Greenhouse Gas Abatement Policies and the Value of Carbon Sinks: Do Grazing and Cropping Systems have Different Destinies?

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Abstract

The impact of two greenhouse gas abatement policies on two Mediterranean-type farming systems, grazing dominant and cropping dominant, is examined. The policies analysed are; an emissions taxation policy and an emissions restrictions policy. For both farming systems the restriction policy is found to be more effective and economically efficient than the carbon permit policy. Absolute cost of abatement is less for the livestock dominant system but relative cost is greater, because of lower total farm profits. The analysis found that at predicted emissions permit prices, trees, if credited as a carbon sink, would be adopted by both farming systems to offset farm greenhouse gas emissions.

Keywords: greenhouse policy, whole-farm modelling, carbon sinks.

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Introduction

Changes in climate are expected to arise from increasing levels of greenhouse gases in the earth atmosphere. Concern by the global community about climate change led to the signing of an agreement in December 1997 in Kyoto, Japan. This agreement, popularly known as the Kyoto Protocol sought to limit greenhouse emissions of developed countries. For Australia the agreed limit was 108% of 1990 emission levels for the first commitment period 2008-2012. In addition to limiting greenhouse emissions, the Kyoto Protocol recognised the use of carbon sinks as emission offsets. Further negotiation in Marrakech in November 2001 between parties to the United Nations Framework Convention on Climate Change resulted in the inclusion of revegetation as a carbon sink under Article 3.4. Revegetation is defined as *direct human induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.5 hectares and does not meet the definitions of afforestation and reforestation* (AGO, 2002a).

Agriculture, excluding land clearing, produced 20% of Australia's total emissions in 1999 and is the largest source of methane and nitrous oxide emissions (AGO, 2002b). Given the significant contribution of agriculture to greenhouse emissions it is reasonable to assume that agriculture could be targeted under policies to reduce methane and nitrous oxide emissions (Hinchy *et al*., 1998). Although it is unclear at this stage whether the Kyoto Protocol will be ratified[1], the Australian Government is nevertheless committed to addressing greenhouse issues (AGO, 1998). The National Greenhouse Strategy, released in 1998, is the primary mechanism through which international commitments will be met.

This paper investigates how two different farming systems would respond to climate change policy. Whole-farm models are used to examine the economic and environmental impacts of abatement policies. The two farming systems analysed are a broadacre-crop dominant system and a livestock dominant system in the south west

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[1] 55 developed countries that account for 55% of 1990 global greenhouse emissions must ratify the Kyoto Protocol for it to be binding. At this stage Australia has not ratified the agreement.

region of Australia. The policies analysed are a regulatory policy and taxation policy. The taxation policy acts in a similar way to a permit policy, if it is assumed that farmers are required to purchase all permits, i.e. no prior allocation or *grandfathering* of permits. The taxation policy does not capture the tradeable aspect of permits that may be possible however. Although an emissions trading system is seen as a preferred approach to meeting greenhouse targets (AGO 1999), looking at the effect of restricting and taxing emissions is useful because it allows a comparison of the costs of abatement for different farming systems.

The analysis also explores the economic and environmental value of revegetation using non-commercial trees. The environmental benefits of trees include sequestering carbon dioxide, possible amelioration of salinity through reduction of recharge, increasing biodiversity and reducing wind and water erosion. The environmental benefits explored in this analysis are carbon dioxide sequestration and reduction of recharge.

The next section of this paper describes the two whole-farm models used and the emissions modelling. Then follows a presentation and discussion of results of the analysis. The paper concludes with a summary of the key findings and a discussion of the implications for policy and avenues for further research.

Methods

2.1 The Model

The model is a steady-state, linear programming model of each farming system. The model, known as MIDAS (Model of an Integrated Dryland Agricultural System), jointly emphasizes the biology and economics of the farming system (Pannell, 1996). The model's objective function is profit maximisation, subject to managerial, resource and environmental constraints (Bathgate and Pannell, 2000). Profit is defined as net cash returns minus non-cash costs (depreciation) minus opportunity cost of capital, exclusive of land. MIDAS is based on a typical season and excludes consideration of extreme climatic events. For a full description of MIDAS, the reader is referred to Kingwell and Pannell (1987) and Kingwell (2002).

The versions of MIDAS used in this analysis describe the farming systems in the Eastern Wheatbelt and Great Southern regions of Western Australia (Figure 1). A brief description of these regions and the corresponding MIDAS model follows.

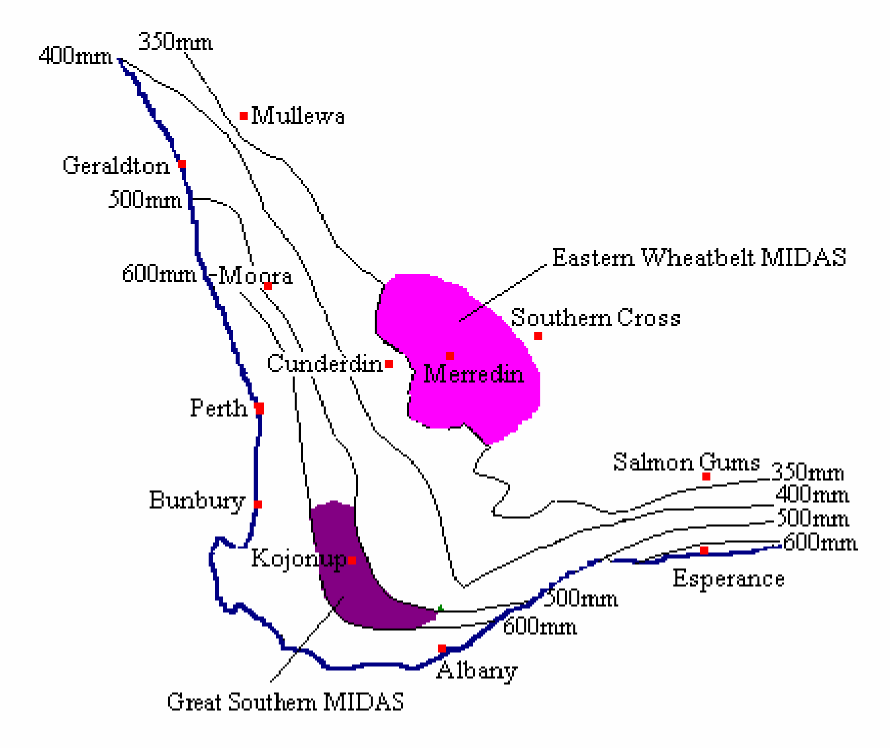

Figure 1: Versions of MIDAS for different regions of the West Australian wheatbelt.

2.1.1 Eastern Wheatbelt Model

The Eastern Wheatbelt version of MIDAS is based on a typical farming system in the Merredin shire of Western Australia (Kingwell and Pannell, 1987 and Kingwell, 2002). The area has a Mediterranean climate, with wet winters and dry summers. Average annual rainfall in the region is about 330mm. Farms in the region typically have a mix of cropping and livestock enterprises, with cropping generally more dominant. Broadly speaking, soils in the region consist of a mixture of deep sands and duplex soils (sand over clay, loam over clay). Farm size has increased in recent years and is now on average 3729 ha for the Merredin shire (BankWest, 2002).

The Eastern Wheatbelt MIDAS (EWM) assumes a farm size of 3750 ha and consists of seven soil classes. A description of each soil class and their area in the model is shown in Table 1.

Table 1: Soil classes used in Eastern Wheatbelt MIDAS.

Soil classes	*Description*	*Proportion of total farm area*
Soil 1	Yellow, loamy or gravelly sands. Native vegetation: wodjil, or sheoak & banksia on deep white sands.	16%
Soil 2	Deep yellow brown, loamy sands. Native vegetation: grevillea, tamma.	23%
Soil 3	Yellow brown, gravelly sands and sandy gravels. Native vegetation: tamma.	7%
Soil 4	Grey sandy loams, loamy sands, gravelly sands and sand over white clay with yellow or red mottles. Native vegetation: mallee.	12%
Soil 5	Red brown, sandy loam over clay subsoil. Native vegetation: salmon gum, tall mallee.	17%
Soil 6	Dark red brown, sandy clay loams. Native vegetation: gimlet, morrel, salmon gum.	16%
Soil 7	Similar to soil 6 but soil is better structured and higher yielding, possibly due to gypsum application.	9%

Cropping options include cereals: wheat, barley, oats and triticale; legumes: lupins, field peas, chickpeas and faba beans; and oilseeds: canola. The livestock enterprise consists of sheep for wool and meat production. The pastures consist of volunteer annual grasses and improved pasture. Improved pasture consists of legumes such as subterranean clover and serradella. The percentage of total farm area selected for cropping is generally between 50% and 70%, depending on prices of commodities.

The EWM assumes an average season with annual rainfall of 310mm and growing season rainfall of 210mm (Kingwell and Pannell, 1987).

2.1.2 Great Southern Model

The Great Southern version of MIDAS represents a farming system in the Kojonup shire of Western Australia (see Figure 1). This area also experiences a Mediterranean climate. Rainfall in this region is higher – average annual rainfall is between 500 and 600 mm. Average farm size at Kojonup is 1,357 ha (BankWest, 2002). Most farms in this region have a mixture of livestock and crop, with livestock being predominant. Livestock in the region includes sheep and cattle; however merino sheep for wool production is the most common. Broadly, the soils of the region are gravelly sands or sandy duplexes.

Great Southern MIDAS (GSM) assumes a farm size of 1000 ha consisting of 5 soil classes, shown in Table 2. The GSM assumes an average season, with annual rainfall of 550mm of which approximately 450mm falls in the growing season (Young, 1995).

Table 2: Soil classes used in Great Southern MIDAS and their proportion of total farm area. Percentage of soil class that is arable for cropping is shown in brackets.

Soil class	*Description*	*Proportion of farm area*
Soil 1	Shallow saline sands over heavy gleyed or mottled clay	10% (100% arable)
Soil 2	Deep sands, often waterlogged, over grey, gleyed clay	15% (100% arable)
Soil 3	Deep sands, not waterlogged, over mottled clay	5% (100% arable)
Soil 4	Gravels and sandy gravels to 50cm over clay or gravelly clay	50% (80% arable)
Soil 5	Sandy loam, loamy sand over clay, rock outcropping in landscape.	20% (80% arable)

Wheat, barley, oats, lupins and field pea production are possible on all soil classes. Soils 1 and 2 are relatively infertile and are normally not cropped. Canola production is possible only on soils 4 and 5. Soil 4 is the most suitable soil type for crop production. Pasture can be grown on all soil types. The percentage of total farm area used for crop enterprises is generally 10% to 20%, depending on relative prices.

The livestock enterprise is modelled as a self-replacing merino flock capable of high quality wool production and meat production. The reader is referred to Young (1985) for a more detailed description of the GSM model.

2.2 Greenhouse emissions accounting

Greenhouse gas emissions were modelled according to the methodology outlined by the National Greenhouse Gas Inventory (NGGI) Committee of the Australian Greenhouse Office (NGGI 1996a, NGGI 1996b). The NGGI identifies sources of greenhouse gas emissions from the crop and livestock component of the agricultural sector to be enteric fermentation of livestock, livestock excreta, nitrous oxide emissions from soil disturbance and fertiliser use, fuel use and burning of agricultural residues. Of these, enteric fermentation, nitrous oxide from soil disturbance and fertilisers, stubble burning and fuel use are accounted for in this analysis as described in more detail below. Methane emissions from livestock excreta were not considered, due to the fact that conditions for anaerobic fermentation are rare.

Greenhouse gas emissions in the two farming systems consist primarily of carbon dioxide, methane, and nitrous oxide. All greenhouse gases are aggregated in carbon dioxide equivalents (CO_2-e). To convert methane and nitrous oxide to CO_2-e, the concept of Global Warming Potential (GWP) is used. The GWP is an index which approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in today’s atmosphere relative to that of carbon dioxide (AGO, 2002b). The CO_2-e of a non-carbon gas is calculated by multiplying the mass of the emission of the gas by its GWP. Table 3 shows the GWP’s used in this analysis.

Table 3: The Global Warming Potential of the main greenhouse gases, based on a 100-year time horizon.

Greenhouse gas	*GWP*
Carbon dioxide (CO_2) Carbon monoxide (CO) Non-methane volatile organic compounds	1
Methane (CH_4)	23
Nitrous Oxide (N_2O)	296

Source: AGO 2002

2.2.1 Enteric fermentation

In both MIDAS models enteric fermentation comes from sheep, as no cattle are included. Emissions from sheep were modelled using the NGGI methodology (NGGI, 1996b) that estimates methane production using daily intake figures.

2.2.2 Nitrogen fertiliser

Nitrous oxide emissions from nitrogen fertiliser use are calculated using NGGI methodology (NGGI, 1996a). Nitrous oxide emissions are a function of mass of nitrogen per unit of fertiliser, an emission factor and a conversion factor to convert nitrogen to nitrous oxide. Both the EWM and GSM use urea, DAP and Agras as nitrogen fertilisers. Table 4 shows the nitrous oxide emissions for each of these fertilisers.

Table 4: Kilograms of nitrous oxide emitted for each tonne of fertiliser used.

Fertiliser	*% Nitrogen*	*Kg nitrogen / t fertiliser*	*Emission factor (%)*	*Conversion factor*	*Kg N_20 emitted / t fertiliser*
Urea	46	460	1.25	1.57	9.03
DAP / Agras	17.5	175	1.25	1.57	3.43

2.2.3 Fuel use

Fuel use is calculated on a rotational basis. Each rotation (on each soil class) uses a varying amount of diesel and petrol. Assumptions were made regarding the fuel use of different operations, such as seeding and harvest. The frequency of these operations in each rotation determines the fuel used.

Fuel use is converted to CO_2-e by applying three factors. These are energy density of the fuel, volume of CO_2 emitted per unit of fuel burned and the proportion oxidised. Table 5 shows this calculation for diesel and petrol.

Table 5: CO_2 emissions per litre of fuel used on farm

Fuel type	*Energy density (MJ/L)*	*grams of CO_2 per MJ of fuel burnt*	*Proportion oxidised*	*CO_2 emissions (kg/L)*
Diesel	38.6	69.7	0.99	2.66
Petrol	34.2	66.0	0.99	2.23

2.2.4 Stubble burning

In both Great Southern and Eastern Wheatbelt farming systems the practice of burning crop residues is becoming less common. Modern seeding operations allow the previous year’s stubble to be retained, which can prevent erosion and the loss of nutrients from the soil. However a proportion of crop stubble is still burnt and the NGGI estimates this to be approximately 23%. This analysis assumes that 23% of crop stubble in both the GSM and EWM are burnt. Greenhouse emissions from stubble burning are calculated using NGGI methodology (1996b).

2.2.5 Soil disturbance

Emission of N_2O from soils arises from microbial and chemical transformations that produce and consume N_2O in the soil (Galbally *et al.*, 1996). Clearing of native vegetation and replacing it with annual crop and pastures has caused emissions of N_2O to increase (Meyer, pers. comm.). The difference in annual emissions between cultivated land (unfertilised and ungrazed) and the natural ecosystem is the emission due to soil disturbance (Galbally *et al.*, 1996). The difference is referred to as enhanced emissions. This analysis uses the NGGI methodology to calculate enhanced emissions. There is no differentiation between enhanced emissions from cropland and improved pastures. Therefore all agricultural land is assumed to emit N_2O. The enhanced rate of emissions assumed by the NGGI is 0.25kg N/ha/year. This is converted to N_2O by multiplying by a factor of 1.57 (see section 2.2.2 above). N_2O is then converted to CO_2-e by multiplying by the GWP of N_2O, which is 296. The resulting emissions due to soil disturbance are 116 kg CO_2-e/ha/year for both the cropping and livestock farming systems.

2.3 Non-commercial trees

As outlined in the introduction, Article 3.4 of the Kyoto Protocol provides that carbon sequestered by land management activities such as revegetation might be credited against a nation's greenhouse gas emissions. In keeping with this provision, this analysis assesses the value of trees planted for revegetation purposes as carbon sinks. It was decided to use non-commercial trees rather than commercial trees because there is controversy as to whether the carbon is released when trees are harvested. Instead it is assumed here that the trees are not harvested.

It has been assumed further that the non-commercial trees can not be grown for CO_2 sequestration purposes on soil 1 in the GSM. Trees grown on this soil class would most likely not grow well, due to the saline and waterlogged nature of the soil, and consequently may not perform well enough to earn greenhouse credits. Growth is possibly 33% to 50% that of growth on the better soil types (J. Young, pers. comm.).

2.3.1 Costs

Establishment of the trees involves ripping the ground where each row of trees will be planted and spraying for weeds. A mix of residual and knockdown herbicides is necessary for successful weed control (DAWA, 1998a). It was assumed that some extra fencing would be required in order to keep out stock. The total cost of trees was converted to an annuity payable over the lifetime of the trees (taken as 30 years). The equivalent cost was estimated to be $7.50 per hectare per two months. The cost for trees on soil class two in the GSM was estimated to be $8.40 per hectare per two months. The higher cost reflects the need for mounding of the ground, as this soil type is prone to waterlogging (DAWA, 1998b) (see Table 2).

2.3.2 Carbon sequestration

Petersen *et al.* (2001) examined using oil mallee eucalypt trees as carbon sinks. Oil mallees have commercial value for their oil and biomass and are harvested initially after six years and subsequently every third year. As a result the CO_2 sequestration that can be claimed is low. However even given low CO_2 sequestration rates, Petersen *et al.* (2001) found that oil mallees still proved to be of value for greenhouse gas abatement.

The Carbon Accounting Model for Forests (CAMFor) developed by the Australian Greenhouse Office estimates CO_2 sequestration of trees in the low rainfall area (Eastern Wheatbelt) to be 6.4 t CO_2 per hectare per year, on average over 30 years. The estimate for carbon sequestration for the medium rainfall area (Great Southern) is 9.7 t CO_2 per hectare per year, on average over 30 years (AGO, 2001a).

The CO_2 sequestration rates used in this analysis are slightly lower than the figures above, because the trees are assumed to be planted for revegetation purposes only and therefore their growth may not be monitored as closely, and they may not grow as well. The sequestration rates are based on values determined by Hassall and Associates (1996). Their analysis modelled the carbon accumulation of eucalypt trees and established average annual CO_2 sequestration rates for six different productivity classes (see Table 6). In this analysis, trees in the EWM were assumed to rate in the lowest productivity class (E5) and trees in the GSM in the second lowest productivity class (E4).

Table 6: CO_2 sequestration by eucalypt productivity class

Productivity class	*t CO_2 / ha / year*
E0	29
E1	22
E2	17
E3	12
E4	7
E5	4

Source: LWRRDC (1999)

2.3.3 Recharge

Recharge values for each rotation were estimated using recharge-rainfall relationships developed by Petheram *et al*. (2002). Examples of recharge values for annual crops and perennial vegetation on different soil classes are shown in Table 7. As recharge is dependent on annual rainfall, values for EWM are lower than GSM because of lower rainfall in that region.

Table 7: Recharge under annual crops and perennial vegetation for different soil classes in GSM and EWM in mm/year.

	GSM			EWM		
	Soil 2	Soil 3	Soil 4	Soil 1	Soil 4	Soil 6
Annual	12.9	39.3	26.4	6.0	4.8	3.6
Perennial	0.8	1.4	1.0	0.1	0.1	0.1

Results and Discussion

This section comprises two parts. The first looks at the effect of the restriction and taxation policies on both farming systems when trees are not available as a carbon sink, and compares the economic efficiency of the two policies. The second part assumes that trees can be credited as a carbon sink to offset farm emissions.

Table 8 shows results from each model when no abatement policy applies. The EWM represents an extensive farm versus the more intensive GSM. The intensive nature of the GSM is highlighted by a higher stocking rate and higher profit per hectare. However, due to its larger farm size the EWM has higher total profits.

The high stocking rates possible in the GSM mean that livestock are more profitable than cropping. Therefore in the GSM the ratio of crop area to pasture area is 0.17. In the EWM, where such high stocking rates are not possible because of lower rainfall and where large farm size reduces the costs of cropping, the equivalent ratio is 1.7.

The high stocking rate in the GSM is possible because of more productive pastures which arise from higher rainfall. This high stocking rate means that on a per hectare basis greenhouse emissions are almost three times that of the EWM. In terms of total emissions the two farming systems produce about the same amount.

Table 8: Baseline results for the crop dominant farming system (EWM) and the livestock dominant farming system (GSM) when no abatement policy applies.

Item	*Unit*	*Crop dominant (EWM)*	*Livestock dominant (GSM)*
Farm size	ha	3750	1000
Profit [2]	$	144,000	76,000
Profit per hectare	$/ha	38.4	76.4
Crop	% of arable area	63	14
Pasture	% of arable area	37	86
Stocking rate	DSE/ha	5.0	10.4
Total emissions	t CO_2-e	1930	1762
Emissions per hectare	t CO_2-e/ha	0.51	1.76

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[2] Profit is farm cash operating surplus less non-cash costs minus the opportunity cost of capital.

3.1 Restriction vs. taxation policies without carbon sink credits.

3.1.1 Restriction policy

Forcing reduced emissions (i.e. abatement) in the EWM and GSM has, of course, a negative impact on the profit of both farms (see Figure 2). The restrictions force a substitution away from livestock to cropping, as livestock is the higher emitting enterprise. This causes a shift in the optimal farm plan and a decrease in profit.

Abatement is more expensive overall in the EWM compared to the GSM. To achieve a given level of abatement reduces profits more in the EWM (see Figure 2), plus the marginal cost of each unit of CO2-e abated is higher (see Figure 3). As cropping percentage is already high in the EWM, further increasing cropping to abate CO_2-e causes the model to crop soils where the relative advantage of pasture rotations over crop rotations is high, i.e. there is a high opportunity cost of selecting a crop rotation. Hence, to generate abatement incurs high marginal costs. In comparison, in the GSM where the optimum cropping percentage is low, the model is able to select soils where the comparative advantage of pasture over crop is small, causing lower marginal costs. This is demonstrated in Figure 4 which shows the effect on farm profits of increasing the percentage of the farm cropped. As the crop percentage increases beyond the optimum, profit decreases more rapidly for the EWM than the GSM.

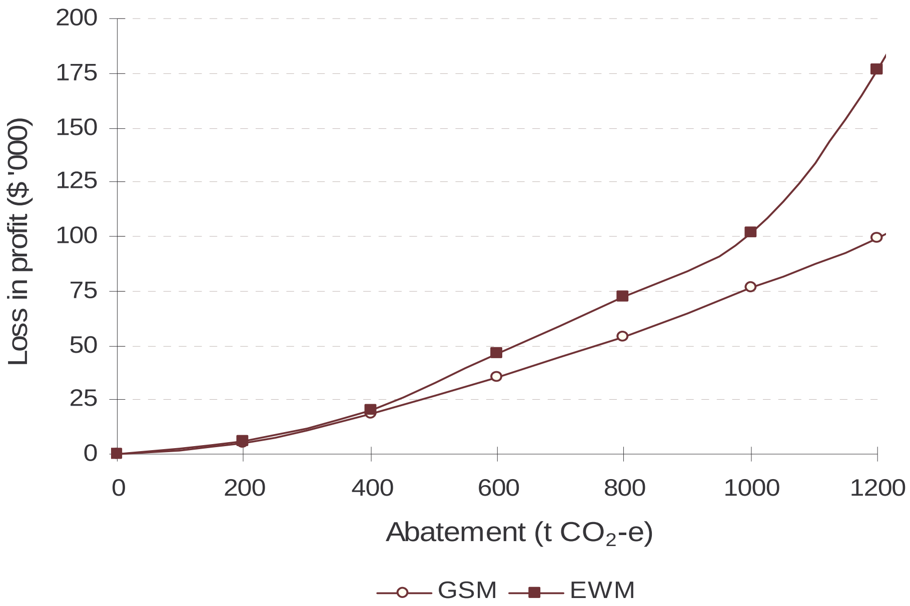

Figure 2: Loss of farm profit due to increasing greenhouse gas restrictions.

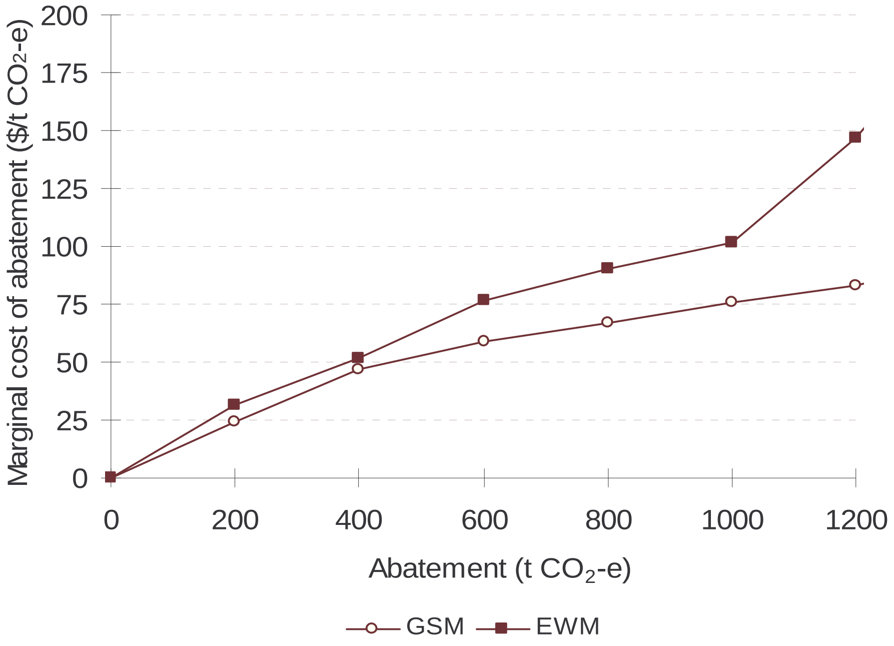

Figure 3: Cost of abatement (measured by decrease in farm profit per tonne of CO_2-e abated) for EWM and GSM as total farm abatement increases.

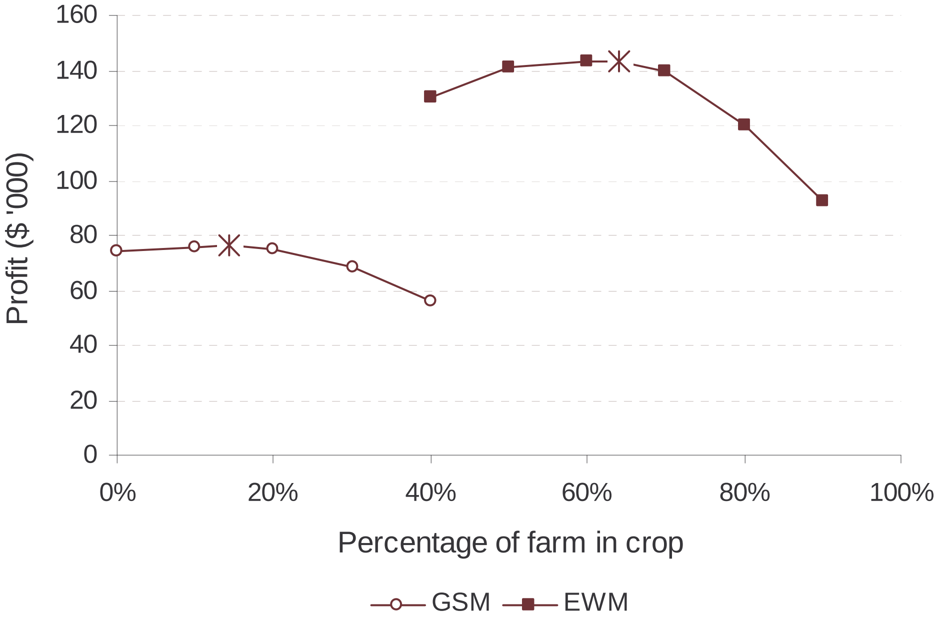

*Figure 4: Effect of increasing percentage of farm cropped on farm profit for EWM and GSM. The * indicates the optimal area the model would select to crop. Note: no greenhouse policy applies.*

If compensation was offered to offset losses incurred by farmers meeting emission targets, then in general it would be more economically efficient to encourage Great Southern farmers to abate, than Eastern Wheatbelt farmers. That is, to “buy” 400t of abatement would cost $1,000 less from an average Great Southern farmer than from an average Eastern Wheatbelt farmer and, as Figure 2 shows this difference increases as the level of abatement increases. However, as Figure 3 shows, the cost of abatement increases as the restriction level increases, therefore it would be more economically efficient to buy 200t of abatement firstly from a Great Southern farm and then an Eastern Wheatbelt farm, rather than buy 400t of abatement from a Great Southern farm alone. This would save the policy maker approximately $9,500, or close to 50% of the cost of abatement.

The cost per unit of abatement increases as total abatement rises because the model adopts the least costly methods of abatement first. As the emission restriction increases, the model has fewer options for abatement and more expensive methods are adopted.

The marginal cost of abatement curve for the EWM (see Figure 3) has a change of curvature at the 1000t CO_2-e restriction level. The reason for this is that at this point the model has decreased the number of sheep to zero and so to meet any further CO_2-e restrictions it must decrease the cropping enterprise. At levels of abatement greater than 1000t the model puts land back into pasture rotations but is not carrying any sheep. This causes a rapid increase in the cost of abatement.

Although in absolute terms abatement is less costly in the GSM, the loss in profit as a percentage of total farm profit is greater. Because the GSM is making approximately half the total profit of the EWM, the relative effect on profit is greater. For example, to meet a 400t restriction will cost the EWM 14% of its profit and the GSM 25% of its profit. As the models are generating similar total emissions (see Table 8) a restriction imposed as a percentage of total farm emissions also costs the GSM a greater percentage of profit. This means that if farms were forced to meet *uniform* restrictions (applied as either an absolute amount or percentage of total farm emissions) without being offered compensation, in general the average Great Southern farmer would be losing a greater percentage of their profit than their average

Eastern Wheatbelt counterpart. From the farmers' point of view, the cost of abatement is much higher for the Great Southern farmer and a policy which forces uniform emissions restrictions would most likely be viewed by them as inequitable.

3.1.2 Taxation policy

Figure 5 shows the whole-farm abatement as a result of imposing a tax on CO_2-e production. The relative effectiveness of the taxation policy on each of the farming systems varies across tax rates. Abatement is quite close for both systems although at the likely tax rate, which is between \$10 and \$50 per tonne CO_2-e [3], the GSM abates slightly more than the EWM.

The curve for abatement for the EWM flattens at the \$70-\$90 /t CO_2-e tax rate. At this level it would be more profitable for the farm to maintain rotations and pay more tax than to switch to less profitable rotations. The opportunity cost of abatement is greater than the tax. Thus, for the EWM a tax of \$90 is no more effective at reducing emissions than a tax of \$70.

The curve for abatement by the EWM is more a step function than the smooth GSM curve. The reason for this is the difference in profitability of rotations on the various soil classes. In the EWM, the difference in profitability between the optimal set of rotations on particular soil classes and the next optimal set may be quite large, so a shift to a new farm plan may take a couple of tax rate increases. The difference in profitability of rotations on various soil classes in the GSM are less than in the EWM so a tax rate increase of \$10 is generally sufficient to shift the model to a new set of rotations which produce less greenhouse emissions. The reason for the greater difference between EWM rotations is due to the EWM having fewer options available to reduce emissions because it is already cropping dominant.

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[3] likely permit price for carbon (AGO, 2001), so tax is equivalent if it is assumed the farmer would need to buy all of their permits (Petersen *et al.*, 2000).

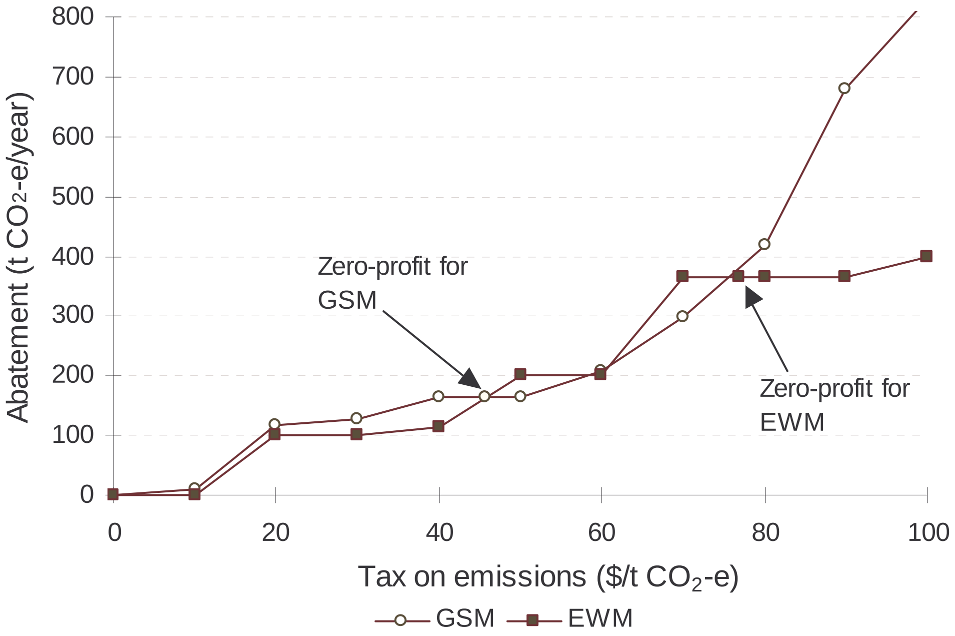

Figure 5: Total farm abatement at each tax rate for GSM and EWM. The tax rate at which each systems incurs zero-profit is shown ($46/t CO_2-e for the GSM and $78/t CO_2-e for the EWM).

Figure 5 shows the zero-profit tax rate for both farming systems. This is the point where farm profit, as defined earlier, is zero. The zero-profit tax rate for the GSM is $46/t CO_2-e, which is much lower than the rate for the EWM which is $78/t CO_2-e. Zero-profit tax rate is higher for the EWM because this model is generating almost twice the profit than the GSM (see Table 8). Therefore the level of tax that results in zero-profit is higher.

Greenhouse gas abatement at which the GSM is making zero-profit is small, 164t CO_2-e, only a 9% reduction. Abatement is higher for EWM at 364t CO_2-e, a 19% reduction, but is still low considering the farm has lost all its profits. This highlights the inefficiency of the taxation policy in reducing greenhouse gas emissions from farming systems. This tax can be likened to a tax on petrol, where consumption does not decrease as a result of the tax, but the tax revenues generated are high.

Table 9 shows a sensitivity analysis of the zero-profit tax rate to some historical wool prices. For the GSM, at the 1998/99 wool price of 483 c/kg clean, a tax of just $18/t CO_2-e results in zero-profit. At current high wool prices a tax rate of $96/t CO_2-e results in zero-profit. The difference in the zero-profit tax rate between the 2002/03 wool price and the 1998/99 wool price is $78. For the EWM the difference is only

\$32. This shows the sensitivity of the Great Southern farm to wool prices, which is expected due to the dominance of livestock in this region.

Considering the projected price for carbon permits is in the range \$10-\$50 per tonne (AGO, 2001), an average Great Southern farm would make no profit in four of the previous five years, if they were forced to buy all permits. At wool prices above 700c/kg they would be severely financially penalised for relatively small reductions in CO_2-e emissions. As a result, the taxation policy does not appear to be a politically realistic solution to carbon dioxide abatement.

While high wool prices mean that the zero-profit tax rate is higher, at the same time the cost to abate a unit of CO_2-e is higher because of the profit forgone. This means that in years where Great Southern farmers could most afford to abate, they would be least likely to because of high opportunity costs (presuming farmers have only economic goals, which is not always the case).

Table 9: Effect of wool price (Western Market Indicator) on zero-profit tax rate.

Wool price (c/kg clean)	*Year of price*	*Zero-profit tax rate (\$/t CO_2-e)*	
		GSM	*EWM*
483	1998/99	18	67
506	1999/00	21	69
618	2000/01	37	74
700	2001/02	49	79
800		63	84
900		78	91
1025	2002/03	96	99

3.1.3 Efficiency of restriction and taxation policies

As found by Petersen *et al.,* (2000), the restriction policy is more cost-effective for reducing total emissions than the taxation policy. The taxation policy causes very large losses in profit with relatively little abatement (see Figure 6). Using zero-profit as a reference point then, under the restriction policy, the EWM abates 1150t CO_2-e while under the taxation policy it abates only 365t CO_2-e. The case is similar for the GSM, where under the restriction policy zero-profit abatement is 1000t CO_2-e, while under the taxation policy it is 165t CO_2-e.

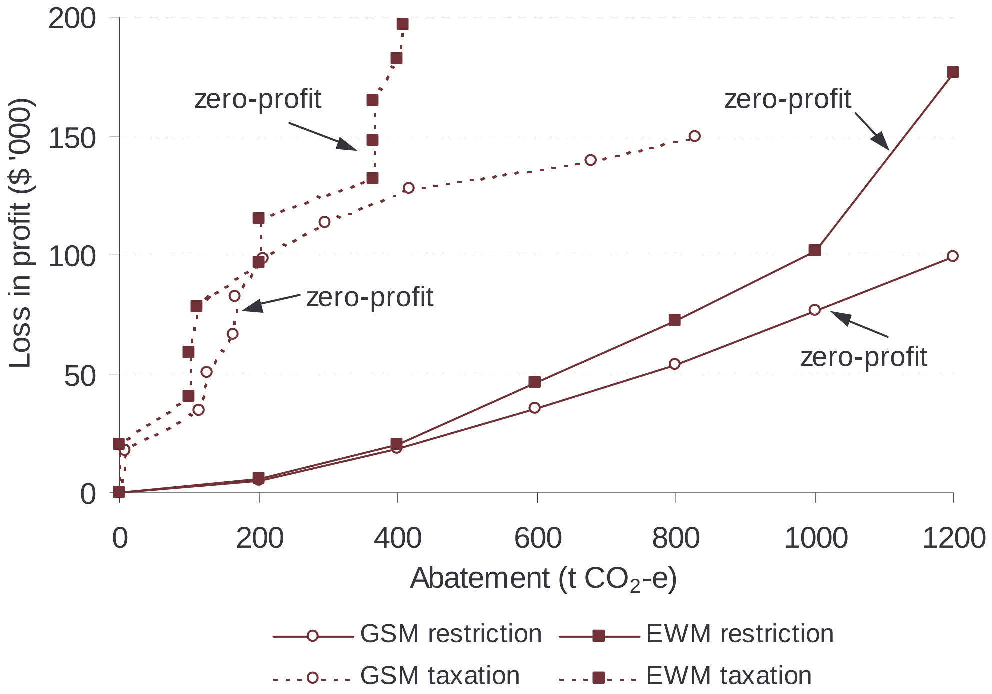

Figure 6: Comparison of restriction policy and taxation policy for EWM and GSM.

The taxation policy imposes a financial penalty on every unit of CO_2-e emitted in addition to forcing the farmer into less profitable rotations. The restriction policy only does the latter, i.e. the farmer can move into less profitable rotations that generate less emissions, but does not get penalised for emissions generated by those rotations. The taxation policy distorts the profit and emission relativities of the rotations. In some cases it may be more profitable for the farm to remain in the same rotations and just pay the tax, rather than moving to less profitable, less emitting rotations, on which tax would still have to be paid (albeit less than applies to the first set of rotations). This is demonstrated in Figure 5, where an increase in tax from $70 to $90 does not result in a decrease in emissions for the EWM.

The restriction policy is more effective at reaching target abatement levels and allows the farm to do so at a lower cost than under the taxation policy. If the aim of the policy were to maximise emissions abatement, at least cost to the farmer, then the restriction policy would be preferred.

3.2 Restriction vs. taxation policies with carbon sink credits

The second part of this analysis assumes firstly that trees can be credited as a carbon sink to offset emissions and secondly, the trees have no commercial value. In addition to sequestering carbon, trees can provide other environmental benefits, such as reducing recharge, improving biodiversity and reducing erosion. The value of trees in reducing recharge is also explored in this part of the analysis.

3.2.1 Restriction policy

Attributing a CO_2 sequestration rate to trees, as per section 2.3.2 (see Table 6) allows both farming systems to remain more profitable when subjected to emission restrictions. This is shown in Figure 7 (note that the curves for EWM and GSM without trees are the same as displayed in Figure 2, but are shown again for comparison). For example, at 400t abatement the reduction in profit for the GSM, with trees as carbon sinks is $6,260 compared with $18,804 when trees have no value as a carbon sink. This is an 8% decrease in profit compared to a 25% decrease. As the level of forced abatement increases the area allocated to trees increases. The availability of trees as carbon sinks allows the farm to retain high emission enterprises (i.e. sheep) while still meeting the restriction.

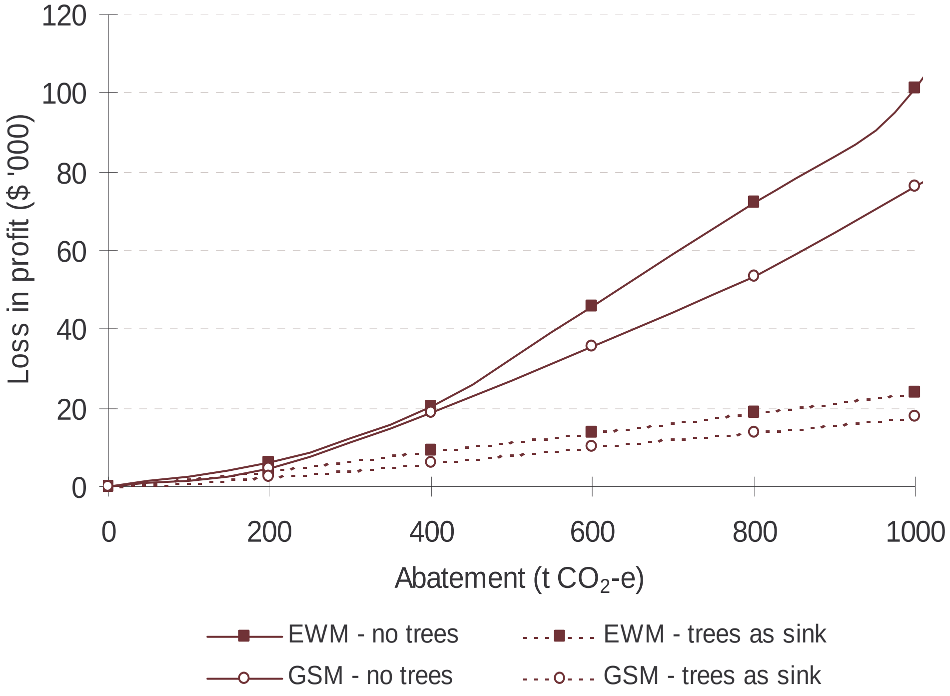

Figure 6: Effect of CO_2-e abatement on farm profit with and without trees as a carbon sink for the Great Southern and Eastern Wheatbelt models.

In both systems trees are allocated optimally to land least profitable for sheep or crop production. In both models the rotation grown on these lands is continuous pasture. The allocation of this land to trees results in a decrease in sheep numbers. As the trees have no commercial value, farm profit decreases due to the income forgone on this land.

3.2.2 Taxation policy

The effect of a taxation policy on the EWM is shown in Table 10. At levels of tax \$10 and \$20 there is no difference in emissions or profits when trees are available as a carbon sink. At the lower levels of tax the trees are not a profitable option for reducing emissions and avoiding tax. However when the tax reaches \$23.30/t CO_2-e it becomes profitable for the farm to allocate some land to trees to partially offset CO_2-e emissions. It does this on soil 6, which is the soil with the lowest marginal value. When the tax rate reaches \$23.70/t CO_2-e the most profitable scenario is for the farm to plant enough trees (in this case 387ha or 10.3% of farm area) to completely offset all emissions and not pay any tax. It is interesting to compare this with the 5% abatement that occurs at a tax rate of \$23.70 when trees are not available as a carbon sink.

Similar findings occur for the GSM (see Table 11), although the allocation of land to trees occurs over a greater range of tax levels. At a tax rate of \$17.90/t CO_2-e the model selects to grow 35 ha of trees, which results in 24% abatement. As the tax rate increases, more land is allocated to trees and abatement increases. Complete abatement occurs when the tax rate reaches \$27.60/t CO_2-e. At this point the model has allocated all of soil 2, all of soil 3 and 4 ha of soil 4 (204ha in total) to trees.

The cost of complete abatement (measured by profit forgone) is \$34,400 for the GSM compared with \$46,500 for EWM. Therefore, with trees available as a carbon sink the cost for each farm to be emissions neutral is on average \$19.50 per tonne of CO_2-e for the GSM and approximately \$24 per tonne of CO_2-e for the EWM. In comparison, under the restriction policy without trees, a 1400t CO_2-e reduction in emissions in the GSM costs on average \$95 per tonne of CO_2-e and for the EWM the average cost is \$210 per tonne of CO_2-e.

Table 10: Effect of a CO_2-e tax on farm profit, CO_2-e abatement and area of trees for the EWM, with and without trees available as a carbon sink.

TAX RATE ($/t CO_2-e)	*WITHOUT TREES*		*WITH TREES*		
	Decrease in profit (%)†	*Abatement (%)*†	*Decrease in profit (%)*†	*Abatement (%)*†	*Area of trees (% of total farm area)*
10	14	0	14	0	0
20	28	5	28	5	0
23.30	31	5	31	42	4
23.40	31	5	31	81	8
23.70	32	5	31	100	10

† This the percentage decrease from optimum profit and emissions, when no policy is applied.

Table 11: Effect of a CO_2-e tax on farm profit, CO_2-e abatement and area of trees for the GSM, with and without trees available as a carbon sink.

TAX RATE ($/t CO_2-e)	*WITHOUT TREES*		*WITH TREES*		
	Decrease in profit (%)†	*Abatement (%)*†	*Decrease in profit (%)*†	*Abatement (%)*†	*Area of trees (% of total farm area)*
15	33	7	33	7	0
17.90	39	7	39	24	3.5
21.50	46	7	43	73	15
22.70	50	7	44	98	20
27.60	61	7	45	100	20.5

† This the percentage decrease from optimum profit and emissions, when no policy is applied.

A comparison of Tables 10 and 11 shows that the initial tax rate which prompts some allocation of land to trees is lower in the GSM than in the EWM. This is despite the fact that the marginal value of land under no policy is higher in the GSM ($80/ha for the lowest value land) than the EWM ($68/ha for the lowest value land). Given higher marginal values of land we would expect the opportunity cost of planting trees to be higher in the GSM and so tree planting would happen at higher tax rates. However when a tax on emissions is introduced the marginal value of land in the GSM decreases more rapidly because the emissions produced per hectare of land are higher. At a tax rate of $15/t CO2-e the marginal value of the lowest value land is $56/ha for both models.

The range in tax rates required to prompt allocation of land to trees in the GSM is greater because the GSM is sequentially allocating trees to three different soil types which have varying marginal values. The GSM firstly uses soil type 2 for trees, but when the area of soil 2 becomes limiting it then uses soil type 3. Eventually soil type 4 also is used. In the EWM it is only necessary to allocate trees to one soil type (because there is sufficient area of this soil type) so this happens in response to smaller changes in the tax rate. Due to both the smaller area of soil classes and their different marginal values the GSM, in comparison with the EWM, adopts trees initially at lower tax rates, yet requires higher tax rates to prompt sufficient adoption of trees for complete abatement.

3.2.3 Recharge

An additional benefit of planting trees is their ability to reduce recharge. It is widely accepted that the problem of dryland salinity in farming regions of Western Australia is due to the increase in recharge, caused by the removal of natural perennial vegetation and its replacement with annual crops and pastures. Increasing areas of perennial vegetation may reduce recharge and prevent further salinisation in some areas. Therefore, it is worthwhile to consider the additional effect on recharge of using trees to offset greenhouse gas emissions. In this manner, the benefits from planting trees are considered to reflect the combination of two of their environmental contributions.

As described above, at a tax rate of approximately \$24/t CO_2-e the EWM selects to plant 387 ha of trees to offset the greenhouse emissions. The model selects the trees on soil type 6 as this soil type has the lowest marginal value. Total recharge from the farm when no trees are included is 18,435 mm/year. When 387 ha of trees are included total recharge is 17,145 mm/year. This is a reduction of 1,290mm or 7% (see Table 12).

As described earlier in Table 1, soil 6 is a heavy clay soil. Recharge from annual crops is less on clay soils than sandy soils because the movement of water through a clay soil is less than occurs in sandy soil. If the model is forced to plant the trees on soil 1 (a sandy soil) recharge decreases by 12% (see Table 12). Total recharge is less because the trees are replacing an annual system on soil 1 that has greater recharge than the annual system on the clay soil. However, this also results in a greater loss of profit as soil 1 has a higher opportunity cost than soil 6. This shows a conflict that arises when trees are used for environmental purposes. The area where the trees may have the most impact on recharge abatement may be an area where the opportunity cost of planting trees is relatively higher than other areas. The landholder is then faced with the question of how much they are willing to pay for salinity mitigation.

Although the overall cost of putting the trees on soil 1 is higher, the cost per millimetre of recharge abated is less. The cost per millimetre is $36 with trees on soil 6 and $21 with trees on soil 1. Therefore in efficiency terms where the desirable outcome is maximum recharge abatement for least cost, soil 1 is the better option.

Table 12: Reduction in recharge in the EWM when trees are planted to offset 100% of greenhouse gas emissions (387ha) on soil type 6 or soil type 1.

Trees planted on:	*Total reduction in recharge (mm)*	*Reduction in recharge per ha (mm)*	*Percent reduction in recharge*	*Reduction in profit ($ ‘000)*	*Cost per millimetre ($/mm)*
Soil 6	1,290	0.34	7%	46	36
Soil 1	2,287	0.61	12%	49	21

Table 13: Reduction in recharge in the GSM when trees are planted to offset 100% of greenhouse gas emissions (204ha).

Trees planted on:	*Total reduction in recharge (mm)*	*Reduction in recharge per ha (mm)*	*Percent reduction in recharge*	*Reduction in profit ($’000)*	*Cost per millimetre ($/mm)*
Soil 2 & Soil 3	3,834	3.83	15%	34	9

Reduction in recharge as a result of including trees to offset greenhouse emissions is greater in the GSM than the EWM (see Table 13), even though less trees are planted (204 ha, instead of 387 ha). The reason for this is that recharge under annual crops and pasture is greater in the GSM than the EWM because of the higher rainfall of the region. When annual systems are replaced by trees, recharge decreases proportionally more in wetter areas than it does in drier areas. However recharge per hectare, with trees included, is still much higher in the GSM, 21.2 mm/ha/ year, than the EWM, 4.6mm/ha/year.[4]

Although there is some reduction in recharge for both systems it is questionable whether the reduction is sufficient to have any significant effect on groundwater rise and salinity. George *et al.* (1999) report that 70-80% of catchment areas may need to be planted to trees to have significant reductions in water tables. Further to this, O'Connell (2002) found that achieving significant reductions in recharge through planting of non-commercial trees would incur unacceptably large losses in profit.

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[4] Recharge per hectare when enough trees are planted to completely offset greenhouse emissions.

Conclusion

This paper compares the responses of two different farming systems to greenhouse gas abatement policies. One farming system is livestock dominant, smaller in area, supporting a higher stocking rate with higher profit per hectare but a lower overall farm profit. As a result of its higher profits per hectare, the marginal value of land in the livestock dominant farm is greater. Such structural differences between the two systems explain most of the differences in response to the abatement policies.

One key finding is that the absolute cost of lowering emissions is less in the livestock dominant system than the crop dominant system. A government offering subsidies for lowering emissions would get better value from targeting the livestock dominant system than the cropping dominant system. However, the relative cost is greater for the livestock dominant farm. If farmers were forced to abate at their own expense, then the average Great Southern farmer would be worse off than the average Eastern Wheatbelt farmer, because they lose a greater percentage of their profits under abatement policy.

Another key finding, as also found by Petersen *et al*. (2000), is that for both the livestock dominant system and the crop dominant system, the restriction policy is more effective than the taxation policy. The use of MIDAS, a profit maximising model, shows that in some cases it is more profitable to continue emitting and pay increasing tax than to cut back on greenhouse producing enterprises. This is particularly the case for the crop dominant system where options for abatement are limited. The result of the taxation policy is very high losses in profit for low levels of abatement.

A third key finding is that, given the option to use trees as carbon sinks, farmers in both regions would choose to plant trees to offset CO_2-e emissions within the predicted permit price range of \$10-\$50 per tonne of CO_2-e. Because of a high rate of greenhouse emissions per hectare, the marginal value of land (and therefore opportunity cost) decreases more rapidly for the livestock dominant system than the crop dominant system under a taxation policy. Therefore the livestock dominant system adopts trees at a lower tax rate than the crop dominant system.

With trees as a carbon sink the livestock dominant system achieves emissions neutrality for an average cost of $19.50 per tonne of CO_2-e. For the crop dominant system the average cost is $24 per tonne of CO_2-e. The cost for both is well within the predicted range of permit prices.

A fourth key finding is that trees, besides acting as a carbon sink, can also be located on a farm to reduce recharge and therefore lessen salinity impacts resulting from rising water tables. The effectiveness of trees in reducing recharge will depend on the soil type chosen. Planting trees on a heavy clay soil in the Eastern Wheatbelt would be the cheapest option, but in terms of cost per millimetre of recharge abated, planting trees on a sandy soil is lower because the recharge is reduced by almost twice as much. In using trees for both greenhouse and salinity benefits the choice of soil type on which to plant the trees would depend on the farmers' (or the public's, if subsidies were to be offered) willingness to pay for salinity mitigation.

This paper has shown that the marginal cost of CO_2-e abatement increases as the abatement level increases. Therefore, a policy that engages more farms, in both regions, in low amounts of abatement would reach abatement targets at lower cost than a policy of targeting few farmers from one region. This would, however, increase administration costs.

Additionally, targeting farmers from different regions with the same policy would raise questions about equity and fairness, since, as discussed earlier, the relative effect on profit is greater for the livestock dominant system. A restriction policy uniform across regions would most likely be seen as inequitable by Great Southern farmers and be politically unpopular.

This raises the question of spatial differentiation of abatement policies. Should different policies or different levels of restrictions be applied to different farming systems? Or if an initial allocation of permits were to be issued, should a livestock dominant farming system be issued with more because of the nature of their business? Although this analysis has shown that the relative effect on profit is greater for a livestock dominant system than for a crop dominant system, this may not necessarily be the case for a smaller crop-dominant system making less profit. A smaller crop-dominant farm would have lower total emissions but if subject to the same absolute emissions restrictions would most likely lose a greater percentage of their profits than a livestock dominant system. So while parallels can be drawn to other farms in the Eastern Wheatbelt region, it is difficult to predict relative effects for crop-dominant farms in different regions. Each region, and indeed each farm, will vary in their cost of abatement.

It is unclear at this stage what policies the Australian government will implement to reduce Australia’s total greenhouse gas emissions, and even if the agricultural sector will be targeted under any abatement policies. This analysis has shown that applying farm level policies will be inefficient and will carry high costs for small reductions in CO_2-e emissions. However if policies were to be introduced, this analysis has shown that trees, if credited as a carbon sink, could play a vital role in offsetting farm emissions. Using trees as a carbon sink greatly reduces the cost per tonne of abating CO_2-e for both farming systems.

There are limitations to this analysis which arise from the model used. Using a steady-state model such as MIDAS means that variations in prices and seasonal conditions are not included. A second limitation is that the cost of administering the policies is not included. Due to the large number of individual farms, this cost is likely to be high if policies were introduced. A third limitation is that the carbon sequestration rates of trees, particularly trees grown only for revegetation purposes, are not well documented. The carbon sequestration rate per hectare will depend on the density, species and age of the trees, which can vary from site to site.

This analysis has highlighted the value of trees for carbon dioxide abatement. Given that trees can also provide other environmental benefits such as salinity mitigation and improved biodiversity, further analyses could explore emerging markets for environmental services. Such analyses could explore what price signals land-owners would need to receive to provide an environmental service such as planting trees. This could be done by modelling a tradable permit scheme, where the manager of the farming system could choose to sell environmental credits if the benefits of doing so are greater than their abatement costs.

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