EVERCROP CARBON PLUS ECONOMIC ANALYSIS

An Economic Analysis of Carbon Sequestration in a Managed Tagasaste Cattle Grazing System

Abstract

Tagasaste has been shown to boost productivity beyond that of annual pastures by up to three times. With the advent of carbon emissions abatements schemes, there is additional potential for Tagasaste to provide an income stream from carbon sequestration.

This report looks at the profitability of Tagasaste with sequestration income under the Emissions Reduction Fund.

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Disclaimer

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Executive Summary

In this report we investigate the economics of including emissions abatement as a new enterprise within systems using the fodder shrub tagasaste grown on deep sands and grazed by cattle. Four scenarios are modelled:

1. the Block scenario models dense Tagasaste rows at 7m intervals;
2. the Wide Alley scenario models less dense Tagasaste alleys at 30m intervals;
3. the Annual scenario that models an annual pasture; and
4. the Unmanaged scenario that models an ungrazed, dense Tagasaste plantation for carbon sequestration.

To conduct the analysis we have developed a cattle enterprise model, an emissions model, and a sequestration model. These models feed into a discounted cash flow (DCF) where the net present value (NPV) for each scenario can be calculated so that comparisons between scenarios can be made.

Figure 1 illustrates the NPV results from our modelling with default parameters. The NPV from the abatement enterprise only includes the costs and income that are not part of the cattle enterprise. The positive NPVs from the abatement enterprises **are sufficient to pay the establishment costs**.

The Block scenario is by far the best proposition with its NPV being in excess of $2,000/ha more than the NPV attained under the Annual scenario. Figure 2 illustrates the total abatement from each scenario over the lifetime of the project. Of the grazing systems, the Block scenario abates the most carbon dioxide; 4 times more than the Wide Alley scenario. To calculate the net abatement, the Annual scenario is treated as the emissions baseline for the other scenarios. Therefore the net abatement is even greater, and **the Block scenario still achieves more than twice the net emissions abatement of the Wide Alley scenario**. While the Unmanaged scenario abates the most carbon dioxide, the **Block scenario manages to achieve 43% of the Unmanaged net abatement** while tripling the Unmanaged NPV.

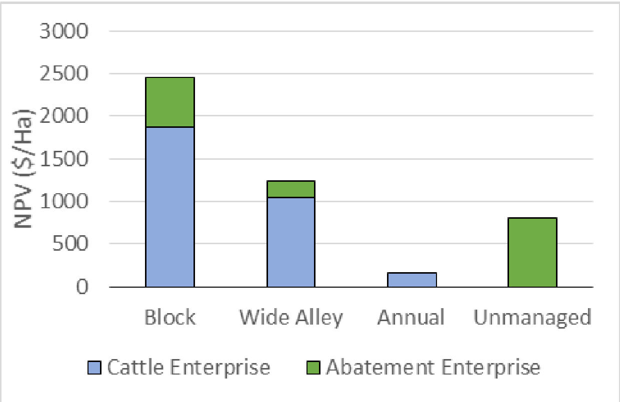

Figure 1 NPV results for the four scenarios under default parameters.

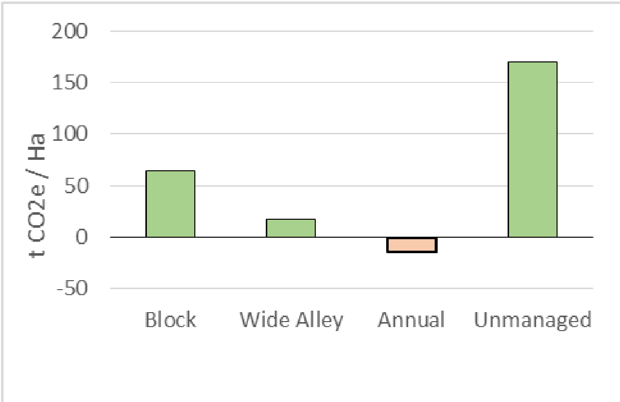

Figure 2 Total Abatement achieved by each scenario over the project lifetime. Note that the Annual scenario can be used as a baseline to calculate Net Abatement.

Introduction

The objective of the EverCrop Carbon Plus project was to assess the effectiveness of a range of perennial based farming systems in storing carbon in soils. This report analyses some of the economics resulting from the work done in the EverCrop Carbon Plus project.

The project found that few farming systems showed significant soil carbon sequestration, with the exception being Tagasaste (Chamaecytisus proliferus), which is an evergreen, perennial, leguminous fodder shrub (Lefroy, et al., 1997). The soil carbon project on which this work is based (Wocheslander pers comm) observed a difference of 29.9 t/ha in soil carbon between annual pastures and Tagasaste in a 22 year old experimental site at Moora in Western Australia. Managed Tagasaste plantations have been demonstrated to provide very good productivity for both sheep and cattle systems ((Oldham, et al., 1994); (Edwards, et al., 1997) (Lefroy, et al., 1997) and (Abadi, et al., 2006)) compared to alternative annual pastures. Given recent developments in carbon farming in Australia, such as the Emissions Reduction Fund (ERF), there is potential for Tagasaste to provide Carbon Dioxide (CO_2) emissions abatements and hence, provide an additional revenue stream in such farming systems.

Tagasaste is well suited to poor deep sandy soils. (Lefroy, et al., 1997) estimated that approximately 1.3 million hectares of land in Australia was suitable for Tagasaste. Figure 3 illustrates the regions in Australia identified by (Lefroy, et al., 1997) as suited to Tagasaste. Note that only a small proportion of land in these regions is suitable for Tagasaste.

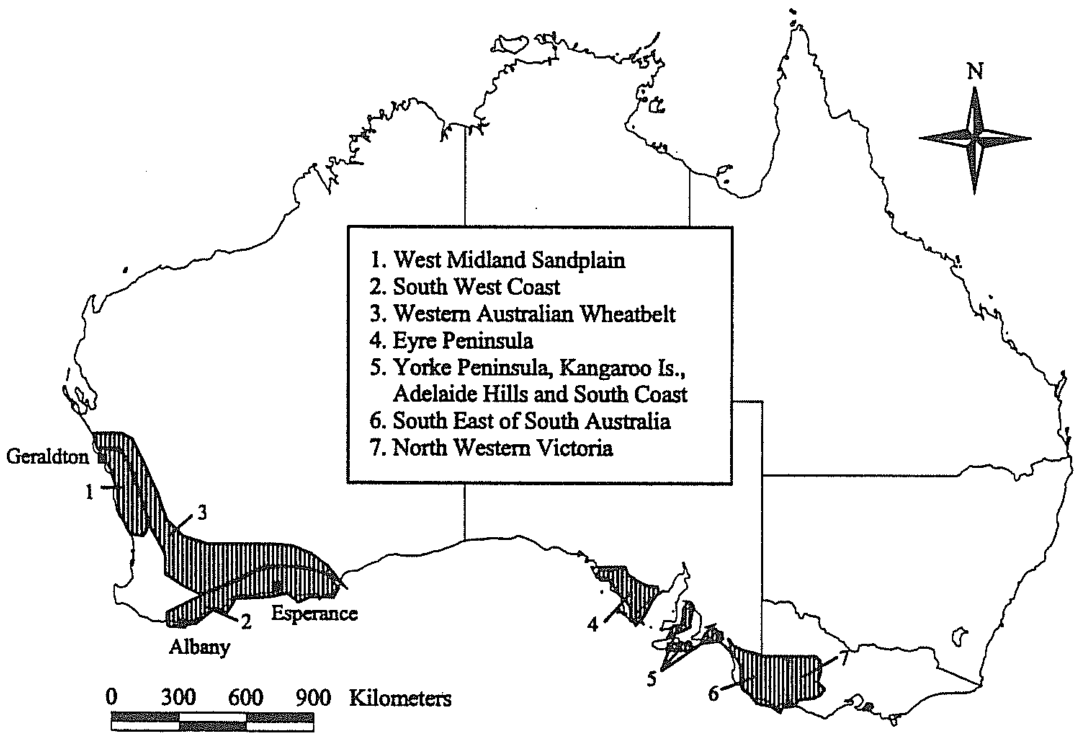

Figure 3 Farming areas of southern Australia suited to Tagasaste. (criteria: significant areas of deep sandy soils, annual rainfall > 350mm, pronounced lack of Autumn stock feed.) From (Lefroy, et al., 1997).

This report describes a model for a cattle enterprise grazing Tagasaste and investigates the economic benefits of including carbon sequestration (including soil carbon and above and below ground carbon) in the farm business model, with and without grazing. The sequestration benefits that flow into the enterprise are based on the rules set out for sequestering carbon in soils for grazing systems under the Emissions Reduction Fund (ERF) scheme (Department of the Environment, Government of Australia, 2014) and are subject to a risk-reversal discount, a 25-year permanence period discount, and are offset by emissions from cattle and residues.

We have based our modelling on a large body of research funded by the Martinadale Research Project and MLA (Edwards, et al., 1996; Oldham, 1992; Oldham, et al., 1994; Edwards, et al., 1997; Lefroy, et al., 1997) and a case study of an existing cattle enterprise, Tagasaste Farm (DAFWA, 2014). Tagasaste Farm is run by the president of Evergreen Farming, Bob Wilson. It is based on 1,000 ha of 'Block' plantings of Tagasaste established in 1987 near Lancelin in Western Australia. The Tagasaste is growing on deep sandy soils and has run cattle at approximately 10 DSE/ha for 28 years to date. This compares to around 3 DSE/ha before Tagasaste. Our analysis covers four scenarios; three cover a grazing enterprise and range from dense Tagasaste to no Tagasaste, while the other models Tagasaste as a carbon sequestration plantation. For each scenario we present the calculations of the NPV from either the cattle enterprise, the carbon abatement enterprise, or both (as appropriate), along with the net carbon abatement.

To confirm the robustness of the results, we also present a sensitivity analysis on the discount rate, the carbon price and our sequestration rates before summarising our findings in the concluding section.

Methodology

In this report we investigate three alternative scenarios for a cattle enterprise on poor sandy soils, along with one plantation scenario. A farm's cattle enterprise will usually involve a number of paddocks and have livestock rotated between them, which is one of the assumptions we make here, however we restrict our analysis to a single paddock and consider only the income and costs attributable to this paddock, based on the carrying capacity of the paddock.

The carrying capacity of the Block and Annual scenarios are based on the values observed on similar paddocks on the case study farm and the published information on biomass production and stocking rates described in the Introduction.

To compare the financial benefits of the scenarios we conduct a Discounted Cash Flow (DCF) analysis to determine the Net Present Value (NPV) of each scenario.

Scenarios

The purpose of this report is to compare Tagasaste based enterprises with the existing annual pasture systems common in the areas suited to Tagasaste.

Annual Pasture

Our default scenario assumes that low-cost annual pastures are grazed. Due to the poor soils, this scenario provides a low carrying capacity of 3.25 DSE/ha, which is based on production numbers realised in both experimental studies (Oldham, 1992; Oldham, et al., 1994) and on the case study farm before Tagasaste was introduced.

Block Tagasaste

The Block Tagasaste scenario models a relatively dense plantation based on layouts used in paddocks on the case study farm.

Double rows of Tagasaste shrubs, 2m apart, are spaced 5m apart with a spacing of 0.7m between plants within rows. Annual pasture grows in the inter-row and is also grazed by the cattle.

The carrying capacity of the Block scenario is modelled to be 10 DSE/ha, which is conservatively based on the production figures of our case study farm and supported by (Oldham, et al., 1994).

Wide Alley Tagasaste

The Wide Alley scenario models a less dense plantation, again with annual pasture in the inter-row. Row structure is the same as the Block scenario with double rows of Tagasaste planted 2m apart with a spacing of 0.7m within rows, but with the belts spaced further apart at 30m (centre-to-centre) rather than the 7m spacing used in the Block scenario.

The shrubs in this scenario will be able to grow into, and make use of, more of the inter-row area due to the lower density. While less rows are planted, each row in the Wide Alley scenario is expected to be more productive than the rows in the Block scenario. This assumption is implemented by estimating that shrubs will utilise the soil in a zone up to 5m either side of the rows with equivalent production in this zone as would be seen in the Block scenario.

The remaining area of the paddock is assumed to be as productive as the Annual scenario.

These assumptions lead to a calculation for the carrying capacity of 5.95 DSE/ha.

Unmanaged

The unmanaged scenario models a plantation of Tagasaste with the same layout as the Block scenario, but left alone to grow, with no grazing. The only income is from the abatement enterprise.

Discounted Cash Flow Analysis

The cash flow of a project is the set of costs and income at various stages during a project. Alternative projects will have different cash flows, and so are not directly comparable. Discounted Cash Flow Analysis allows us to calculate the Net Present Value (NPV), which *can* be used to directly compare projects.

Time Preference for Money

It may at first seem as though summing up all the income and subtracting all the costs in a cash flow would provide a useful number, but this is not the case because income in the future is worth less than the same income in the present, and costs in the future are less costly than immediate costs.

This is because of the time preference for money. People prefer to receive income sooner, rather than later and to pay costs later, rather than sooner. If you receive money now, you may be able to take advantage of certain opportunities that would be unavailable to you had you had to wait. These opportunities have value. The minimum value of having money sooner is the interest that would be earned on that money when put into a risk-free investment such as a term deposit, or government bonds.

Net Present Value

Because of the time preference of money, we discount future cash flows, with the discount compounding over time, so the further out a cash flow is, the more it is discounted. NPV of a project is the sum of the discounted cash flows.

This single number represents the value of a project in the present. If the discount rate used is the current rate of risk-free interest, the NPV represents the sum which if invested at that rate would lead to an equivalent fiscal outcome by the end of the project. The NPV allows for alternative projects to be compared directly by comparing their NPVs, with the project with the greatest NPV representing the best value.

To bring a cash flow item back to present value terms, it is discounted according to the formula

$$b_i = \frac{a_i}{(1+r)^i}$$

Where a_i is the cash flow in year i , r is the discount rate and b_i is the present value of a_i .

Discount Rate

The discount rate used may vary according to the investor. At a minimum, the risk-free interest rate should be used. However, investors may increase this according to their time preference for money. Therefore there is no prescribed rate that should be used for analysis. The analyst chooses the discount rate according to prevailing and forecasted interest rates, the time preference for money, and how inflation is being treated in the analysis.

In our modelling, we use 'real' incomes and costs, which means we use uninflated prices. Of course, prices will inflate over time and must be accounted for in the analysis. However, we can simplify the analysis by accounting for inflation in the discount rate that we use by subtracting the expected rate of inflation from the discount rate. That way, our prices stay constant throughout the analysis.

If the discount rate is simply the risk free interest rate, then the discount rate minus the inflation rate is simply the rate of interest above inflation.

Currently interest rates are at record lows of around 3%, but these lows are not expected to persist over the long term. Additionally, many farmers will have a significant time-preference for money, as well as long-term loans, which can effectively act as a savings account with a higher rate of interest meaning that it is appropriate to use lending rates rather than savings rates. The risk-free rates available to farmers plus their time preference for money was estimated to be 10% over the long term. When combined with an estimated long term inflation rate of 3%, the default discount rate used in our analysis was chosen to be 7%.

Cattle Enterprise Model

Full details of the cattle enterprise model may be found in Appendix A. Here we provide a summary.

The cattle enterprise model is based on a self-replacing herd, with vealers turned off at 9 months. We assume an annual death rate of 2% and a weaning rate of 90%.

The Block scenario is based on a 200 cow herd, which with bulls, replacements, and vealers, totals 386 head or 3,496 DSE. As the Block scenario is estimated to support 10 DSE/ha, we have modelled the paddock to be 350 ha.

The herd modelled in the other scenarios is scaled according to the carrying capacity of the scenario.

The costs modelled in the cattle enterprise model include purchases and sales, animal treatments, supplementary feeding, fertilizer, Tagasaste management (periodic cutting), vehicle costs, finance costs, and paddock/farm maintenance costs.

Sequestration Model

There are three pools of carbon sequestration that need to be estimated for this analysis; Above Ground Biomass (AGBM), Below Ground Biomass (BGBM), and Soil Carbon (SC).

In 2014 the Australian Government brought in new legislation for the Emissions Reduction Fund (Government of Australia, 2014), which provided for proponents of sequestration projects to opt for either a 25 or 100 year permanence period for their project. If opting for the 25 year permanence period, the sequestered amounts are discounted by 20%. In addition, a 5% 'risk of reversal' discount is applied to every project.

In this analysis, we have opted to model the project under a 25 year permanence period and we therefore discount the sequestration amounts by the full 25%.

Under the EverCrop Carbon Plus Project, Wocheslander investigated the carbon sequestration potential under an experimental site where Tagasaste had been established as replicated versions of both blocks and alleys but unmanaged for the last 22 years. These results apply directly to the Unmanaged scenario.

Unfortunately the authors are not aware of research into the carbon sequestration patterns of managed Tagasaste systems in grazing enterprises. For modelling purposes we have made assumptions about how the unmanaged data may be adjusted to apply to a managed situation.

Above Ground Biomass

Wocheslander found that the unmanaged Tagasaste plots store 29.9 t C/ha in AGBM over a period of 22 years, which averages to 1.36 t C/ha/year.

However, the unmanaged stands were planted at different densities and grow differently to the managed hedgerows in a grazing system, which are cut every 4 years to maintain fodder at reachable height for the cattle. The managed hedgerows grow a high proportion of edible leaf and stem from a very dense multi stemmed base over time as they are cut back, so it is not straightforward to estimate the relative carbon sequestration potential between the two systems. However, after consulting subject matter experts in the field this was discounted to 50% of the above ground sequestration rate of the unmanaged stands, or 0.68 t C/ha.

We can use this figure to estimate the average long-term biomass of each shrub. The planting layout of the hedgerows (with 2 rows at 7m intervals, and plant spacing within rows of 0.7m) means that there are 100/7 x 2 x 100/0.7 ≈ 4000 stems/ha. Given that carbon makes up approximately 50% of dry matter by weight, we can calculate the average dry matter growth per shrub per year to be 0.68 / 0.5 / 4000 = 0.34 e-3 t. Over 22 years this indicates an accumulated dry weight of approximately 7.5kg per shrub, which seems reasonable and gives credence to the 50% discount rate used.

Below Ground

While Wocheslander found the below ground biomass reached 5.2 t C/ha after 22 years for low density unmanaged stands, there are probably differences in below ground sequestration between lower density, unmanaged stands, and managed, higher density stands.

Therefore, the below ground biomass in the managed scenarios was estimated based on the amount of above ground biomass grown per year using a conservative estimate of the roots:shoot ratio of

0.25. A conservative root:shoot ratio was used due to the uncertainties around the storage of carbon below ground in managed systems. Higher root:shoot ratios have been reported for a range of environmental plantings in southern Australia (Paul, et al., 2013), with root:shoot ratios being higher in younger plantings and in nutrient or water limited environments. Consistent with this the root:shoot ratio also declined as productivity increased. Given these complexities and uncertainties it was decided to use a conservative allocation to roots.

(Engelke, 1992) sampled Tagasaste sites and found a range of edible dry matter (EDM) productivity of between 2.6 t/ha/year and 8.4 t/ha/year, with a median of 5.7 t/ha.

It is also possible to estimate the total EDM production by considering fodder intake and the carrying capacity of the paddock. For this estimation, we assumed that each DSE represents 50kg of livestock and that EDM intake is 3% of livestock weight per day. For a carrying capacity of 10 DSE/ha, this indicates a rate of EDM production at 10 * 50 * 0.03 = 15kg EDM/ha/day, or 5.475 t EDM/ha/year. Given that there is wastage from uneaten fodder and periodic cutting, this rate represents a floor for the productivity of EDM per year, and lends credence to the figure of 5.7 t EDM/ha/year that we adopted.

In a real Tagasaste grazing system, the fodder will be intensely grazed periodically rather than constantly grazed at the carrying capacity of the paddock, as the herd is moved between paddocks. It was felt that the 25% root-to-shoot ratio is more applicable to unmanaged stands that are left alone and so a further 50% discount was applied to the EDM to include in the root-to-shoot ratio calculation.

As well as the EDM, we have estimated a permanent average increase of approximately 1.36 t AGBM DM/ha/yr. Applying the 50% discount to the EDM to account for the decrease in above ground biomass due to episodic grazing and adding on the stored biomass AGBM gives a conservative estimate of 0.5 x 5.7 + 1.36 = 4.21 t AGBM DM/ha/year, 25% of which gives 1.05 t BGBM DM/ha/year, of which approximately 50% will be carbon. Therefore, the carbon sequestration rate used for the BGBM pool of grazed Tagasaste in our analysis is 0.53 t C/ha/year.

Soil Carbon

Wocheslander found an average soil carbon sequestration rate of 28.8 t C/ha in the top 2m of soil of the unmanaged Tagasaste, which averages to 1.31 t C/ha per year over 22 years. This is the value we used for the unmanaged scenario. For the managed scenarios, as with the AGBM calculation, we applied a 50% discount to the rate of soil carbon sequestration observed in the unmanaged stand to estimate the rate in the managed stand. Therefore the rate of sequestration modelled was 0.65 t C/ha/year.

The authors expect that the 50% discount is a conservative estimate as an argument can be made that the managed Tagasaste stands are more productive in terms of total biomass production per year and that, in a grazed managed system, the below ground biomass accumulation and soil carbon sequestration may be more closely linked to total EDM production than to long term AGBM sequestration. More research is required to more accurately and confidently model carbon sequestration in managed Tagasaste systems.

CO_2e Abatement

The rate of CO_2e abatement from carbon sequestration is given by the molecular mass of CO_2 to C. The molecular mass of CO_2 is 44 (12 + 16 x 2), and for C is 12, so this ratio is 44/12 = 3.67.

The sequestration rates given so far in this section are in terms of t C/ha. Table 1 summarises the results and applies the 25% discount required under the 25 year ERF project rules.

U: Unmanaged **M: Managed**	**Sequestered Carbon** t C / ha / year		**Abatement** t CO2e / ha / year		**Discounted Abatement** t CO2e / ha / year	
	U	M	U	M	U	M
AGBM	1.36	0.68	4.99	2.49	3.74	1.87
BGBM	0.24	0.53	0.88	1.94	0.66	1.46
Soil Carbon	1.31	0.65	4.80	2.38	3.60	1.79
Total	**2.91**	**1.86**	**10.67**	**6.82**	**8.00**	**5.12**

Table 1 Sequestered Carbon and CO2 Abatement Rates

It is interesting to note that under our assumptions, the sequestration in each pool is very similar – each source is important. Of particular interest to the EverCrop Carbon Plus project is the soil carbon component which by our estimates contribute 45% and 35% of the abatement attributable to the unmanaged and managed stands, respectively.

Sigmoidal Model

In Table 1 we listed the average estimated abatement per year for each source of carbon sequestration. A linear accumulation of carbon sequestration is a simple model and may have merit, although an alternative model that follows a sigmoidal accumulation curve towards an upper asymptote is also reasonable. Given the nature of DCF analysis, where the timing of payments makes a difference, we considered both models, and ultimately chose to run our analysis with the sigmoidal model.

Figure 4 shows our proposed sigmoidal growth model for the managed scenarios. Under the sigmoidal model, 95% of the total carbon accumulation over 25 years occurring in the first 15 years. When compared to the average accumulation model, the sigmoidal model produces a slower start to the accumulation, with more rapid accumulation towards the centre of the project life and very slow accumulation over the second half of the project as the carbon accumulation reaches its asymptotic limit. Figure 5 shows the sigmoidal growth model for the unmanaged scenario.

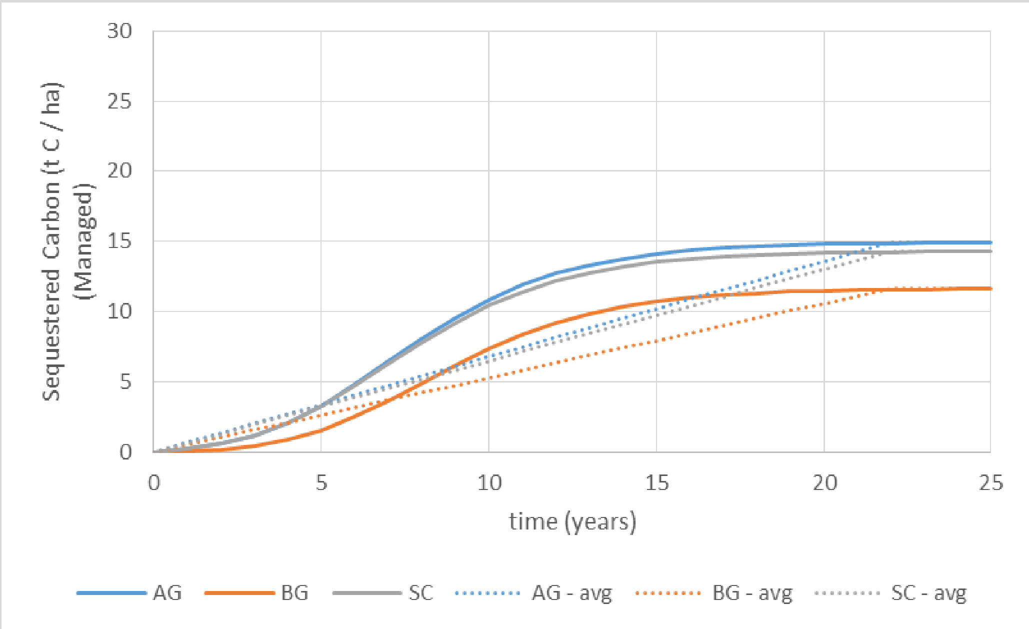

Figure 4 Sigmoidal Sequestration Model for the managed scenarios. Total C accumulation by pool over project period. Note that the AG an SC curves are almost identical. Alternative Constant Accumulation model is indicated by the dashed series.

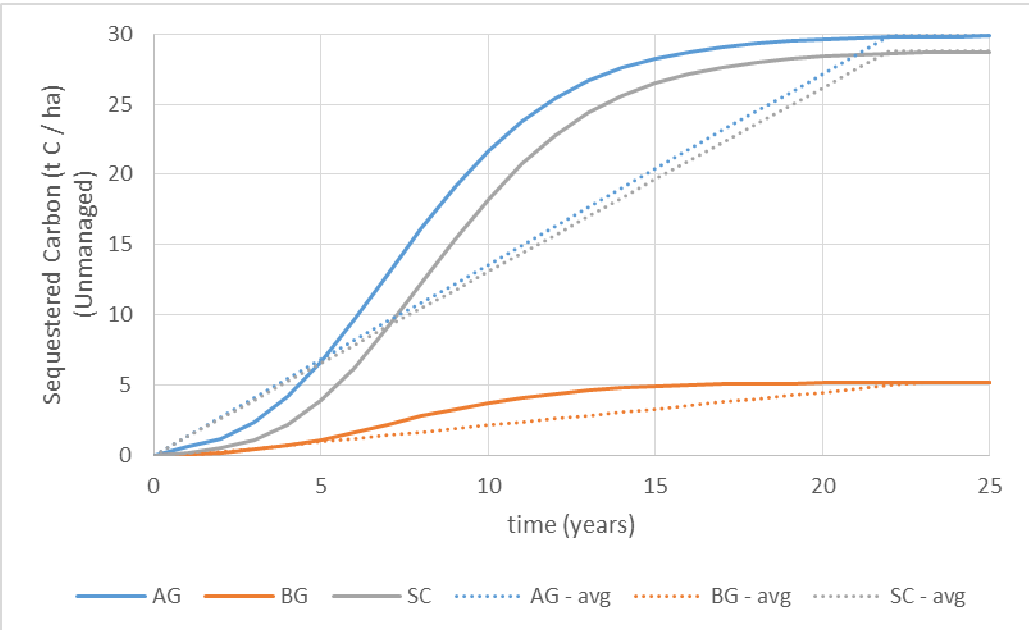

Figure 5 Sigmoidal Sequestration Model for the Unmanaged scenario. Total C accumulation by pool over project period. Alternative Constant Accumulation model is indicated by the dashed series

Both the constant-accumulation and the sigmoidal models accumulate to the same total, which is equivalent to the average accumulation over 22 years given that the average accumulation figures were estimated from the observations of the unmanaged plots which were 22 years old, and, given the assumptions of the sigmoidal model, would have been close to reaching their asymptotic limit of accumulation. Note that it is important to run the analysis over the full 25 year permanence period because emissions need to be accounted for over the entire project, not merely the period during which carbon is being sequestered at a rate above any emissions.

The sigmoidal model was chosen for use in the analysis as it was deemed to be a more realistic model for when sequestration would occur. The precise nature of the sigmoidal curve was not considered to be crucial to the model – the key was the implementation of a suitable curve, with the same total as the average model over the lifetime of the project, with a slow start, a slow finish, and faster accumulation in the middle.

It should be stressed that while this model represents our best estimate given the available data, there is significant uncertainty in its accuracy. Further research is required to develop better models to estimate both the total amounts of carbon sequestered in each pool, and the rates of sequestration over time.

Assessment Costs

The ERF rules (Department of the Environment, Government of Australia, 2014) require that sequestration is regularly assessed, every 1 to 5 years. In this analysis we assume that assessments occur every three years. The cost for assessment is based on advice from a local consultant forester sourced during the analysis. The advice was that assessment costs are based on one plot per 5 ha Costs of establishing and measuring plots range from $60 to $100 per plot, with an additional 50% to account for data collation and reporting. In our analysis we have assumed a rate of $80 x 1.5 per 5 hectares for the Block and Unmanaged scenarios, and scaled this according to the number of trees in the Wide Alley scenario. These assumptions lead to costs of $24.00/ha for the Block and Unmanaged scenarios and $5.60/ha for the Wide Alley scenario, every three years.

Emissions Model

The Ministerial Determination (Department of the Environment, Government of Australia, 2014) covering the net abatement that can be claimed for soil sequestration in grazing systems under Australia's Emissions Reduction Fund (the ERF) sets out which sources of emissions need to be taken into account. In our case, these emissions will include the methane (MH_4) emissions generated by livestock and the Nitrous Oxide (N_2O) generated from residues from organic material in the soil.

The Department of Environment has issued a set of Standard Parameters and Emissions Factors (Department of the Environment, Government of Australia, 2014), which have been used to estimate both the cattle emissions and the residue emissions.

Emissions Baseline

Under the ERF rules (Department of the Environment, Government of Australia, 2014), the claimable emissions abatement is measured from the existing enterprise emissions – the emissions baseline. The cattle emissions of the Annual scenario can be argued as setting a conservative emissions baseline for the other scenarios.

To implement the baseline, the net cattle emissions calculated for the Block and Wide Alley scenarios will be the total cattle emissions in those scenarios minus the total emissions from the Annual scenario. In the Unmanaged scenario, the magnitude of the emissions from the Annual scenario is added to the net abatement.

Cattle Emissions

Table 2 lists standard parameters for estimating the CO_2 equivalent emissions from cattle. The herd structure we model has each class of animal on the farm all year round, except for the vealers, which are absent in Autumn, as the previous year's vealers are sold at 9 months age in late summer, and the new calves are born at the beginning of winter.

Class	**Bulls**		**Steers**		**Cows**		
Age	**< 1**	**< 1**	**< 1**	**1 to 2**	**< 1**	**1 to 2**	**> 2**
Spring	5.374	5.834	4.101	5.433	4.101	5.433	6.052
Summer	4.116	4.199	3.459	4.547	3.459	4.547	4.52
Autumn	1.875	3.299	1.714	3.357	1.714	3.357	4.588
Winter	3.223	4.115	2.654	3.733	2.654	3.733	5.336

Table 2 Standard parameters for estimating cattle emissions in kg CO2e/day by season.

Based on these parameters and the herd structure for each scenario we found total emissions rates of 1.81 $t\ CO_2$ e/ha, 1.08 $t\ CO_2$ e/ha, and 0.59 $t\ CO_2$ e/ha for the Block, Wide Alley and Annual scenarios, respectively. By taking the Annual scenario rate of 0.59 $t\ CO_2$ e/ha as the baseline, the net cattle emissions are 1.23 $t\ CO_2$ e/ha and 0.49 $t\ CO_2$ e/ha for the Block and Wide Alley scenarios, respectively.

Residue Emissions

Fine root material is broken down in soil over time. Sequestration of some of this organic material is one consequence of this process, but release of nitrous oxide is another. It was not straight-forward estimating residue emissions from data available. Our modelling was based around estimating the Nitrogen content in the fine root material, estimating how much of the fine root material is mineralised, relating this amount to the amount of mineralised carbon (i.e. soil carbon sequestration), and therefore the CO_2 e emissions due to Nitrogen mineralisation per tonne of soil carbon sequestration.

N in fine root material

It was estimated that the concentration of N in the fine root material would be approximately 40% of that in leaf material based on the ratio of above ground and below ground N content in residues in pastures which is provided as part of the Standard Parameters and Emissions Factors (Department of the Environment, Government of Australia, 2014).

Given the level of crude protein in the leaf material of between 10% to 25% of dry weight, (depending on fertilisation) (Edwards, et al., 1996), a level of 15% was chosen to be a suitable estimation for our situation. Approximately 1/6 of protein is N, which leads to an estimated concentration for N in leaf material of 2.5% by dry weight. Given the estimate that 40% of this rate is appropriate for root material, the concentration of N in root material is estimated at 1% by dry weight.

N related to C

Only a fraction of the fine root material that is mineralised remains in the soil. It is estimated that for every 4 tonnes of fine roots, that 1 tonne of C is converted to soil organic matter. It is generally accepted that all the fine root material to is broken down annually. Thus each tonne of fine root material, in which we estimate the N concentration to be 1%, provided 0.01 tonnes of N or 4 tonnes provides 40 kg of nitrogen.

Assuming that all this N is emitted through the breakdown processes and also assuming that this pool of N behaves in a similar manner to other residues we used the estimate for the rate of N emissions of CO2 emission for residues of 4.68 t CO_2 e / t N (from the Standard Parameters and Emissions Factors (Department of the Environment, Government of Australia, 2014)). Therefore, the rate of emissions per tonne of sequestered soil carbon derived from 4 tonnes of fine roots is 0.04 x 4.68 = 0.187 CO_2 e / t SC. This relatively small emission does not significantly influence the emissions from these systems.

Results

Analysis settings

Two settings crucial to analysis, yet subjective, are the discount rate and the carbon abatement price ($ / t CO_2e). As discussed in the Methodology section earlier, we have chosen to use a discount rate of 7% as our default for this analysis.

In April 2015, the first auction under the ERF was held, with the average price per tonne of CO_2 abatement coming to $13.95 (Clean Energy Regulator, 2015), which is the default price used in our analysis.

These two parameters are not fixed and could reasonably vary over some range. A sensitivity analysis on both parameters is provided in the following section.

Cattle Enterprise vs Emissions Abatement Enterprise

This report looks at the potential for the inclusion of carbon sequestration as a secondary income stream in Tagasaste grazing enterprises. In this section we have sought to separate the cattle enterprise from the CO_2 emissions abatement enterprise. The two components are related through the Tagasaste shrubs with some costs such as establishment essential to both enterprises. However, for the purposes of this analysis, we have allocated all costs essential to the cattle enterprise to the cattle enterprise as it is primary and have attributed only the additional income and additional costs of the emissions abatement enterprise to the abatement enterprise.

General Results - NPV

To determine the NPV of each scenario, we developed a discounted cash flow model for each scenario in Excel with our Cattle Enterprise, Sequestration and Emissions models feeding into these.

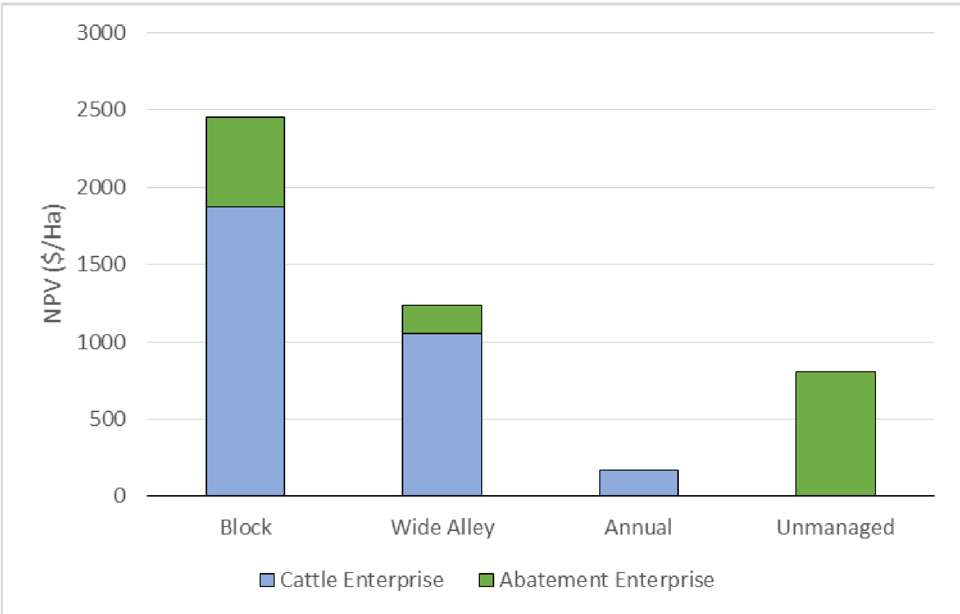

Figure 6 Overall NPV/ha for each scenario, separated into Cattle Enterprise and Abatement Enterprise components.

The NPV results are depicted in Figure 6, with the Block scenario clearly providing greater value in both the underlying cattle enterprise (due to far superior productivity from the Tagasaste) and the carbon sequestration income stream. This is a win-win situation and clearly warrants serious consideration from farmers with suitable soils in regions well suited to Tagasaste. Remarkably, the Unmanaged scenario generated a substantial NPV at approximately two thirds that of the Wide Alley scenario and one third that of the Block scenario which demonstrates the sequestration potential of Tagasaste. However, it is clear that combining Tagasaste sequestration with a cattle grazing enterprise is much more profitable.

In the Block scenario, the abatement component of the NPV is 24%; it's 15% in the Wide Alley scenario. Perhaps importantly from a grazier's perspective, the abatement NPVs from both these scenarios are sufficient to cover the cost of Tagasaste establishment.

General Results – Total and Net Abatement

Total emissions abatement is positive for the three Tagasaste scenarios. That is, the rate of sequestration is greater than the level of emissions under these scenarios. The default Annual scenario provided no sequestration benefits to offset its cattle emissions and so can be said to have had a negative abatement. The total emissions abatement over the project lifetime for the Block, Wide Alley, Annual and Unmanaged scenarios are 64, 17, -15, and 170 t CO2e/ha, respectively, as illustrated in Figure 7.

However, farmers are paid for their net emissions abatement, which is the net improvement on existing practice. The default scenario is the Annual scenario, which generates emissions at a rate of 0.59 t CO2e/ha/year. The net abatement for the other scenarios is measured from this baseline, effectively adding 0.59 t CO2e to their total abatement per hectare each year.

Measured from this baseline, net emissions abatements across the entire enterprise average to 3.16 t CO2e/ha/year for the Block scenario and 1.26 t CO2e/ha/year for the Wide Alley scenario over the lifetime of the project. Unsurprisingly, the Unmanaged scenario achieved the greatest net abatement with an average of 7.39 t CO2e/ha/year.

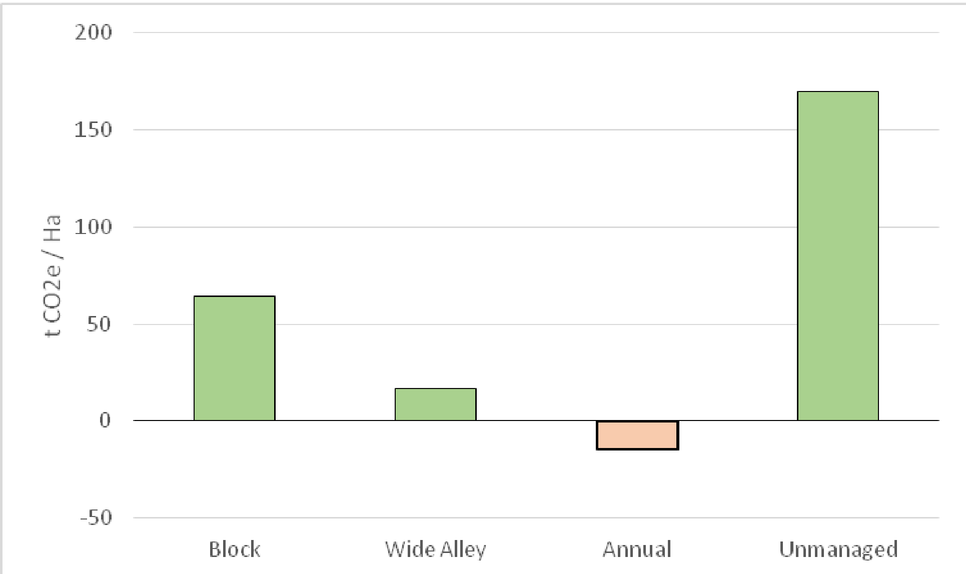

Figure 7 Lifetime total abatement per hectare by scenario.
Net abatement is measured using the Annual scenario as a baseline.

Block Scenario Breakdown

The Block scenario was the most profitable, benefiting from the superior productivity enjoyed from Tagasaste as well as the CO2 abatement income stream. The NPV for this scenario was $2,455/ha.

Figure 8 illustrates the contribution of various costs by NPV, while Figure 9 illustrates the income breakdown. Note that emissions from cattle and residues are not included as costs, but serve to diminish the net abatement income figure.

Figure 10 shows the net emissions from the Block scenario as a proportion of total sequestration, at approximately 30% of sequestration. Emissions are almost entirely a result of cattle, with emissions from residues comprising just 8% of the total emissions.

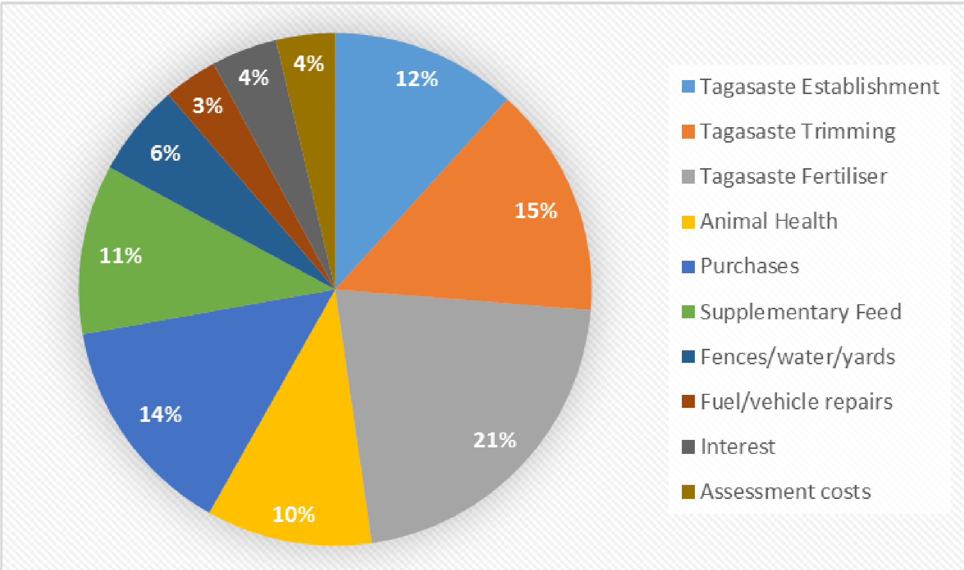

Figure 8 Division of costs in Block Scenario

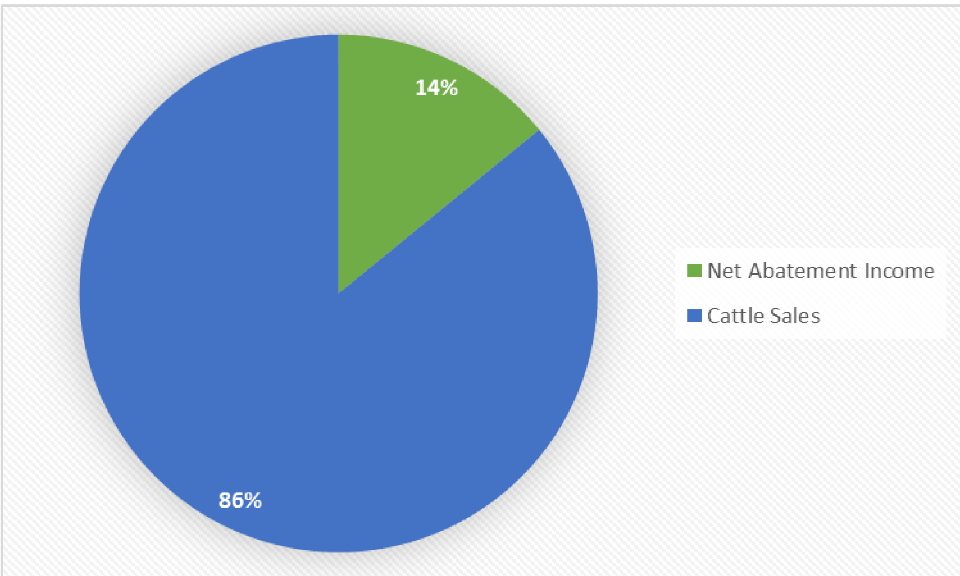

Figure 9 Division of Income in Block Scenario

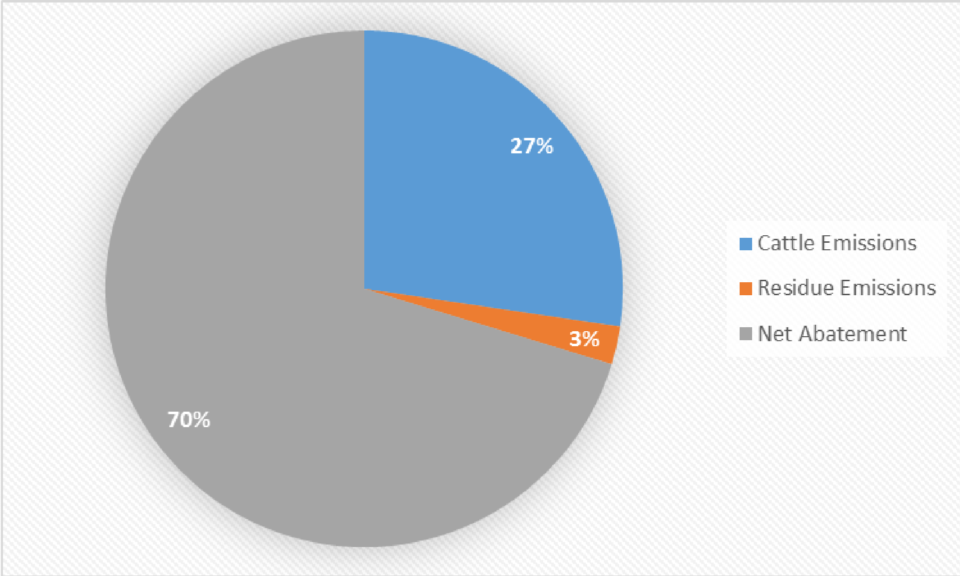

Figure 10 Emissions under the Block scenario as a proportion of total sequestration.

Wide Alley Scenario Breakdown

The Wide Alley scenario straddled the middle ground between the highly profitable Block scenario and the more marginal Annual scenario, with an NPV of $1,236/ha.

Figure 11 and Figure 12 illustrate the breakdown of costs and income for the Wide Alley scenario, respectively. While there is very little income from the abatement enterprise, there is a positive NPV and so the productivity gains from Tagasaste are paid for.

Figure 13 depicts the magnitude of emissions sources against the total sequestration. Note that these proportions are the same as for the Block scenario.

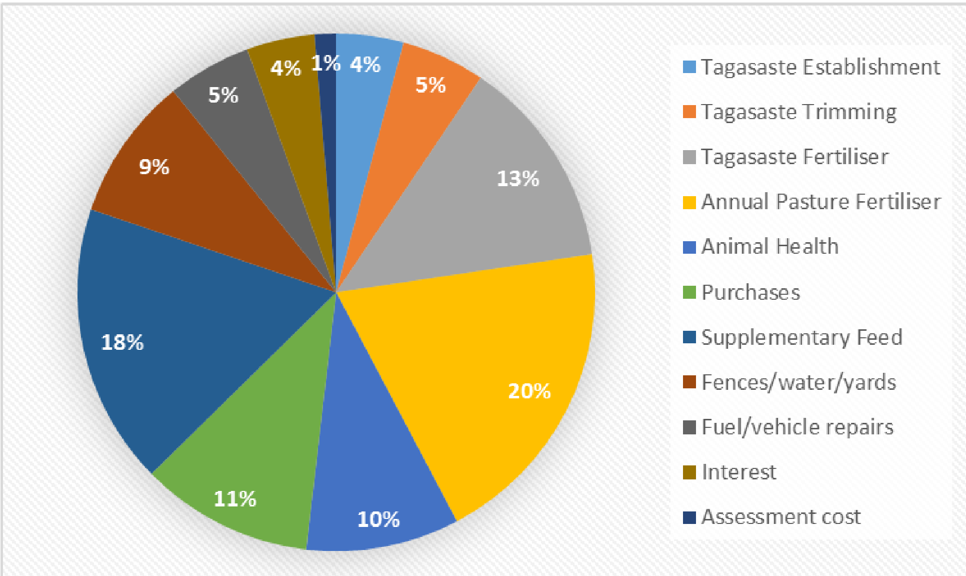

Figure 11 Division of costs for the Wide Alley scenario.

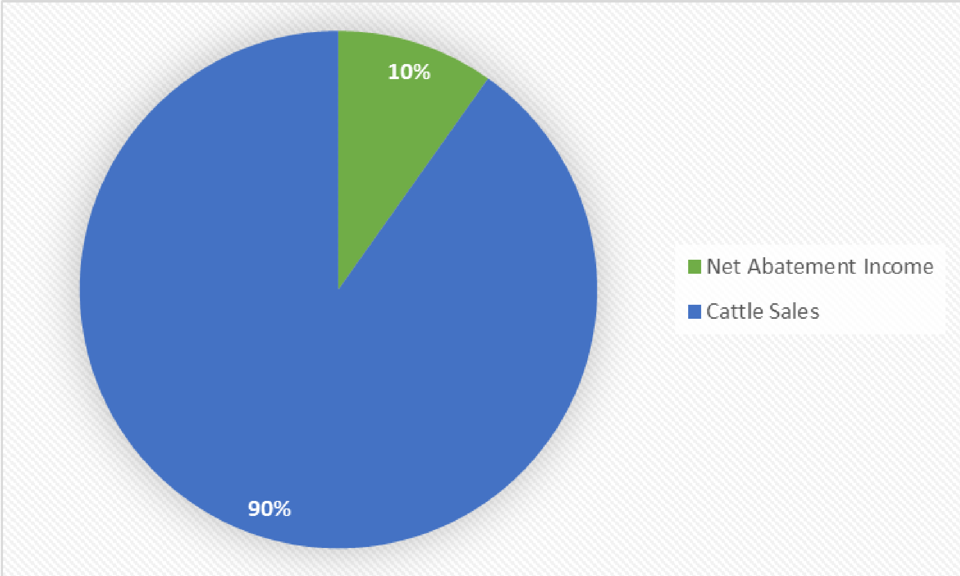

Figure 12 Division of income for the Wide Alley scenario

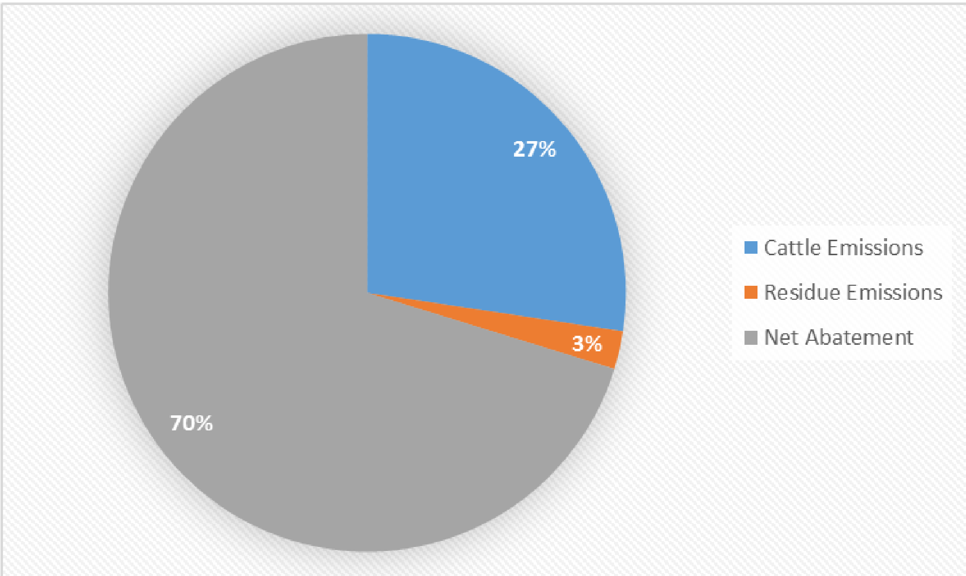

Figure 13 Emissions under the Wide Alley scenario as a proportion of total sequestration.

Annual Scenario Breakdown

The Annual scenario was not run under the ERF and had no revenue (or costs) from carbon emissions abatements. The only income was from cattle sales. Due to the poor productivity of the annual pasture, this was by far the worst performing scenario with an NPV of only $166/ha; slightly less than 7% of the NPV from the Block scenario.

The breakdown of costs for the Annual scenario is illustrated in Figure 14. The greatest cost was supplementary feed, by a significant margin.

In the Annual scenario model, every year produces the same results as there is only the cattle enterprise contributing. Each year the paddock gross margin was only $14/ha/year.

Because the scenario is so marginal, the results are highly sensitive. Small reductions in costs or improvements in revenue can make big changes to the NPV in percentage terms. The two greatest costs are the fertiliser costs and the supplementary feed costs at 36% and 24%, respectively.

The fertiliser cost is possibly over estimated at $42/ha. If the fertiliser cost is reduced to $30/ha, the NPV almost doubles to $312/ha. While a doubling may seem significant, the fact that it is doubling a small number means that there is only a small gain in dollar terms, or when compared to the magnitude of the other two scenarios.

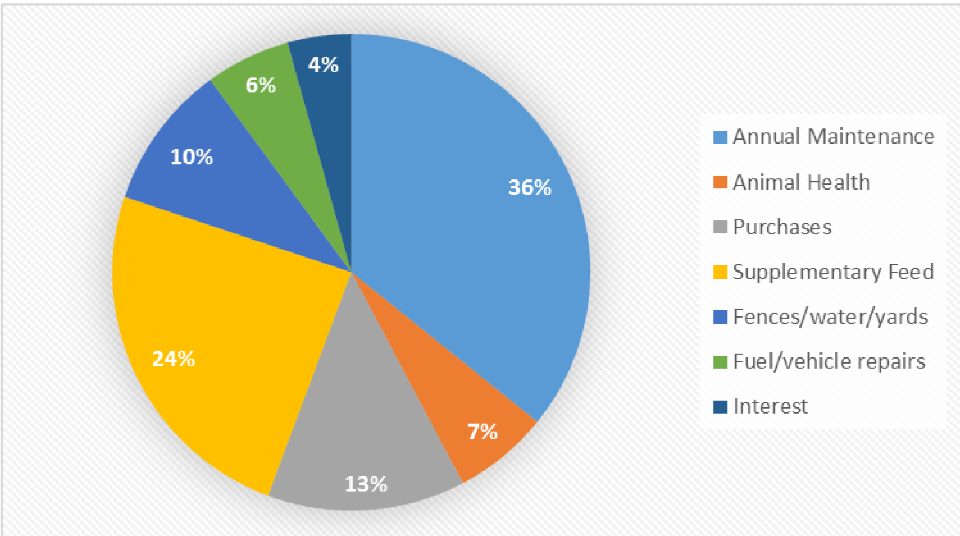

Figure 14 Division of costs for the Annual scenario

Unmanaged Scenario

The ungrazed Unmanaged scenario generated an NPV of $802/ha solely from an abatement enterprise. Given the scenario was based on an experimental site not geared towards making a profit, the NPV found is probably an under-estimate for this scenario.

Figure 15 shows the division of costs for the Unmanaged scenario. While the establishment costs are the largest contributor at 43%, fertiliser costs are very close at 40%. As Figure 16 illustrates, there were almost no emissions to account for with the residue emissions reducing the net abatement by only 3%.

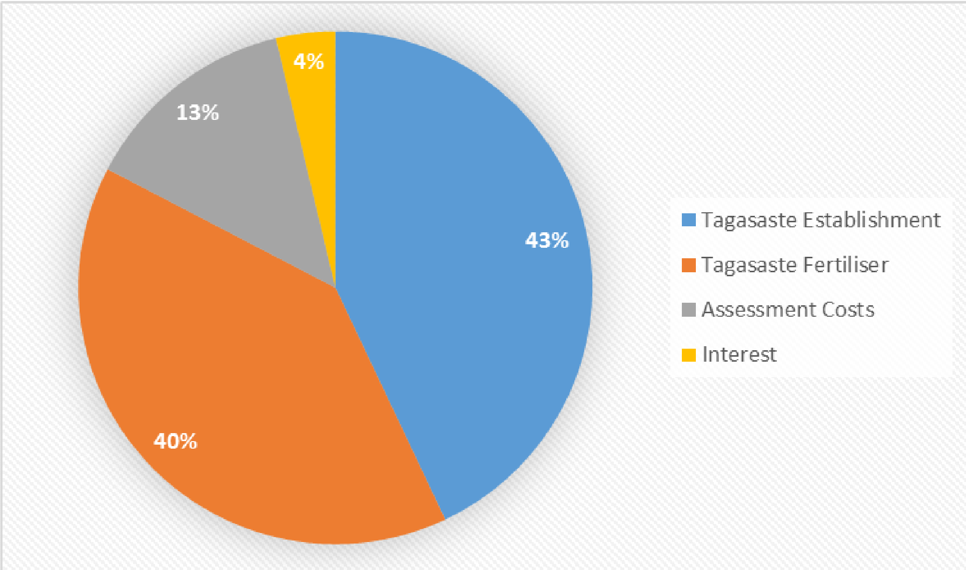

Figure 15 Division of costs for the Unmanaged scenario

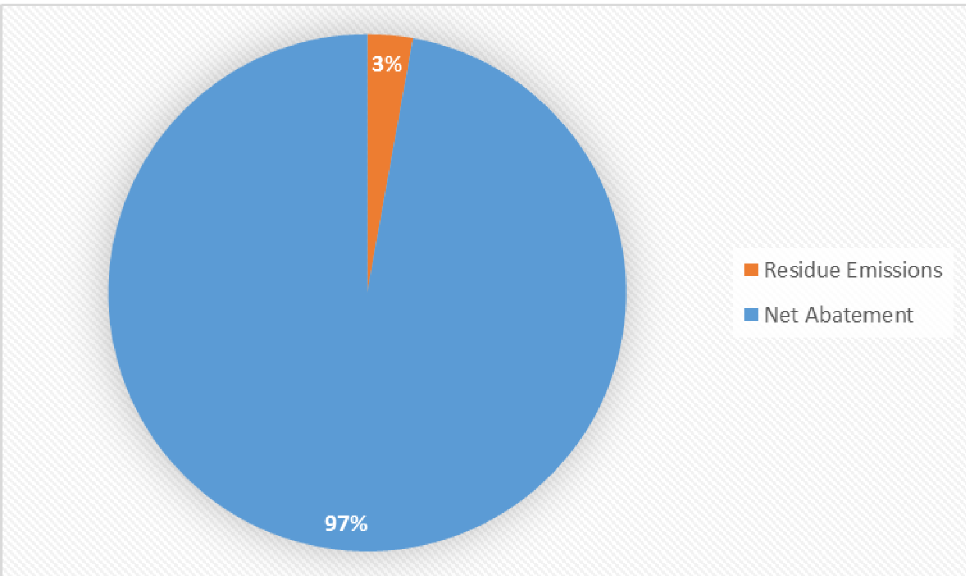

Figure 16 Emissions under the Unmanaged scenario as a proportion of total sequestration.

Sensitivity Analysis

Discount Rate

The cash flows within our scenarios are spread out over a relatively long period of 25 years. A high discount rate will reduce cash flows towards the end of the project to mere fractions of their nominal (future) values, whereas a low discount rate will tend to preserve those values. For example, using our default discount rate of 7%, cash flows in year 25 are reduced to just 18% of their nominal values, whereas with a very low discount rate, of say 2%, cash flows that far in the future retain 61% of their nominal value.

Depending on the point in a project at which positive and negative cash flows lie, the choice of discount rate can make significant changes to the NPV, and the best alternative among a number of scenarios may not be fixed when varying the discount rate. It is therefore important to investigate the robustness of results under a varying discount rate.

It makes sense to limit the range in which the discount rate can vary only to those rates that are plausible. It may well be the case that interesting effects occur at the boundary cases. In our analysis we have used real costs and so our discount rate is the rate above inflation plus an additional fraction to account for an investor's time preference for money. If the investor is risk-averse, this may be zero. For example, they may be happy to invest all their money at a savings rate at the bank, with very little risk.

Over the last several years, interest rates have been at record lows, with the return above inflation very low at only 1 or 2 percent. This situation may last for some years, though based on history, sustaining such low rates over 25 years would appear exceedingly unlikely.

For this analysis we have chosen to vary the discount rate between 1% up to 10%. Higher rates, even up to 20% are not entirely unreasonable, depending on the investor. However, over such a long project, rates above 10% will have very similar outcomes, with only the upfront portion of the project playing a significant role.

In this analysis, the discount rate was varied while holding all else constant and the NPV figures for each scenario recorded. The chart in Figure 17 displays the results.

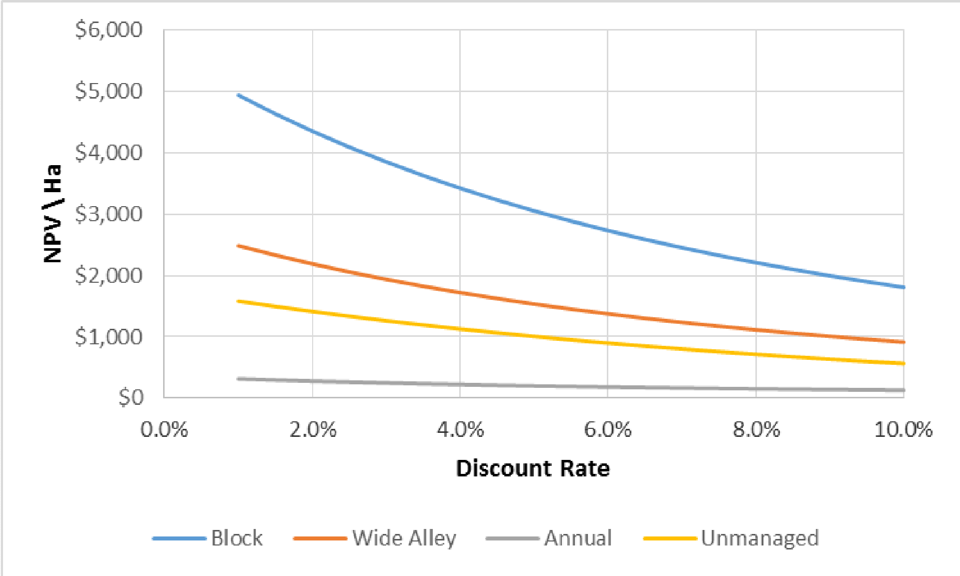

Figure 17 NPV/ha by Discount Rate, for each scenario

In Figure 17 we can see that as the discount rate increases, the NPV is reduced. This is to be expected for projects with relatively regular positive cash flows. Importantly, the curves do not cross over at any point, which indicates that the order of the scenarios is robust under a varying discount rate; the Block scenario is always the best, and the Annual scenario is always the worst.

Carbon Price

Like the discount rate, the carbon price we use, i.e. the price per tonne of CO2e abatement, is not pre-determined. Under the ERF in Australia, proponents submit projects to abate emissions at a particular price in a periodic 'reverse auction'. The government will choose the best value projects, up to a point that is within their budget, meets their abatement goals, and falls within their limit for an acceptable price per tonne of abatement.

The first auction was held in April 2015 and resulted in an average price per tonne of abatement of $13.95, which is the default price used in our analysis. However, an average price suggests the existence of a range of prices, with the limits confined to the subject of speculation.

The ERF comes after an earlier scheme (the Carbon Pricing Mechanism) set up by the Australian Government under which CO2e emissions were priced at $24.15 in 2013-14 (Clean Energy Regulator, 2015).

In our analysis on the carbon price we have looked at a range from $0 up to $30, though these extremes are unlikely price points, with a range from $5 up to $20 much more plausible.

The analysis assumes a discount rate of 7%.

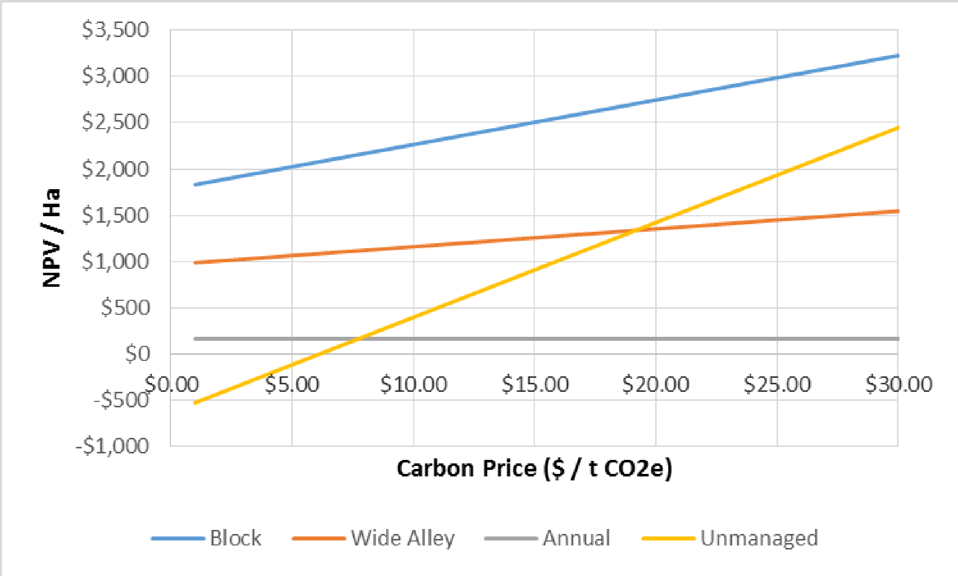

Figure 18 NPV vs Carbon Price for each scenario

The carbon price was varied while keeping all other parameters constant while the NPV for each scenario was recorded. Figure 18 illustrates the relationship between NPV and carbon price. Trivially, the Annual scenario is unaffected, as there are no abatement related cash flows present in that scenario. The curves of the grazed scenarios do not cross and so the ordering of these scenarios can be said to be robust under a varying carbon price. However, the Unmanaged scenario is particularly sensitive to the carbon price due as all the income for that scenario is scaled by the carbon price, with it losing money when the carbon price falls below approximately $6/t CO2e.

It is clear that for every price (even when the carbon price is $0) the Block scenario is the best and by a substantial margin.

One of the more interesting points that can be made from this chart is the component of the NPV that comes from the carbon price in the grazed Tagasaste scenarios. For the Block scenario, the NPV is approximately 40% greater under a carbon price of $13.95 than with a price of $0. It is also interesting to note that the Block scenario is much more sensitive to changes in the carbon price than the Wide Alley scenario, for which its curve is nearly flat.

Break-even Carbon Price

If the net abatement income from Tagasaste can pay for its own establishment, this may help persuade some graziers to start implementing or expanding Tagasaste in their cattle businesses. In this analysis we calculate the carbon price required in order for the net abatement payments to cover the upfront establishment costs, which we will refer to as the 'break-even' carbon price. Note that this is not a true break-even price because it doesn't reflect the additional benefits from the higher productivity Tagasaste. Rather, we are asking the question, "At what carbon price do we see the net abatement income covering the costs of establishment, such that we enjoy the increased production benefits of Tagasaste for free?"

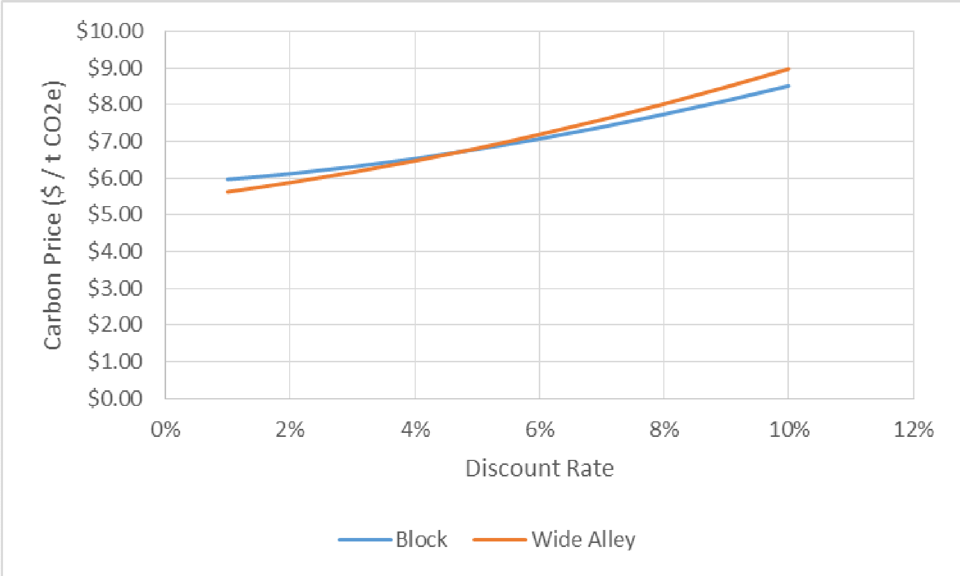

Figure 19 'Break-even' Carbon Prices for Abatement Enterprises by Discount Rate

At the default discount rate of 7%, the break-even carbon price is $7.39 and $7.59 for the Block and Wide Alley scenarios, respectively.

Figure 19 shows how the discount rate affects the break-even carbon price for the abatement enterprises. This chart indicates that as the discount rate increases, the break-even carbon price must also increase. This is because the abatement income occurs in the future, whereas the establishment cost is up-front. The future income will contribute less as the discount rate increases, meaning the carbon price must rise to compensate.

While the price increases with discount rate, the increase is relatively flat with the price ranging between $6 and $9 for the discount rates considered. These prices are comfortably below the default carbon price we have used of $13.95 suggesting that not only should we expect the enterprise to pay for the Tagasaste establishment, but that it would provide additional income under a carbon price above $9.

Carbon Sequestration

Our carbon sequestration model is based on the best information we have, but there are gaps in the research on how sequestration progresses in managed Tagasaste systems. Therefore, in this section we look at what happens to these scenarios if we modify the sequestration rates in our model. The Unmanaged scenario is based directly on field experiments so the sequestration rates are more certain and have not been included in this sensitivity analysis.

The analysis assumes that the sequestration attributable to each source is scaled by a modifier, from a 50% discount, up to a 50% increase on our estimated values.

We adjusted the sequestration rates while keeping all other parameters constant and stored the NPV. The results are depicted in Figure 20.

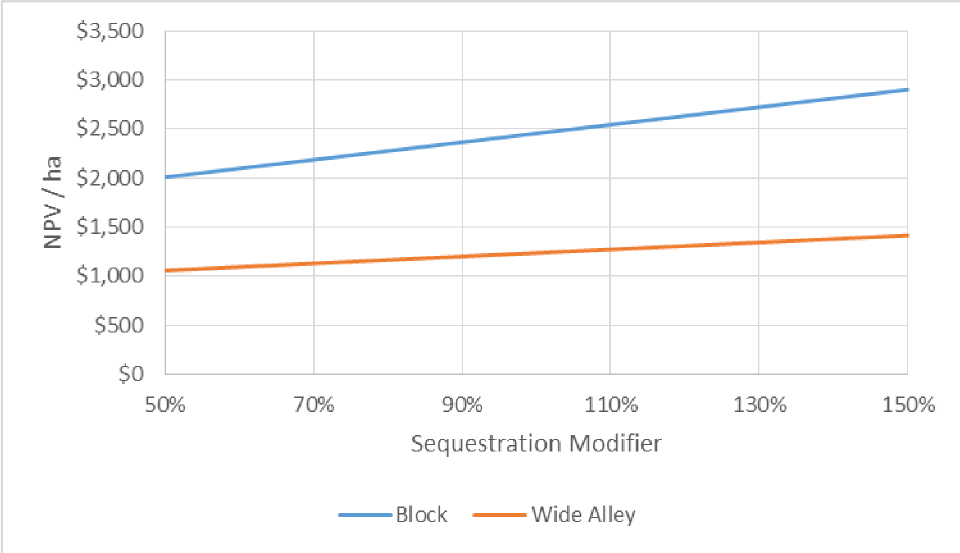

Figure 20 Sensitivity scan results over a sequestration rate modifier.

Unsurprisingly, changing the amount of sequestration has an effect similar to changing the carbon price. Should the sequestration rate be half, but the carbon price be double, one might suppose that the NPVs of all scenarios would be left unchanged. However, this is not the case because of how emissions affect the NPV under both changes.

Both emissions and sequestration contribute to the net abatement, so the net abatement is scaled in proportion to the carbon price change. However, if the sequestration rates are scaled, there is no effect on the emissions. If the sequestration rates are lifted, they are lifted further beyond the emissions. What may have been a marginal positive net abatement (or even a small negative abatement) can be dramatically changed if the sequestration rate is lifted.

In our default modelling, the sequestration rates are already substantially higher than emissions, so there is only a relatively small effect, such that Figure 18 and Figure 20 look quite similar. The effect is there though; adjusting the sequestration rates up and down by 50% gives a range for NPV / ha for the Block scenario of $2,009 to $2,902, whereas adjusting the carbon price in the same way gives a range of $2,120 to $2,791, a range that is larger by approximately 33%.

Therefore the sequestration rates can be said to be about 33% more sensitive than the carbon price, underscoring the importance of further research into sequestration in managed Tagasaste systems.

Conclusion

In this report we have developed an economic model of a cattle grazing enterprise on Tagasaste and investigated the effect of incorporating a carbon emissions abatement enterprise that takes advantage of the carbon sequestration potential of the Tagasaste.

We modelled four scenarios; three with different levels of Tagasaste from dense alleys to wide alleys to no Tagasaste at all and one Tagasaste plantation for carbon sequestration.

The results clearly indicate that the Block Tagasaste scenario is preferable with a NPV about 50% greater than the NPV of the Wide Alley scenario. The Annual scenario proved to be marginal with a NPV at only a fraction of that from the Block scenario. The Unmanaged scenario provided about one third the NPV of the Block scenario – from income solely derived from carbon emission abatement.

The ranking of the grazed scenarios is unchanged by the inclusion of the abatement enterprise. However, the carbon sequestration potential is significant. With incomplete information, we have modelled the carbon sequestration from above ground biomass, below ground biomass and soil carbon, with a bias towards conservative sequestration estimates. Over the lifetime of the project, net abatement rates were estimated to be, on average, approximately 3.16 t CO_2e/ha/year for the Block scenario and 1.26 t CO_2e/ha/year for the Wide Alley scenario. The less profitable Unmanaged scenario achieved net abatement of 7.39 t CO_2e/ha/year. These net abatement levels treat the Annual scenario emissions of 0.6 t CO_2e/ha/year as the emissions baseline.

Given the uncertainties in the modelling, it was appropriate to conduct sensitivity analysis on some of the key parameters of the model to test the robustness of the results. The discount rate, carbon price and sequestration rates were varied within plausible ranges, confirming the robustness of the results; the Block scenario is consistently better than the Wide Alley scenario, and so too the Wide Alley scenario is better than the Annual scenario.

The Block scenario is profitable due to the increased productivity of the Tagasaste. Under our default parameters, the income from the abatement enterprise was approximately 16% of the income from the cattle enterprise. While certainly not the primary income source, this is a significant boost to income. Given that we have consistently used conservative values for the abatement enterprise parameters, it would not be unreasonable to expect the proportion of income from abatement to rise in practice.

A sensitivity analysis on the carbon price found that even without a carbon price, the Block scenario is the most profitable and if the carbon price is above $9 then both the Block and Wide Alley scenarios will receive enough abatement income to pay for the upfront establishment costs of the Tagasaste, under the discount rate regimes considered (up to 10%).

Given the impressive results from the Block scenario, the increased productivity, and the exciting potential for carbon sequestration and abatement income, further research into Tagasaste sequestration is warranted. While no model is perfect and our modelling contains a number of assumptions, the magnitude of the increase in NPV of the Block scenario over the Annual scenario is highly suggestive that annual pastures on deep sandy soils could benefit from the introduction of managed Tagasaste systems. Moreover, it is highly likely that the upfront cost of establishment can be recovered over time if the net abatements are sold as carbon credits and priced accordingly.

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Appendix A: Cattle Enterprise Details

Herd Structure

Each grazed scenario models a self-replacing herd, with vealers turned off at 9 months. We assume an annual death rate of 2% and a weaning rate of 90%.

Block Scenario

The herd structure in the Block scenario is based on 200 cow-calf units which are rated at 15 DSE. In addition, 40 heifers are retained as replacements and are rated at 10 DSE. 6 bulls, rated at 16 DSE are required for the 200 cows. Complete details are listed in Table 3. The paddock size required for this herd was 350 ha, which was kept the same for the other two scenarios.

Class	Start	DSE Rate	Start	Births	Purchases	Deaths	Sales	End
	hd	DSE/hd	DSE	hd	hd	hd	hd	hd
Bulls	6	16	96	-	2	-	2	6
Cows	200	15	3,000	-	-	4	35	161
Heifer (replacements)	40	10	400	40	-	1	-	79
Heifer Vealers	50	-	-	50	-	1	49	50
Steer Vealers	90	-	-	90	-	2	88	90
TOTAL	**386**		**3,496**	**180**	**2**	**8**	**174**	**386**

Table 3 Herd Structure in Block Scenario

Wide Alley Scenario

In the Wide Alley scenario, the carrying capacity was only 5.95 DSE/ha compared to the 10 DSE/ha of the Block Scenario. The paddock area of 350 ha was maintained, but the size of the herd reduced to

Class	Start	DSE Rate	Start	Births	Purchases	Deaths	Sales	End
	hd	DSE/hd	DSE	hd	hd	hd	hd	hd
Bulls	4	16	64	-	1	-	1	4
Cows	119	15	1,785	-	-	2	22	95
Heifer (replacements)	24	10	240	24	-	-	-	48
Heifer Vealers	30	-	-	30	-	1	29	30
Steer Vealers	53	-	-	54	-	1	53	53
TOTAL	**230**		**2,089**	**108**	**1**	**4**	**105**	**230**

meet the reduced carrying capacity. Table 4 gives the full herd structure used.

Table 4 Herd Structure in Wide Alley Scenario

Annual Scenario

In the Annual scenario, the carrying capacity was only 3.25 DSE/ha compared to the 10 DSE/ha of the Block Scenario. As with the Wide Alley scenario, the herd size was reduced to meet the carrying capacity of the annual pasture. Details of the herd structure for this scenario are given in Table 5.

Class	Start	DSE Rate	Start	Births	Purchases	Deaths	Sales	End
	hd	DSE/hd	DSE	hd	hd	hd	hd	hd
Bulls	2	16	32	-	1	-	1	2
Cows	65	15	975	-	-	1	12	52
Heifer (replacements)	13	10	130	13	-	-	-	26
Heifer Vealers	16	-	-	16	-	-	16	16
Steer Vealers	29	-	-	29	-	1	28	29
TOTAL	**125**		**1,137**	**58**	**1**	**2**	**57**	**125**

Table 5 Herd Structure for the Annual Scenario

Purchases/Sales

The sales and purchase prices for the cattle were based on current market rates (Meat and Livestock Australia, 2015) and examples of gross margin analysis of cattle enterprises in (Department of Agriculture, 2003) and (NSW DPI, 2012). While recent cattle prices have greatly improved, there is evidence that they may retain these levels into the future as they are not record highs in real terms and there is forecasted growth in demand from China (Meat and Livestock Australia, 2015). Therefore, the current market rates are used and held constant in our analysis, and are listed in Table 6.

Class	Sale Price	Purchase Price
	$/hd	**$/hd**
Bulls	2000	5500
Cows	975	
Heifer (replacements)	800	
Heifer Vealers	800	
Steer Vealers	850	

Table 6 Cattle Sale and Purchase Prices

Animal Treatments

Animal health and other related costs were included in our analysis and were based on examples found in other published gross margin calculations such as (Department of Agriculture, 2003), (NSW DPI, 2012), and (GRDC, 2015). Where applicable, prices were adjusted for inflation based on inflation figures from the Reserve Bank of Australia's website, (Reserve Bank of Australia, 2015).

Class	Drenching	Ear Tags	Tail tags	Pregnancy Testing	Veterinary
	$/x	$/x	$/x	$/x	$/x
Bulls	10.76				6.73
Cows	7.40			5.38	6.73
Heifer (replacements)	7.40	1.35	0.27		6.73
Heifer Vealers	4.30	1.35	0.27		6.73
Steer Vealers	4.30	1.35	0.27		6.73

Animal treatment prices used in our analysis are listed in Table 7.

Table 7 Animal Treatment Costs

Note that cows were drenched twice as per (Department of Agriculture, 2003) and (GRDC, 2015).

Supplementary Feeding

Tagasaste is a perennial leguminous shrub and therefore provides edible leaf and stem at all seasons of the year (Bob Wilson pers. comm.; (Oldham, et al., 1994; DAFWA, 2014). Hence, no supplementary feeding is required for bulls, cows, or replacement heifers over the summer period. However, a small amount of lupins may be fed to increase the weight of the vealers to prepare them for sale. In the Wide Alley scenario, some hay was required for each class as well as some lupins for the vealers. In the Annual scenario, additional hay and lupins are required. In our analysis, we used the supplementary feed rates found in Table 8 over a period of 60 days. Based on market rates, we priced hay at $170/t and lupins at $400/t

Class	**Block**		**Wide Alley**		**Annual**	
	Hay kg/day	Lupins kg/day	Hay kg/day	Lupins kg/day	Hay kg/day	Lupins kg/day
Cows			3.5		7	
Heifer (replacements)			3.5		7	
Heifer Vealers		2.5	1	1.5	1.5	3.5
Steer Vealers		2.5	1	1.5	1.5	3.5

Table 8 Supplementary Feeding Rates

Pasture Maintenance

Cutting

Tagasaste requires regular cutting in order to maintain the highly productive 'broccoli' form and to keep the fodder low enough to be readily available to graze (Bob Wilson pers. comm.; (Oldham, et al., 1994; Edwards, et al., 1997). Cutting occurs once every 4 years and is contracted out at a rate of $130/hr. As it happens to take about an hour to cut each hectare of the Block scenario, this is modelled in our analysis as $130/ha.

The cutting costs in the Wide Alley scenario are scaled against the costs of the Block scenario by the ratio of the number of rows in the Wide Alley scenario to the Block scenario, which is 7 / 30 or approximately 23%.

Cutting is not required in the Unmanaged scenario.

Fertiliser

Tagasaste is a leguminous shrub and so does not require nitrate fertilisers however (Edwards, et al., 1996) found that an annual application of phosphorous increased both the production (DM/ha) and feed quality. It was estimated that 9kg/ha/year of phosphorous would be required for the Block scenario to maintain its carrying capacity of 10 DSE/ha. The price for triple-super-phosphate (TSP) was readily available at $520/t. TSP contains 21% phosphorous by weight and so 43kg of TSP is required for the 9 kg P/ha. At $520/t, 43kg is approximately $22, which is the rate per ha. Allowing a further $20/ha for transportation and spreading costs, this gives a conservative (high) estimate for fertilising costs of $42/ha.

As a typical annual pasture also requires annual application of super-phosphate (Bob Wilson pers. com.), this cost is modelled to be the same as for the other scenarios.

The Unmanaged scenario will also require phosphorous inputs. The sequestration rates of our model are based on the observations of an experimental site at which 13kg P/ha were applied during the 6 years of the experiment (Lefroy, et al., 2001). This level of P requires 62 kg TSP, and costs $32/ha. Combined with spreading costs this comes to a total of $54/ha.

Other Costs

Water / Fences / Yards

These overheads deal with maintenance issues on the paddock and associated infrastructure on the farm related to the cattle enterprise and are applied to each scenario on a per year basis. Based on inflated costs from (Department of Agriculture, 2003) these were estimated at $4035 / year.

Fuel / Vehicle Repairs

Again, based on inflated prices from (Department of Agriculture, 2003), these were estimated to be $6.73 / ha and applied to each scenario equally.

Interest on Working Capital

Working capital is often supplied via short term loans. For this analysis we have assumed that a short term loan is required in each scenario to fund the total costs of the activities of each year. The loan period is estimated to last 6 months with interest at a rate of 9%. This approximation for the cost of finance is equivalent to imposing a 4.5% increase in all costs.