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ALTERNATIVE POLICIES WITH COMPLEMENTARY BENEFITS: TARGETING GREENHOUSE EMISSIONS OR WATER RECHARGE ON FARMING SYSTEMS?

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Abstract

Policies introduced to address one environmental objective can often have the side-benefit of also addressing other environmental objectives. This analysis uses a whole farm bioeconomic model to explore the farm level implications, economic and environmental, of a policy initially designed to reduce greenhouse emissions. We model a regulatory policy which imposes an upper limit on farm greenhouse emissions but allows trees to be used as carbon sinks to offset emissions. The implementation of this policy causes a reduction in whole farm profit, but in addition to decreasing emissions it also decreases groundwater recharge from the farming system and therefore contributes to the prevention of dryland salinity. The analysis compares this approach with using a recharge restriction policy to achieve recharge and emissions reductions. The analysis finds that the position of trees in the landscape affects the extent to which groundwater recharge can be reduced for a given reduction in emissions and that there is a three-way trade-off between profit, emissions reduction and recharge.

Introduction

As public awareness and concern for the environment grows, policy makers are being forced to design agricultural policies that limit the impact of agriculture on the environment and promote sustainability, while maintaining productivity. Encouragingly, the implementation of a policy to achieve one environmental objective can often have the benefit of contributing to another environmental objective, a case of complementary environmental impacts or outputs. For example a policy to reduce dryland salinity may result in increased revegetation, which in turn provides erosion, shelter, biodiversity and greenhouse benefits.

In this analysis we have focused on the environmental objectives of reducing farm greenhouse emissions and reducing farm recharge. Reducing recharge is necessary for the prevention of dryland salinity. We have analysed how the implementation of a greenhouse gas reduction policy impacts on both farm emissions and recharge and conversely, how

the implementation of a recharge reduction policy impacts on both objectives. This should allow us to know whether it is more efficient to target greenhouse gas reductions and cash in recharge benefits or target recharge reductions and cash in on greenhouse emissions. More importantly, we aim to highlight some of the factors that underlie the preferred choice. Thus, this study serves as a starting point to investigate the more general, multidimensional problem: where more than two environmental impacts are involved, which of the interrelated impacts should the policy choose as its target?

The policy analysed is a restriction policy, where the farming system is forced to reduce emissions or recharge by a certain amount. The analysis assumes that non-commercial trees can be used to sequester carbon dioxide to offset emissions, as per article 3.4 of the Kyoto Protocol. The analysis was done using a whole-farm bioeconomic model which represents a typical farming system in the Great Southern region of Western Australia.

Methodology

The model

This analysis uses the Great Southern version of the MIDAS model (Model of an Integrated Dryland Agricultural System (Kingwell and Pannell, 1987)). MIDAS is a steady-state, linear programming model, that 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, using a discount rate of 7%. 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 Great Southern MIDAS model represents a farming system in the Kojonup shire of Western Australia. This area experiences a Mediterranean climate with average annual rainfall between 500 and 600mm. 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. A brief description of these is shown further below in Table 1. Annual rainfall is assumed to be 550mm, of which approximately 450mm falls in the winter-spring growing season (Young, 1995). The model includes both crop and livestock enterprises. The reader is referred to Young (1995) for a more detailed description of the GSM model.

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. Methane emissions from livestock excreta were not considered, due to the fact that conditions for anaerobic fermentation are rare. For further detail of emissions accounting the reader is referred to the NGGI workbooks (1996a, 1996b).

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, 2002). The CO_2-e of a non-carbon gas is calculated by multiplying the mass of the emission of the gas by its GWP. The GWP of methane is 23 and the GWP of nitrous oxide is 296 (AGO, 2002).

Carbon sequestration by trees

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

The CO_2 sequestration rate used in this analysis is slightly lower than the figure 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 rate is 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. In this analysis, trees are assumed to be of the second lowest productivity class (E4) and have an annual average sequestration rate of 7 t CO_2/ha/year.

The sequestration rate of eucalypts is assumed to be the same across all soil types, except soil class 1 where it is assumed to be 50% of the standard due to the low productivity of the soil type (Young, pers. comm. 2002).

Recharge

Recharge is water that is not used by plants and leaks through the soil to the groundwater. This causes salinity when the groundwater rises, dissolving salts that are present in the soil. Recharge values for annual crops or pastures and trees on each soil type were estimated using generic recharge-rainfall relationships developed by Petheram *et al.* (2002). Different soils have different properties which affect their recharge rate. In general, fine-textured soils such as clays will have high water storage capacity and low levels of recharge while coarse-textured soils such as deep sands will have high levels of recharge (Moore, 2001). The recharge values used in the model are shown in Table 1.

Table 1: Recharge in millimetres from annual crops or pastures and trees for each soil class.

Soil class	Description	Annual crops or pastures	Tree
Soil 1	Shallow, saline sands	26.4	1.1
Soil 2	Deep sands, often waterlogged	12.9	0.8
Soil 3	Deep sands, not waterlogged	39.9	1.4
Soil 4	Sandy gravels over clay	26.4	1.1
Soil 5	Loamy sand over clay	26.4	1.1

Results and Discussion

Greenhouse policy

Imposing a greenhouse restriction on the farming system, forces the model to select some area of trees to offset the farms CO_2-e emissions. This causes a decrease in farm profit (see Table 2), because the trees are returning no income to the farm and there is a cost of establishing them. The cost per tonne of CO_2-e abated increases as the restriction increases because the farm adopts the least costly methods of abatement first.

A restriction policy was used in this analysis because previous work (Petersen *et al*, 2003 and Flugge and Schilizzi, 2003) has demonstrated that a restriction policy is more effective than a taxation policy at reducing greenhouse emissions at the farm level.

At the level of greenhouse restrictions imposed the model selects to grow trees on soil 2. After soil 1, this soil type has the lowest marginal value. However the sequestration rate of trees on soil 1 is assumed to be only half that of the other soil types, meaning that twice the area of trees are needed to generate the same abatement. Therefore the opportunity cost is the least when the trees are grown on soil 2.

The inclusion of trees to offset greenhouse emissions has the flow-on effect of decreasing the recharge from the farm. Table 2 shows the decrease in recharge.

Table 2: Decrease in profit and recharge when greenhouse restrictions are applied, and cost per unit reduction.

Greenhouse reduction (%)	Decrease in profit (%)	Cost per tonne CO_2-e ($)	Decrease in recharge (%)	Cost per mm of recharge ($)
10	1	5.25	0.1	53.34
20	4.3	11.48	1.2	15.15
30	7.6	13.55	2.3	13.86

A 30% emission restriction costs the farm 7.6% of its profit and $13.55 per tonne of CO2-e. It is worth noting that this is within the range of predicted prices for carbon of $10 to $50 (AGO, 2001). This means that if a firm was willing to purchase permits to produce greenhouse emissions for $13.55, then this farm could supply 579 tonnes and be no worse off financially. In addition the farm would gain the environmental benefit of recharge abatement for nothing.
As mentioned above, the trees are selected on soil 2. Soil 2 has the lowest level of recharge (see Table 1), meaning the impact on recharge is minimised. If the trees were planted on soil 3 instead, a high recharge soil, then the impact on recharge could be maximised. Figure 1 below shows the profit trade-off curves when the trees are planted on soil 2 and soil 3.

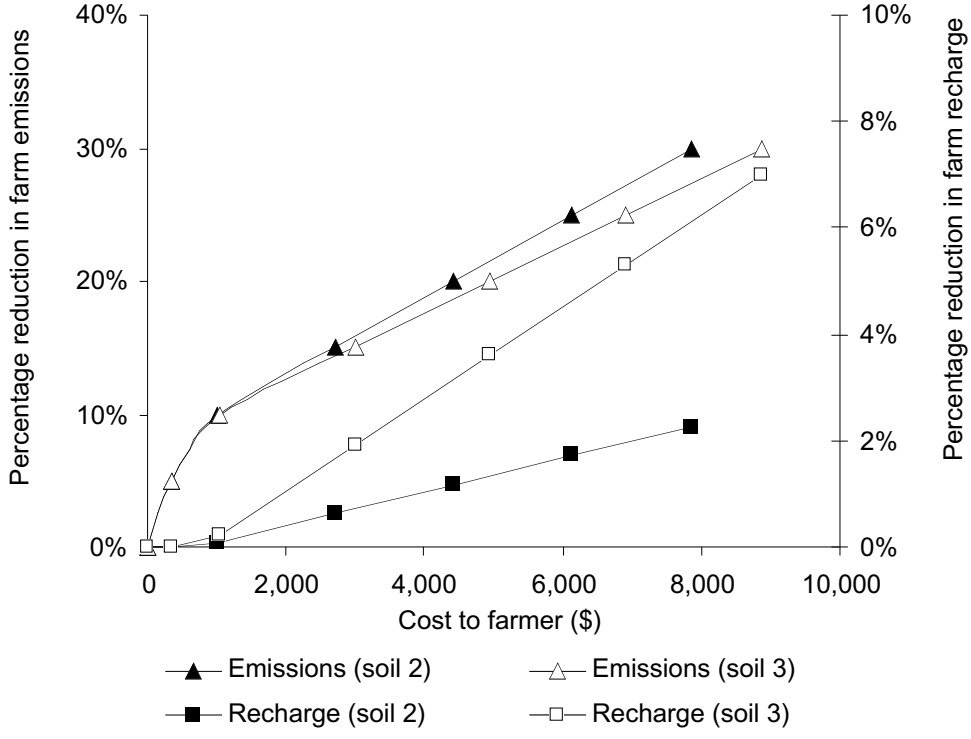

Figure 1: Trade-off between cost, emissions reduction and recharge reduction when the trees are planted on soil 2 or soil 3.

Figure 1 shows that the cost of meeting the greenhouse restrictions is increased when the trees are planted on soil 3, rather than soil 2. This is because the marginal value of soil 3 is higher than soil 2 and the opportunity cost of planting trees there is greater. Figure 1 also shows that the recharge response is more significant when the trees are on soil 3. The reduction in recharge is approximately three times the response when trees are on soil 2.

Again, assuming a firm was to pay $13.55 per tonne of CO_2-e for 579 tonnes, then for an extra $1,015 (0.9% of farm profit, the cost of putting the trees on soil 3 rather than soil 2), the farmer could reduce recharge by a further 1,186mm.

This equates to a marginal cost of $0.86 per extra millimetre of recharge. This means that there is now a cost to the farmer, but the recharge benefits are more substantial.

Put another way, $6000 will buy a 1.7% decrease in recharge and a 25% decrease in emission when the trees are on soil 2, or a 4.6% decrease in recharge and 23% decrease in emissions when the trees are on soil 3. From this it appears that soil 3 provides a more cost effective way of meeting two objectives. Another alternative is to apply the policy on recharge rather than greenhouse emissions. This approach is explored in the next section.

Recharge policy

If the policy used is a recharge reduction policy, then the model will select soil 3 as the optimum soil to plant trees on. Because recharge is highest on this soil, a smaller area of trees is necessary to meet the recharge restriction. However, a smaller area of trees means the greenhouse reduction is lower; again there is a trade-off. For example, a 6% reduction in recharge costs $4.60/mm when the trees are on soil 3 and $12.50/mm when the trees are on soil 2 (Table 3). The 6% reduction in recharge results in a 55% decrease in greenhouse emissions when the trees are on soil 2 and only an 18% decrease in greenhouse emissions when the trees are on soil 3.

Table 3: Decrease in profit and greenhouse emissions and cost per unit reduction, when recharge is reduced by 6% by planting trees on either soil 2 or soil 3.

Soil class	Decrease in profit (%)	Cost per mm of recharge ($)	Decrease in CO_2-e emissions (%)	Cost per tonne CO_2-e ($)
2	18	12.50	55	17.75
3	7	4.60	18	20.30

Comparison of two policy approaches

A policy-maker may be interested in knowing whether implementing a greenhouse reduction policy or a recharge reduction policy will bring about the best response for both greenhouse and recharge objectives. Table 4 below shows a comparison of the two policy approaches on meeting the targets of reducing emissions and reducing recharge, for the same change in profit.

Table 4: Decrease in recharge and greenhouse emissions and cost per unit reduction, for the two policy approaches when the overall cost is the same.

Policy	Cost ($)	Recharge reduction (%)	Cost per mm of recharge ($)	Decrease in CO_2-e emissions (%)	Cost per tonne CO_2-e ($)
Greenhouse	6,000	1.75	13.69	24.5	12.69
Recharge	6,000	5.25	4.56	15.5	20.06

The above results show that applying either a restriction on recharge or a restriction on greenhouse emissions will bring about a response in the other environmental objective. But although trees can reduce farm emissions and reduce recharge simultaneously, the extent to which each of these objectives is attained will depend on the policy used. For example if the policy is one of reducing greenhouse emissions, then the model seeks to minimise the cost of reducing emissions. If the policy is one of reducing recharge from the farming system, then the model seeks to minimise the cost of reducing recharge.

The chart below (Figure 2) shows the possible combinations of recharge abatement and greenhouse abatement for a given cost. The upper end of each segment represents the emissions recharge combination when a recharge abatement policy is imposed and the lower end of each segment represents the combination when a greenhouse abatement policy is imposed. Once the policy-maker has decided how much to spend and what value there is for each of the environmental objectives, then a policy mix can be designed that would achieve the optimal combination. The costs represent only the change in farm profit; they do not include the cost of measuring and implementing the policies.

Figure 2 shows that as the cost increases the slope of the trade-off curve between the two objectives is changing. As the cost increases, recharge is traded off at a higher rate relative to emissions. For example, when the cost is $1,000 the ratio of change in emissions to change in recharge is 9.4. When the cost is $6,000 the ratio is 2.6. As more money is spent on achieving the outcomes, there is relatively less impact on greenhouse and relatively more impact on recharge. The reason for this is, soil 3 (on which the trees are planted under the recharge policy) has a higher marginal value than soil 2 (on which trees are planted under the greenhouse policy) and so as the money spent on the policy increases, the relative effect on recharge increases.

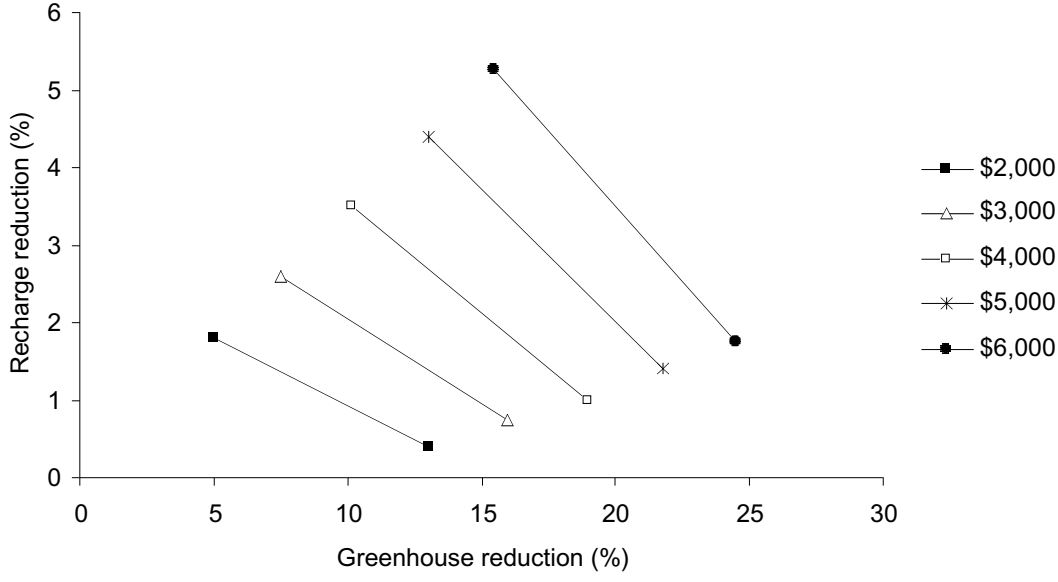

Figure 2: Trade-off between emissions reduction and recharge reduction for different costs, using a greenhouse policy, recharge policy or combination.

If soil 2 had the highest level of recharge (instead of the lowest as currently) then it would also be the optimal soil type to plant trees for recharge reduction. This would mean that the outcomes under each policy would be more closely aligned. However it is likely, that the outcome would be still different under each policy. This is because the model initally selct methods of emissions abatement that do not contribute to the reduction of recharge at all. For example, initially the model changes the enterprise mix to more crop (a low emitting enterprise) and less livestock (a high emitting enterprise), but does not select to grow any trees. This doesn't have any effect on recharge as pastures and crops are assumed to have the same level of recharge.

The recharge reductions analysed so far are likely to only delay the onset of salinity occurring. 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. Adoption of non-commercial trees on this scale would result in this farm going out of business. Therefore commercial plantings of perennial vegetation will be necessary. Similarly, emission reductions using carbon sinks only buys time, as the trees eventually die or are harvested, releasing carbon back into the atmosphere.

Conclusion

This paper demonstrated how the implementation of a policy to achieve an environmental outcome, such as greenhouse reduction, can have a secondary environmental outcome, such as recharge reduction. The aim of this paper was firstly to explore trade-offs that exist between profit and the degree to which both outcomes are achieved. Secondly, the aim was to address the question: which objective should be targeted in order to get the maximum benefit from both?

This analysis has shown that there is a trade-off between profit and maximising both greenhouse and recharge outcomes, for this particular farming system. The most cost-effective location for the trees, to achieve greenhouse targets, is not that which maximises the recharge. When trees are put in a position that also maximises recharge the total cost is higher. However, the cost per millimetre of recharge is reduced.

While secondary environmental effects can be achieved with the implementation of one policy, they will not necessarily be maximised. This is because of a couple of reasons, firstly, as described above, there is spatial difference in the land and the way in which different land management units can be used to achieve the environmental objectives. Secondly, it may be possible that the farming system can respond to the policy in a way that doesn't contribute the secondary outcome at all. For example, when a greenhouse policy is implemented, this farming system responded firstly by changing the enterprise mix to from high emission activities to low emission activities.

In this analysis we have assumed that the carbon sequestration rate of trees is the same on all soil types, except soil 1. This was assumed because there is a lack of data on sequestration rates of trees for this region. However, it is likely that this is not the case; trees will have different growth rates on different soil types and therefore different sequestration rates. This means that the trade-off between recharge and emissions reduction due to the positioning of the trees in the landscape may have been underestimated or overestimated depending on the sequestration rate on particular soil types.

The study has shown that implementing a recharge policy will have different outcomes for recharge and emissions reduction than implementing a greenhouse policy. Therefore it will be necessary for the policy maker to value each of the environmental outcomes and design a policy that maximises the objective with the highest value.

Limited funds and an increasing number of environmental priorities means that research into integrated multi-outcome resource management will come to the fore. Further research could investigate correlations between other environmental objectives, such as biodiversity, improving wetland ecosystems or reversing land degradation. This will aid policy-makers in designing policies that achieve a number of environmental outcomes simultaneously while optimising the use of funds.

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