock systems, the main emission was enteric methane. Enteric methane comprised 76% of Dunkeld pastoral emissions. The remaining sources of emissions at the Dunkeld property are displayed in* Fig. *6. Total on-farm (Scopes 1 &2) and total emissions (Scopes 1-3) for Dunkeld are included in Table 16.*

Figure 6: Sources of emissions from the Dunkeld operation. Orange is CH4 emissions, green is N2O emissions, blue is CO2 emissions. Solid is scope 1 emissions, diagonal line is Scope 2 emissions, and spotted is Scope 3 emissions. On farm fuel contains a small amount of N2O.



Net Farm Emissions

On-farm emissions have to be reduced, offset, and/or inset to claim a farm is carbon neutral. Total emissions (including Scope 2 and 3) have to be reduced, offset and/or inset to claim a product from a farm, such as beef or wool, is carbon neutral.

Over a 30-year planning period carbon sequestration from tree planting was about 37% of on-farm emissions and a third of total emissions on the Dunkeld property (Table 16). Sequestration varies over time with tree growth, rising to peak and then declining as tree mature and fully occupy the site. At its peak in 2033, carbon sequestration in proposed tree plantings can reduce net on-farm emissions by 66% and net emissions, including scope 3, by 60%.

Biophysical Modelling of effects of shelter on lambing

At the Blackwood property near Dunkeld, the base case was assumed to be 100% wind speed, as there are currently little vegetation on the property. A reduction of 30% in the windspeed experience by the herd there

Table 16: Comparison of peak and annual sequestration with on-farm and total emissions at Dunkeld

Boundary	Sequestration (t CO_2e)	Percent of emissions sequestered	
		On farm (Scope 1 & 2, 24,590 t CO_2e)	Total emissions (Scopes 1-3, 27,020 t CO_2e)
Peak in 2033 Proposed plantings	16,180	66%	60%
30-year average Proposed plantings	9,000	37%	33%
Peak in 2033 All plantings	18,600	76%	69%
30-year average All plantings	11,130	45%	41%

was considered reasonable with the proposed plantings. We also investigated a 60% reduction in windspeed to investigate the impacts of more effective reduction in wind speed experienced by the herd.

Production increased noticeably at Dunkeld with increased shelter. The increase in average lambs per ewe in August increased from 1.24 with 100% wind to 1.32 with 70% wind to 1.41 with 40% wind. This is a 6.5% increase in lambs per ewe with a 30% reduction in wind speed and a 9.2% increase with a 60% reduction in wind speed. The impact this has on traded livestock is shown in Table 17. It is expected that the larger percentage of lambs sold compared to percentage increase in lambing reflects that in a self-replacing system a given increase in lamb numbers results in a greater percentage of lambs sold.

Table 17: Number of extra lambs sold at Dunkeld with shelter from plantings reducing wind speeds by 30% and 60%

	30% reduction in wind speed	60% reduction in wind speed
10th percentile	3245	7066
median	3382	7380
90th percentile	3935	8647

Economic Analysis

Based on assumptions about reduced wind speed from tree shelterbelts and increased lamb production, an investment in trees on 750 ha of land on the Dunkeld case study farm could increase farm wealth over the 30-year assessment period. However, this is dependent on the productivity of the land where the trees are grown, the costs of auditing the carbon sequestered, and the likely reduction in wind chill from the trees (e.g. the corresponding number of extra lambs that are sold). Mean annual real return on extra capital invested in planting trees ranged from negative to 10% (Table 18).

If wind reductions are large, carbon audit costs are low (as defined in the methods, section 3.2.4), and the trees are replacing lower quality pastures, then on average the investment in trees could earn 10% p.a. real return on extra capital invested. However, if the carbon audit costs are high and trees are replacing high performing pastures (18 DSE/ha), it is unlikely that planting trees would be a good investment.

Table 18. Mean annual real return (Internal Rate of Return) on extra capital invested in planting trees on 750 ha of land that had previously grown pasture.

	Mean annual real return on extra capital (SD)		Chance of earning 10%	
Scenario	***Trees replacing 9 DSE/ha pastures***	***Trees replacing 18 DSE/ha pastures***	***Trees replacing 9 DSE/ha pastures***	***Trees replacing 18 DSE/ha pastures***
Auditing cost: 10% carbon value Shelter benefit: 60% wind speed reduction, average of 7,700 extra lambs	10% (0.9%)	5% (1.9%)	64%	Unlikely
Auditing cost: 30% Shelter benefit: 60% wind speed reduction, average of 7,700 extra lambs	8% (1%)	2% (2.2%)	1%	Unlikely
Auditing cost: 10% carbon value Shelter benefit: 30% wind speed reduction, average of 3,500 extra lambs	7% (1%)	1% (3%)	Unlikely	Unlikely
Auditing cost: 30% carbon value Shelter benefit: 30% wind speed reduction, average of 3,500 extra lambs	4% (1%)	Negative return	Unlikely	Unlikely

Based on the assumptions made for the threshold analysis at Dunkeld annual co-benefits from year 7 to 30 would need to be valued between $350,000 in the optimistic scenario (low carbon auditing costs and low quality of replaced pasture) to $920,000 in the pessimistic scenario (high carbon auditing costs and high quality of replaced pasture) for the investment in trees to achieve a 10% p.a. return. The number of extra lambs required is based on the average net benefit per extra lamb of $45. The values required for each scenario are displayed in Table 19.

If growing extra trees on the Dunkeld property provide no additional benefits to the farm system, then the value of the carbon sequestered needs to more than $90/ t CO_2e every year for the investment to earn on average 10% p.a. real return on extra capital (Table 20).

Table 19: Threshold analysis: The minimum value of annual co-benefits in dollars and number of extra lambs sold, starting in year 7, that are required for the investment in trees to average 10% p.a. real return (if assumptions above hold)

	Trees replacing pasture that carried 18 DSE/ha & auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 9 DSE/ha, auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 18 DSE/ha & auditing costs are 10% of carbon benefit	Trees replacing pasture that carried 9 DSE/ha & auditing costs are 10% of carbon benefit
Minimum value of co-benefits	$920,000	$520,000	$750,000	$350,000
Number of extra lambs required	20,440	11,560	16,670	7,780

Table 20: Minimum value of carbon ($/tCO$_2$e/yr) needed over 30 years to earn on average 10% p.a. real return on extra capital invested if trees provide no co-benefits to the farm system.

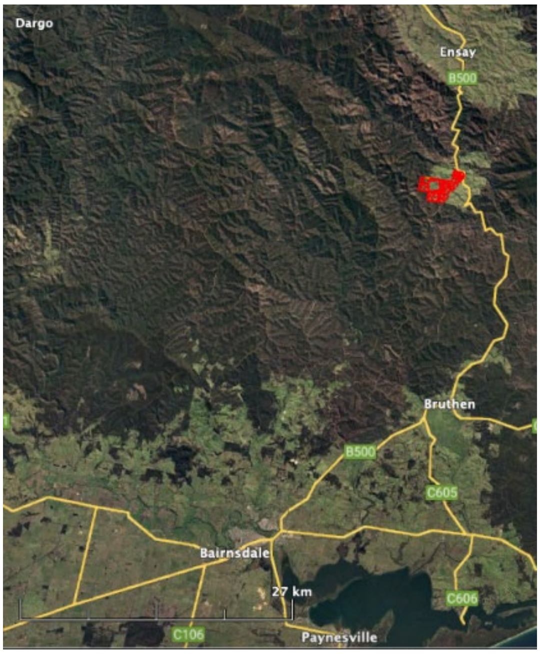
	Trees replacing pasture that carried 18 DSE/ha & auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 9 DSE/ha, auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 18 DSE/ha & auditing costs are 10% of carbon benefit	Trees replacing pasture that carried 9 DSE/ha & auditing costs are 10% of carbon benefit
Minimum value of carbon	$160/ t CO$_2$e	$115/ t CO$_2$e	$120/ t CO$_2$e	$90/ t CO$_2$e

4.2.2 Tambo crossing

Description

Sheep (prime lamb) enterprise plus a Beef enterprise (also a NEXUS case study)

Figure 7. Location of the Tambo Crossing case study.



*<u>Location</u>: Tambo Crossing and Clifton Creek in East Gippsland (*Fig. 7*).*

<u>Agro-ecological region</u>: Temperate cool-season wet. Annual rainfall of 750-800 mm.

<u>Size</u>: 660 ha across two properties with approximately 60 ha of woody vegetation and infrastructure, plus 160 ha share-farmed across two properties.

<u>Livestock</u>: A 'steady state' livestock enterprise has been defined with the case study farmer. The first part is a self-replacing composite flock comprising 800 mature ewes and 400 ewe lambs joined each year. Lambing in July, with 140% lamb making. All wether lambs sold in January (44 kg live weight), and 400 ewes lambs sold in May (50 kg live weight).

The second part is a self-replacing Angus herd of 250 mixed-age cows joined, with 95% calving for mature cows and 85% for first-calf heifers. Approximately 50 steers and 50 heifers sold in May (280 kg live weight); a further 70 steers sold in September (340 kg live weight). The overall stocking rate is 16 per ha.

<u>Ownership structure</u>: Family partnership across two generations.

<u>Farming experience of operators</u>: Two people, each with 12 years of experience.

Existing vegetation and proposed plantings

Table 21 summarises the area of existing woody vegetation and proposed plantings at Tambo Crossing. Appendix 3 includes the map of the plantings at Tambo.

For the Tambo Crossing case study, we use the following calibrations:

- *Environmental Planting calibration, Block configuration; and*
- *Environmental Planting calibration, Belt configuration, <1500 stem per ha.*
- *Eucalypt plantation (see details below)*

In addition to the environmental planting block and environmental planting belt with less than 1,500 stems/ha, a Eucalypt plantation calibration was used at Tambo Crossing. Areas of each of these planting types is provided in Table 21. FullCAM had calibrations for three eucalypt plantation species but not for species native to the locality. We consulted with a FullCAM expert (Geoff Roberts, pers comm (2022)), and developed an approach to model abatement in the proposed eucalypt plantation, which led to the use of a user-defined calibration in FullCAM (Appendix 4). We also developed a silvicultural regime for the proposed plantation (Appendix 5).

At Tambo, there were numerous paddock trees and trees along watercourses that were not mapped during this exercise; collectively, these trees may have provided about another 1% of tree cover on the farm.

Table 21: Size of the Tambo Crossing case study, with the area of existing woody vegetation and proposed plantings.

Land use	Area (ha)	Proportion of farm area
Owned land	642	
Leased land	128	
Whole farm	770	
Remnant forest	70.6	9.2%
Existing shelterbelts	2.9	0.4%
Total existing treecover	73.5	9.6%
Proposed shelterbelts	7.0	0.9%
Proposed environmental plantings	4.5	0.6%
Proposed eucalypt plantation	28.4	3.7%
Total proposed	39.9	5.2%
Potential treecover on the property	**113.3**	**14.7%**

Mapping of vegetation and modelling of sequestration

Following a site visit, we constructed the shapefiles for remnant vegetation on the property from a farm paddock map provided by the owners and from polygons for the various parcels of land obtained from (Department of Energy Environment and Climate Action, 2023b). Using Google Earth, we then delineated the areas of remnant native forest.

We then created polygons for remnant areas of the property that had been burnt by wildfires, using spatial data for wildfires in Victoria since 1903 (Department of Energy Environment and Climate Action, 2023a). These data showed that the property had been affected by wildfires in 1939, 1965, 2007 and 2020. We grouped areas of remnant native forest with the same wildfire history, which led to four CEAs, with a total area of 70.4 ha.

Existing shelterbelts established at Tambo Crossing – one in 2012 and four in 2021 were planted with mixed species native to the area. The widths of the belts varied from 12 m to 30 m. These were mapped in Google Earth. The total area was 1.3 ha. There were two shelterbelts of Radiata Pine on the leased land at Tambo Crossing with an area of 1.6 ha. These were excluded from the carbon sequestration analysis.

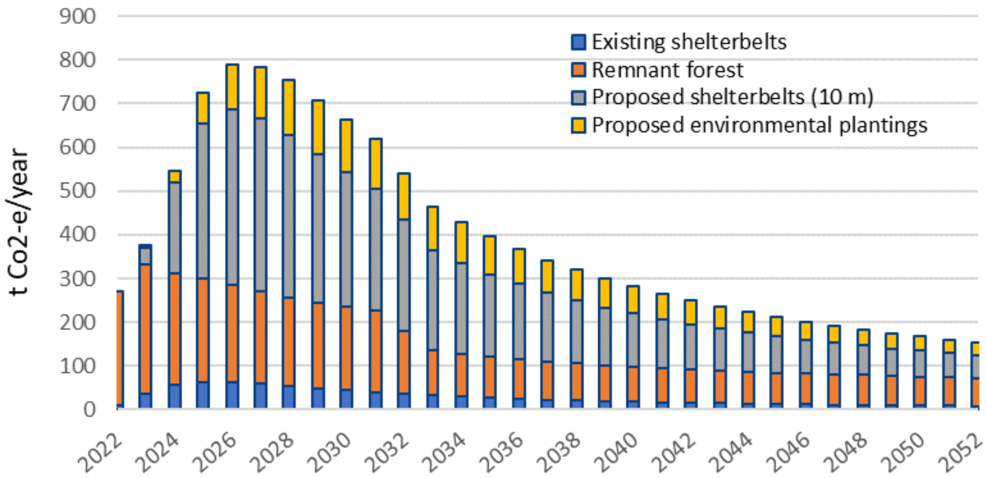
The mapping of proposed plantings started with a meeting with the farmer to identify areas on the property where he would like to establish shelterbelts (10 m wide) to improve the farm business. We also discussed opportunities to establish less productive areas of the farm with environmental plantings and a eucalypt plantation to produce timber for sawing. The proposed plantings were mapped in 23 CEAS as follows: shelterbelts 16 CEAs, environmental plantings 3 CEAs, eucalypt plantation 4 CEAs.

Carbon Sequestration

The long-term carbon sequestration (t CO_2e/year) predicted in existing vegetation and the planting scenario with 10-m wide shelter belts and environmental plantings is shown in Fig. *8. The estimated total sequestration over the simulation period for this scenario was 12,082 t CO_2e. The peak carbon sequestration for the proposed plantings was predicted to be 515 t CO_2e /year in 2027, falling to 82 t CO_2e /year by 2052. The peak including existing vegetation was 788 t CO_2e /year in 2026, falling to 154 t CO_2e /year in 2052 (*Fig. *8).*

The existing vegetation at Tambo sequestered a total of 4810 t CO_2e over the 30-year simulation period, with about 82% of this from the remnant vegetation. This is due to regeneration following the 2007 and 2020 wildfires. The sequestration from the existing vegetation including burned areas slowly declines, which is expected in natural forest systems.

Figure 8. Total carbon sequestration (t C/ha/year) predicted for plantings at Tambo crossing by planting type.

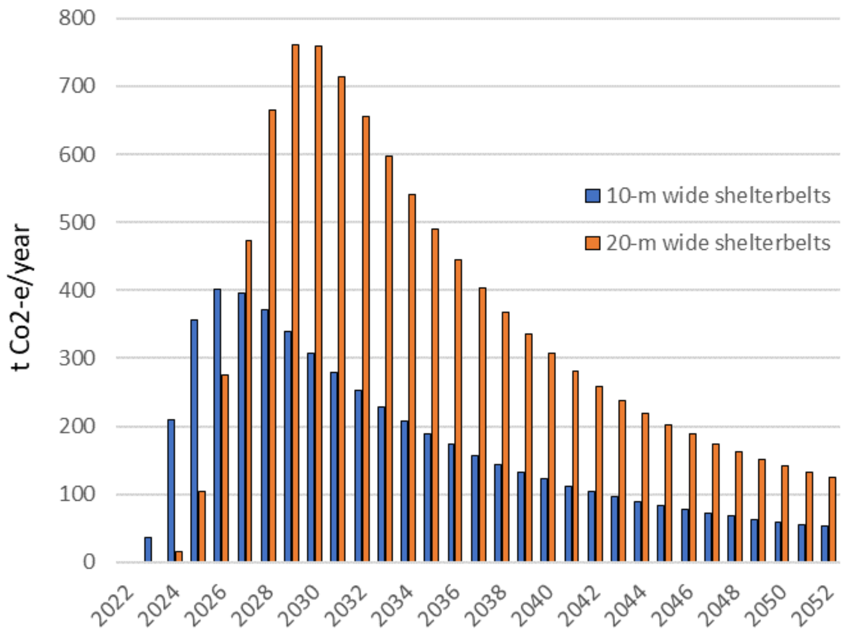


*In an alternative scenario for this case study shelterbelts were doubled in width, for a total of 14 ha of shelterbelts, and with planting occurring over a 5-year period. The peak sequestration for 10-m wide shelterbelts was 401 t CO_2e /year in 2026, whereas the peak sequestration with 20-m wide shelterbelts planted from 2023 to 2026 was 760 t CO_2e /year in 2029 (*Fig. *9). Cumulative sequestration was 5,239 t CO_2e and 10,183 t CO_2e for the 10- and 20-m wide shelterbelt scenarios, respectively.*

This case study incorporated a timber planting scenario with a 28.4 ha plantation of Eucalyptus species native to the area. We applied a user-defined calibration in FullCAM to predict carbon sequestration for a plantation managed on a 30-year rotation to produce timber for sawing.

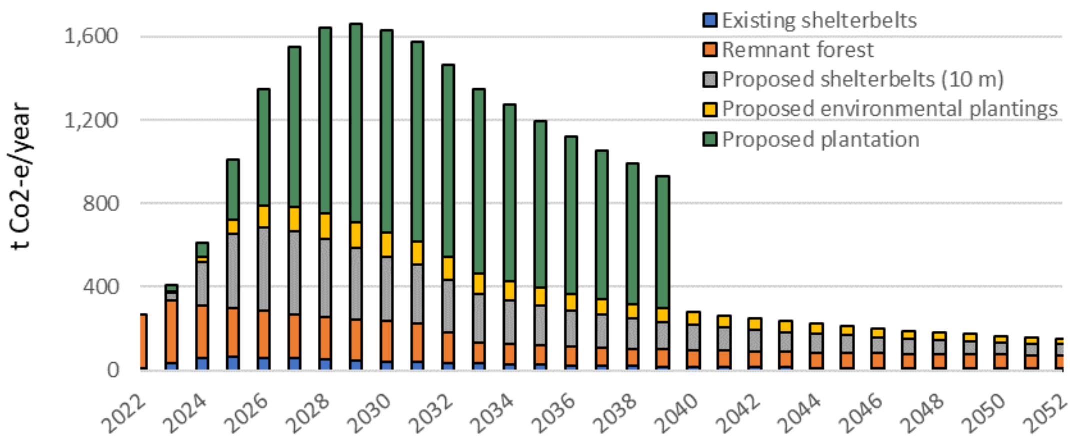
Plantations managed in the long term for timber production will have fluctuating carbon stocks as trees are grown and harvested in an ongoing cycle. To ensure that a plantation does not receive more carbon credits than the carbon that would be accrued over the project life, carbon credits are not issued for any growth in trees beyond the estimated long-term average carbon stock for the project which is the maximum net abatement claim for the project. The net abatement takes into account sequestration from trees growing and carbon stored in harvested wood products minus emissions from harvesting, thinning, fire, fuel and fertiliser use resulting from the project. The long-term average carbon stock is normally calculated over 100 years. The result from our simulations was that the cumulative abatement for the proposed plantation was equal to our estimate of the long-term average carbon stock in 2039 when the plantation was 17 years old. Beyond that age, no further carbon sequestration was assigned to the proposed eucalypt plantation.

Figure 9. Total carbon sequestration (t C/ha/year) for 10-m and 20-m wide shelterbelts.



*Carbon sequestration at Tambo Crossing was boosted significantly with the proposed 28.4-ha eucalypt plantation. The plantation reached a peak sequestration of 964 t CO_2e/year in 2030 and based on the accounting guidelines sequestered a total of 11,676 t CO_2e from 2023 to 2039 (*Fig. *10). The fast-growing species and comparatively large area of planting leads to the timber plantation sequestering a substantial portion (62%) of the carbon associated with the tree planting in this scenario.*

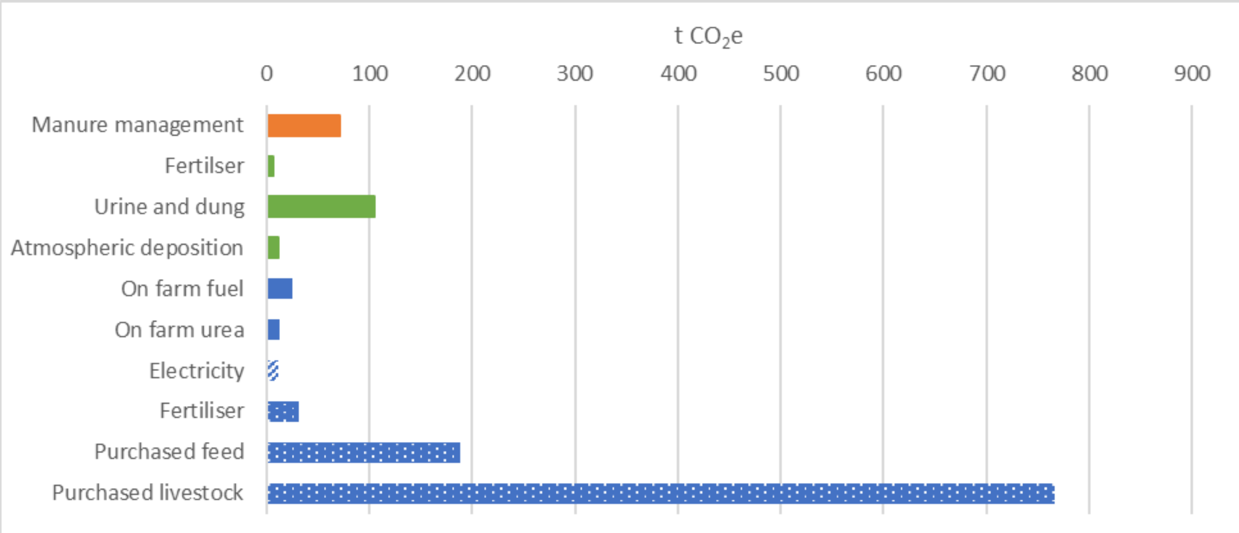
Figure 10. Carbon sequestration (t C/ha/year) associated with the scenario with existing plantings, 10-m wide shelterbelts, environmental planting, and a Eucalypt plantation.



Emissions

At Tambo Crossing the on-farm (Scopes 1 &2) emissions were 1,743 t CO_2e and the total emissions (Scopes 1-3) were 2,732 t CO_2e. The main emission was enteric methane comprising 86% (1,497 t CO_2e) on-farm emissions at Tambo crossing. The remaining sources of emissions are displayed in Fig. *11. The large number of purchased livestock in this case study resulted in large amount of Scope 3 emissions compared to typical systems.*

Figure 11: Sources of emissions from the Tambo crossing operation. Orange are CH4 emissions, green is N2O emissions, blue is CO2 emissions. Solid is scope 1 emissions, diagonal line is Scope 2 emissions, and spotted is Scope 3 emissions. Enteric methane and emissions sources with less than 5 t CO_2e are not listed. On farm fuel includes a small amount of N2O emissions.



Net Farm Emissions

The proportion of the farm emissions that can be offset by sequestration from tree plantings at Tambo crossing are displayed in Table 22. This includes a calculation using peak sequestration and another based on the annual average sequestration over 30 years. For this case study, results of three tree planting scenarios are shown. Only in the scenario with the most planting did trees more than offset on-farm emissions; this occurred at Tambo Crossing in 2028 to 2031.

Table 22: Comparison of peak and annual sequestration with on-farm and total emissions at Tambo Crossing

	Percent of emissions offset	
	On farm (Scope 1 and 2) 1,740 t CO_2e	Total (Scope 1,2 &3) 2,730 t CO_2e
Scenario 1: 10-m wide shelterbelts, environmental planting		
Peak in 2027 (515 t CO_2e)	30%	19%
30-year average (242 t CO_2e)	14%	9%
Scenario 2: 10-m wide shelterbelts, environmental planting, and a timber plantation		
Peak in 2029 (1,411 t CO_2e)	81 %	52%
30-year average (632 t CO_2e)	36%	23%
Scenario 3: 20-m wide shelterbelts, environmental planting, and a timber plantation		
Peak in 2030 (1,886 t CO_2e)	108%	69%
30-year average (824 t CO_2e)	47%	30%

Figure 12: View of the pasture and topography of the Tambo Crossing property

Biophysical Modelling

*At Tambo crossing the topography and existing shelterbelts mean sheep are already have some shelter from the wind (*Fig. *12). To reflect this the base case was an 15% reduction in windspeed, or 85% of ambient wind. This was compared to 100% windspeed and a further reduction in windspeed to 50% with the proposed plantings.*

*There was little difference in production with reduced wind speeds at Tambo Crossing. Average lambs per ewe in July was 1.28 with 100% wind, 1.29 with 85% wind and 1.31 with 50% wind speed. This is a 0.8% increase with a 15% reduction in wind speed and a 2.3% increase with a 50% reduction in wind. The impact this has on traded livestock did was skewed to lower animal numbers. Over the 30-year period there were many cases of a relatively small increase in livestock production with a long tail of few observations with greater increases. For instance, with a 15% reduction in wind speed on average there were about 20 extra lambs sold and in about 80% of years there were less than 40 extra lambs with the shelter (*Fig. *13).*

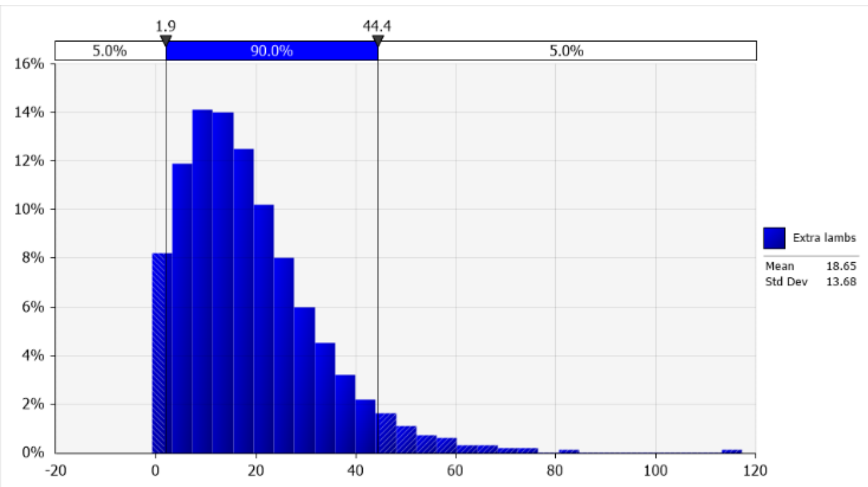


Figure 13: The distribution of extra lambs sold due to shelter reducing wind speed by 15%

Economic Analysis

It is unlikely that an investment in growing 40 ha of trees on the Tambo Crossing case study farm (instead of 40 ha of pasture) would earn 10% p.a. real return on the extra capital invested in any scenario. If the Tambo Crossing farm business expects that an extra 60 lambs is likely to be sold as a result of the reduction in wind chill the extra trees grown provide, if the cost of auditing the carbon sequestered is only 10% of the benefit from the carbon sold, and the trees are replacing low performing pasture (9 DSE/ha) then an investment in extra trees could earn on average 7% p.a. real return on the extra capital invested. In the other scenario investigated, the farmer would likely earn a lower return on their investment (Table 23). The similarity between the different scenarios suggests that the timber revenue is providing the bulk of the return on investment in this case study, since the revenue from timber does not change in the different auditing cost and shelter effectiveness scenarios.

Table 23. Mean annual real return (Internal Rate of Return) on extra capital invested in planting trees on 40 ha of land that had previously grown pasture.

	Mean annual real return on extra capital (SD)	
Scenario	***Trees replacing 9 DSE/ha pastures***	***Trees replacing 18 DSE/ha pastures***
Auditing cost: 10% carbon value Shelter benefit: 50% wind speed reduction, average of 60 extra lambs	6.7% (0.2%)	4.0% (0.3%)
Auditing cost: 30% carbon value Shelter benefit: 50% wind speed reduction, average of 60 extra lambs	5.3% (0.2%)	2.8% (0.3%)
Auditing cost: 10% carbon value Shelter benefit: 15% wind speed reduction, average of 20 extra lambs	6.4% (0.2%)	3.8% (0.3%)
Auditing cost: 10% carbon value Shelter benefit: 15% wind speed reduction, average of 20 extra lambs	5.1% (0.2%)	2.6% (0.3%)

The threshold analysis at Tambo crossing found that a minimum annual return from Year 7 to year 30 would need to be between 35,000 (optimistic case) and $75,000 (pessimistic case) for the investment in trees to earn a 10% p.a. return (Table 24). This is using the base assumption outlined in the methods including the value of carbon sequestered starting at $35/t CO_2e and rising at 5% every year to a value of

Table 24: Minimum value of annual co-benefits, starting in year 7, required for the investment in trees to average 10% p.a. real return (if assumptions above hold)

	Trees replacing pasture that carried 18 DSE/ha & auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 9 DSE/ha, auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 18 DSE/ha & auditing costs are 10% of carbon benefit	Trees replacing pasture that carried 9 DSE/ha & auditing costs are 10% of carbon benefit
Minimum value of co-benefits	$75,000	$46,000	$60,000	$35,000
Number of extra lambs required	1,670	1,020	1,330	780

$80/t CO_2e. The number of extra number of lambs that need to be sold is based on the assumed average net margin of $45/head.

If planted trees provide no additional benefits to the farm system, then the value of the carbon sequestered needs to be more than $85/t$CO_2$e every year for the life of the investment to provide a 10% annual return (Table 25).

Table 25: Minimum carbon value ($/t CO_2e) required from year 1 to earn on average 10% p.a. real return on extra capital in investing in trees.

	Trees replacing pasture that carried 18 DSE/ha & auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 9 DSE/ha, auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 18 DSE/ha & auditing costs are 10% of carbon benefit	Trees replacing pasture that carried 9 DSE/ha & auditing costs are 10% of carbon benefit
Minimum value of carbon	$140/ t CO_2e	$105/ t CO_2e	$110/ t CO_2e	$85/ t CO_2e

4.2.3 Rosewhite

Figure 14. Location of the Rosewhite beef system case study

Description:
Angus beef enterprise

<u>Location</u>: Property in a valley at the base of the alps of northern Victoria west of Myrtleford and east of Rosewhite (Fig. 14).

<u>Agro-ecological region</u>: Temperate, cool season wet with an average rainfall of 1020 mm[††].

<u>Property size</u>: The property used in the case study is 298 ha. It currently has 36 ha or 12% remnant vegetation and 3.0 ha or 1% area with existing tree plantings. The planting scenario includes 14 ha, leading to a total of 53 ha or 17.7% comprised of woody vegetation.

<u>Livestock</u>: The property carries a 175 self-replacing herd of Angus cattle at an average of 14.1 DSE/ha. Calving occurs in winter and the start of spring. All steers and most heifers are sold in autumn, steers at an average weight of 320 kg and heifers at an average weight of 300 kg.

<u>Ownership structure</u>: Family owned.

<u>Farming experience of current operators</u>: Over 25 years for both individuals.

Existing vegetation and proposed plantings

Table 26 shows the area of existing woody vegetation and proposed plantings at Rosewhite. Paddock trees and trees along watercourses were not mapped during this exercise. Collectively, these trees may have provided about another 1% of tree cover on the farm.

[††] *Bureau of Meteorology. Myrtleford (Ovens Research Station) 83057, statistics for 1962-2022*

Table 26: Size of the Rosewhite case study, with the area of existing woody vegetation and proposed plantings.

Land Use	Area (ha)	Proportion of farm
Whole farm	297.9	100%
Remnant forest	35.8	12.0%
Existing farm trees	3.0	1.0%
Proposed planting	14.0	4.7%
Tree cover on property	52.9	17.7%

Mapping of vegetation and modelling of sequestration

Remnant

Following a site visit on 6 May 2022, we obtained shapefiles for the property for the various parcels of land from MapShareVic[‡‡]. Using Google Earth, we then delineated the areas of remnant native forest. We then created polygons for those areas of the property that had been burnt by wildfires, using spatial data for wildfires in Victoria since 1903.[§§] These data showed that the remnant forest on the property had been affected by wildfires in 2009.The remnant forest occurred in eight separate patches. An image of the forest is provided in Fig. *15. We grouped these areas into one CEA with a total area of 35.8 ha (Appendix 6).*

In consultation with a FullCAM expert (Geoff Roberts, pers comm (2022)), we modelled abatement in the remnant native forest starting in the year 1920 and ran the simulation until 2053. The forest was on private land, so we used the human-induced regeneration calibration for 'native species regeneration >= 500 mm rainfall'. The key events modelled for the various CEAs that were delineated based on their fire history included: 1920 - Plant trees, natural regeneration; 7 February 2009 - Wildfire –trees not killed.

Planted woody vegetation

Fifteen shelterbelts had been established at the Rosewhite property from 2007 to 2022. The belts were planted with mixed species native to the area. The widths of the belts varied from 5 m to 12 m, and the stocked areas ranged from 0.03 ha to 0.23 ha. Two plantings had been established around farm dams and another along Jacksons creek. We mapped these in Google Earth. The total stocked area was 3.0 ha.

On 25 July 2022 we held a virtual meeting with the farmer. She identified areas on the property for the establishment of shelterbelts and environmental plantings to improve the farm business, notionally during 2023-2026. We agreed to exclude from the analysis the rehabilitation of Willow-infested riparian zones of Jacksons creek and Happy Valley creek, as some of these areas had been treated using funds from a program conducted by the Northeast Catchment Management Authority. We discussed the opportunity to establish a Radiata Pine plantation on the farm to produce timber for sawing, but this was excluded from the final design of tree plantings. The farmer provided final shapefiles for the proposed plantings in August 2023. These were mapped as nine CEAs (Appendix 6).

Sequestration

The results of carbon abatement for existing trees and proposed tree planting at Rosewhite are shown at Table 27. *The carbon sequestration of the remnant forest was predicted to be 333 tonnes of carbon dioxide equivalent in 2011 (t CO_2e /year), falling to 26 t CO_2e /year by 2053. For the existing plantings, the peak*

‡‡ MapShareVic. https://mapshare.vic.gov.au/mapsharevic/.

§§ Victorian State Government. *Fire history records of fires across Victoria showing the fire scars*. https://discover.data.vic.gov.au/dataset/fire-history-records-of-fires-across-victoria-showing-the-fire-scars.

Figure 15. View of pasture and remnant forest in the bush block of the Rosewhite property

carbon sequestration was predicted to be 73 t CO_2e /year in 2025, falling to 11 t CO_2e /year by 2053; for the proposed plantings, the peak carbon sequestration was predicted to be 284 t CO_2e /year in 2030, falling to 68 t CO_2e /year by 2053.

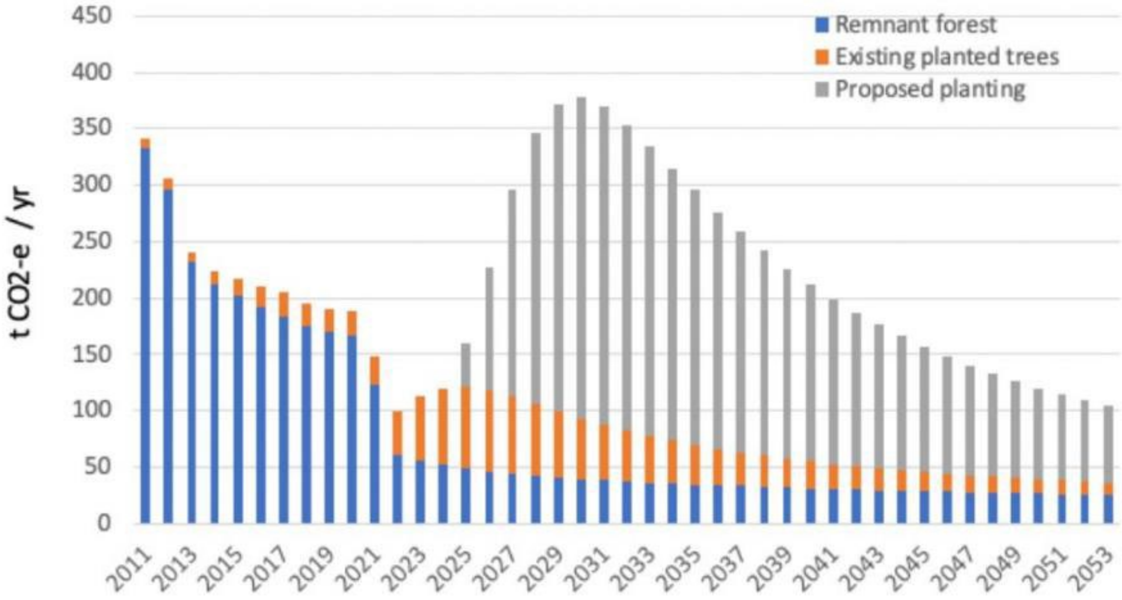
Table 27. Carbon abatement for existing trees and proposed plantings at Rosewhite

Type	Description	Area (ha)	Year of Planting	Peak sequestration (t CO_2e/year)	Year of peak sequestration	Sequestration in 2053 (t CO_2e/year)
Remnant	Eucalypt forest	35.8	n.a.	333	2011	26
Existing	Shelterbelts & environmental plantings	3.0	2007-2022	73	2025	11
Proposed	Shelterbelts & environmental plantings	14.4	2023-2026	284	2030	68

The long-term carbon sequestration by existing trees together with proposed planting during 2023-2026 at the Rosewhite property is shown at Fig. *16. Sequestration varied over time driven by the establishment of all proposed plantings over a four-year period and the pattern of tree growth that peaks at an early age and then slows once the trees fully occupy the site. The carbon sequestration by the remnant forest during the period 2011-2021 was high relative to the long-term average for this forest type. Between 2011 and 2021, the annual rate of sequestration by the remnant native forest decreased from about 334 t CO_2e /year to about 125 t CO_2e /year as the effects of the 2009 wildfire in stimulating regeneration and hence additional carbon stocks dissipated. Beyond 2021 there was a slow, steady decline in the annual rate of carbon sequestration, which is what is expected in these natural forest systems.*

Combined, the predicted peak annual carbon sequestration by existing trees and proposed planting at the Rosewhite property of 378 t CO_2e /year occurred in 2030. With no further planting, the annual rate of carbon sequestration by existing trees and proposed plantings falls to a predicted 105 t CO_2e /year by 2053.

Figure 16: Long-term carbon sequestration by existing and proposed planting during 2023-2026 at the Rosewhite property.



Over the 30-year timeframe from 2024 to 2053 the total sequestration was 6,664 tonnes CO_2e giving an annual average sequestration over the 30-year period of 222 tonnes of CO_2e. Of the total sequestration 69.5% was from the 14 ha of plantings which sequestered an average of 11 tonnes of CO_2e/ha/year over the 30 years.

Emissions

The total emissions associated with beef production at Rosewhite was 758 tonnes CO_2e. The vast majority of this, 82%, was from enteric methane. The next largest source was nitrous oxide from urine and dung at 5.7%. Scope 3 emissions totalled just 20 tonnes CO_2e with 68.5% of these emissions from the purchase of bulls. Sources of emissions are shown in Fig. *17.*

Net Farm Emissions

Given the low values of Scope 3 emissions from this system, the difference in the percent of on-farm and percent total emissions that is sequestered by trees is small (Table 28). The 14.4 ha of proposed planting sequesters 284 t CO_2e at its peak in 2030 and sequesters an annual average of 154 over 30 years.

The peak sequestration across existing and proposed plantings vegetation of 340 tonnes CO_2e/year occurred in 2030. Thus in 2030, assuming livestock emissions do not change, tree carbon sequestration from plantings was 47% of on-farm emissions. The annual average sequestered over 30 years for all plantings was 190 tonnes of CO_2e per year. This is represents a 25% reduction in total emissions for every year over a 30-year period, assuming estimated emissions stay constant at 2022-23 values.

High amounts of sequestration in remnant vegetation in the 2011-2021 period reflects recovery of the bush block following fire. This is not included in the sequestration or net emissions estimates since it is outside the 30-year analysis period.

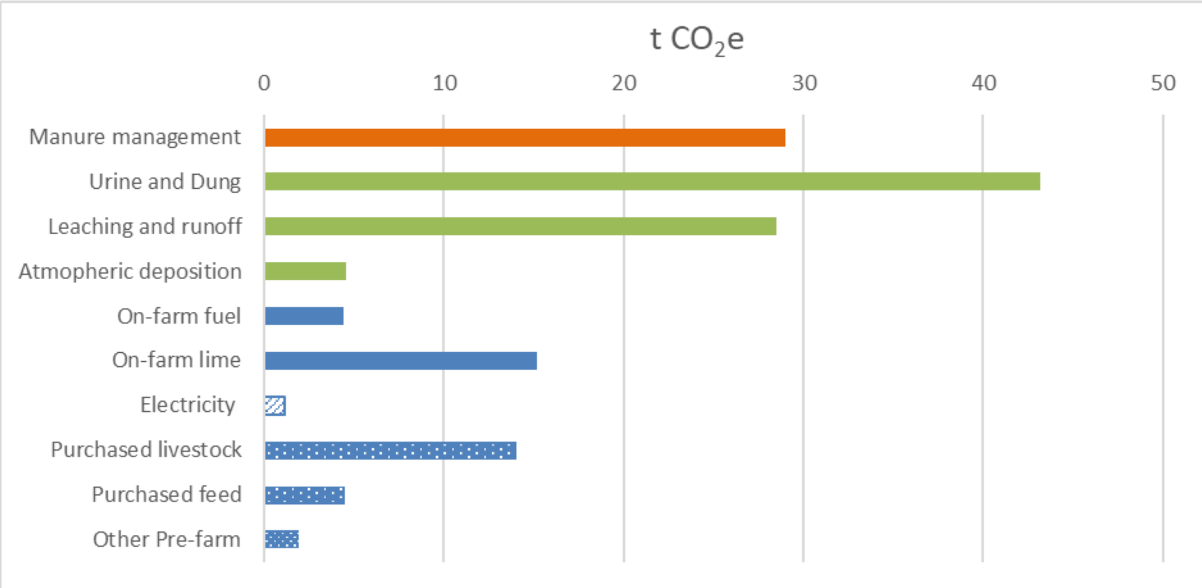
Biophysical Modelling

Given there are no sheep in this system, biophysical modelling was not undertaken for this case study. The threshold value required calculated as part of the economic analysis is compared to values in the literature for increases in weight gain with reduced heat and cold stress.

Table 28: Comparison of peak and annual sequestration with on-farm and total emissions at Rosewhite

Boundary	Sequestration (t CO_2e)	Percent of emissions sequestered	
		On farm (Scope 1 & 2, 738 t CO_2e)	Total emissions (Scopes 1-3, 758 t CO_2e)
Peak in 2030 Proposed plantings	280	38%	37%
30-year average Proposed plantings	150	20%	20%
Peak in 2030 All plantings	340	47%	45%
30-year average All plantings	190	26%	25%

Figure 17 Sources of emissions from the Rosewhite operation. The orange bar is CH4 emissions, green bars are N2O emissions, blue bars are CO2 emissions. Solid bars are scope 1 emissions, diagonal line is Scope 2 emissions, and spotted bars Scope 3 emissions. Enteric methane and sources with less than 1 t CO_2e are not listed. On farm fuel includes a small amount of N2O emissions.



Economic Analysis

If trees are grown on 14 ha of land on Rosewhite, that has little to no grazing and it was assumed there was no co-benefits, then the investment is likely to earn on average 10% p.a. real return on the extra capital if the price of carbon was more than \$96/t CO_2e in the scenario with low costs and \$136 in the scenario with the highest cost of lost pasture area and carbon auditing (Table 29).

The extra trees may provide a benefit to the Rosewhite farm business, but valuing this extra benefit is more difficult. The trees may increase the dry matter grown and may reduce heat or cold stress in cattle which may increase liveweight gain. Rather than try to estimate these benefits, only a threshold analysis was performed. This calculated the minimum value of the co-benefits for trees earns on average 10% p.a. real return on extra capital, assuming the value of carbon sequestered by the trees was \$35/t CO_2e (which increased over time to \$80/t CO_2e). To earn on average 10% p.a. real return, the extra benefits could be as low as \$10,500 or as high as \$16,200 depending on the opportunity cost of the trees and the cost of auditing the carbon sequestered (Table 30).

Table 29: Minimum value of carbon ($/t$CO_2$e) required from year 1 if trees provide no co-benefits to the farm system, for the investment to earn on average 10% p.a. real annual return on extra capital invested.

	Trees replacing pasture that carried 3 DSE/ha & auditing costs are 30% of carbon benefit	Trees grown in areas not used for grazing, auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 3 DSE/ha & auditing costs are 10% of carbon benefit	Trees grown in areas not used for grazing & auditing costs are 10% of carbon benefit
Minimum value of carbon	$136/ t CO_2e	$124/ t CO_2e	$106/ t CO_2e	$96/ t CO_2e

Given the farm sells an average of 163 animals every year this equates to a per animal improvement of between $64.42 and $99.39. If one assumes the average price per kg liveweight from October 2018 to October 2023 of $3.87 (Meat and Livestock Australia, 2023), that results in a required added weight gain of between 16.6 to 25.7 kg due to shade and/or shelter to achieve a 10% p.a. real return. Although the increased weight gain may not be attributed solely to shelter, increases in liveweight of up to 40 kg have been observed on this farm when comparing animals wintering in a bush block to those in more open country. There is very little information on the impacts of cold stress on cattle weight gain but cold does increase maintenance requirements (Bird, 1984) and has been shown reduce daily gain and lower body weights (Wang et al., 2023).

Table 30: Minimum annual value of co-benefits, starting in year 7, required for the investment in trees to average 10% p.a. real return on extra capital invested (if assumptions above hold)

	Trees replacing pasture that carried 3 DSE/ha & auditing costs are 30% of carbon benefit	Trees grown in areas not used for grazing, auditing costs are 30% of carbon benefit	Trees replacing pasture that carried 3 DSE/ha & auditing costs are 10% of carbon benefit	Trees grown in areas not used for grazing, & auditing costs are 10% of carbon benefit
Minimum value of co-benefits	$16,200	$14,000	$13,000	$10,500

Studies on the impact of shade from trees on weight gain in extensive cattle systems in Australia are limited. It is well understood that dry matter intake is reduced in hotter conditions, and it has been shown that shade reduced the impacts of heat stress on dry matter intake (Chang-Fung-Martel et al., 2021). Research on shade structures and shade cloths in feedlots in summer suggest increases in weight gains of the magnitude needed at Rosewhite (17 -26 kg) are plausible. In Queensland, Angus steers with access to shade had an exit weight that was on average 17.7 kg heavier than non-shaded animals after 120 days (Gaughan et al., 2010). Similarly shaded Black Angus steers in a Queensland feedlot had an average daily gain that was 0.74 kg/day greater than unshaded animals over 90 days starting from 2 January (Sullivan et al., 2011). In South Africa crossbred steers with access to shade were on average 6 kg heavier after a 36-day trial (Blaine and Nsahlai, 2011) and shaded crossbred heifers in Texas were an average of 27 kg heavier following 131-day experiment (Mitlöhner et al., 2001). It should be noted that there is evidence suggesting that trees are more effective at reducing temperature and temperature indices than shade structures (Cheung and Jim, 2018).

4.3 The decision framework

*A decision framework was co-designed with a small group of farmers using input from interviewees and from those attending various events, (*Fig. *18). Individual components of the decision framework can be used independently, or in combination, depending on farmer requirements. Both the information summaries and the index of resources can support the use of the planning tools. Farmers may start in any component and move between them as needed.*

This project has involved many outreach activities to present results and provide opportunities to incorporate farmer input into outputs. This includes farmer specific events such as field days and a landcare forum as well as more formal presentations and conferences. A webpage is also being developed to host this information. A table of events where results or draft versions of the decision framework from the Trees on Farm project was presented is included in Appendix 7. This does not include ongoing discussions interview participants, consultants, and collaborators with other organisations that have shown interest in receiving project updates.

Planning Tools

Planning tools include a step-by-step guide and the decision matrix for tree planting decisions (Fig. 18). The step-by-step guide provides an overall context to planting including planning, timing and budgets, tips from experienced farmers and considerations for plantings with specific objectives. This is particularly helpful to farmers inexperienced with tree planting.

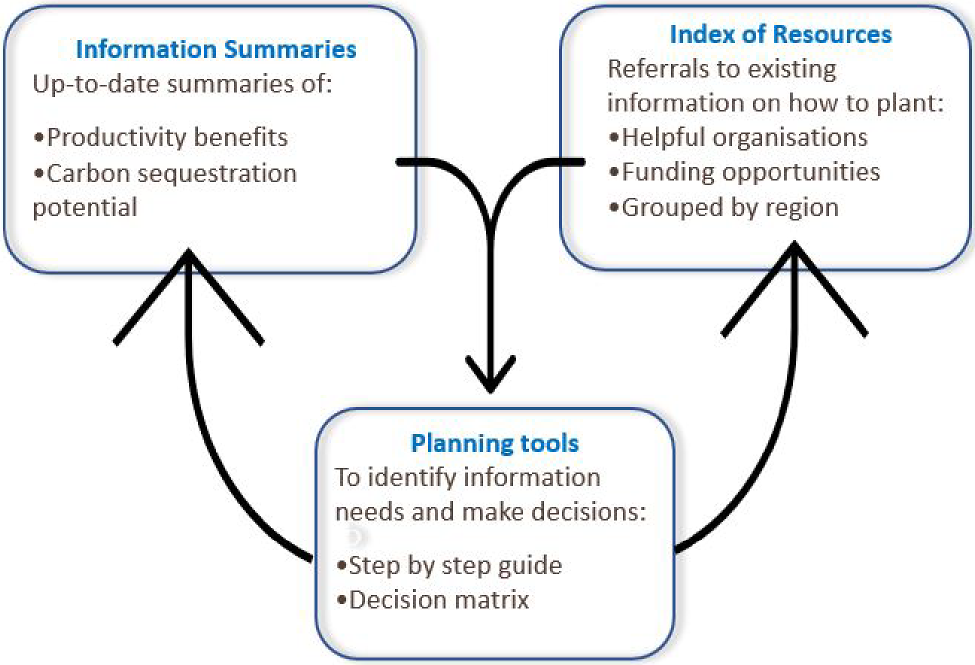


Figure 18: Tree growing decision framework components and their potential interactions.

The decision matrix generally supports farm decisions and is particularly useful when several factors of varying importance are involved. The decision wizard is an online tool that walks users through the decision matrix process. Decisions matrices relevant to tree planting can be found in the e-library on this site by searching for "trees".

Information summaries

Two fact sheets summarising up-to-date information on carbon sequestration and productivity co-benefits. They are based on the data obtained from the literature reviews and incorporate quotes from the interviews. These resources are focused on data available on these topics so farmers understand the potential and limitations of carbon sequestration on farm and the potential co-benefits that may occur on their farm. The values from these fact sheets can inform the decision-making process including comparing to values that farmers select if they undertake the decision matrix process.

Index of resources

Considerable information is available on tree planting on farms. The extent of these resources can make it difficult to find specific information relevant to a given situation. The index of resources organises these "how to" resources so farmers can easily find what they need to be able to implement tree planting on their farm.

5 Discussion

For continuity and to improve readability the discussion for interview analysis was incorporated into the interview results section (Section 4.1). Discussion here focuses on points arising from the case study analysis.

5.1 Carbon sequestration

Factors influencing sequestration rate: *Climate and soils largely influence the underlying growth rates at a particular site. FullCAM predictions are heavily influenced by the parameter M, which defines the maximum aboveground biomass accumulation for undisturbed, mature native vegetation at the site in question.*

Across the four properties at Dunkeld Pastoral, there was considerable variation in the parameter M in the FullCAM model (that is, the estimated maximum biomass at that site): the mean values of M for CEAs modelled, expressed as tonnes per hectare of dry aboveground biomass, were 162 at Blackwood, 155 at Devon Park, 108 at Warragoon, and 76 at Mt Sturgeon. Hence, the rates of sequestration predicted for environmental plantings at Blackwood were about double those predicted at Mt Sturgeon.

At Tambo Crossing the M parameter was high, for the four CEAs (and the property in general) with an average of 240 t dry matter/ha for undisturbed native vegetation. Given the native forest at the location is productive forest when fully stocked, the timber production of the Eucalypt plantation was predicted to be similar to the environmental planting. The FullCAM simulations for the proposed eucalypt plantation indicated that the increase in carbon stocks from our user-defined calibration was only 5-9% more than predicted by the environmental planting calibration for the four plantation CEAs. If the plantation was established, periodic inventory could be used to compare measured growth with predicted growth by FullCAM, and the results used to adjust carbon sequestration where appropriate.

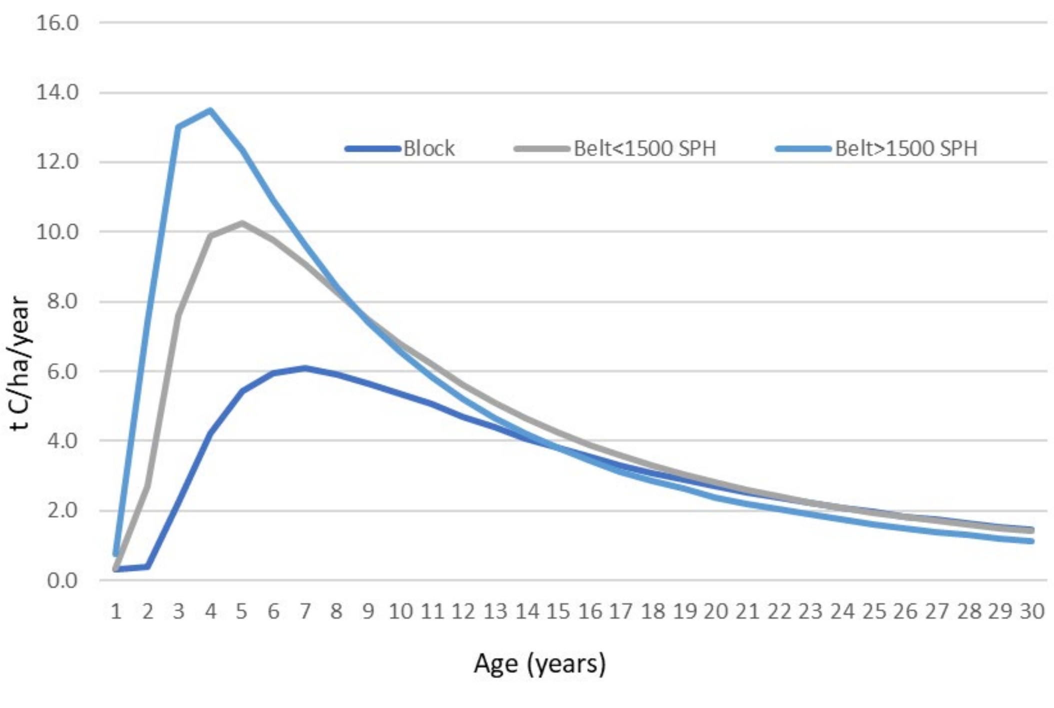
Planting configuration: Nearly one-fifth (18%) of the proposed plantings at Dunkeld, all the shelterbelts at Tambo, and one of the shelterbelts at Rosewhite were designed to be linear belts less than 40 m wide. This meant that they could be modelled in FullCAM using the belt plantings <1500 stems per ha growth calibration instead of the block plantings growth calibration. At Rosewhite at peak growth, the rate of sequestration for belts was nearly double block plantings. By about 20 years of age the annual rate of sequestration was similar for both types of plantings. Over the 30-year simulation period, FullCAM predicted that the cumulative sequestration for belts would be about 30% more than by the block plantings on a per hectare basis. For a site at Blackwood (Dunkeld property), with average productivity according to FullCAM, *we modelled the carbon stocks using three calibrations: block, belt <1500 stems/ha and belt >1500 stem/ha (Fig. 19). The high density might be achieved on sites direct seeded rather than planted with tubestock; some of the proposed planting at Dunkeld Pastoral properties will be direct seeded.*

Investigating these calibrations allowed us to assess the difference in sequestration that can be achieved in belt plantings compared to block plantings and directing seeding (>1500 stem/ha) compared to planting seedlings (<1500 stems).

In FullCAM, the parameter 'G' is the tree age of maximum growth, in years, which is usually the age at which the canopy closes. For the growth calibration for environmental plantings established in belts (no more than 40 m wide) with >1500 stems/ha, G was 4.0 years while in belts with <1500 stems per ha G was 4.5 years, For environmental plantings established in blocks calibration, G was 6.3 years (DISER, 2020). FullCAM predicted that annual carbon sequestration of belt plantings with >1500 stems/ha peaked at age 3 to 4 years with a rate of 13.5 t C/ha/year and for belt plantings with <1500 stems/ha the peak was 4 to 5 years at about 10 t C/ha. This is compared to a peak annual sequestration at age 6 to 7 years of about 6 t C/ha for block plantings. By about age 20 years, the annual rate of sequestration was similar for all three types of plantings

Over a 30-year growth period, FullCAM predicted the cumulative sequestration for the belt plantings would be 144.2 t C/ha for plantings with densities >1500 stems/ha and 134 t C/ha for those <1500 stems/ha, and 98.6 t C/ha for the block plantings at the Blackwood site. Compared to the block plantings, the belt plantings at >1500 stems/ha were predicted to accumulate 46% more carbon over 30 years and the belt plantings at <1500 stems/ha were predicted to accumulate 36% more carbon over the same period.

Figure 19. Carbon sequestration (t C/ha/year) predicted for environmental plantings established as belts and blocks for one site at the Blackwood property.

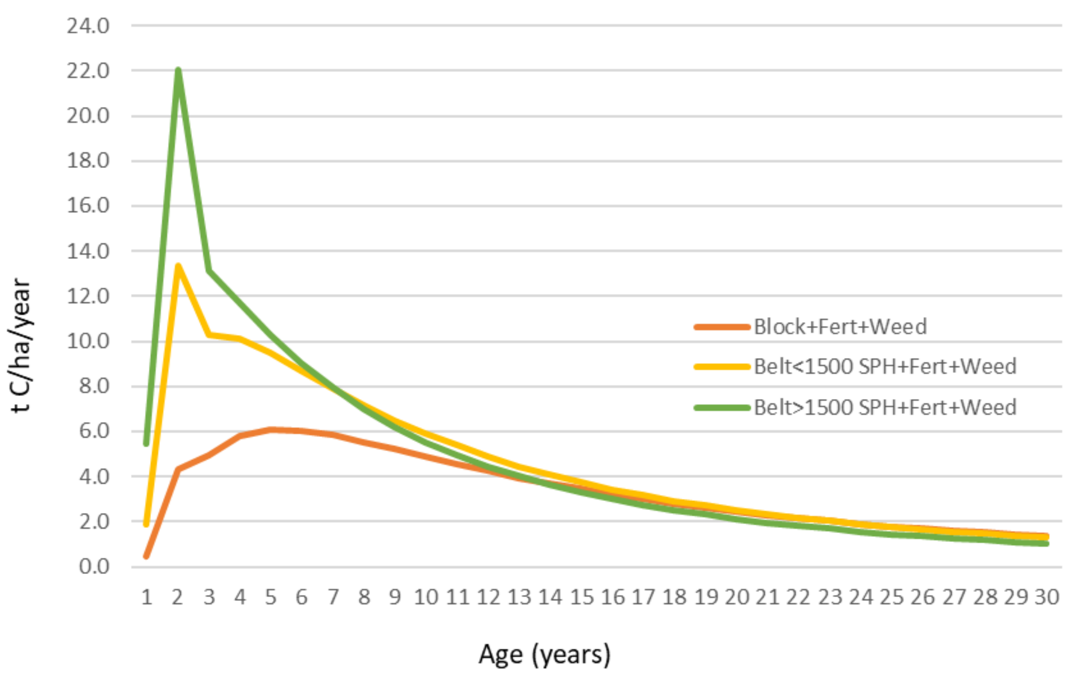


The increase in sequestration in belts compared to blocks has been observed from measurements of plantings across northern Victoria (Bennett, 2022 unpub.). However, caution should be exercised when making inferences, as the differential in tree growth and hence carbon sequestration between these two planting configurations will largely depend on the width of the belt. For example, a 10 m wide belt will have a higher proportion of 'edge' trees that will generally be larger than internal trees due to less inter-tree competition, than say a 40 m wide belt. Thus, in practice, the narrower the belt, the greater the expected *differential between carbon sequestration per unit area when comparing belt configurations to block configurations.*

Site preparation: FullCAM also estimates the impact of weed control and fertiliser application on sequestration rates. The effect of starter fertiliser is to advance the growth by 0.5 of a year, while the effect of weed control is to advance growth by 1.0 years. Comparison of the results from Fig. 19 with fertiliser and weed control to the same configuration without this management (Fig. 20) demonstrate earlier and larger peak sequestration. We took a conservative approach and did not model fertiliser and weed control treatments when estimating carbon sequestration.

Estimating sequestration rates: FullCAM calibrations reflecting different configurations and establishment methods (block v belt, density, and the use of weed control and application of fertiliser) have large impacts on FullCAM's estimate of sequestration rate. The peak rate of carbon sequestration for the most productive regime (belt >1500 stems per ha + starter fertiliser + weed control, Fig. 20) was 3.6 times that of the least productive regime of a block planting (a peak sequestration rate of 22 t C/ha/year, Fig. 20, vs 6 t C/ha/year, Fig. 19) on a site at Dunkeld Pastoral. The carbon sequestration after 30 years for these two calibrations was predicted to be 145.8 t C/ha and 98.6 t C/ha, an increase of 48% for the most productive regime. Most of this difference was due to changing the establishment method from planting seedlings at a low density (<1500 stems per ha) to direct seeding at a high density (>1500 stems per ha), rather than the effects of fertiliser and weed control.

Figure 20. Carbon sequestration (t C/ha/year) predicted for environmental plantings established as belts and blocks under different management regimes for one site at the Blackwood property.



We treat these comparisons with a great deal of caution. We recently measured carbon stocks in environmental plantings in western Victoria and compared the results with FullCAM predictions. We found that tree densities about one-third higher at direct seeded sites compared to planted sites (1360 vs 1000 stems per ha) did not lead to markedly different carbon stocks for plantings of similar age. Also, we are not convinced that the growth responses to starter fertiliser and weed control modelled in the FullCAM calibrations accurately reflect the responses when environmental plantings are established on improved pastures on farmland. It is common for plantings done without weed control to fail entirely.

Our recent research in western Victoria also indicated that FullCAM (2020 Public Release version) underpredicted live biomass carbon stocks relative to the actual carbon stocks in well-stocked environmental plantings. This may be the case at Dunkeld Pastoral, particularly for those properties with a lower M value for specific plantings. We therefore recommend that the FullCAM predictions are checked once the plantings have achieved canopy closure (say between 5 and 10 years) by conducting field-based measurements on a range of plantings.

5.2 Net Emissions

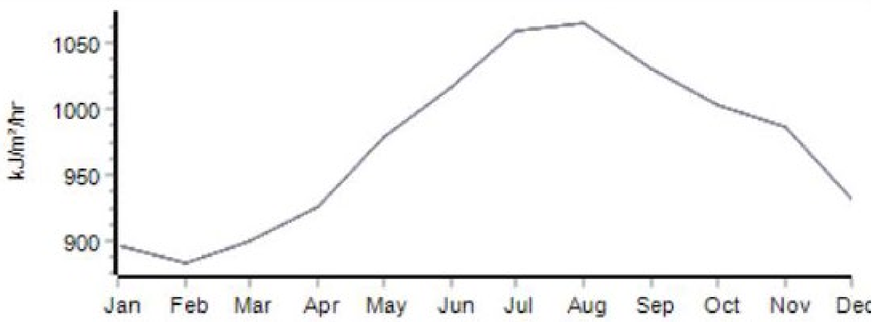
There was no scenario in the case study farms where the carbon sequestration in trees offset all emissions, including Scope 3. When looking at Scope 1 emissions only, carbon neutrality was achieved at Tambo Crossing for a few years around 2030 when shelterbelts were 20 metres wide. Although in most instances, the tree plantings considered for these case studies do not achieve carbon neutrality, they offset a substantial proportion of emissions. Based on the 30-year average sequestration, emissions at the Dunkeld were reduced to a third due to tree planting. At Tambo, scenarios including the timber plantation and using the 30-year average sequestration reduce net emissions by about a quarter. At Rosewhite the 14-ha planting resulted in a reduction over 30 years of 20%. These reductions are much greater than any that could be achieved by other currently available mitigation options. Reductions in net farm emissions when excluding Scope 3 were even greater.

5.3 Biophysical modelling

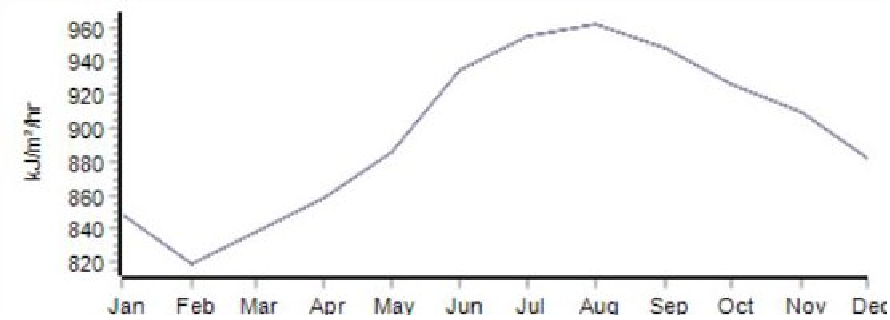
The large difference in the impact of shelter on productivity at the two case study sites is due to the extent to which the animals at the sites are exposed to conditions that lead to lamb mortality. Previous work in GrassGro demonstrated that the Hamilton area experienced detrimental conditions frequently and that wind speed reductions at the site reduced chill experienced. Wind speeds experienced (Broster et al., 2012) at Tambo crossing and the associated chill index were lower than occurred at Dunkeld on average (Figure 21). Since these graphs show averages, they are not reflecting chill in particularly cold years. At 1100 kJm2/hr lambs are at high risk from chill.

Figure 21: The long-term average chill index (1992-2021) for Tambo Crossing & Dunkeld. Note the differing y axes.

DUNKELD



TAMBO CROSSING



It is also important to note that the smaller increase in sold livestock at Tambo reflect a smaller operation than Dunkeld, which carries about 25 times more stock than Tambo. However, even taking this into account, the impact of shelter at Tambo Crossing is substantially less than at Dunkeld.

5.4 Economic analysis

5.4.1 Limitations

Several assumptions have been outlined in the methods section of this report. Although justified in the context of this study it is important to note the implications they have on the results. For instance, the value of the production lost due to planting trees had a large impact on the odds of the planting being a good investment. Thus, if a specific farm experienced a substantial loss or gain of pasture in the adjacent paddocks, it's likely the return on investment would negatively or positively impacted, respectively.

This analysis did not include the impacts of a changing climate. Although it is possible that climate change will decrease the frequency of chill events in some areas, the benefits of shade will increase. The increasing frequency of extreme events suggests that shade and shelter will be integral to resilient farms in the future.

Several risks associated with plantings trees were not included in this analysis. The preparation associated with our proposed plantings contributes to the costs involved but also maximises the odds of a successful planting. However, there are risks to plantings such as poor weather conditions after planting and herbivory by native and introduced animals. Fire is also a risk but can be reduced though planting design and species selection.

There are also numerous co-benefits that were not addressed in this analysis. These include benefits to water quality which has the potential to lead to increased weight gain of livestock as well as downstream impacts. The shelter provided by trees can reduce wind erosion of soils and improve waterlogging and salinity issues. In cases where plantings have been effective in rehabilitating degraded land, increasing the productive area on the farm, there is a high likelihood the investment has provided a good return. On farm tree plantings are associated with an increase in biodiversity. Increases in insectivorous birds and bats has the potential to reduce pest loads. There is also the amenity value which can improve the wellbeing of farmers and employees. More research is needed to be able to quantify the extent to which including these co- benefits would improve the return on the investment of incorporating trees into the farming system. However, the more a planting can take advantage of multiple co-benefits the better the return on the investment.

6. Conclusion

The interviews results demonstrate the diversity of reasons farmers incorporate trees into their operations. Although the dairy farming sample size was small, all dairy farmers associated the trees with an increase in productivity. Over 50% of interviewed sheep farmers associate the shelter with improvements in productivity. Only 14% of cattle graziers attributed shelter to increases in production. This is clearly associated with the sensitivity of the animals to heat or cold stress conditions. Dairy cows are sensitive to heat at comparatively low temperatures and sheep are susceptible to cold as young lambs and after sheering. It should be noted that although dairy production has been shown to improve with shade in hot conditions, this has been tested almost exclusively with shade cloths and other structures.

In addition to sensitivity, the ability to detect changes is likely also playing a role. Milk production is known daily and impacts of cold during lambing or post sheering are evident. However, interactions with cattle in extensive systems are uncommon and measurements of weight or other productivity related factors are often only occurring once or maybe twice a year. The difficulty in attributing any differences in weight gained over months to particular events or drivers is another factor in the low reporting of productivity benefits of trees on cattle and was mentioned by some interviewed farmers.

Based on the MLA segmentation questions, nearly half of farmers were classified as 'winding down'. Although answers to questions about incorporating new information or being willing to make changes didn't align with the typical "winding down" farmer, these participants were less likely to borrow heavily to increase the size of their operation and unlikely to borrow to diversify. It is noteworthy that such a high proportion of farmers integrating trees into their farming operation are comparatively fiscally risk adverse. This and direct input from the farmers demonstrate the perceived value of integrating trees into the farming system.

The consistent perception of the risks and uncertainties associated with the carbon market supports the premise of this project, in that a focus on the other benefits trees can provide to farming systems is more compelling to many producers than growing trees to participate in the carbon market.

The case study results demonstrate that in highly productive farming systems a significant proportion of the property needs to be planted to achieve carbon neutrality, and the period of peak carbon sequestration is relatively short. However, reductions in net emissions associated with the proposed plantings in the 3 case studies examined in this project were substantial compared to any mitigation options currently available for extensive pasture systems. With new plantings comprising 4.8% to 11.6% of properties reducing average net emissions over 30 years by 20% to 33%, respectively. The case studies also highlight the temporary nature of the carbon sequestration associated with tree planting. As trees reach maturity, carbon sequestration slows. It is expected that by the end of the 30-year timeframe used for this analysis farmers will have many more options to directly reduce emissions, including enteric methane emissions.

Modelling of carbon sequestration of case study farms also highlighted some strategies to maximise sequestration. On a per area basis, belts will generally have a greater sequestration rate than block plantings. Although some caution needs to be applied in extrapolating this to a given site, FullCAM modelling will attribute more carbon abatement to belts than block plantings. This can be at odds with other potential farm goals, such as biodiversity. Priorities and trade-offs will need to be considered in such cases. However, for farmers looking to maximise carbon sequestration in shelterbelts a maximum width of 40 metres is recommended. This provides double the carbon to a 20-metre-wide belt with a slightly higher fencing cost.

FullCAM is a national level model that may under or overestimate carbon stocks on any particular farm depending on what you have planted and the type of native vegetation that originally occurred on the property. For example, if you have a high proportion of large eucalypts in a dense mixed species planting on *a site where the native vegetation was woodland, it is likely that FullCAM could underestimate the carbon sequestered in the plantings.*

In some circumstances the livestock productivity benefits associated with integrating trees into the farming system will provide a good return on investment. When the shelterbelt has an impact on the extent to which sheep, lambs and shorn sheep in particular, experience chill, the returns can be high. This depends on the climate on the site and the effectiveness of the shelterbelt. In cold areas where chill conditions are largely driven by low temperatures or in mild areas where animals rarely experience severe conditions the benefits of a shelterbelt are lower than an area in which wind reductions have a noticeable impact on the chill index.

Costs associated with trees also have a large impact on the extent to which trees prove to be a good investment. If the area was not grazed or supported limited grazing before planting and the cost associated with auditing carbon sequestration on the farm is low (10% of it's value), then the planting is much more likely to be a good investment.

These findings and those from farmer engagement have been included in the project outputs, namely the decision framework that provides information and structure to incorporate that information into decision-making processes and to easily find need information to implement tree planting.

6.1 Key findings

- *Planting trees on 5-12% of the area of a high productivity farm can reduce net farm emissions over 30 years from 20% to 33%. Carbon sequestration slows as plantings reach maturity.*
- *Farmers goals will inform tree planting design – allowing for plantings to achieve multiple objectives.*
- *The return on investment from tree planting depends on the exposure of the property to cold conditions, the extent to which shelter improves conditions for animals, the value of carbon and the costs associated with the planting, including opportunity costs of quality of the pasture being replaced by trees and auditing costs of carbon.*

6.2 Benefits to industry

- *The case study results provide a better understanding of the benefits and risks associated with integrating trees into farm enterprises.*
- *The decision framework provides easier access to relevant and reliable information and a mechanism to incorporate information into decision making process.*
- *Tree planting on farms can significantly reduce greenhouse gas emissions and contribute to the Australian Red Meat Industry's CN30 goal of being carbon neutral by 2030.*

7. Future research and recommendations

This project identified research gaps that lead to uncertainty in the value proposition of integrating trees into the farming system, particularly for beef systems. This includes conditions in which shelter could reduce mortality (e.g. under what conditions are calves susceptible to cold), liveweight gains that can be expected with reduced cold or heat stress, improvements in fertility and other animal welfare benefits. Research into the impacts of heat stress on liveweight gain in extensive systems and the ability of trees to mitigate this impact would reduce uncertainties around the value proposition of trees for beef systems.

Currently there is limited information on the impacts on farm productivity from co-benefits such as reduced salinity and erosion or increased biodiversity for Australian livestock systems. Getting a complete picture of the benefits from trees will require metrics for environmental factors such as biodiversity that can be applied on farm and research addressing the connection between environmental co-benefits and their *impacts on productivity. Having such metrics is important to other goals of the red meat industry, primarily around improving biodiversity.*

Aside from impacts on sheep due to chill, there are no mechanisms to model the impacts of plantings on farm microclimate and associated productivity of various parts of the system using whole farm models traditionally used in the Australian context. An update of how heat and cold stress impact feed intake and weight gain would be an important step in being able to model changes associated with trees. This is also relevant to modelling the impacts of heat stress with climate change and effectiveness of options to mitigate the impacts both on productivity and on animal welfare. However, it is possible that more data from Australian systems would be required to achieve this.

The application of the insights gained from this project will be achieved through the use of the decision framework (Section 4.3) and the incorporation of its components into MLA information materials, including the CarbonEdge training and e-learning options. These steps will also ensure that the red meat industry achieves full value from the projects findings.

8 References

Australian Government, C.E.R., 2018. Carbon Credits (Carbon Farming Initiative) (Reforestation by Environmental or Mallee Plantings—FullCAM) Methodology Determination 2014, Compilation No. 2, 2018, Authorised Version F2018C00118 registered 26/02/2018.

Baker, T.e.a., In Prep. Global meta-analysis of the impact of trees on farm on pasture and crop production in temperate zones.

Bennett, L., Byrne, P. & Karopoulos, A., 2022 unpub. Assessing carbon and biodiversity values as environmental plantings age. Prepared for Land Life Company,

Bird, P., Lynch, J., Obst, J., 1984. Effect of shelter on plant and animal production. Animal Production in Australia 15 270-273.

Bird, P.R., 1984. Effect of Trees on Agricultural Productivity, Focus on Farm Trees. Proceedings of the 2nd National Conference on the decline of trees in the rural landscape. University of New England, pp. 13-29

Bird, P.R., 1998. Tree windbreaks and shelter benefits to pasture in temperate grazing systems. Agroforestry Systems 41(1) 35–54.

Bird, P.R., Bicknell, D., Bulman, P.A., Burke, S.J.A., Leys, J.F., Parker, J.N., van der Sommen, F.J., Voller, P., 1992a. The role of shelter in Australia for protecting soils, plants and livestock. Agroforestry Systems 18 59-86.

Bird, P.R., Bicknell, D., Bulman, P.A., Burke, S.J.A., Leys, J.F., Parker, J.N., van der Sommen, F.J., Voller, P., 1992b. The role of shelter in Australia for protecting soils, plants and livestock. Agroforestry Systems 20 59-86.

Blaine, K., Nsahlai, I.V., 2011. The effects of shade on performance, carcass classes and behaviour of heat-stressed feedlot cattle at the finisher phase. Tropical animal health and production 43 609-615.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qualitative research in psychology 3(2) 77-101.

Broster, J.C., Robertson, S.M., Dehaan, R.L., King, B.J., Friend, M.A., 2012. Evaluating seasonal risk and the potential for windspeed reductions to reduce chill index at six locations using GrassGro. Animal Production Science 52(10) 921-928.

Bryman, A., 2016. Social research methods. Oxford university press.

Burke, S., 1991. Effect of shelterbelts on crop yeilds at Rutherglen, Victoria, The Role of Trees in Sustainable Agriculture: A National Conference. The role of trees in providing shelter and controlling erosion: Albury NSW

Chang-Fung-Martel, J., Harrison, M., Brown, J., Rawnsley, R., Smith, A., Meinke, H., 2021. Negative relationship between dry matter intake and the temperature-humidity index with increasing heat stress in cattle: a global meta-analysis. International Journal of Biometeorology 65(12) 2099-2109.

Cheung, P.K., Jim, C.Y., 2018. Comparing the cooling effects of a tree and a concrete shelter using PET and UTCI. Building and Environment 130 49-61.

Cleugh, H., Hughes, D., 2002. Impact of shelter on crop microclimates: a synthesis of results from wind tunnel and field experiments. Australian Journal of Experimental Agriculture 42(6) 679-701.

Cleugh, H., Prinsley, R., Bird, P., Brooks, S.J., Carberry, P., Crawford, M., Jackson, T., Meinke, H., Mylius, S., Nuberg, I., 2002. The Australian National Windbreaks Program: overview and summary of results. Australian Journal of Experimental Agriculture 42(6) 649-664.

Crosthwaite, J., MacLeod, N., Malcolm, B., 1997. Case studies: theory and practice in agricultural economics, In: Vanclay, F., Mesiti, L. (Eds.), Sustainability and Social Research. Centre for Rural Social Research Charles Sturt University: Wagga Wagga, Australia.

Davis, D., Pascale, A., Vecchi, A., et al, 2023. Modelling Summary Report. Net Zero Australia, https://www.netzeroaustralia.net.au/

Department of Energy Environment and Climate Action, 2023a. Fire History Records of Fires across Victoria showing the fire scars. vic.gov.au: Data Vic.https://discover.data.vic.gov.au/dataset/fire-history-records-of-fires-across-victoria-showing-the-fire-scars2

Department of Energy Environment and Climate Action, 2023b. MapshareVic. https://mapshare.vic.gov.au/mapsharevic/

DISER, D.o.I.S.E.a.R., 2020. FullCAM, 6.20.03.0827 ed: Australia

Doran-Browne, N., Wootton, M., Taylor, C., Eckard, R., 2017. Offsets required to reduce the carbon balance of sheep and beef farms through carbon sequestration in trees and soils. Animal Production Science 58(9) 1648-1655.
Gaughan, J.B., Bonner, S., Loxton, I., Mader, T.L., Lisle, A., Lawrence, R., 2010. Effect of shade on body temperature and performance of feedlot steers. Journal of animal science 88(12) 4056-4067.
Greiner, R., Gregg, D., 2011. Farmers' intrinsic motivations, barriers to the adoption of conservation practices and effectiveness of policy instruments: Empirical evidence from northern Australia. Land Use Policy 28(1) 257-265.
Hall, N., Boden, R.W., al, e., 1972. The Use of Trees and Shrubs in the Dry Country of Australia. Australian Government, Canberra.
Kragt, M.E., Dumbrell, N.P., Blackmore, L., 2017. Motivations and barriers for Western Australian broad-acre farmers to adopt carbon farming. Environmental Science & Policy 73 115-123.
Lynch, J., Donnelly, J., 1980. Changes in pasture and animal production resulting from the use of windbreaks. Australian Journal of Agricultural Research 31(5) 967-979.
Malcolm, B., Ho, C.K., Armstrong, D.P., Doyle, P.T., Tarrant, K.A., Heard, J., Leddin, C., Wales, W., 2012. Dairy Directions: a decade of whole farm analysis of dairy systems. Australasian Agribusiness Review 20(1673-2016-136827) 39-58.
Malcolm, B., Makeham, J., Wright, V., 2005. The farming game: agricultural management and marketing. Cambridge University Press.
Mayer, D., Davison, T., McGowan, M., Young, B., Matschoss, A., Hall, A., Goodwin, P., Jonsson, N., Gaughan, J., 1999. Extent and economic effect of heat loads on dairy cattle production in Australia. Australian Veterinary Journal 77(12) 804-808.
Meat and Livestock Australia, 2023. Australia Saleyard Cattle Transactions. https://www.mla.com.au/prices-markets/statistics/cattle-transactions/ [17/10/23]
Meyer, R., Doran-Browne, N., Dooley, K., Eckard, R., 2020. Achieving net negative emissions in a productive agriculture sector: a review of options for the Australian agricultural sector to contribute to the net-zero economy. Energy Transition Hub, 68.
Mitlöhner, F., Morrow, J., Dailey, J., Wilson, S., Galyean, M., Miller, M., McGlone, J., 2001. Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. Journal of animal science 79(9) 2327-2335.
Paul, K., Polglase, P., Nyakuengama, J., Khanna, P., 2002. Change in soil carbon following afforestation. Forest ecology and management 168(1-3) 241-257.
Reid, R., Bird, R., 1990. Shade and shelter, In: Cremer, K. (Ed.), Trees for Rural Australia. CSIRO, Inkata Press: Melbourne and Sydney, pp. 319-335.
Revell, D.K., Norman, H.C., Vercoe, P.E., Phillips, N., Toovey, A., Bickell, S., Hulm, E., Hughes, S., Emms, J., 2013. Australian perennial shrub species add value to the feed base of grazing livestock in low- to medium-rainfall zones. Animal Production Science 53(11) 1221-1230.
Roberts, G., 2022. FullCAM calibration details personal communication,
Sarantakos, S., 1998. Social Research. Macmillan Education Australia, Melbourne.
Schirmer, J., Kanowski, P., Race, D., 2000. Factors affecting adoption of plantation forestry on farms: implications for farm forestry development in Australia. Australian Forestry 63(1) 44-51.
Sherren, K., Fischer, J., Price, R., 2010. Using photography to elicit grazier values and management practices relating to tree survival and recruitment. Land Use Policy 27(4) 1056-1067.
Sinnett, A., Behrendt, R., Ho, C., Malcolm, B., 2016. The carbon credits and economic return of environmental plantings on a prime lamb property in south eastern Australia. Land use policy 52 374-381.
Sinnett, A., Malcolm, B., Lewis, C., Ho, C., 2019. Farm economic research and the case study approach. . Australasian Agribusiness Perspectives 22 221-232.
Sullivan, M., Cawdell-Smith, A., Mader, T., Gaughan, J., 2011. Effect of shade area on performance and welfare of short-fed feedlot cattle. Journal of animal science 89(9) 2911-2925.
Wang, S., Li, Q., Peng, J., Niu, H., 2023. Effects of Long-Term Cold Stress on Growth Performance, Behavior, Physiological Parameters, and Energy Metabolism in Growing Beef Cattle. Animals 13(10) 1619.
Yin, R.K., 2018. Case study research and applications: design and methods. Sage Publications, Thousand Oaks, CA.

9 Appendices

Appendix 1: Guide for interviews with farmers

MLA segmentation questions
Describe the agricultural enterprises and ownership arrangements?
1 *How large is your property/ies? (area, herd size)*
2 *Nature of the production systems? (including location)*
3 *How many years have you been involved in farming?*
4 *What proportion of your income is from farming?*
5 *Are you sole owners or in partnership with others?*
6 *Do you lease or agist land or share farm with other landowners?*
7 *How long do intend to stay on the property? What are your plans for the future?*

Productivity and profitability questions
8 *What was the gross farm income last year?*
9 *What was the net farm income last year?*
10 *What is the trend in farm income over the last 10 years? Increasing? Decreasing? Why so?*
11 *If we were to include your property in a more detailed study, do have any historical data on farm production we can access?*

Extent and types of trees
12 *What is the proportion of farm under trees – remnant native vegetation/planted trees?*
13 *How has this changed over time?*
14 *Nature of remnant woody vegetation?*
15 *Configurations, layout and species of planted trees?*
16 *Extent in shelterbelt, shade, biodiversity plantings or for timber production?*

Impacts of trees
17 *What are benefits or impacts of trees on your property?*
Prompts: shade, shelter, water quality, soil erosion, biodiversity, aesthetics, water table, salinity, fire risks

18 *What are the effects of trees on livestock production?*
Prompts:

- *How do trees affect livestock productivity?*
- *Effect on lambing rates?*
- *Effect on pasture or crop production?*
- *Effect on milk production?*
- *Other effects, eg. animal welfare, capital value, aesthetics*
- *Do you have quantitative measurements of production benefits/impacts?*
- *Can the effects of trees be separated from other changes you have made to the farm operation?*
- *What information do you have that could be used to assess the effects of trees on farm productivity?*
- *How do you think other benefits could be measured?*
- *What is the ideal proportion of your farm under trees?*
    - *What proportion of your farm do you think could be planted to trees without reducing agricultural productivity?*

Long term plans

19 If you plan to stay on the farm, what changes will you make to the farm over the next 3-5 years or longer term (i.e. >10 years)?

Prompts (eg. shift from grazing to cropping or vice versa, invest in irrigation, farm improvements, increase or sell land)

- *Will you harvest and sell wood, and replant these areas?*
- *Will you increase the extent of trees? How? Planned clearing?*
- *What species or types of trees will you plant in future? Native or exotic?*
- *If so, for what purpose? Are you considering timber production or carbon sequestration?*
- *Improve the condition and value of trees?*
- *What are the main factors driving these decisions?*

Deciding factors

20 What factors were important in deciding where to plant trees and what species and design?

Prompts:

- *Briefly describe the process you used to decide when and where to plant trees.*
- *What sources of information and tools do you use to make these decisions? What was most useful?*
    - *Do you used consultants and farm advisors to make these decisions? Who?*
- *Do you use computer software, including apps, paper-based guidance, or other tools to inform your decisions? What types?*
    - *What are the main risks associated with your design?*
    - *What types of information or tools would improve your decision making?*
    - *What types of trade-offs do you consider in making your decisions?*
    - *How has your thinking changed over time?*
    - *What would you do differently?*

Questions specific to certain types of plantings/ planting objectives

Shelterbelts

- *How would you design a shelterbelt to suit a specific location and maximise its benefits?*
- *Your ideas regarding species, number of rows, row and tree spacing, orientation in relation to prevailing wind?*
- *How could livestock and crops benefit from shelterbelts?*
- *To what extent would you manage the shelterbelt for timber production?*
- *What are some of the other potential benefits of a shelterbelt in the farm landscape?*
- *What are some of the challenges associated with shelterbelts?*

Riparian zones and dams

How would you design plantings alongside streams and dams to improve water quality and stabilise banks? What other benefits would you expect from such plantings?

Water tables

What change in pasture production would you expect without plantings to reduce water tables? Do you have data? Are there bores?

Biodiversity

- *How would you design plantings on the farm to improve the extent and connectivity of habitat for fauna?*
- *What positive impacts could increased bird life have on the productivity of a farm?*
- *What is the impact for farm productivity of more plant pollinators due to improvement of biodiversity?*
- *How can trees help to increase soil biota? What benefit does this have for agricultural productivity?*
- *What other benefits would you expect from such plantings?*

Have you considered timber production on the farm?

- *Why (might have off-farm investment) / why not?*
- *What aspects of timber production appeal to you, what aspects concern you?*
- *What are the main barriers to growing trees for timber on the farm?*
- *What are the most appealing types of wood products that could be grown on your farm?*
- *Have you been involved in joint venture or lease arrangements for timber production? What was your experience?*
- *Do you see timber production as more risky than growing trees for other reasons? Can these risks be managed?*

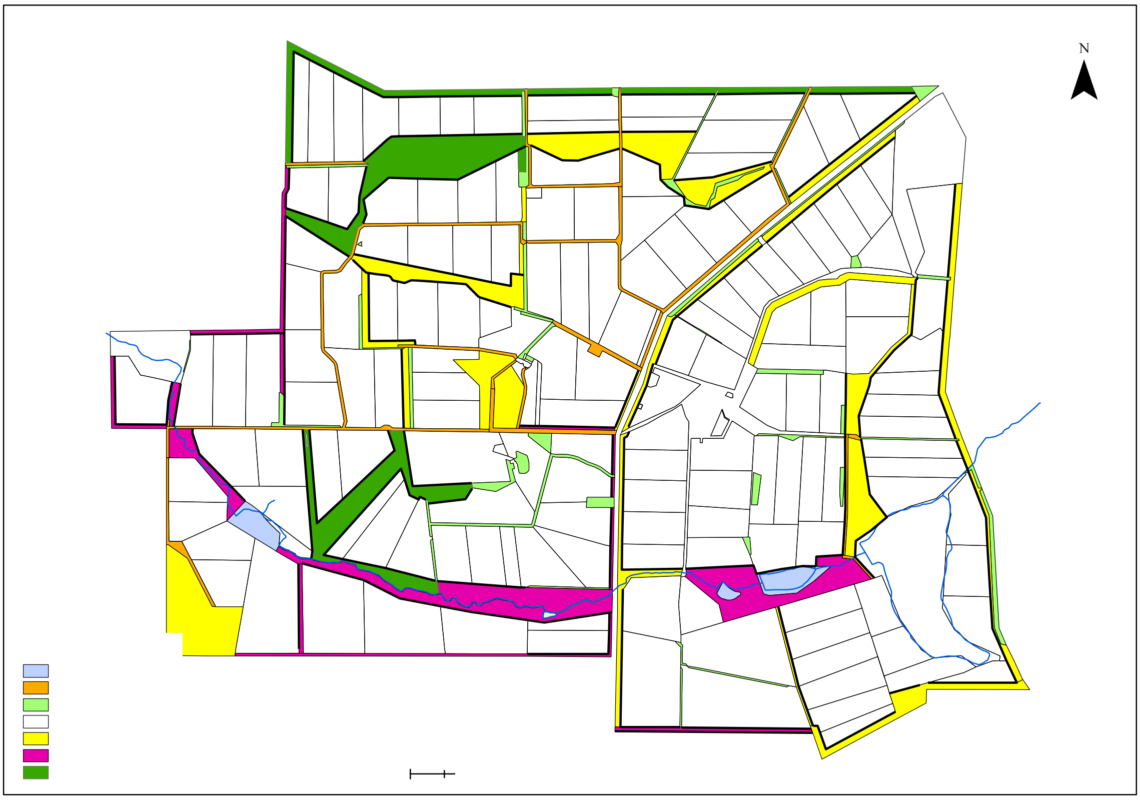
To what extent is tree planting on the farm important for carbon sequestration/carbon offset?

- *What are the key sources of greenhouse gas emissions from your farm business?*
- *Have you prepared a carbon/greenhouse gas account for your property? What are the results?*
- *Have these results led you to change your business practices?*
- *Do you intend to offset emissions by tree planting on the farm?*
- *Do you intend to participate in carbon farming?*
- *What role (if any) do trees play in contributing to increased soil carbon?*

Appendix 2: Maps of the existing and proposed plantings at Dunkeld Pastoral properties

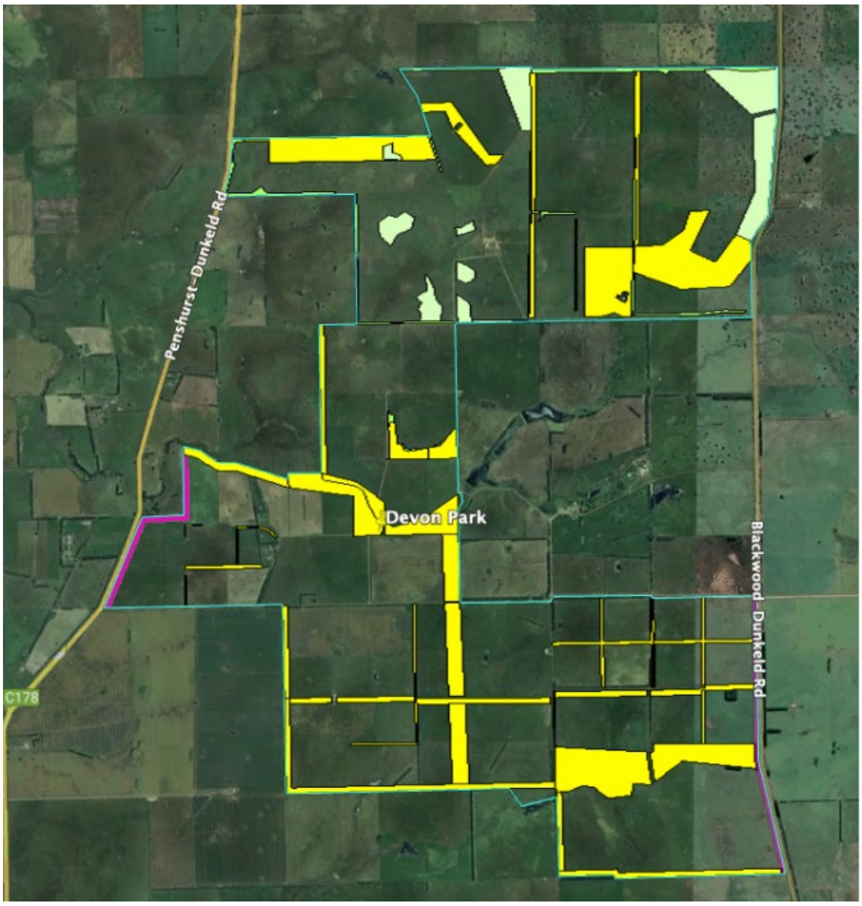
a)

Blackwood tree map (legend description in box below)



b)

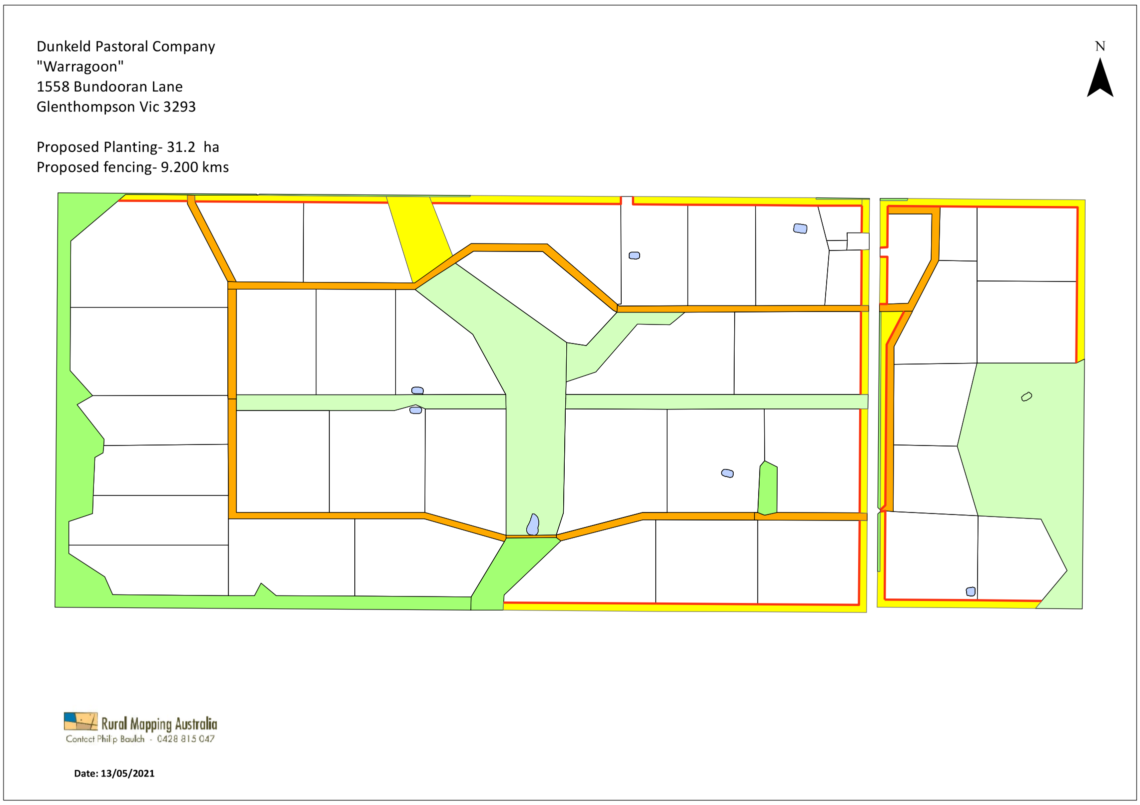
Devon Park tree map

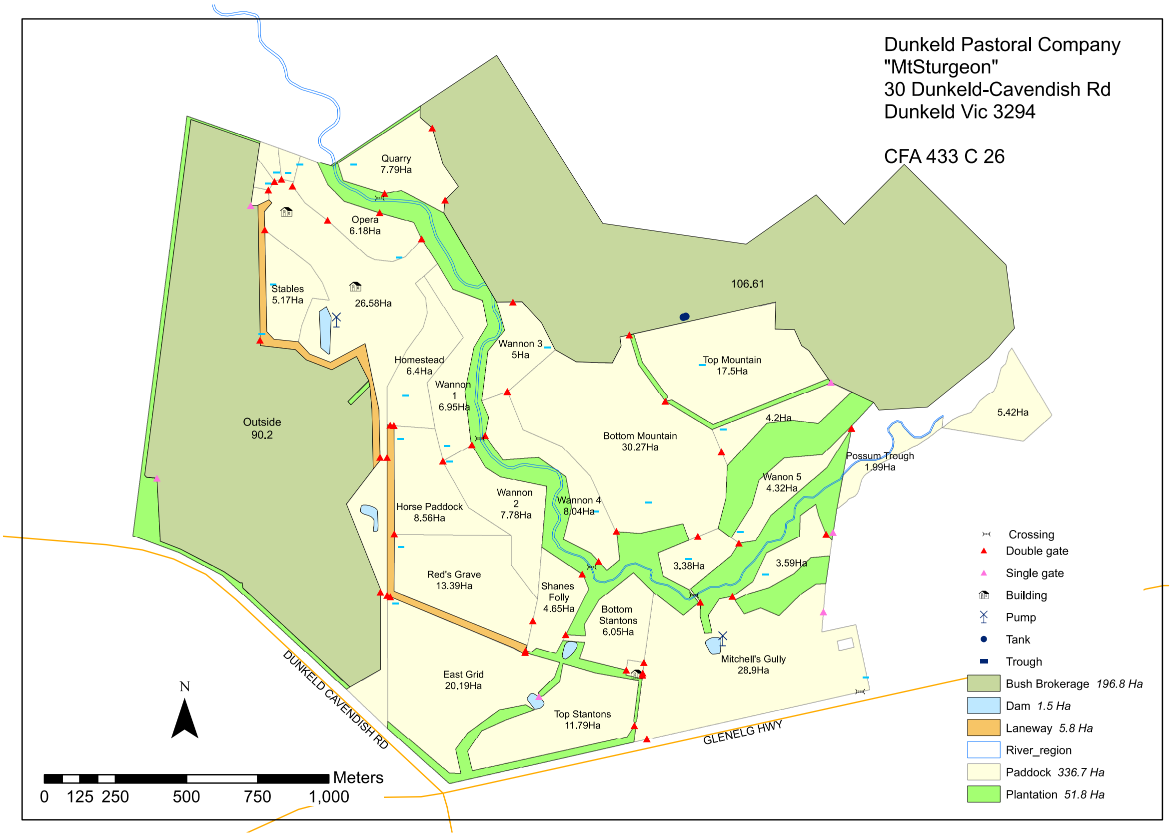


For a) Blackwood b) Devon Park and c) Warragoon, light green shading is existing woody vegetation, purple shading is planting in 2022, darker green shading is proposed planting in 2023-2025, and yellow shading is proposed planting from 2023-2030.

c)

Warragoon tree map

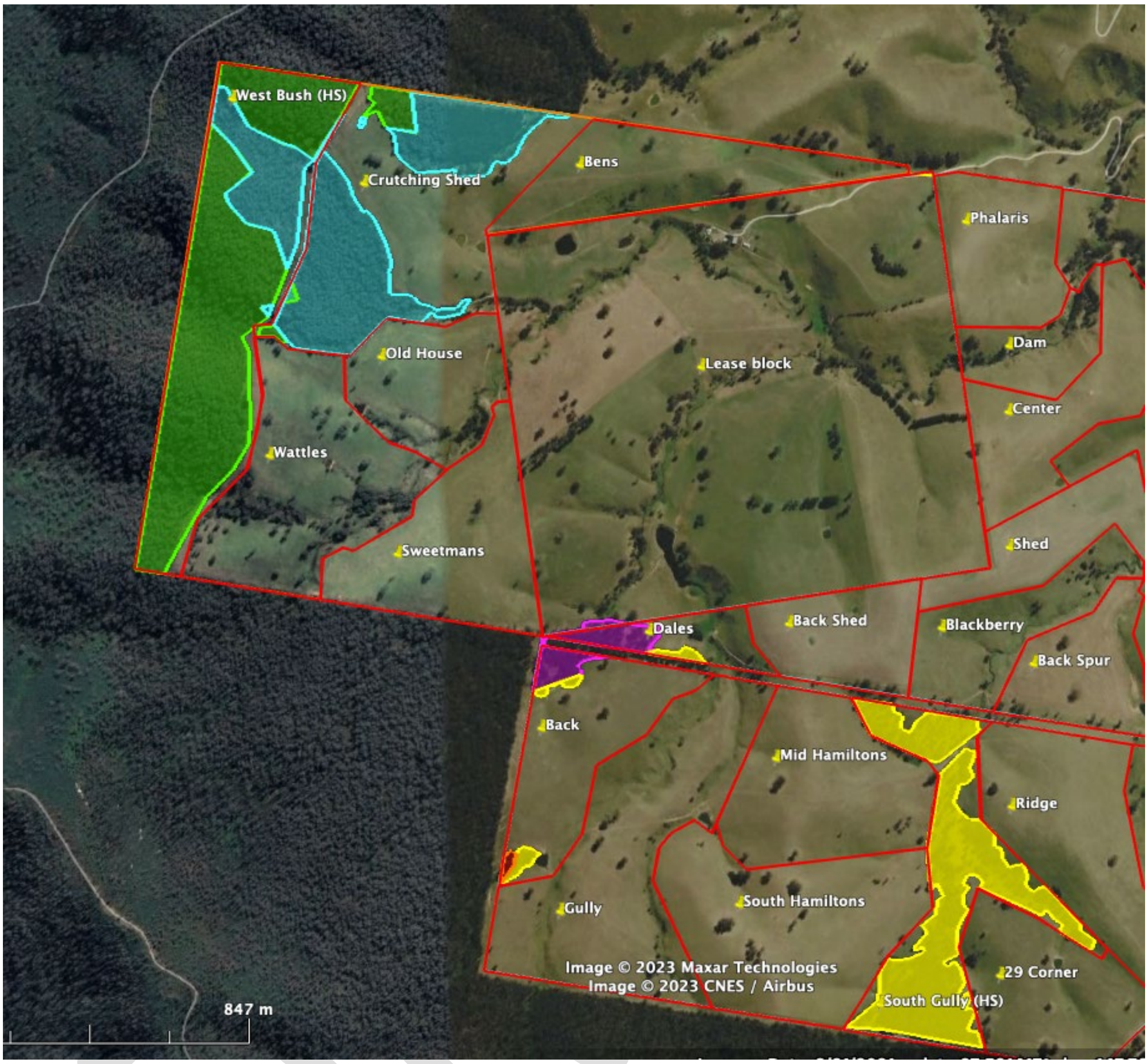




Appendix 3: Maps of the existing and proposed plantings at Tambo Crossing

Existing planted trees [Radiata Pine (dark green), shelterbelts (yellow)], and proposed planting at Tambo Crossing [shelterbelts (light green), environmental plantings (blue), eucalypt plantation (sea green)].

Existing vegetation at Tambo crossing with the four CEAs (different colours) of remnant vegetation



Appendix 4: User-defined calibration in FullCAM for Tambo Crossing Eucalypt plantation

<u>Modelling of carbon stocks – Eucalypt plantation</u>

FullCAM did not have a calibration for the native timber species proposed for this location. When this occurs, FulCAM defaults to an environmental planting calibration. If this was used, it would be a conservative estimate of the potential abatement.

Rather than doing the above, we applied a user-defined calibration. First, we used the calibration for Sugar Gum (Eucalyptus cladocalyx), a species with similar growth habits to eucalypts native to the Tambo Crossing locality. We then applied 'User Defined Growth Calibration Parameters for the Tree Yield Formula' in the Trees / Growth tab of FullCAM, as provided for in FullCAM Help under 'Calculation of G and r for plantation tree species'. The Tree Yield Formula (TYF) predicts yields of aboveground biomass (t dry matter/ha) in stands of trees. FullCAM allows users to define the parameters G, and r in the TYF, where G is the tree age of maximum growth rate (years), and r is the site-productivity-dependent, non-endemic species multiplier, which for tree plantations, is also influenced by M, the maximum aboveground biomass (t dry matter/ha) in undisturbed native vegetation.

Paul et al. (2022, Table 4) provided new recommended default TYF parameters for various tree species and categories of plantings. The data is being used to re-calibrate the TYF, and to expand the range of species, management regimes, and regions that can be modelled, for a new version of FullCAM expected to be released in 2023. We used the parameters for 'OtherEuc' that predominantly comprises the species E. cladocalyx, E. camaldulensis, E. saligna/botryoides, Corymbia maculata, and E. pilularis. For our FullCAM simulations, we used the G parameter of 8.002 for that group of species, and calculated r for each FullCAM plot as r = Exp(ar) x M x br, where ar and br are scaling factors given that each FullCAM plot has a unique value for M.

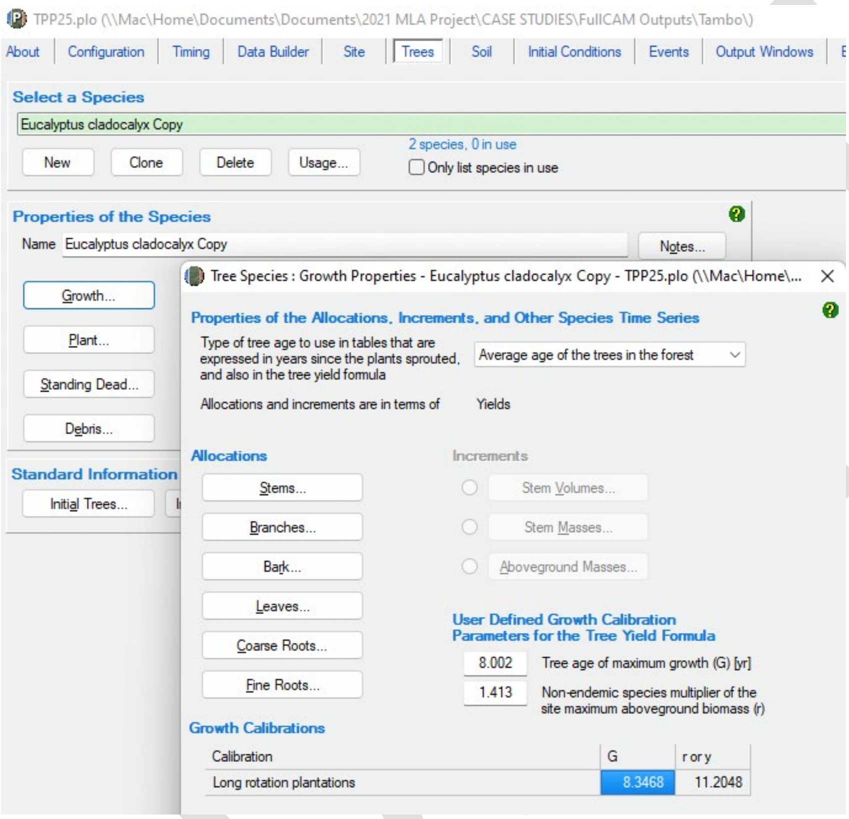
We checked that the age of the plantations we simulated fitted within the temporal domain of application of the TYF calibration, and that the spatial domain of application of the TYF was only applied to areas with M values between the minimum and maximum found within their respective calibration sites and thus, between the corresponding minimum and maximum r × M values, by reference to data in Paul et al. (2022, Tables 1, 5).

Having done the above, we then adjusted the relative allocations of yield of biomass to the various components of the biomass (stems, branches, bark, leaves, coarse roots and fine roots) at the Trees / Growth tab. Then we adjusted the turnover percentages (½ life years) at the Trees / Plant tab and the breakdown percentages (½ life years) at the Trees / Debris tab. Data for these adjustments was taken from the latest version of the Australian National Greenhouse Accounts (Australian Government 2022).

We noted that the FullCAM Guidelines – Requirements for use of the Full Carbon Accounting Model (FullCAM) with the Emissions Reduction Fund (ERF) methodology determination: Carbon Credits (Carbon Farming Initiative—Plantation Forestry) Methodology Determination 2022 had detailed guidance on how to use the FullCAM 2016 model to calculate abatement under the Carbon Credits (Carbon Farming Initiative—Plantation Forestry) Methodology Determination 2022. This included an Excel calculator for G and r when modelling a forest of a certain species and region specified in the Methodology Determination (Fig. A4.a). The species and region we were modelling was not included in the Methodology Determination. We believed that the approach we took, of applying adjusted G *and r parameters to the FullCAM 2020 calibration, provided a reasonable approximation of the results we could expect from the impending release of a revised FullCAM calibration.*

The results of the FullCAM simulations were that the increase in carbon stocks over a modelling period of 2022 to 2052 for our user-defined calibration was only 5-9% more than the environmental plantings calibration for the four plantation CEAs. When we examined the volume growth predicted by FullCAM, it indicated a mean annual increment (MAI) of about 10 cubic metres per ha per year over the first 10 years of growth, and a MAI of about 8 cubic metres per ha per year over a 30-year growing period.

Figure A4.a. Tab from FullCAM showing the adjustment for the parameters G and r in the Tree Yield Formula.



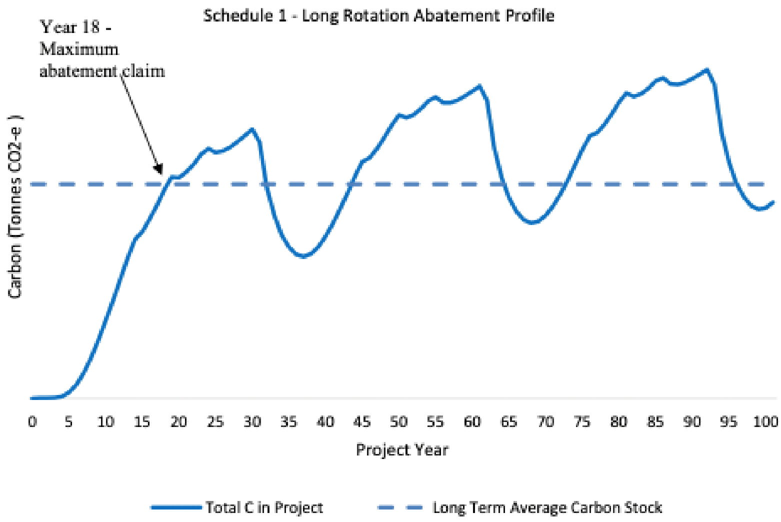
We then reviewed growth data from research trials in East Gippsland (Duncan et al. 2000) to cross-check the tree volumes predicted by FullCAM. The results were summarised by species group, soil type and rainfall (in their Table 7). The most relevant results for the Tambo Crossing property were the Salignae group (E. saligna, E. botryoides and E. grandis) on texture contrast soils where the annual rainfall was 700-899 mm per year. The results showed that the estimated MAI at age 10 years ranged from 7–12 cubic metres per ha per year for ex forest sites, and 15–20 cubic metres per ha per year for former agricultural sites. From this review, we accepted the carbon stocks predicted by FullCAM for our user-defined calibration as a conservative estimate of carbon abatement for the proposed eucalypt plantation at the Tambo Crossing site.

<u>Simulation of long-term carbon stocks in a eucalypt plantation over successive rotations</u>

Our project scenario C included a eucalypt plantation managed for timber production on a 30-year rotation. If the project was registered under the Carbon Credits (Carbon Farming Initiative—Plantation Forestry) Methodology Determination 2022, net abatement would be calculated by *subtracting any project emissions from the project carbon stock, with a cap on maximum abatement represented by the long-term average project carbon stock calculated over 100 years (Fig. A4.b).*

The first step is to calculate the predicted long-term average project carbon stock for the modelling period, as the sum of the predicted mass of carbon in trees, forest debris and forest products harvested. The quantity of carbon stored in harvested forest products depends on the lifespan of the products. For example, forest products used in construction generally have a longer lifespan than paper. Forest products decay over time, and may be placed in landfill, recycled, or burnt. The Methodology Determination requires proponents to specify the types of forest products and the proportions going to end uses such as paper, packaging, furniture, and construction in FullCAM using the information in the FullCAM guidelines. Carbon stock estimates in FullCAM use parameters for each national plantation inventory region, species, log class and end use.

Figure A4.b. Example showing calculation of net abatement for a new plantation[***].



The next step is the calculation of fossil fuel emissions due to plantation management, including forest product harvesting. The long-term average net abatement (i.e., over the modelling period of 100 years) is then calculated. Under the Methodology Determination, carbon credits are issued based on the net abatement achieved in each reporting period. In the example shown at Fig. A4.b, the long-term average net abatement for the project is achieved when the plantation is 18 years of age. No further credits would be issued beyond this point.

The Carbon Credits (Carbon Farming Initiative—Plantation Forestry) Methodology Determination 2022 requires that projects must continue to use the 2016 FullCAM option rather than FullCAM 2020 to calculate net abatement, in anticipation that an update of FullCAM for plantation forestry projects was expected to be released during 2022. This had not occurred when we conducted the Tambo Crossing study.

[***] Source: Australian Government (2022). Understanding your plantation forestry project: Emissions Reduction Fund simple method guide for plantation forestry projects registered under the Carbon Credits (Carbon Farming Initiative—Plantation Forestry) Methodology Determination 2021.

Given that we had used FullCAM 2020 with user-defined parameters to predict the carbon stocks in the eucalypt plantation at Tambo Crossing, we decided to use our results for predicted carbon stocks in trees and debris and apply a ratio to convert the data to long-term net carbon stock or abatement. Drawing on several sources (Australian Government ~2007, Ximenes et al. 2012), we estimated for our case study that the long-term average net abatement was 70% of the predicted mass of carbon in trees and forest debris at the harvest age 30 years.

From the results of our simulation, this meant that the long-term average net abatement for the project was achieved when the plantation was 17 years of age. No further net carbon abatement was allocated to the Tambo Crossing farm from the eucalypt plantation beyond this point.

Appendix 5: Silvicultural regime – Tambo Crossing Eucalypt plantation

When estimating timber production by the proposed plantation, we consulted with a forester[†††] who had many years of experience in establishing and managing eucalypt plantations in Gippsland.

From these discussions, and by reference to relevant research (Duncan et al. 2000), we assumed that the plantation could achieve a mean annual increment (MAI) of merchantable timber of 15 cubic metres per ha per year over a 30-year rotation. This was higher than the volume prediction associated with the FullCAM prediction of carbon stocks in the eucalypt plantation we modelled for the site. However, based on the expert opinion we consulted, and from our review of literature, we believed that this level of productivity was achievable for the proposed eucalypt plantation.

Species planted

Rainfall is adequate for eucalypt plantations.

Frost would be the main factor limiting survival and early growth.

Suitable species:

- *Eucalyptus sieberi* (Silvertop Ash) [Best species for exposed sites.]
- *E. muelleriana* (Yellow Stringybark)
- *E. globoidea* (White Stringybark)
- *E. botryoides* (Southern Mahogany) [Poor form on exposed sites.]
- *Corymbia maculata* (Spotted Gum)

Species would be matched to the soils and topography on the plantation sites.

Silvicultural regime

Plant 1000 trees per ha (2.5 m x 4.0 m).

Age 3 years – First pruning lift to 2.5 m when trees 5-6 m tall, prune 250 trees/ha, and form prune as required.

Age 4 years – Non-commercial thinning to 500 trees/ha, using chemical applied via a spear gun (or could push out trees with small excavator).

Age 5 years – Second pruning lift to 4 m, prune 200 trees/ha.

Age 5 years – foliar analysis and application of micro-nutrients (e.g., Cu, Zn).

Age 7 years – Third pruning lift to 6 m, prune 150 trees/ha.

Age 12 years – Semi-commercial thin to 300 trees/ha, harvest firewood.

Age 20 years – Commercial thin to 150 trees/ha.

Age 30 years – Final harvesting.

Expect an average height growth over 25-30 years of 1 m per year.

Timber yields

Recoverable MAI (m3/ha/yr)		15
Rotation (years)		30
Recoverable volume (m3/ha)		450
Age 12 yrs	Semi-commercial thin, 200 trees/ha	50 m3/ha
Age 20 yrs	Commercial thin, 150 trees/ha (1/3 vol.)	90 m3/ha
Age 30 yrs	Final harvest, 150 trees/ha	310 m3/ha
Total		**450 m3/ha**
Project volume		
Age 12 yrs		1420 m3
Age 20 yrs		2556 m3
Age 30 yrs		8804 m3

Thinning removes ~40% of the basal area.

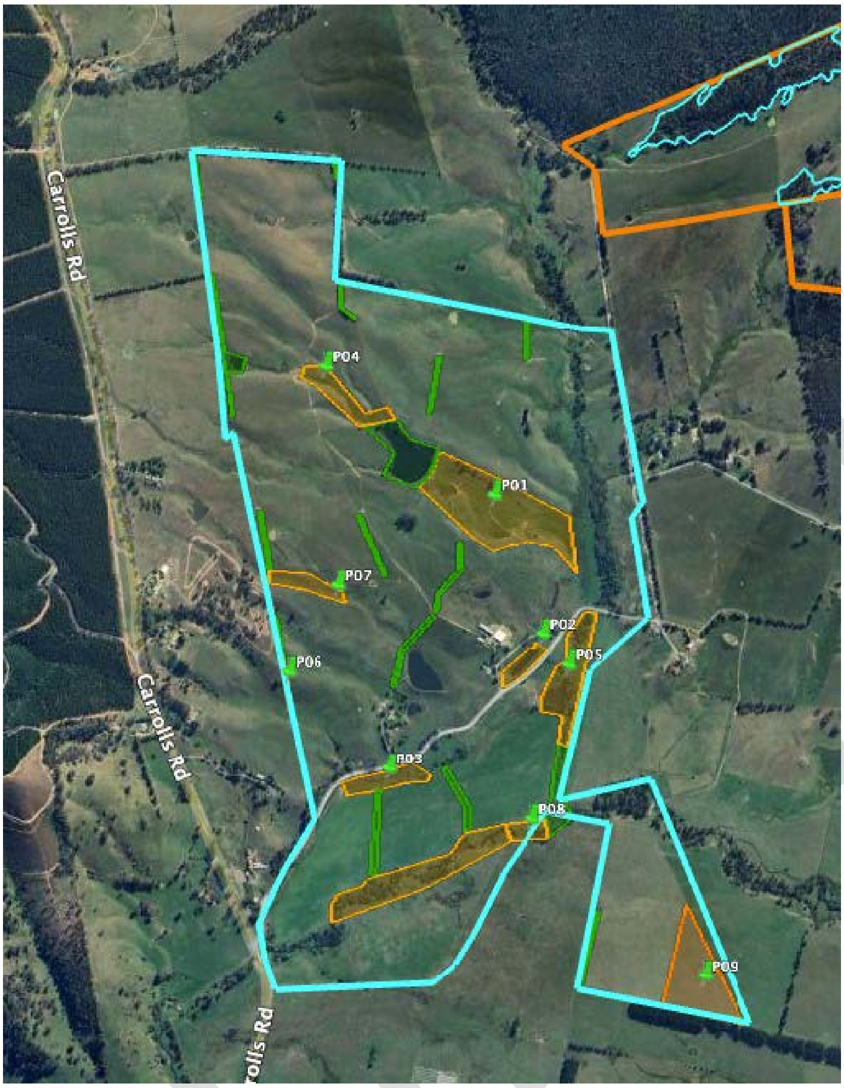
Stand parameters (aim to grow sawlogs with DBHOB of 50 cm).

Final crop stocking (trees/ha)	135
Basal area at age 30 years (m2/ha)	35
Top height at age 30 yrs (m)	27
Form factor	0.36
Calculated volume (m3/ha)	340
Recoverable volume proportion	0.9
Recoverable volume	306
Basal area per tree (m2)	0.26
DBHOB of av. tree (cm)	57.4

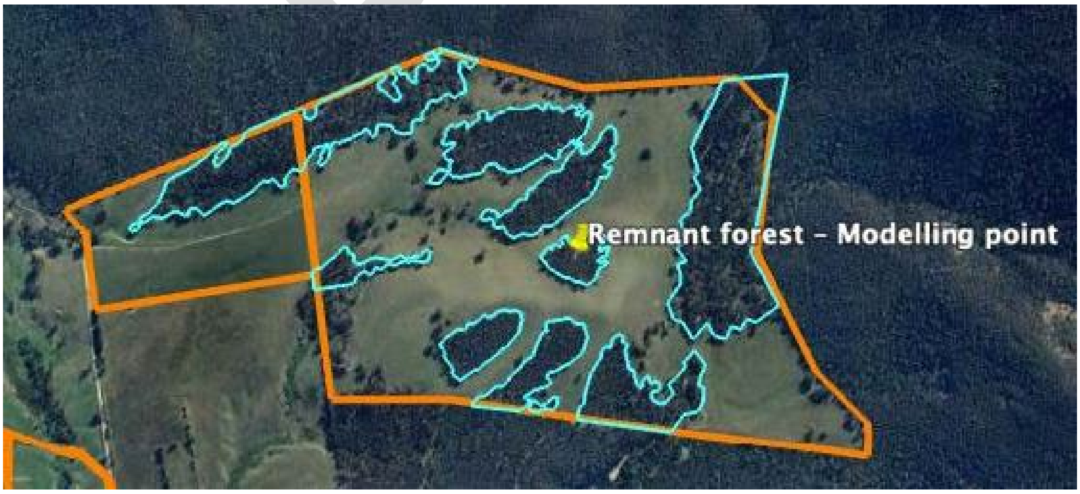
[†††] John Lambert, Heartwood Plantations, *pers. comm.*, 26 April 2023.

Appendix 6: Maps of the existing and proposed vegetation at Rosewhite

Existing planted trees (green polygons)), proposed plantings (orange polygons) and modelling points for proposed planting s(P01, etc) at the Rosewhite property



Remnant forest at the Rosewhite property on the bush block paddocks, modelled as one CEA consisting of 8 parts.



Appendix 7: List of communications associated with the project through November 2023

Date	Outreach/Event	Location	Who	Estimated attendees	Details
Spring 2021	SALRC newsletter	Newsletter	Rachelle Meyer	265, about 70 producers	Interview recruitment
7 October 2021	PF Olsen/ Gippsland forestry hub	Webinar	Rachelle Meyer and Hugh Stewart	11	Brief mention of project for interview recruitment
October 2021	Private Forestry Tasmania	IFA/AFG Conference field day	Molly Daskey-Willis	20	Interview recruitment, project awareness
October 2021	Limestone Coast Landscapes SA	Newsletter	Rachelle Meyer	24	Interview recruitment
February 2022	Murray Dairy newsletter	Newsletter	Rachelle Meyer	1700 total, about half dairy farmers	Interview recruitment
28/10/22	Agricultural Victoria staff webinar	Online	Rachelle Meyer	15	Project awareness and early results
7/05/22	Glensia field day	Glensia	Rodney Keenan	About	Project awareness and early results
Spring 2022	Feedback magazine	Magazine (pg 26-27)	Rachelle Meyer	MLA members and available online	Project awareness
07/22	Australian Animal Association Symposium	Cairns, Qld	Rachelle Meyer	About 50 attendees	Results of literature review and interviews
24/03/23	Landcare forum	Beechworth, Vic	Rachelle Meyer	100	Table in foyer and addressed in announcements, drafts of the decision framework
21-22/04/23	Gippsland field days	Bairnsdale, Vic	Rachelle Meyer	10 farmer discussions, project awareness for thousands of attendees	Table at the VicForests booth, drafts of decision framework
28/04/23	Farm Forestry Development Workshop	Ellinbank, Vic	Rodney Keenan	About 50 attendees	Project description and feedback on the decision framework
29/04/23	Mansfield field day, Landcare organised	Mansfield, Vic	Rachelle Meyer	About 20 farmers	Focus on productivity co-benefit info, highlighted seeking feedback on the decision framework

9/05/23	Dunkeld field day, Trees on Farm project organised	Dunkeld, Vic	Rachelle Meyer	Over 40 farmers, 60 attendees including organisers	Presentation on carbon sequestration and productivity co-benefits at Dunkeld
8/06/23	Emissions community of practice	Ellinbank, Vic	Rachelle Meyer	About 20 farmers	Presentation primarily on carbon sequestration also a bit on productivity co-benefits
20/06/23	Best wool/best lamb conference	Bendigo, Vic	Ainsley MacDonald	About 50 attendees engaged with the flyer	A flyer with carbon sequestration information from the project was included in materials the IMS project distributed
Spring 2023	SheepNotes Newsletter	E-newsletter	Rachelle Meyer	Sent to 16,000 producers	Primarily productivity results from sheep case studies
Summer 2023	Feedback Magazine	Publication	Rachelle Meyer	Delivered to all MLA members and available online	Dissemination of results and the decision framework
16/10/23	Forestry Conference	Tweed heads, NSW	Rodney Keenan	150 attendees	Presentation on case study results
23/11/23	MLA updates 2023	Bendigo, Vic	Rachelle Meyer	Not yet known	Dissemination of results and the decision framework
16/02/23	Understanding Carbon	Winchelsea, Vic	Graeme Anderson	Over 100	Trees on Farm project results mentioned. Factsheet circulated.
19/04/24	Surf Coast, Inland Plains Landcare outreach	Yan Yan Gurt Field Day	Rachelle Meyer	Approx. 20	Field day presentation: video filmed
30/10/24	Annual forestry conference	Forestry Australia Symposium	Rachelle Meyer	50+	Presentation