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An analysis of the spatial and temporal patterns of greenhouse gas emissions by agriculture in Western Australia and the opportunities for agroforestry offsets

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Abstract[1]

If agriculture is included in an Australian emissions trading scheme then it may face from 2015 at the earliest, a price for its greenhouse gas emissions; and thereby have incentives to offset and lessen its emissions. Yet because there is currently little understanding of the spatial pattern of emissions in agricultural regions of Australia, the extent of the challenge the sector faces in reducing its emissions is not fully recognised. To improve our understanding, this study uses the National Greenhouse Accounts methodology to estimate the spatial and temporal patterns of agricultural emissions since 1990 in the key agricultural region in Australia’s southwest. This region generates almost 40 percent of the nation’s winter crop production and supports over a quarter of the nation’s sheep. The quantity and trajectory of emissions from each shire in this region are reported, thereby identifying where emission problems may be worsening or easing. The composition and causes of changes in emissions are discussed. This study also generates spatial estimates of sequestration costs by drawing on land and forestry cost and tree growth data. Many relatively low cost sites for carbon sequestration, based on permanent reforestation, are identified with the implication that agriculture may be able to cost-effectively offset its emissions, as well as some of those from other sectors. However, an implication of this study’s findings is that in some shires eventually there may be strong land use competition between farming and forestry.

Keywords: greenhouse gas emissions, spatial analysis, agriculture, offsets, sequestration

Introduction

The main greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) occur naturally and maintain the earth at a life-supporting temperature through a process known as the greenhouse effect. However, anthropogenic activities have increased the store of greenhouse gases in the atmosphere and arguably led to the enhanced greenhouse effect of global warming and potentially adverse climate change (DAFWA 2003. CSIRO 2007). The Intergovernmental Panel on Climate Change (IPCC) (2008) projects ongoing drought, fire and water problems in Australia, leading to a decline in agricultural production over much of southern Australia by 2030 and a lessening of agricultural productivity. Climate change and

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associated changes in rainfall, temperature and concentrations of atmospheric carbon dioxide (CSIRO 2007) will have both positive and negative effects on pasture and cropping systems (Easterling and Apps 2005; Howden *et al.* 2003; Pittock 2003). However, the negative impacts are likely to dominate, particularly in Western Australia (Pittock 2003). To avoid dangerous climate change, policies to reduce greenhouse gas emissions have been globally advocated.

In Australia, the principal policy response to curb emissions has been the development of an emissions trading scheme, known as the Carbon Pollution Reduction Scheme (CPRS) (Department of Climate Change 2008b). This scheme commences in 2010 and will place a price on greenhouse gas emissions by requiring emitters to hold permits equal to their quantity of emissions. Emissions reductions of 10 per cent or 20 per cent of 2000 levels have been proposed by 2020 (Garnaut 2008b) and the Australian government’s White paper on the CPRS (Commonwealth of Australia 2008) commits the nation to lessening its greenhouse gas emissions by between 5 per cent and 15 per cent below 2000 levels by the end of 2020. The reduction of emissions by 5 per cent (below 2000 levels) by 2020 is an unconditional commitment.

Agriculture’s sensitivity to this scheme depends on both its emissions intensity and its ability to reduce emissions (Garnaut 2008a). Whilst agriculture may be included in the scheme, a final decision will not be made until 2013 and the earliest agriculture will be included is 2015 (Department of Climate Change 2008b, Commonwealth of Australia 2008). Agriculture is both a source and sink of carbon, and its involvement in the scheme would include this dual role (Flugge and Abadi 2006; Garnaut 2008c; PMTG 2007, Commonwealth of Australia 2008)

Agricultural sources of greenhouse gas emissions

Greenhouse gases are released when biomass decays or is consumed or burnt (National Greenhouse Gas Inventory 2007). Agricultural practices have increased these processes through the introduction of cropping and livestock systems. The primary greenhouse gases produced by agriculture are methane (CH_4) and nitrous oxide (N_2O); carbon dioxide is assumed to be in balance as part of a cyclical process (IPCC 2007). Methane and nitrous oxide have a greater Global Warming Potential (GWP) than carbon dioxide at 21 and 310 times respectively (Department of Climate Change 2008c). Greenhouse gases are converted to carbon dioxide equivalents (CO_2-e) by multiplying the GWP by the quantity of gas. This permits comparisons and common accounting practices across greenhouse gases.

Agriculture is responsible for 85 per cent of Australia's total nitrous oxide emissions primarily due to the application of nitrogenous fertilisers, cultivation of nitrogen fixing crops and pastures, and tillage of agricultural soils (Australian Greenhouse Office 2007a; Department of Climate Change 2008c). Agriculture is also responsible for 60 per cent of total methane emissions (Australian Greenhouse Office 2007a). Methane is released from the process of enteric fermentation in the digestive process of livestock, particularly in ruminants. In anaerobic conditions methane can also be produced from manure and this is particularly associated with intensive livestock industries. Nitrous oxide can be released from manure and urine on soil, but emissions are only significant in high rainfall areas (National Greenhouse Gas Inventory 2007).

Although the need for a reduction in greenhouse gases is recognised, and the agricultural sector is known to be a main source of emissions, there is currently little understanding of the spatial pattern of emissions in the agricultural regions of Australia. Understanding the temporal and spatial pattern of emissions in agriculture will help identify the extent of the challenge the sector faces in reducing its emissions. Presently there is a lack of knowledge about both the existence of emission 'hot spots' and the current spatial trajectories of emissions. This study seeks to address this lack of knowledge by using the agricultural region of Western Australia as a case study.

Agriculture as a carbon sink

Agriculture can potentially reduce or offset its greenhouse gas emissions through agroforestry, or farmland tree plantations, that sequester carbon dioxide (Flugge and Abadi 2006; Land and Water Australia 2007). Articles 3.3 and 3.4 of the Australian ratified Kyoto Protocol allow for emission offsets through the sequestration of carbon. Article 3.3 covers reforestation and afforestation activities occurring after 1990, subject to the following conditions (DAFWA 2003):

- Land was cleared prior to 1990
- Trees at a minimum height of 2 metres
- Forest crown cover of at least 20 per cent
- Forest area greater than 1 hectare
- Forest established by direct human methods

Landholders become responsible for the permanency of the sink, which is required to ensure permanent removal of carbon from the atmosphere (Garnaut 2007). Article 3.4 covers sequestration through land management, including management of soils, grazing, cropland and pastures (DAFWA 2003). Australia has chosen to utilise the offsets covered under Article 3.3, with the potential inclusion of Article 3.4 activities at a later stage (Department of Climate Change 2008a). It is likely the Carbon Pollution Reduction Scheme will cover emission sinks under Article 3.3 only (Department of Climate Change 2008b).

Harper *et al.* (2007) identified significant opportunities for carbon sequestration in Western Australia’s agricultural zone through the reforestation of farmland. They suggested the greatest potential for carbon storage by trees is in higher rainfall areas. However, Shaikh *et al.* (2007) argued that carbon sinks on marginal agricultural land can also provide significant emission offsets. The offset activity presents a land use trade-off between agriculture and reforestation. In Western Australia, land in higher rainfall areas tends to be more productive for agriculture and forestry than land in lower rainfall regions. Hence agricultural land in high rainfall zones will have a greater opportunity cost than land in low rainfall regions. Van Kooten *et al.* (2004) found that including the opportunity cost of land causes the average costs of carbon forest sinks to rise significantly. Similarly, Richards and Stokes (2004) found differences between studies that have included land opportunity costs and those that have not.

In this study, information about land opportunity costs is combined with agroforestry cost data and estimates of tree growth to provide a spatial understanding of the cost of provision of carbon offsets (or sequestration) in the agricultural region of Western Australia. This paper will next outline the methodology used to estimate emissions from agricultural shires in Western Australia and the methodology used to form sequestration cost estimates. This is followed by an outline of the study’s results and a discussion of their nature and implications, and finally, conclusions are presented.

Methodology

Emissions accounting

Greenhouse gas emissions were calculated using emissions factors and equations from the National Greenhouse Accounts (replacing the National Greenhouse Gas Inventory (NGGI)) (Department of Climate Change 2008c; National Greenhouse Gas Inventory 2007). Shire level data on livestock numbers and type, crop and pasture production and quantity of nitrogenous fertiliser applied were attained from the Australian Bureau of Statistics (ABS) for the 1990, 1995, 2000 and 2005 census years for eighty-two statistical local areas (shires) in Western Australia's agricultural zone. Gaps in census year data were filled using farm management consultancy data. These data were used to calculate methane emissions from enteric fermentation and manure, and nitrous oxide emissions from direct soil nitrogen (nitrogenous fertiliser application and nitrogen-fixing crops and pastures), indirect nitrogen leaching and from manure and urine on soil. Methane and nitrous oxide emissions were converted into carbon dioxide equivalents (CO_2-e) using Global Warming Potentials (GWP) of 21 and 310 respectively, as used under Kyoto accounting standards by the National Greenhouse Accounts (Department of Climate Change 2008c). The only emissions not included in this study are emissions from residue burning. These emissions are likely to have reduced substantially over the last two decades due to the increasing and now widespread use of retention and incorporation of stubble (Duck *et al.* 2006). Unfortunately there is no farm survey data to provide accurate estimates of the initial or current extent of the practice of burning. When 'guesstimates' about the possible extent of stubble burning have been included, typically the emissions from burning are found to be minor (Australian Greenhouse Office 2007b). Fuel consumption by agricultural practices is not included as this is accounted for under the transport sector in the National Greenhouse Accounts.

Greenhouse gas emissions were calculated on a shire basis for the agricultural zone of Western Australia for the years 1990, 1995, 2000 and 2005. The reader is referred to the *Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Agriculture* (National Greenhouse Gas Inventory 2007) for further details of the accounting methods. These emissions were then mapped using GIS software to determine spatial and temporal patterns.

Marginal cost of abatement

Land values and plantation establishment and maintenance costs were converted into annuity 'in perpetuity' values and combined with Forest Product Commission shire level data on sequestration rates to determine the marginal cost of abatement per shire. A state level marginal cost of abatement curve was generated by aggregating shire level marginal costs of abatement and the amount of sequestration possible on arable land in each shire.

The average value of cleared agricultural land on a shire level was taken from 2005 Landgate rural land valuations. These values were combined with a 10 per cent opportunity cost of capital for agricultural land to reflect current land lease costs. Plantation establishment and maintenance values were used from research by the Rural Industries Research and Development Corporation for viable eucalypt species (Abadi *et al.* 2006). The plantation establishment costs included planning, site preparation, weed and pest control, seedling purchase, machine planting and initial growth monitoring (Abadi *et al.* 2006). Harvest costs were not included in this study as trees were assumed to be unharvested in accordance with the Australian adopted Kyoto accounting standards, which treats harvest as a release of all stored carbon (Australian Greenhouse Office 2006). Land values and plantation costs were converted into annuity 'in perpetuity' values as land is effectively locked into permanent use. An inflation rate of 5 per cent per annum was used to bring all land and plantation cost values into constant 2008 terms.

Greenhouse gas emissions on a shire level were projected to 2020 based on trajectories over the period 1990 to 2005. The cost to Western Australian agriculture of offsetting emissions to 20 per cent and 10 per cent of 2000 levels in 2020 was calculated firstly assuming local sequestration (i.e. within the shire that is the source of emissions) and secondly assuming least-cost sequestration (i.e. within the shire(s) that display the lowest cost of sequestration). These costs were then compared to the expected cost of offsetting emissions through the purchase of permits.

Results and Discussion

Temporal trends

Agricultural greenhouse gas emissions in Western Australia have fallen by 2.85 per cent from 1990 to 2005, from 8.33 to 8.09 million tonnes of CO_2-e (Figure 1). This differs from the National Greenhouse Accounts' (NGA) result which has Western Australian emissions increasing by 3.5 per cent over the same period (Australian Greenhouse Office 2007b). However, this divergence is due to the inclusion of pastoral shires in the state agriculture figures in the NGA (National Greenhouse Gas Inventory 2007). Only agricultural shires were included in this study. Both studies, however, use Australian Bureau of Statistics data for emissions calculations (National Greenhouse Gas Inventory 2007).

Enteric fermentation and direct soil nitrogen were the most important sources of emissions in Western Australian agriculture. The fall in emissions over 1990 to 2005 was principally due to the decrease in enteric emissions, which fell by 21 per cent. Enteric emissions in 1990 were responsible for 70 per cent of all emissions; in 2005 this figure had fallen to 57 per cent. This change was mostly caused by declining sheep numbers. Other livestock related emissions, such as manure and urine on soil, also fell; although methane from manure increased by 17 per cent due to increases in intensive livestock numbers, particularly in pigs and poultry. The decline in emissions from most livestock sources was offset in part by a rise in emissions from direct soil nitrogen, that is, from the application of nitrogenous fertilisers and production of nitrogen-fixing crops and pastures. Direct soil nitrogen emissions more than doubled from 1990 to 2005, accounting for just over 22 per cent of all emissions in 2005. This reflects the move into more intensive cropping systems in Western Australian agriculture (Kingwell and Pannell 2005).

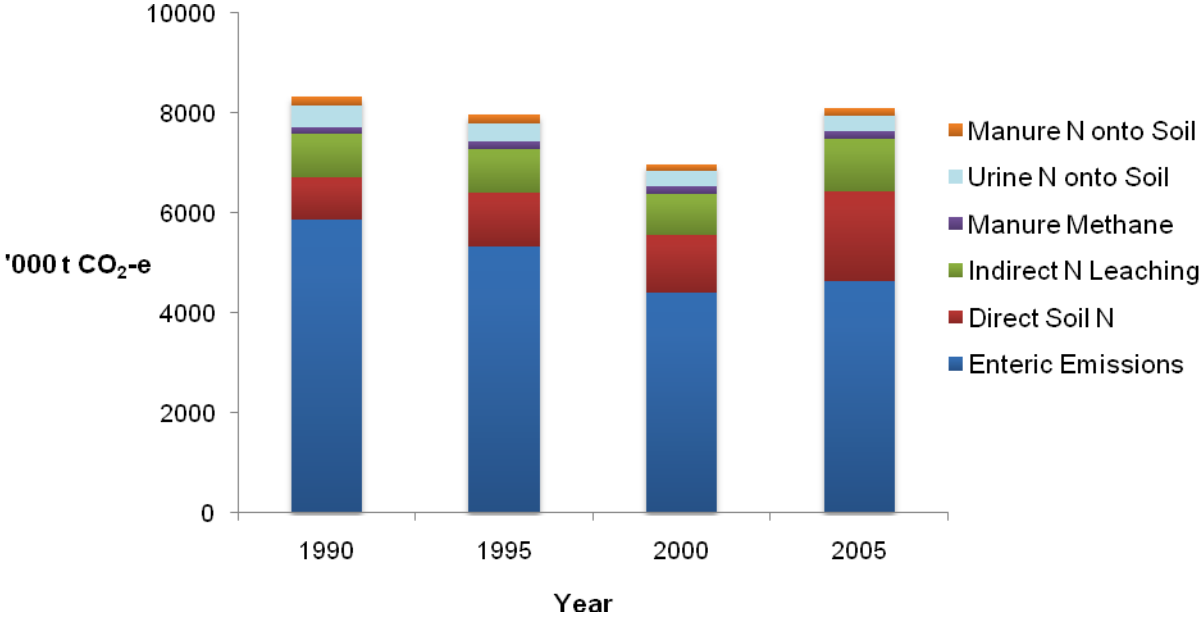

Figure 1. Western Australian agricultural greenhouse gas emissions by source, aggregated over agricultural shires, 1990 – 2005

In the year 2000 there was a drought, leading to a distinct fall in agricultural emissions. Grain and pasture production were poor (Australian Bureau of Statistics 2007), leading to destocking and reduced emissions from both cropping and livestock. In contrast, the 2005 season was above average with strong early growth in pastures and above average grain yields (Duck *et al.* 2006), resulting in increased emissions from cropping and livestock.

Spatial patterns

There was spatial variability underlying Western Australian agricultural emissions. The highest emitting shires were predominately in the south, where livestock dominant and higher crop input farming systems operate and where some shires have a large area (e.g. Esperance, Ravensthorpe, Lake Grace) (Figure 2). The lowest emitting shires were mainly in the northern wheatbelt, where the sheep population has been greatly reduced.

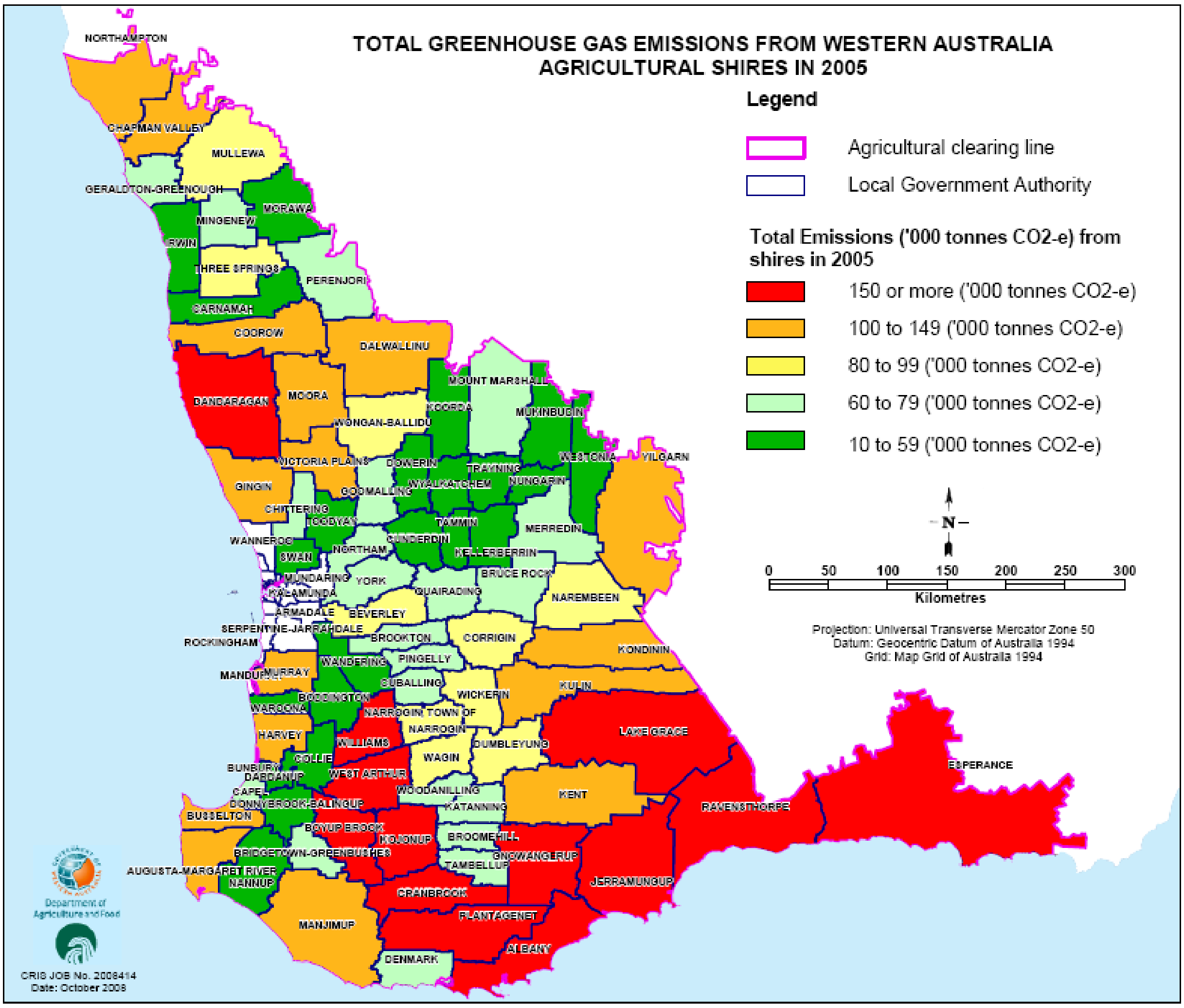

Figure 2. Total greenhouse gas emissions ('000 tonnes of CO_2-e) of agricultural shires in Western Australia, 2005

Just over half of Western Australian agricultural shires reduced their emissions from 1990. There was a strong decline across the high-emitting southern shires and smaller reductions in the wheatbelt and north-eastern shires (Figure 3). The highest emitting shires in 2005 tended to have reduced their emissions since 1990, with the exception of the shires of West Arthur, Williams and Gnowangerup in the south and Dandaragan in the north. These southern shires increased their emissions by less than 10 per cent since 1990. This was due to small declines in the shires' enteric emissions combined with a large increase in direct soil nitrogen emissions. In Dandaragan, however, there was an increase in both enteric and direct soil nitrogen emissions from 1990, leading to an increase in its total emissions of slightly over 25 per cent from 1990 levels.

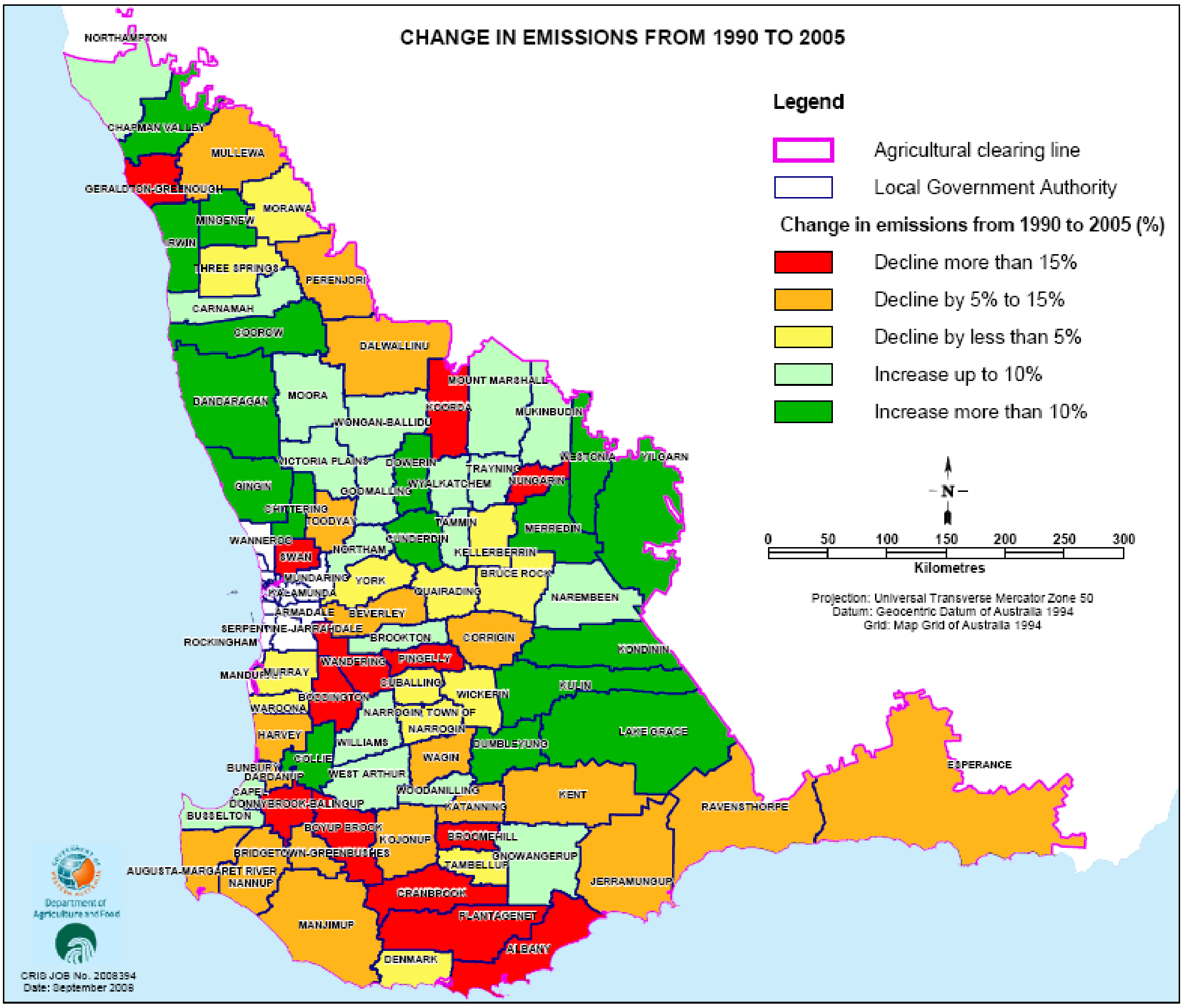

Figure 3. Percentage change in Western Australian agricultural greenhouse gas emissions from 1990 to 2005

In parts of the eastern wheatbelt, emissions increased by more than 10 per cent of 1990 levels. This was largely due to increased direct soil nitrogen emissions, reflecting increased production of nitrogen fixing crops and application of nitrogenous fertiliser in this region. There were stronger increases in parts of the north, with seven shires increasing emissions by over 20 per cent of 1990 levels. The Shire of Gingin, for example, had an increase of 72 per cent of 1990 levels. In the Shire of Coorow and those shires north of Coorow, the increase was due to greater pulses production and nitrogenous fertiliser use, leading to larger soil emissions.

In the shires south of Coorow increases in enteric emissions were responsible for the overall increases in emissions of these shires, though direct soil nitrogen emissions also increased strongly, doubling or more than doubling over the period.

Overall, enteric fermentation and direct soil nitrogen emissions determined the spatial and temporal patterns of agricultural emissions. Enteric emissions (Figure 4) declined in most shires over the period while cropping related emissions increased in 95 per cent of shires. This growth in cropping system emissions was responsible for the increase in emissions for two thirds of the shires that increased their emissions from 1990. The shires with the greatest rise in emissions were shires that had increased their livestock or cropping intensity. Shires with an overall decrease in emissions tended to have a fall in enteric emissions that exceeded any rise in cropping emissions.

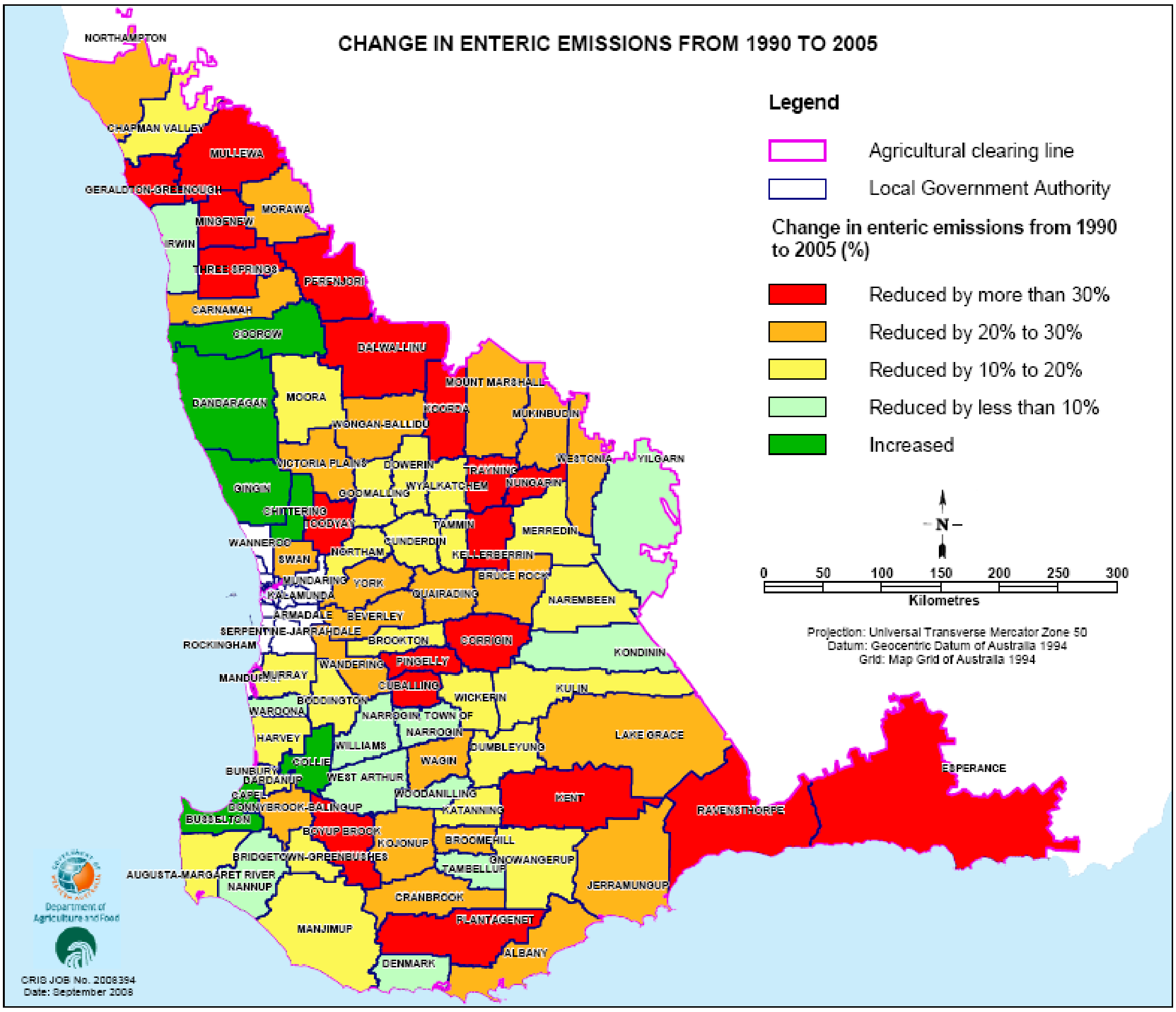

Figure 4. Percentage change in enteric emissions across all agricultural shires from 1990 to 2005

Enteric emissions declined in over 90 per cent of shires and decreased by more than 30 per cent in nearly a quarter of all shires. This was mainly due to a fall in sheep numbers throughout the state; Western Australia's sheep numbers fell by 33 per cent from 1990 to 2005 (ABARE 2007). The only increases in enteric emissions occurred in four shires to the north of Perth and in three shires in the south west corner, and this was due to increases in cattle numbers, particularly beef cattle. However, for the Shire of Busselton an increase in dairy cattle led the increase in enteric emissions, and for Capel shire both dairy and beef cattle numbers increased.

Enteric emissions declined for nearly all shires; however, they remained the dominant source of emissions. For nearly a quarter of all shires, particularly those in the south west corner of the State, enteric emissions were responsible for over 70 per cent of each shire's emissions in 2005 (Figure 5).

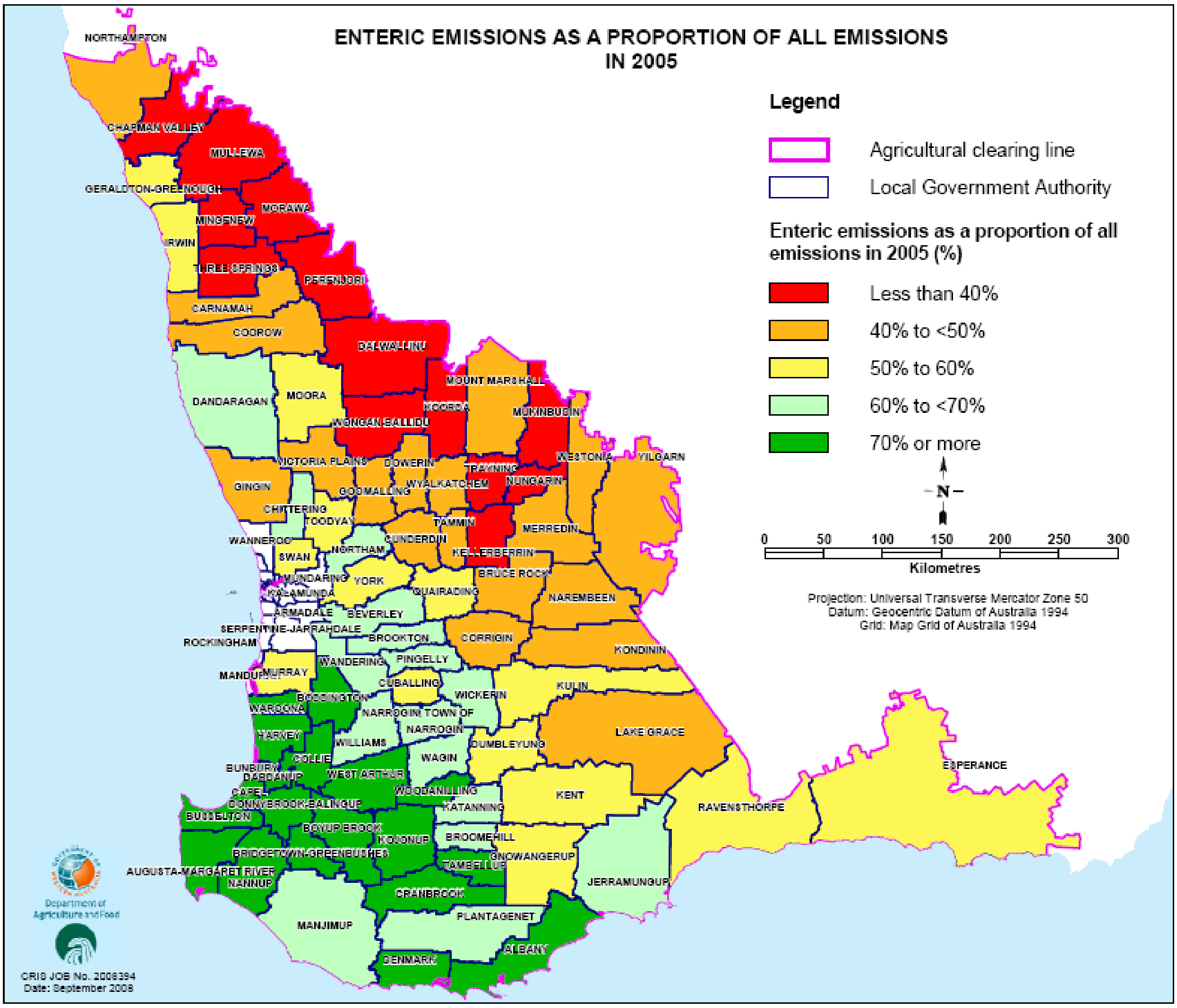

Figure 5. Enteric emissions as a proportion of the total emissions of a shire in 2005

The proportion of a shire’s emissions that are enteric emissions falls as annual rainfall declines as the land supports fewer livestock. The decline in enteric emissions since 1990 has been greater in southern shires where farm enterprises have switched into more cropping thereby reducing sheep numbers that previously were often the dominant enterprise.

Direct soil emissions mostly showed an inverse pattern to that of enteric emissions (Figure 6). Direct soil emissions include emissions from the application of nitrogenous fertilisers and from nitrogen fixing crops. Direct soil emissions increased as a proportion of total emissions as farming systems swung toward greater crop dominance and more reliance on nitrogenous fertilisers. Direct soil emissions had the greatest importance in the northern and eastern shires, particularly those on the eastern boundary of the agricultural zone, where crop dominant farms proliferate.

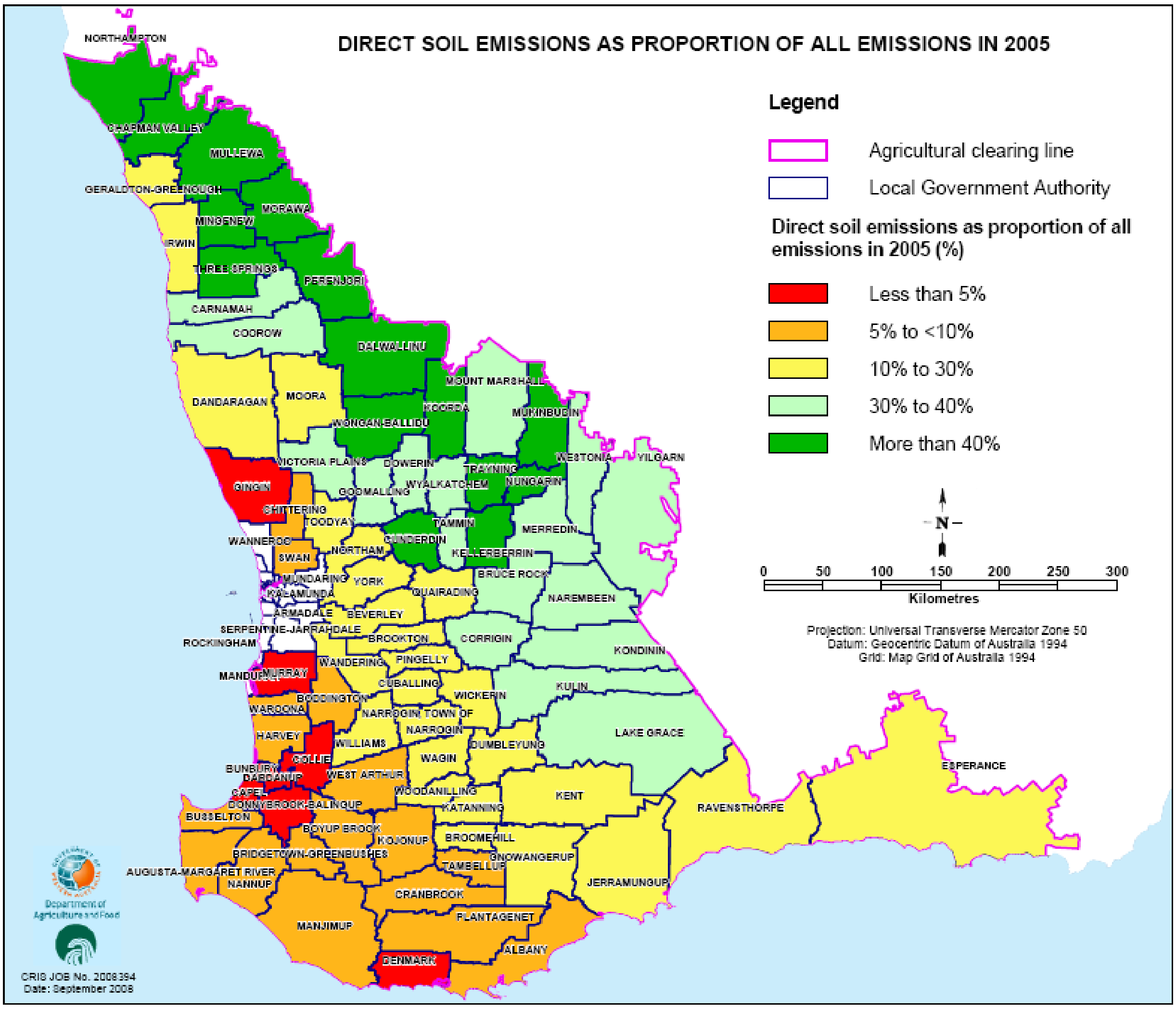

Figure 6. Direct soil emissions as a proportion of the total emissions of a shire in 2005

The future distribution of agricultural greenhouse gas emissions will change according to shifts in the enterprise mix. The sheep population, and hence enteric emissions, may continue to decline if the relative profitability of enterprises continues to favour cereal production (ABARE 2006, Dalton and Keogh 2007). Continuing economic growth in several Asian countries is likely to cause an expansion in their demand for feedgrains and fodder from which Australian grain farms will benefit (Dalton and Keogh 2007). If the farming systems in Australia's southwest become more crop dominant as a result of growth in export demand for crop products then the emissions trends evident since 1990 will continue with rising direct soil emissions and indirect nitrogen leaching offset by lesser enteric emissions, assuming the sheep population continues to decline. However, as pointed out by Dalton and Keogh (2007) the burgeoning growth in several Asian countries may additionally stimulate growth in dairy production in Australia and thereby add to emissions from that industry.

Farming systems may also become more crop dominant if agriculture is included in the Australian government's Carbon Pollution Reduction Scheme (CPRS). Agriculture's coverage by the CPRS would likely penalise emissions intensive livestock production and so lower the profitability of livestock dominant farming systems relative to cropping systems, thereby further encouraging the growth in cropping systems and decline in sheep and cattle numbers.

Marginal cost of abatement

Besides identifying spatial and temporal emission trends in Australia's southwest agricultural region this study also examines the marginal cost of abatement for shires in this region, where the abatement is based on offsetting emissions through permanent reforestation. The CPRS will provide farmers (and others) will the opportunity use reforestation to reduce net emissions. However, for the southwest of Australia there is limited information on the spatial marginal cost of abatement, based on reforestation.

The *Methodology* section of this paper outlined how various data (shire land values, forest plantation establishment and maintenance costs, and sequestration rates across shires) could be combined to generate estimates of the cost of sequestration and hence the marginal cost of abatement in each shire. Drawing on these data, Figure 7 displays the spatial distribution of the costs of sequestration.

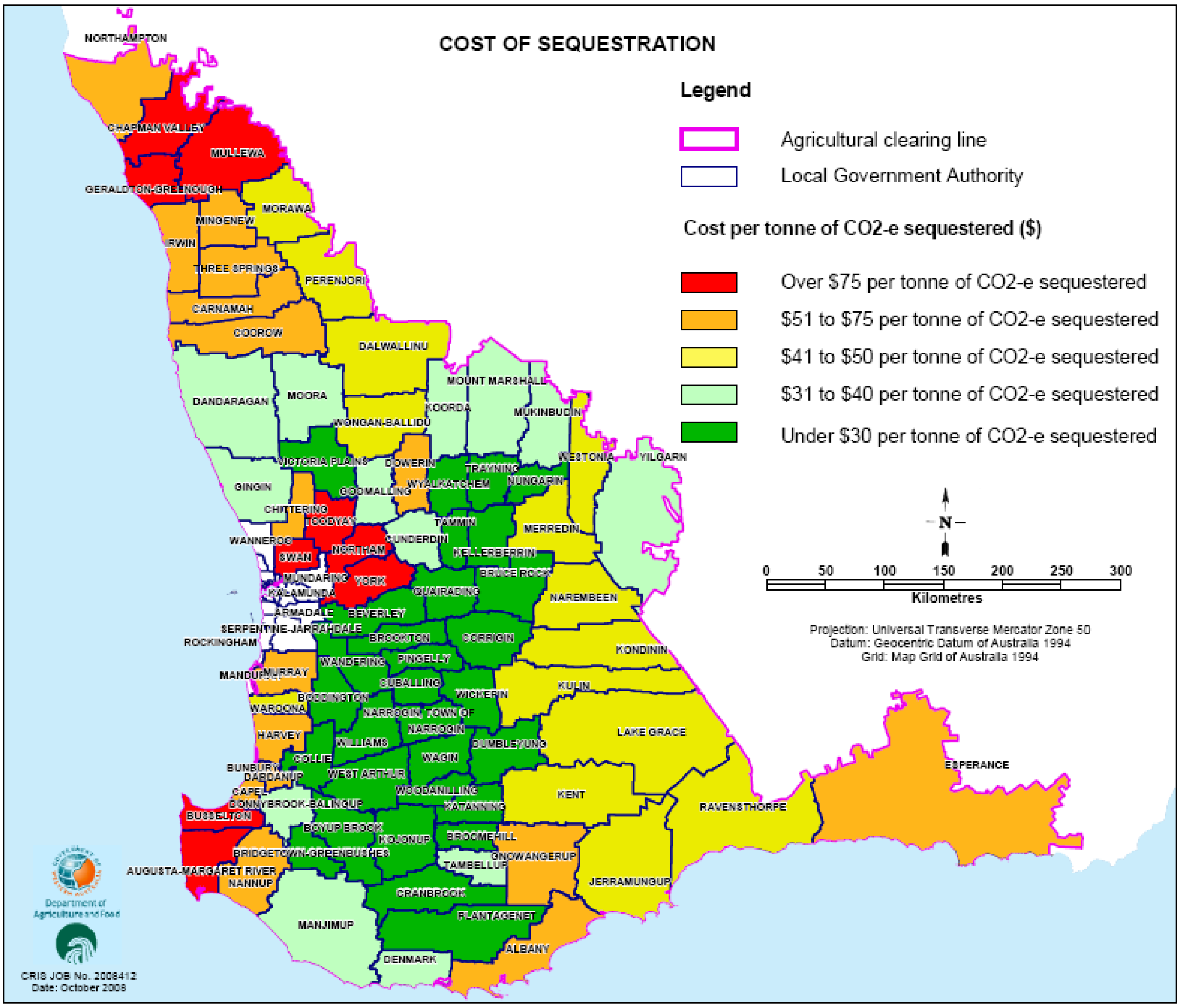

Figure 7. Cost per tonne of CO_2-e sequestered through reforestation on arable land, in 2008 terms

The most cost effective sites for carbon sequestration are in the medium rainfall zone, where sequestration rates were medium to high (10–25 t CO_2-e/ha) and where the cost of farmland was relatively affordable. Some shires in the higher rainfall zone also were cost effective sites because, although their land was more expensive, their sequestration ability was higher. Also a few shires in the lower rainfall zone were also cost effective sites for sequestration as their land costs were low and their sequestration rates, although smaller, were still sufficiently high to render those shires cost effective sites.

Elsewhere in the lower rainfall zone land tended to have lesser land values but poor sequestration rates (1–5 t CO_2-e/ha), so greater quantities of land were required to sequester an equivalent amount of carbon, which led to a higher cost of abatement. At the extreme, for example, the Shire of Mullewa had low land values but such a low sequestration ability (1 t

CO_2-e/ha) that the quantity of land required made the overall investment prohibitively expensive. At another extreme, land in the high rainfall south west corner or other shires close to Perth were not cost effective sites for investing in sequestration as, although sequestration rates were relatively high, this was overwhelmed by the greater expense of the land.

The data behind Figure 7 can be re-formulated to form a marginal cost of abatement curve (Figure 8). Data shown in Figure 8 are generated by @RISK, an Excel add-in, and assume that the cost and sequestration data that underpin Figure 7 are in fact subject to some uncertainty, modelled as normally distributed variables with coefficients of variation of 20 percent. In Figure 8 the marginal cost of abatement rises as sequestration becomes either less technically feasible or the cost of land on which sequestration is proposed becomes too expensive relative to the carbon able to be stored in trees grown on that land. The marginal cost of abatement commences at around $18 per tonne of CO_2-e sequestered.

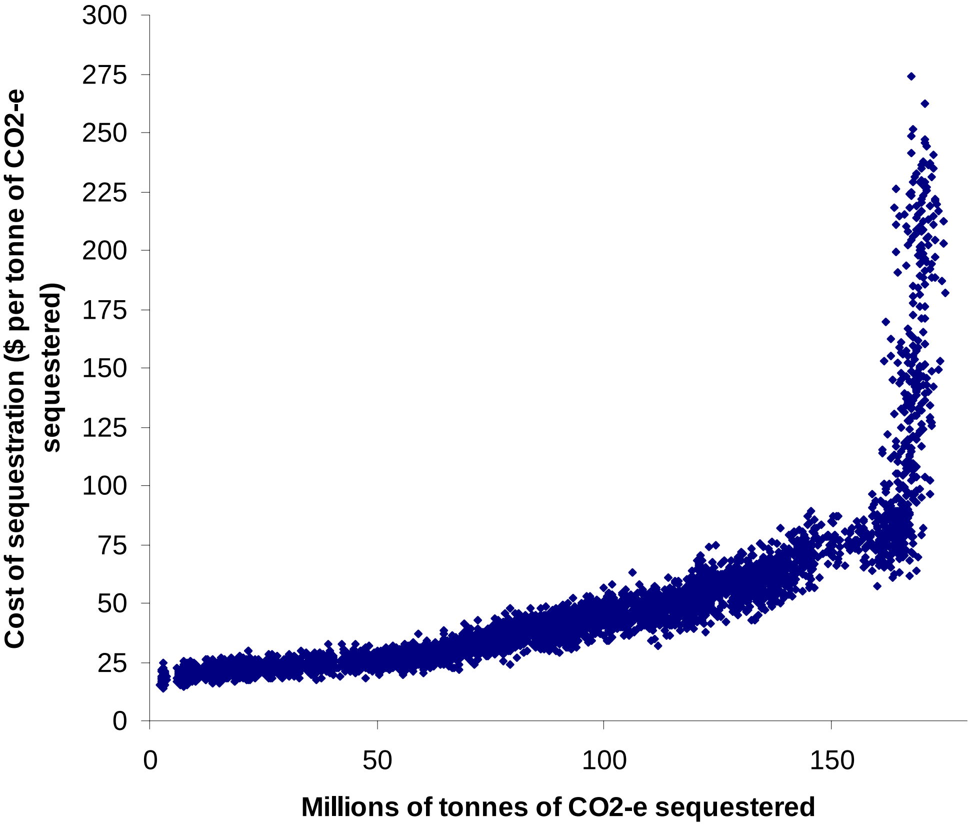

Figure 8. Marginal cost of sequestration based on reforestation of farmland in Western Australia ($ per tonne of CO_2-e sequestered)

Up to 50 million tonnes are estimated as being able to be sequestered at a price less than $30 per tonne of CO_2-e. Western Australian agricultural shire emissions in 2005 were just under 9 million tonnes of CO_2-e so there are abundant low cost abatement options for agriculture, based on reforestation. If agricultural land was solely used for the abatement of its own emissions then, for Australia's southwest region, all agricultural emissions could be sequestered at a price of around $20 per tonne.

As illustrated by the point variation in Figure 8, the actual cost of sequestration in practice will depend on land valuations, *in situ* sequestration rates and actual costs incurred in plantation establishment and management. This means that the cost effectiveness of sequestration will vary not only across shires, but also within shires.

It is more likely that the marginal cost of abatement curve will shift up rather than down in response to future price, cost and climate changes. The main driver of cost effectiveness is land price, which is likely to appreciate, based on historical experience. Moreover, the price of land may also rise because of competing land uses between farming and agroforestry, particularly if agroforestry increases demand for arable land. Establishment and maintenance costs are also likely to increase, at least in the short term, if sequestration becomes a popular abatement method for industry. The abatement curve may shift down if sequestration rates improve through identification of superior provenances of trees or tree species. However, against this is the projected adverse impact of climate change and associated changes in rainfall and temperature (CSIRO 2007) that will lessen future sequestration rates in many shires and thereby raise the cost of sequestration.

The CPRS White Paper (Commonwealth of Australia 2008) states that the impacts of the scheme are such that "The Government therefore expects that most forests established as a result of the Scheme will be not-for-harvest forests grown on marginal or less productive farm land, ..." (p. 6-48). Later a similar statement is made: "new forests are likely to be established on more marginal or less productive agricultural land and will not undermine food security." (p, 6-49).

The implication of these statements is that the Australian government believes the CPRS will unleash little land use competition between agriculture and forestry; with marginal and less productive farmland being targeted for land use change. However, the analysis reported in this paper suggests that due to its cost-effectiveness in growing trees, farmland in productive agricultural shires, particularly medium rainfall regions of Western Australia, may well be targeted for permanent forestry. Although there may be pockets of cheaper land in many shires that also are cost-effective sources of permanent forests, nonetheless it remains true that farmland in some shires are currently productively used for agriculture represent attractive options for conversion to permanent forestry.

Marginal cost of abatement for Western Australian agriculture

If agriculture is included in the Carbon Pollution Reduction Scheme (CPRS) in 2015 it will become subject to emissions reductions (below 2000 levels) of at least 5 per cent and up to 15 per cent by 2020 (Commonwealth of Australia 2008). Agriculture may reduce its net emissions through reforestation, either in shires that are least-cost sources of sequestration or locally where each shire provides a sequestration option. Under local sequestration, farmers might offset their emissions by sequestering carbon on land within their shire and so may face a higher marginal cost than if they offset at least-cost in other shires. The least-cost shire for sequestration is Wickepin at \$18.6/ t CO_2-e. The Shire of Wickepin could potentially sequester over 2.7 million t CO_2-e through sequestration of its arable land.

Assuming a reduction requirement of 20 per cent (a more ambitious target than the 15 per cent CPRS current upper limit), it is 60 per cent cheaper for all shires to undertake sequestration in Wickepin than require each shire to undertake local reforestation (Table 1). Larger reductions can be achieved at a lower cost if least-cost sequestration options, such as in shires like Wickepin, are used in preference to options within each shire.

Table 1. Cost of reduction requirements using different abatement strategies, in 2008 dollar terms

Emission target	Reduction required in 2020 ('000t CO_2-e)	Cost of local sequestration (\$million)	Cost of least-cost abatement (\$million)	Cost of reduction with permits (\$million) at permit price (\$/t CO_2-e)	
				61*	50*
20% reduction	1,779.6	83.9	33.1	108.7	89.3

*Based on projections from Garnaut (2008b), rounded to whole numbers and given in 2008 dollar terms

Although sequestration on land with low marginal cost of abatement is more likely to be initially targeted as sites of emissions abatement, nonetheless it is acknowledged that there are reasons why some other sites would also be used. For example, large local social costs associated with significant local change in land use away from agriculture into reforestation may militate against such a change in land use. Also some farmers may choose to offset their emissions in sequestration on local land (i.e. on arable land in their local shire) because they can more easily visually monitor their investment and because it creates local investment and enterprise diversification.

Farmers will also have the opportunity to offset emissions through the purchase of carbon permits. However, as shown by data in Table 1, at projected prices for those permits in 2020, farmers would always prefer not to buy the permits but rather invest in least-cost or local sequestration. The future permit price would need to fall to around \$15 t/CO_2-e before farmers would no longer find sequestration attractive.

Caveats

Agriculture may be awarded free carbon permits given its role as an emissions intensive, trade exposed industry (Department of Climate Change 2008b). In Western Australia, livestock dominant enterprises are the most highly emissions intensive and so will potentially receive an allocation of free permits (Department of Climate Change 2008b). This will lessen the cost of emissions reductions and scheme involvement; and sequestration may no longer be the least-cost option. Further analysis will be possible when a final decision is made on agriculture and assistance it may receive as an emissions intensive, trade exposed industry. This information will also send signals to producers on future abatement costs and may influence their production decisions.

The discount rate used for land values and plantation costs will affect the optimal strategy preferred by agriculture for emissions reductions. In this study a discount rate of 10 per cent was used to reflect current land lease costs. However, landholders may demand a premium for their land due to the permanency of the land use change and the perceived undesirable social costs associated with converting farmland into forestry. This will raise the marginal cost of abatement and so make permit purchase a more attractive option. However, as suggested by the data in Table 1, the permit price is currently a long way from being a preferred option.

The price premium sought by farmers to allow their land to be permanently reforested may not be uniform. Some risk-averse landholders may find attractive the prospect of a constant income stream from the ‘permanent’ lease of their land for sequestration and some farmers may have some parcels of farmland that are marginally profitable in agriculture yet are adequate for forestry. Such farmers might be the ‘low-hanging fruit’ selected by investors in carbon sequestration.

Transaction costs may also play a large role in determining the cost effectiveness of a particular abatement strategy (Ancev 2008). These costs are not accounted for in this analysis. Transaction costs are expected to be high for agricultural enterprises but are currently unknown (Cacho and Lipper 2007). The regulation and implementation costs surrounding the establishment of carbon markets may lead to additional costs being borne by market participants, thereby changing the optimal abatement strategy, but further research is required.

Conclusion

The need for a reduction in greenhouse gases is well recognised and the agricultural sector is known to be a main source of emissions. However, there is currently little understanding of the spatial pattern of emissions from agricultural regions of Australia. Understanding the temporal and spatial pattern of these emissions from agriculture will help identify the extent of the challenge the sector faces in reducing its emissions.

This paper begins to address this lack of knowledge by presenting a spatial and temporal analysis of emissions from agricultural shires in the southwest of Australia. The highest emitting shires were predominately in the south of this region, where livestock dominant and higher crop input farming systems operate. The lowest emitting shires were mainly in the northern wheatbelt, where the sheep population has been greatly reduced.

There was a reduction in emissions in just over half of the shires since 1990. There were greater declines in emissions across the high-emitting southern shires compared to the wheatbelt and north-eastern shires. The highest emitting shires in 2005 tended to have reduced their emissions since 1990, with a few exceptions. This was largely a result of declining enteric emissions as sheep numbers declined. The shires with the greatest rise in emissions were shires that had increased their enteric emissions from growth in livestock numbers, particularly beef cattle.

Although enteric emissions have fallen for nearly all shires, they remain the dominant source of emissions. Despite the decline in enteric emissions since 1990, enteric emissions remain responsible for over 70 per cent of emissions for most shires in the south west or nearly a quarter of all shires.

Direct soil emissions grew in importance from 1990, with about 95 per cent of shires increasing their cropping emissions. Direct soil emissions increased as a proportion of total emissions according to the crop dominance of the farming system in the region. Direct soil emissions had the greatest importance in the northern and eastern shires, particularly those on the eastern boundary of the agricultural zone.

This study also provides a marginal cost of abatement for agricultural shires offsetting their emissions through reforestation. Abundant cost-effective sites (shires) for sequestration were identified. The preferred least-cost shires providing sequestration were centred in the medium rainfall zone in shires with medium land prices and medium to high sequestration ability.

Sequestration on local sites where each shire’s emissions were offset by reforestation within that shire was less efficient than reforestation at least-cost sites. Least-cost sequestration of agricultural emissions was 60 per cent cheaper than sequestration on local sites.

If agriculture is covered under the Carbon Pollution Reduction Scheme it will become subject to emissions reductions, and the optimal strategy, given current conditions and expected prices, will be to offset emissions through sequestration at the least-cost sites identified. However, one implication of this study’s identification of least-costs sites is that other sectors may also wish to use this same land for their own offset activity. Hence, in some locations strong land use competition may arise between farming and forestry. Furthermore, the farmland best suited for cost-effective conversion to permanent forestry is not necessarily unproductive or marginal country. Farmland in some medium rainfall, agriculturally productive shires may be some of the first land targeted for conversion to forestry.

There is a need for further research on this land use competition. More accurate estimates of sequestration rates and suitable tree species in Western Australia’s agricultural region are needed. Information on transaction costs and social costs associated with land use change is also required. Such information will reduce uncertainty surrounding investment in sequestration and assist farmers and others to make better decisions regarding abatement and land leasing.

References

Abadi A, Lefroy T, Cooper D, Hean R, Davies C (2006) Profitability of agroforestry in the medium to low rainfall cropping zone. Rural Industries Research and Development Corporation,.

ABARE (2007) Australian Commodity Statistics. (Ed. Australian Bureau of Agricultural and Resource Economics). (Commonwealth of Australia: Canberra).

Ancev, T. (2008) All costs considered: Should agriculture be part of a national ETS? Farm Policy Journal 6(4): 21-30.

Australian Bureau of Statistics (2007) Western Australian Statistical Indicators March Quarter 2007. (Ed. Australian Bureau of Statistics)Canberra).

Australian Greenhouse Office (2006) Planning Forest Sink Projects: A Guide to Forest Sink Planning, Management and Carbon Accounting. (Ed. Department of the Environment and Heritage). (Commonwealth of Australia: Canberra).

Australian Greenhouse Office (2007a) National Greenhouse Gas Inventory. Analysis of Recent Trends and Greenhouse Indicators 1990 to 2005. (Ed. Department of the Environment and Water Resources). (Commonwealth of Australia: Canberra).

Australian Greenhouse Office (2007b) State and Territory Greenhouse Gas Inventories 2005. (Ed. Department of the Environment and Water Resources). (Commonwealth of Australia: Canberra).

Cacho O, Lipper L (2007) Abatement and transaction costs of carbon-sink projects involving smallholders.

Commonwealth of Australia (2008) Carbon Pollution Reduction Scheme :Australia’sLow Pollution Future, White Paper, Volume 1, December 2008. Available at www.climatechange.gov.au

CSIRO (2007) Climate Change in Australia: Technical Report - Chapter 5: Regional climate change projections (temperature and precipitation). Available at http://www.climatechangeinaustralia.gov.au/resources.php

DAFWA (2003) Greenhouse, Land Management and Carbon Sequestration in Western Australia. (Department of Agriculture and Food Western Australia, South Perth.

Department of Climate Change (2008a) The Australian Government's Initial Report Under Kyoto. (Ed. Department of Climate Change). (Commonwealth of Australia: Canberra).

Department of Climate Change (2008b) Carbon Pollution Reduction Scheme Green Paper. (Ed. Department of Climate Change). (Commonwealth of Australia: Canberra).

Department of Climate Change (2008c) National Greenhouse Accounts (NGA) factors. (Ed. Department of Climate Change). (Commonwealth of Australia: Canberra).

Duck A, Lawrance L, Fletche S, Smirl L (2006) Australian Crop Report 137. ABARE, Canberra.

Easterling W, Apps M (2005) Assessing the consequences of climate change for food and forest resources: A view from the IPCC *Climatic Change*, 165-189.

Flugge F, Abadi A (2006) Farming carbon: an economic analysis of agroforestry for carbon sequestration and dryland salinity reduction in Western Australia. *Agroforestry Systems* **68**, 181-192.

Garnaut R (2007) Issues Paper 1 Climate Change: Land use - Agriculture and Forestry. (www.garnautreview.org.au.

Garnaut R (2008a) Emissions Trading Scheme Discussion Paper. (March 2008, www.garnautreview.org.au.

Garnaut, R. (2008b). Targets and trajectories: Supplementary draft report. Garnaut Climate Change Review, Available at www.garnautreview.org.au).

Garnaut R (2008c) Interim Report to the Commonwealth, State and Territory Governments of Australia, February 2008, Available at www.garnautreview.org.au).

Harper RJ, Beck AC, Ritson P, Hill MJ, Mitchell CD, Barrett DJ, Smettem KRJ, Mann SS (2007) The potential of greenhouse sinks to underwrite improved land management. *Ecological Engineering* **29**, 329-341.

Howden SM, Ash A, *et al.* (2003) An overview of the adaptive capacity of the Australian agricultural sector to climate change – options, costs and benefits. CSIRO Sustainable Ecosystems.

IPCC (2007) Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. (Ed. Intergovernmental Panel on Climate Change). (IPCC, OECD, IEA: Paris).

IPCC (2008) Climate Change 2007: Synthesis Report. Assessment of the Intergovernmental Panel on Climate Change. Cambridge University, Cambridge, United Kingdom and New York, NY, USA.

Kingwell R, Pannell D (2005) Economic trends and drivers affecting the wheatbelt of Western Australia to 2030. *Australian Journal of Agricultural Research* **56**, 1-9.

Land and Water Australia (2007) Agriculture, Forestry and Emissions Trading: How do we participate? Issues Paper. (Ed. Land and Water Australia). (Commonwealth of Australia: Canberra).

National Greenhouse Gas Inventory (2007) Australian methodology for the estimation of greenhouse gas emissions and sinks 2006: Agriculture. (Eds Department of Climate Change, National Greenhouse Gas Inventory Committee). (Commonwealth of Australia: Canberra).

Pittock B (2003) Climate Change: An Australian Guide to the Science and Potential Impacts. (Ed. Australian Greenhouse Office). (Commonwealth of Australia: Canberra).

PMTG (2007) Report of the Task Group on Emissions Trading. (Prime Ministerial Task Group on Emissions Trading, Commonwealth of Australia, www.pmc.gov.au/publications/emissions/docs/emissions_trading_report.pdf: Canberra).

Richards K, Stokes C (2004) A review of forest carbon sequestration cost studies: a dozen years of research. *Climatic Change* **63**, 1-48.

Shaikh S, Sun L, van Kooten GC (2007) Are agricultural values a reliable guide in determining landowners' decisions to create forest carbon sinks? *Canadian Journal of Agricultural Economics* **55**, 97-114.

van Kooten GC, Eagle AJ, Manley J, Smolak T (2004) How costly are carbon offsets? A meta-analysis of carbon forest sinks. *Environmental Science and Policy* **7**, 239-251.