Greening Australia

Investment in Natural Infrastructure to Offset the Environmental Impact of Future Development of Built Infrastructure

Natural Infrastructure Consultancy Report

Table of Contents

1. ..... Executive Summary 4

2. ..... Project Scope 6

3. ..... Offset calculator and financial model 7

4. ..... Emissions factors for transport infrastructure 10

5. ..... Preliminary scenario analysis 16

5.1 .... Input data 16

5.2 .... Model assumptions 16

5.3 .... Scenario results (outputs) 17

5.4 .... Scenario discussion 17

6. ..... Reducing model uncertainty 18

7. ..... The Case for biodiverse carbon sinks 19

8. ..... Ecosystem Services from Diverse Offset Plantings 21

8.1 .... Habitat provision 21

8.2 .... Improved River Health 22

8.3 .... Air pollution reduction 23

8.4 .... Reducing the Urban Heat Island Effect 23

9. ..... Agricultural benefits 26

9.1 .... Provision of shade and shelter for livestock 26

9.2 .... Shelter for crop production 27

9.3 .... Salinity reduction 27

9.4 .... Reduction in agricultural pests 27

9.5 .... Improvement in pollination services 28

10. .... References 29

1. Executive Summary

Greening Australia has delivered to Infrastructure Australia a model that:

1. Estimates the likely green house gas emissions from the construction and maintenance of public transport projects (roads, rails, bridges and tunnels). This component of the model is based on per unit area emissions factors (e.g. $tCO_{2\text{-}e}$/km of lane) published in scientific journals.
2. The model calculates the required area of diverse native vegetation plantings that are required to offset the emissions from each transport project. This modeling is based on Greening Australia's existing in-depth knowledge of biosequestration rates of native vegetation found within 12 priority landscapes located in every State except the ACT and NT.
3. The financial viability of each emission offset is based on Greening Australia's comprehensive business model that is sensitive to the price of carbon, land access strategies and other financial variables.
4. A 'user manual' and glossary are embedded within the spreadsheet.

This model has been developed in Excel and delivered separately to Infrastructure Australia.

This report provides:

1. A summary of the methodologies used to develop the emissions offset model.
2. This includes a literature review of the emission factors used in the model. This review concludes that these published emissions factors are adequate for a first iteration approximation of likely emissions. A more accurate calculation of emissions of a specific (actual) project will require the use of much more sophisticated emissions calculators that can be developed by other organisations.
3. An example of using the model for a public transport development scenario for the Sydney basin is provided. This scenario analysis suggests that the financial cost of offsetting the greenhouse gas emissions from construction and infrastructure maintenance will likely be less than 1% of total construction costs.
4. Recommendations to improve the offset modeling system include linking the model to more accurate construction, maintenance and use emissions factors for public infrastructure based on Australian studies and modeling capacity.
5. A summary of different options for carbon forest sinks is provided showing that sinks based on the planting of native trees and shrubs provides a low risk and highly resilient type of emissions offset.
6. A literature review of the additional ecosystem services provided by investment in biodiverse carbon sinks is provided. This review indicates that there are numerous, but

difficult to quantify environmental, economic and social benefits that can be gained from investment in biosequestration by diverse native vegetation. Benefits include:

a. Improvements in conservation assets particularly riparian vegetation that plays an important role in delivery of high quality water into rivers, as well as improved wildlife habitat;
b. Improvements in landscape scale resilience and adaptation to climate change (e.g. bio-linkages and habitat buffers);
c. Improvements in agricultural productivity and sustainability including provision of shade and shelter for livestock and reduced risk of salinity;
d. A reduction in the Urban Heat Island Effect when biosequestration plantings include urban and peri-urban areas.

2. Project Scope

Greening Australia was contracted to provide a consultancy service to Infrastructure Australia to:

1. Deliver a modelling system that can be used by Infrastructure Australia to assess quantifiable costs of investment in native vegetation plantings to offset emissions generated from the construction and maintenance of public infrastructure (e.g. transport). The model was required to be flexible and scalable to estimate different levels of emissions to allow for both analysis of specific infrastructure projects as well as analysis of regional infrastructure plans;

2. A literature review of scientifically robust methods for determining emissions generated by the construction and maintenance of public infrastructure (roads, rails, bridges and tunnels);

3. A broad literature review of the additional environmental benefits (ecosystem services) of native vegetation plantings over and above carbon biosequestration.

3. Offset calculator and financial model

An emissions offset calculator and financial model was created using Excel that has been submitted to Infrastructure Australia separately
(Filename: InfrastructureAustralia_emissions_offset_model_V8.xlsx).
This modeling system is based on three components:

1. A calculator that estimates the green house gas emissions (in tonnes $CO_{2\text{-}e}$) from the construction and maintenance of public transport infrastructure on a project by project basis.
2. The area (ha) of diverse native plantings that is required to offset the emissions from each infrastructure project is then calculated.
3. A business model provides analysis of the financial viability of each emissions offset project (planting) based on user input variables that include price of carbon and expected inflation, interest and discount rates.

1. **Emissions calculator**

This section of the modeling system is based on a scientific literature review of emissions factors researchers have developed for various transport infrastructure projects in various industrialised countries. A summary of this review is found elsewhere in this report. The emissions calculated from user input (e.g. km of roads) are indicative only. The emissions from any one infrastructure project depend on many factors including distance construction materials are transported, construction methods and maintenance requirements. This modeling system is designed for policy analysis, not the accurate calculation of emissions from a specific project. However, more accurate emissions calculated using specialized commercial systems (e.g. Energetics) can be easily substituted into this model.

2. Carbon sequestration rates

This component of the modeling system is based on Greening Australia's advanced capacity to confidently model carbon sequestration rates for a diversity of native vegetation within Greening Australia's 12 priority landscapes (Figure 1). This model incorporates carbon sequestration yield curves developed by collecting the largest carbon yields data set in Australia for environmental plantings and old growth (remnants). This data set includes tree and shrub girth measurements taken from 91,669 stems in 1298 plots within 410 sites across Greening Australia's 12 priority landscapes requiring substantial restoration of degraded land.

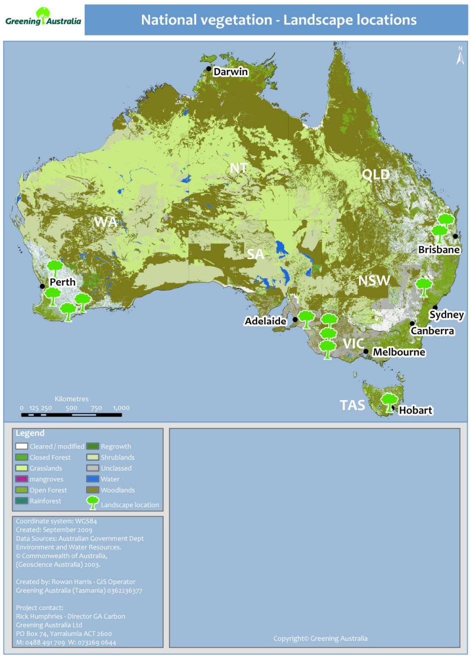

Figure 1. Broad locations of Greening Australia 12 priority restoration landscapes earmarked for biodiverse carbon sequestration plantings.

Greening Australia's data set consistently demonstrated that diverse native plantings of known age have a high potential to sequester carbon well above the Australian Government's National Carbon Accounting Toolbox (NCAT) modeled predictions, in the majority of cases 200% to 300% higher than NCAT (Figure 2). (http://www.climatechange.gov.au/en/government/initiatives/ncat.aspx).

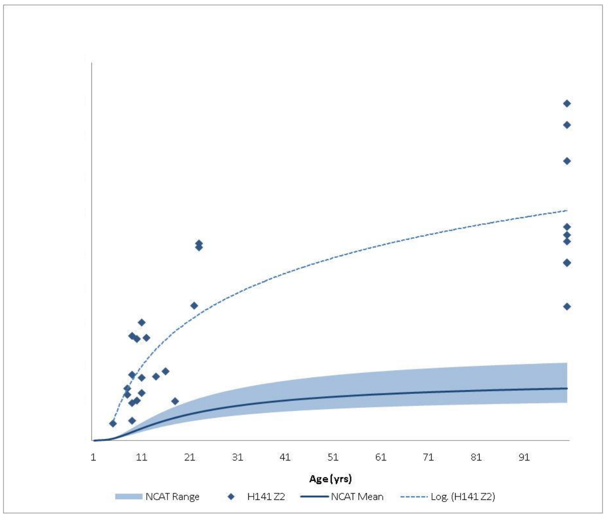

Figure 2. An example of the carbon yield from known age plantings and remnants of native vegetation compared to NCAT predictions from each of the sites measured by Greening Australia within one of 12 landscapes researched.

The modeling system developed for Infrastructure Australia uses a mean yield curve developed from these field measurements for each of the 12 landscapes. The detailed yield curves used in this emissions offset calculator have been hidden within the spreadsheet to protect the IP that is owned by a third party investor in Greening Australia's carbon yield research.

The emissions calculator is based on establishing offset plantings across the 12 landscapes shown in Figure 1. This approach aims to create a pool of sequestered carbon in order to spread environmental risks due to fire or drought that may temporarily reduce carbon yields in any one landscape (region). However, the user of this modeling system can select what proportion of any one offset project is allocated to one, some or all of these landscapes.

3. Financial model

This section of the modeling system is based on Greening Australia's substantial investment in building its biodiverse carbon sequestration business. The financial viability analysis is based on Greening Australia's business model that has been developed, tested and reviewed with assistance from Bakers and McKenzie and Pacific Strategy, among others.

The financial model includes:

- The average cost of land access (purchase of lease) based on 2009 prices, including land tax and stamp duties;
- Greening Australia's field proven planting costs;
- Carbon business overheads (e.g. company salaries, legals, comms & marketing, financial services and project field staff).

Details of the financial model have been hidden to protect Greening Australia's IP.

4. Emissions factors for transport infrastructure.

Methods

A comprehensive literature search was conducted by utilising the CSIRO 'InfoSearch' database that simultaneously searches over 30 technical databases across the full spectrum of scientific research disciplines. Key search terms included: 'road/pavement/bridge/tunnel life cycle analysis'.

Results

There is a small but growing scientifically peer reviewed literature on the greenhouse gas emissions from public infrastructure development based on comprehensive life cycle analysis from construction to end of life disposal. Much of the earlier literature is unpublished technical reports compiled by government agencies or university departments. The earlier literature reports emissions in a wide range of units that would be difficult to use for the present study (e.g. MJ of energy per passenger km).

Fortunately, the latest research (2009 and 2010) conducted by university based scientists reviews this earlier technical analysis and provides comprehensive tabulations of the components and uncertainties in estimating the emissions generated over the full life cycle of road, rail, tunnel and bridge construction.

For rail emissions, the modeling system delivered to Infrastructure Australia used emission factors from Milford and Allwood (2010; from the Dept of Engineering, Cambridge University). Table 1 below summarises the factors used for the modeling system.

Table 1. Breakdown of $C0_{2-e}$ emissions over track life for rails constructed from 100% virgin (non-recycled) materials (from Milford and Allwood 2010, Table 8). Emission factors are for traditional construction with concrete sleepers (least emissions compared to wood and steel).

Stage of life	Construction (kg $C0_{2-e}$/m/yr)	Maintenance (kg $C0_{2-e}$/m/yr)	End-of-life (kg $C0_{2-e}$/m/yr)
Low use rail	13.7	0.3	2.56
High use rail	31.7	1.77	2.85

Low use rail factors (10 equivalent million gross tonnes per annum, EMGTA) are unlikely to be relevant for the present study. The modeling system uses the high use rail factors (60 EMGTA) as the most relevant for future infrastructure development across the Sydney Basin. The emission factors shown in Table 1 have been normalized to a metre of single-lane track per year. According to Milford and Allwood (2010) the service life of rail sections under UK conditions is 13-38 years and the life of concrete sleepers is 24-45 years. For the model, a service life of new rail infrastructure was assumed to be 50 years to maintain consistency with the estimated service life of roads, bridges and tunnels. Hence, within the modeling system each emissions factor in Table 1 was multiplied by 50 to estimate the emissions of each service-life phase of a high use rail.

For road infrastructure, the model used emission factors from Santero and Horvarth (2009, University of California, Berkeley). The values used are shown in Table 2, based on mean factors found on Figure 2 of Santero and Horvarth and factors shown in the supplementary data associated with this paper.

Table 2. Approximate greenhouse gas emissions from the construction and maintenance of high and low traffic pavements over a 50 year service life (From Santero and Horvarth 2009 and supplementary data available electronically).

(t CO_2-e/lane-km)

Sources of emissions	High traffic	Low traffic	Min	Max	Likely
Materials extraction/production	500	300	80	500	300
Transport	6	3	1	1100	6
Onsite equipment use	10	3	3	24	6
Traffic delays	50	50	0	1000	50
Roadway lightning	100	150	109	309	150
Vehicular use	40,000	20,000	25,000	60,000	31,000

High traffic refers to dual carriageways (freeways) including heavy truck usage and low traffic refers to residential road development that supports primarily passenger vehicle use. These figures are based on an approximate average of the wide range of possible emissions reported in various forms in Santero and Horvarth 2009.

The greater material production emissions for high traffic roading (Table 2) is due to the greater depth of aggregate, asphalt and re-enforced concrete required, particularly for high volume truck usage. Materials emissions also depend on the amount of recycled material (e.g. aggregate) used in construction. For the modeling system, a minimal use of recycled materials was assumed. Emissions due to transport of materials to the construction site naturally varies considerably. The model assumed materials will be sourced from distances of 50-100 km for the site. Emissions from traffic delays are due to slower flows of vehicles through road construction zones. The model assumed modest delays, due to the already congested nature of Sydney Basin. Emissions from roadway lighting are greater for low traffic roads due to the greater number of intersections. Also low traffic roads are usually surfaced in black asphalt which is less reflective, hence needs greater lighting.

The emissions from the construction of bridges are naturally highly variable, but the model used the emissions factors from Hammervold *et al*. (2009; Norwegian Univesity of Science and Technology). This study also provided a comprehensive life cycle analysis, including end of life disposal, but did not include emissions from vehicular use. The model used their figure of 750 kg $C0_2/m^2$ for a concrete and steel bridge with a 50 year life span. Keoleian et al. (2005) also conducted a comprehensive life cycle analysis for two different bridge construction methods, but this study did not provide accurate bridge dimensions nor tabulated data, only graphs, so emissions could not be confidently normalized to $CO_{2\text{-}e}/m^2$.

The modeling system used emissions factors from Ridley and Stacey (2009). These authors report calculated emissions form an Australian case study of a 4.8 km long tunnel. This study provides detailed emissions calculations for both two lane and three lane tunnels (Tables 3 and 4). Emissions vary due to type types of tunnel construction. Road head construction uses traditional machinery (e.g. trucks and backhoes) for excavation and spoil removal. Specialised machinery based on a rotating grinding face is used for tunnel boring construction. This later type of construction generates more emissions due to a far greater use of concrete linings.

Emissions factor uncertainties

The potential emissions (global warming potential) from transport infrastructure development are highly variable depending on (Santero and Horvath 2009; Ridley and Stacey 2009):

- distance materials have to be transported to the construction site
- use of recycled materials
- service life
- traffic loads
- road roughness (vehicular rolling resistance)
- construction materials
- traffic congestion due to construction
- pavement colour (dark pavements require more street lighting) and
- degree of road-bed cut and fill
- rock hardness of excavated materials
- distance travelled for materials disposal

Table 3. Emissions factors for a two lane tunnel based on two different construction methods (adapted from Ridley and Stacey 2009).

Two lane tunnels (t CO_{2e}/km per lane)	Amortised annually (t CO_{2-e}/yr)	50 year service life (t CO_{2-e})
Road head construction		
Excavation	27.1	1,356.3
Spoil removal	2.6	128.3
Construction materials embodied emissions	89.6	4,479.2
Lighting	252.3	12,614.6
Ventilation	0.4	19.8
	372	**18,598**
Tunnel Boring Machine Construction		
Excavation	14.9	747.3
Spoil removal	2.9	144.6
Construction materials embodied emissions	124.1	6,204.2
Lighting	252.3	12,614.6
Ventilation	0.4	19.8
Totals	**394**	**19,730**

Table 4. Emissions factors for a three lane tunnel based on two different construction methods (adapted from Ridley and Stacey 2009).

Three lane tunnels (t CO_{2-e}/km per lane)	Amortised annually (t CO_{2-e}/yr)	50 year service life (t CO_{2-e})
Road head Construction		
Excavation	29.5	1,472.7
Spoil removal	2.8	139.4
Construction materials embodied emissions	161.2	8,061.0
Lighting	362.3	18,114.6
Ventilation	0.6	29.2
	556	**27,816**
Tunnel Boring Machine Construction		
Excavation	28.8	1,438.5
Spoil removal	5.2	258.8
Construction materials embodied emissions	302.8	15,139.4
Lighting	362.3	18,114.6
Ventilation	0.6	29.2
Totals	**699**	**34,980**

These variables result in large uncertainties in likely emissions from construction, maintenance and disposal or rebuilding. For example, ranges in emissions from materials transport varied from 1 t CO_2/km of lane for low traffic roading and materials sourced within 10 km of the construction site to 1100 t CO_2/km of lane for a California highway constructed with materials brought in over 2400 km by coastal freighters and then trucked 300 km to the site. The modeling system developed for Infrastructure Australia uses an average or likely value reported in Santero and Horvath (2009) for road construction. These are useful emissions factors when used to estimate the broad quantum of emissions from a scenario analysis of possible transport development options. These emissions factors should not be used to calculate the likely emissions from a specific infrastructure project that has detailed engineering specifications. At this later stage of planning, robust predictions of emissions should be conducted by specialists in commercial firms, state agencies or university departments. The modeling system developed for Infrastructure Australia is set up to accept emissions input data from separate studies (e.g. total quantum/project), or the model can broadly estimate possible emissions using the factors described above (Tables 1-4).

Table 2 above does not include emissions due to the 'urban heat island effect'. This effect is due to the greater energy absorbed by dense surfaces such as roads and this absorbed energy is later radiated as heat, particularly at night. This radiated heat load causes greater use of air conditioning that leads to greater greenhouse gas emissions. This heat island effect is partially offset by CO_2 sequestration by concrete during the curing process (carbonation effect) and partially offset by the albedo (radiative forcing) of bright concrete surfaces. The urban heat island effect can also be reduced by establishing carbon sequestration plantings (sinks) in urban basins as described later in this report.

Including the large emissions due to vehicular use over the life span of transport infrastructure (e.g. Table 2 above) is problematic. The full scope of vehicular use should include (Eriksson *et al*. 1996):

- Combustion of fuel;
- Production of fuel;
- Production of vehicles and treatment of vehicle after use;
- Service and maintenance of vehicles;
- Production, use and final treatment of tyres and
- Handling at terminals of freight transports

From a policy perspective, the 'ownership' of vehicle emission liabilities is also uncertain and complex. Hence the emissions from vehicular use, over the lifespan of transport infrastructure, are excluded from the modeling system delivered to Infrastructure Australia.

The emissions factors quoted above are based on recent studies from reputable research organisations that have reviewed and incorporated pre-existing scientific and technical literature from a wide range of sources. The rail and roading studies have been published in internationally reputable science journals with recognized rigorous scientific peer review. All three studies adopt international standards for whole of life cycle analysis and provide emissions factors in a useable form (e.g. t $CO_{2\text{-}e}$/km of roading per lane).

Earlier studies often quoted emissions factors in units that are more problematic to use for the current project. For example, the Australian study by Treloar *et al.* (2004) showed emissions for road construction and used either units of GJ per $100 or the total embodied energy of 5 km length of roading (e.g. 135, 987 GJ/5 km length of continuously reinforced concrete). Converting embodied energy to global warming potential (t $CO_{2\text{-}e}$) is problematic as it depends on many assumptions of what energy sources are used to create the embodied energy.

5. Preliminary scenario analysis

5.1 Input data

In order to test the functionality and utility of the modeling system, an infrastructure transport scenario was run using input data provided by Infrastructure Australia (Table 5).

Table 5. Input variables for preliminary scenario of infrastructure development in the Sydney Basin (data provided by Infrastructure Australia)

Project	Type	(km)	Number of lanes	Estimated Cost
F6 Extension (surface connection between Rosebery and Sutherland, including a major bridge over the Georges River)	Highway	15	4 (plus shoulder)	$2.2 Billion
South-West Rail Link	Rail	11.4	2	$2.4 billion
M4 East (15 km tunnel)	Tunnel	15	6	$12 billion
North-West Rail Link	Rail	6	2	Part of a $4.9 B project
North-West Rail Link	Rail Tunnel	13	2	Part of a $4.9 B project

For this scenario, it was assumed that emissions generated per kilometer by a 2-lane road tunnel would be equivalent to the emissions per kilometer of a single line railway tunnel as no data was found in the literature for rail tunnel emissions factors. Note also in this modeling scenario, the length of the M4 East tunnel (15 km) was doubled to 30 km since it is a 6 lane tunnel and the modeling system only estimates emissions from two or three lane tunnels.

5.2 Model assumptions

For the purpose of running this scenario it was assumed via inputs to the ‘Economics Variables’ worksheet in the model that:

- Emissions offset plantings would commence in 2011 (year 3 of the modelling system)
- An initial carbon price of $22
- The Treasury Departments’ CPRS-15 modelling of future prices for carbon (spot-market)
- A discount rate of 8%
- A constant CPI of 2.5 %, land inflation of 6.5% and initial wage of 5%
- Interest on credit of 4% and 10% on dept
- An equal proportion of plantings in each of 12 landscapes

5.3 Scenario results (outputs)

Given these scenario inputs and financial assumptions, the quantum of emissions and necessary carbon sink offsets are shown in Table 6.

Table 6. Model outputs from the scenario input variables shown in Table 5.

Scenario Emissions Totals (cumulative over 50 years)	**$tC0_{2\text{-}e}$**
Roads	38,400
Railway	63,197
Bridges	1,530
Tunnels	1,076,282
Total emissions over life of projects (50 years; $tCO_{2\text{-}e}$)	1,179,409
Total emissions amoritised per year ($tCO_{2\text{-}e}$/yr)	23,588
Timeframe for emissions offset delivery (years)	40
Total area of emissions offset plantings (ha)	4,514
Scenario economics	
Transport Infrastructure Project Costs	$ 21,500,000,000
Offset Costs (total costs @8% discount rate)	$ 21,640,309
Offset Costs as Proportion of Infrastructure Costs	0.10%
NPV of offset planting investment	$ 21,640,309
NPV of value of offset permits (at spot price)	$ 27,805,509
IRR of investment	10%

5.4 Scenario discussion

This scenario illustrates that the emissions generated by the construction and maintenance of a number of large public transport projects can be offset by the establishment of a modest sized carbon sink (4500 ha). The cost of establishing such a sink is substantial (nearly $22 million), but this is a small proportion (0.10%) of total construction costs ($21.5 billion).

However, it should be noted that this scenario analysis does not include the emissions generated by vehicular use over the 50 year life cycle of this public transport scenario. Table 2 above suggests that vehicular use could generate over 50 times more emissions than those emitted during construction and on-going maintenance. Vehicular emissions have been omitted from the modeling system because such emissions are not likely to be a liability imposed on the construction and maintenance of public transport infrastructure.

6. Reducing model uncertainty

This modeling system is based on Greening Australia's 28 year experience in restoring and managing native vegetation. The financial components of the model include the costs of establishing and managing carbon sinks and these are conservative and based on this experience. The likely rates of carbon sequestration (e.g. tree growth) built into the model are based on Greening Australia's comprehensive field measurements of known age plantings and native vegetation remnants (old growth) within 410 sites across southern Australia. The carbon yield curves within the model are greater than NCAT forecasts, but are within a conservative range of curves derived from our field research. We are confident in the model's ability to confidently predict the quantum (ha) of native vegetation that will need to be established for every tonne of $CO_{2\text{-}e}$ emitted by the construction and maintenance of an infrastructure project. We are also confident in the costs of establishing and maintaining each hectare of vegetated carbon sink. Therefore we are confident in the price of carbon that is required to make each emissions offset financially viable.

However, this modeling system provides a limited capacity to accurately estimate the emissions from a specific infrastructure project. The 'emissions calculator' component of the modeling system is based on approximate and average emissions factors gleaned from the international scientific literature. The emissions factors reported in this literature for roads, rails and tunnels are naturally highly variable and reported in a wide range of emission units. Much of the uncertainty in the per kilometer emissions of transport projects is due to the highly variable nature of any specific project. Emissions vary due to the type of construction, the costs in transporting materials, exaction requirements, etc.

Consequently, the certainty in estimating the costs of offsetting emissions from infrastructure development and maintenance is dependent on accurate predictions of emissions. Therefore this offset modeling system developed for Infrastructure Australia can be improved by:

1. Investment in a more detailed and accurate emissions 'calculator' for forecasting the emissions of individual infrastructure projects
2. Investing in an emissions calculator that can also forecast operational emissions generated by daily use by rolling stock (e.g. cars and trains).

The capacity to develop such emissions calculators lies outside of Greening Australia's capability. Such capacity lies within commercial organisations such as Energetics or Net Balance (note Net Balance has developed an emissions calculator for Vic Roads), or university departments (e.g. UC Berkeley, USA).

Any new emissions calculator can be easily 'bolted' onto the current modeling system developed by Greening Australia simply by importing in the total emissions calculated from an external model into the 'Project Scenario' page the Greening Australia model.

7. The Case for biodiverse carbon sinks

For the first time in modern history, the emerging carbon market provides a commercial value for forests *in situ*. A tree does not have to be harvested to have value in the national and international market places. Forest carbon sinks are no longer constrained by years to harvest and distance to markets. Rather, the market comes to the forest and photosynthesis is the value-add process. This represents an opportunity to re-think forestry designs and management practices rather than slavishly follow models of the past. Carbon sinks provide an outstanding opportunity to profitably restore marginal agricultural lands across Australia.

Sink Design Options

There are three basic options for the design and establishment of emissions offset sinks:

1. Plantation monocultures
2. Assisted natural regeneration
3. Biodiverse plantings of regionally native trees and shrubs

We argue that plantation sinks (monocultures) have a use as sinks, but plantation forestry has not been designed as carbon sinks, rather they have been designed to rapidly deliver a uniform timber product. Current plantations species grow in only a few high rainfall, low elevation regions. They are highly susceptible to prolonged drought, flooding and are killed by crown fires. Emissions associated with plantation management regimes negatively impact the overall carbon sequestration benefits. Plantations are a limited and high risk option as carbon sinks. There are practical alternatives including biodiverse sinks based on the restoration of native vegetation.

Carbon sinks based on assisting natural regeneration have the potential to be a low cost option. Natural regeneration, particularly on land cleared over the past 10-20 years, can be assisted by removing livestock for a number of years, or the use of fire or by causing low impact soil disturbance (e.g. one-off cultivation). However, there is no certainty whether natural regeneration will be covered by national or international carbon market regulations.

Greening Australia defines biodiverse carbon sinks as those established by planting a diversity of regionally native tree and shrub species on cleared land that meets Kyoto standards. This should restore a very long lived and self-replacing diversity of native vegetation.

Biodiverse carbon sinks meet multiple performance criteria for economically and ecologically robust bio-sequestration. Biodiverse systems are a long-term, low risk option. They have a proven record of rapid recovery from droughts, fire and floods. They are likely to adapt to rapid climate change due to their ability to thrive in a wide range of environments. Millions of years of evolution are the foundation for this resilience. This lower risk profile is a core attribute of biodiverse carbon sinks. This sink option protects long-term investments by reliably delivering and securing carbon emissions offsets over 50-100 year time frames. Biodiverse carbon sinks reduce risk exposure to ever increasing climate instability likely over these time frames. Under these circumstances it is important that potential investors elevate risk profile in the hierarchy of issues they need to consider along side price and establishment costs.

Unlike other alternatives, biodiverse carbon sinks have the flexibility to match the right native plant species to the inherent variations in micro-climate and soils that characterise Australia's ancient landscapes. Native species based carbon sinks can be established any where in Australia, Kyoto rules not with standing. Biodiverse carbon sinks are a lower risk, cost effective strategy for reducing global emissions and are specifically designed to provide Australia Carbon Pollution Permits under the proposed CPRS. The establishment of biodiverse carbon sinks should leave a century's long legacy of social, economic and environmental benefits.

8. Ecosystem Services from Diverse Offset Plantings

Native vegetation provides a diversity of ecosystem services beyond just carbon sequestration. It provides self replacing habitat for Australia's wildlife. It helps protect catchments and improves water quality, stabilizes soil and enhances on-farm productivity. Employment will be generated by sink establishment and long-term management on agriculturally marginal land. There are also less tangible cultural benefits given that a healthy Australian landscape is deeply embedded in both Aboriginal and non-Aboriginal cultures. The primary services described in this report are:

- Provision of habitat for wildlife populations
- Improvement in water quality
- Reduction in air pollution
- Reducing the Urban Heat Island Effect
- Improved agricultural productivity and sustainability including
    - Shade and shelter
    - Salinity risk reduction
    - Insect pest control
    - Pollination services

These ecosystem services from native vegetation plantings are generally difficult to quantify with certainty so are described below in more qualitative terms.

8.1 Habitat provision

The support of fauna populations is a key environmental benefit from the establishment of carbon forest sinks based on the restoration of native vegetation. Re-establishment of native vegetation can support fauna populations through the provision of habitat, landscape scale connectivity and additional resources such as food and nesting places. Areas replanted with native tree species have been found to provide habitat for:

- 85% of bird species otherwise recorded in local ecosystems including declining woodland birds (Bennett *et al*. 2008).
- Koalas and gliders (Bennett *et al*. 2008),
- Butterflies (Lomov *et al*. 2006) and
- Birds of conservation significance like the Mallee fowl (Mercer and Brittain 2009).

Re-establishment of native vegetation allows for increased fauna movement between existing areas of native vegetation by providing stepping stones and corridors. These landscape elements support fauna populations by allowing them greater opportunities to access food, water and breeding opportunities and to flee disturbances such as drought and fire. For example, squirrel gliders can only to glide a maximum of 75 meters between remnants (van der Ree *et al*. 2003) whilst the threatened bird, the white-browed tree-creeper, will only fly a maximum distance of 3 kilometers to move between remnants (Radford and Bennett 2003). Replanted areas provide opportunities for birds and bats to forage for insects (Law and Chidel 2006; Loyn *et al*. 2007). They also provide opportunities for nesting and breeding for birds (Taws and Bond 2006).

Wildlife populations have a tendency to collapse when the total amount of vegetation cover across a particular landscape falls below a given threshold. In many Australian landscapes, the thresholds for severe ecosystem decline varies from 10-30% vegetation cover. When vegetation levels fall below these thresholds, the number of fauna species supported by a landscape reduces dramatically (Radford *et al*. 2005). The re-establishment of biodiverse carbon forest sinks can limit the species decline by increasing vegetation cover above these levels.

8.2 Improved River Health

When properly located, forest carbon sinks can benefit the health of rivers and improve the water quality and consistency of river flows. Many of these benefits accrue when the vegetation is re-established in the riparian zone (the land interface with the river) and there are broader benefits when the vegetation is re-established in other areas.

Restored riparian vegetation provides an array of environmental benefits. It provides self-replacing habitat and connectivity for fauna (Price and Tubman 2007). In addition, the higher levels of soil fertility and the greater moisture in the riparian zone support faster and more reliable plant growth and a consequential increase in animal populations.

Restored riparian vegetation improves stream bank stability and therefore reduces bank erosion (Rutherford 2007). Wide vegetation strips located alongside waterways also prevents sediment and nutrients from entering waterways thus improving water quality. Eroded nutrients and fine sediments contribute to blue green algae and aquatic weed blooms. This in turns can lead to anoxic conditions within the waterway and subsequent fish kills.

The shade provided by riparian vegetation reduces and moderates in-stream water temperatures that limit aquatic weed and algae growth and anoxic river conditions (Davies *et al*. 2007). Small un-vegetated streams have been found to be up to 12^{o}C warmer than fully vegetated streams (Marsh *et al.* 2005). Over a thee year period after revegetation, a small stream showed a consistent reduction in water temperature approaching that of the forested reference stream as the plants grew and began to shade the water.

Riparian revegetation can be seen as a catchment scale tool that can have a beneficial effect on flooding in lowland areas. At catchment scale, the cumulative effect of riparian revegetation is to increase flood stage and duration in headwater streams where flooding is usually not a problem, but decreases flood stage in larger streams further downstream where flooding in the past have been a problem (Rutherfurd *et al.* 2007). Broadscale revegetation can slow the loss of soil and promote water infiltration by providing beneficial pathways to help bind the soil (Polglase and Hairsine 2003).

8.3 Air pollution reduction

Particulate pollution can cause severe and damaging health effects. Particles exist in the atmosphere in many forms from sub micron aerosols to clearly visible grains of dust and sand. Particles are removed from the atmosphere when they are entrapped by terrestrial surfaces. Particles in an airstream are most readily entrapped onto moist, rough or electrically charged surfaces. Vegetation is effective at trapping and absorbing many pollutant particles due to their high surface roughness which results in turbulent atmospheric mixing. This mixing promotes efficient deposition of pollutant materials (Beckett *et al.* 1998). Hence large scale revegetation can reduce particulate pollution downwind of such plantings.

8.4 Reducing the Urban Heat Island Effect

Reduction in the Urban Heat Island Effect is another potential ecosystem service that can be derived from the establishment of carbon forest sinks that offset the emissions from infrastructure development. The Urban Heat Island Effect is defined as a localised warming due to the increase in the amounts of paved and dark coloured surfaces like roads, roofs and car parks. This localised warming is due to solar radiation being absorbed by these constructed surfaces and not reflected. Heat produced from combustion of fuels (e.g. heating and vehicles) and from air conditioners also contributes to the Urban Heat Island Effect (Rizwan *et al*. 2008).The relationship between outdoor weather and energy consumption within the built environment is a complex one, but it is essentially driven by human thermal discomfort (Akbari and Konopacki 2005). Higher temperatures drive increased air conditioner use, which in turn, drives higher temperatures.

A strong Urban Heat Island Effect exists for Western Sydney. This region is particularly exposed as it does not receive the moderating influence of a cooling sea breeze experienced by coastal suburbs. Over the last 40 years all Western Sydney weather stations have experienced a rise in annual temperatures over and above what would be expected from global warming. The hottest day of the year is now 4-6ºC hotter than it was in the 1960s. The number of days per year in Western Sydney over 35ºC has increased by 250% in just over 40 years (Standing Committee on Natural Resource Management 2008). The Urban Heat Island Effect is strongest in Blacktown but is also apparent in Richmond, Camden, Liverpool and Parramatta. In summary “In the Sydney Basin if you wanted to locate a population in the most vulnerable region possible for global warming and urban heat island and air pollution you would put them in Western

Sydney." [Professor Andy Pitman, NSW Standing Committee on Natural Resource Management (Climate Change) Proceedings 16 May 2008].

The loss of trees and other vegetation is another contributor to the Heat Island Effect. Tree respiration includes the evaporative loss of water from the large surface area of a tree's leaves. This evaporation cools the air. In general less trees means less evaporative cooling.

Loss of tree cover in urban areas will continue with increased growth. For example, some 2000 hectares of Cumberland Plain Woodland is likely to be cleared as a result of urban development in these zones (Growth Centres Commission 2007). These figures do not include the clearing of individual paddock trees. The clearing is biased slightly towards smaller remnants with bushland in large patches or in floodplains being the best protected. Some of this net vegetation loss will be offset by compulsory revegetation of riparian areas in urban development zones. However, additional vegetation loss could be offset by investment in carbon sinks.

Carbon plantings funded by emission offsets could be established in urban air catchments to reduce the Urban Heat Island Effect (Coutts *et al*. 2007). Emission offset plantings could include:

- **Incentives for tree and shrub planting on private residential blocks**. In the 1940's, the North Shore suburbs were nearly devoid of tree cover. Over successive decades councils provided tree giveaways and encouraged tree planting in yards and gardens. These areas now have an almost continuous urban tree canopy that is providing a significant cooling effect.
- **Street tree planting.** This type of planting is one of the most direct and beneficial approaches to mitigating the urban heat island effect. They reduce the temperatures of roadways through shading and provide evaporative cooling. As this cooling is provided very close to living quarters, its impact on human health is significant.
- **Block planting in public open space.** Within Western Sydney there is scope to increase tree cover on public land such as parks. Specific areas include Western Sydney Parklands, Ropes and South Creek Riparian Corridors, Orchard Hills Defence Base, and local council creek line corridors.
- **Block planting on private land constrained from residential development** (floodplains etc). These areas include the South Creek Floodplain, Nepean River Floodplain, and the Hawkesbury River Floodplain that were forested but have been cleared for primarily pasture production.

Additional benefits of investment in urban carbon sinks include: reduced energy use, reduced deaths and hospitalisations from heat stress, improved biodiversity values due to increased wildlife habitat, and improved landscape scale connectivity (Rizwan *et al*. 2008).

Predicting the quantitative benefits of investing in emissions offset plantings in urban climate basins would require significant new research. For example, the research program required to support urban heat island mitigation in Western Sydney would need to include:

- Modeling current extent of urban heat problem;
- Modeling future climate under various climate change scenarios;
- Modeling future climate with various heat reduction strategies including cooler built surfaces (e.g. more reflective) and revegetation;
- Investigating environmental and health impacts of the heat problem.

9. Agricultural benefits

Native vegetation has ecological and conservation values that extend beyond the boundary of the remnant. Although ecological processes have been compromised by extensive clearing for agriculture, the reverse does not apply. Long term agricultural productivity depends on maintaining and enhancing remnant native vegetation (LWRRDC 1995).

9.1 Provision of shade and shelter for livestock

One of the primary benefits to agricultural production from increasing vegetation cover comes from the increased shelter and shade for livestock and crops. The provision of shelter and shade by vegetation has been found to increase stock fertility, reduce energy requirements, prevent stock losses especially of newborns, lift carrying capacity and increase wool, meat and milk production. The type and magnitude of benefit depends on the species of trees planted, the immediate environment and the intended uses of the farm. The arrangement of the plantings such as alley plantings or shelter belts, individual paddock trees or adjacent block plantings also has an effect on the benefits.

The primary mechanism by which these benefits are produced is the protection from cold and wet winds. By converting as little as 2% of a landscape to tree windbreaks (20 m tall spaced 25 tree heights apart) can achieve a 30% reduction in wind speed across a region (Kimber *et al.* 1999). Lamb mortality during windy, wet and cold weather can be reduced by 50% with the provision of shelter (Bird *et al*. 1992; Wakefield, 1990).

The provision of shade by trees in hot periods also benefits livestock productivity by improved fertility. Heat stress can reduce ram fertility and reduce ovulation, oestrus, conception and embryo survival in ewes. Heat stressed cows produce smaller calves and longer intervals between calving (Bird *et al*. 1992).

A tree sheltered paddock provides a better environment for stock to covert feed into meat, wool or milk. A 33% reduction in wind speed can result in a 10% saving in energy for livestock maintenance. A 55% reduction in wind speed can provide a 17.5 % energy savings. Shelter can also improve grazing behavior that improves feed intake (Bird *et al*. 1992).

The benefits of shelter provided by trees can improve financial returns from livestock production. A modest but significant 10% increase in gross margins per livestock unit was found from the extra pasture growth and savings in feed uptake provided by tree shelter over a 14 year period (Moll *et al*. 2005).

9.2 Shelter for crop production

Vegetated shelter belts also provide benefits to crops by reducing water loss from the soil and reducing soil erosion. Crops grown near shelterbelts can have higher yields than crops grown in exposed paddocks (Kimber *et al*. 1999). A study reported increases in wheat yields by up to 18% in some paddocks protected by shelter belts due to less crop damage (sand blasting) and improved soil moisture retention (George- Jaeggli 1998). The productivity of crops between 40 m to 300 m from remnant native vegetation is enhanced by about 20% where the average height of the remnant is 20 m high (Lockwood *et al*. 2000). Yield increases of 44% in lucerne, 25% in barley and 23% in winter wheat have been reported where windbreaks and shelter belts are in place, compared with paddocks where there are none (NSW Agriculture VegNotes, 1998). Similarly Burke (1991) reported wheat yield gains of up to 25% in the sheltered zone with up to 47% yield gain for oats.

9.3 Salinity reduction

In many regions, particularly the cropping zone of Western Australia, replacement of woodlands with annual, shallow-rooted, winter-growing crops and pastures has resulted in increased groundwater recharge and rising water tables. Rising water tables can mobilize salts stored in the unsaturated soil horizons, transporting the salts to the ground surface and resulting in the onset of dry land salinisation (Eldridge and Freudenberger 2005). Increasing vegetation cover through establishing biodiverse forest carbon sinks can redress these degradation processes. Native vegetation is much more effective at intercepting rainfall, so reducing recharge to groundwater. It is also more effective at drawing water from deeper in the soil profile reducing the risk of saline groundwater rising to the surface (LWRRDC 1995). For example, a study in Western Australia with a 700mm annual rainfall indicated a salinity decline of 11% over the first seven years of planting (Schofield 1992).

9.4 Reduction in agricultural pests

By retaining and increasing native vegetation cover across a landscape, the ecosystem service of pest control can be improved. Native vegetation is likely to harbour beneficial fauna that prey upon invertebrate pests of crops and pastures. For example, numbers of predatory mites and spiders were higher in shelterbelts and in adjacent pasture when there was a high cover of tall grass in the shelterbelts. Research indicates that shelterbelts contribute to the provision of natural enemies of pasture pests to the extent that earth mite populations can be suppressed (Tsitalis 2006). Furthermore, tree belts and blocks can trap diseases attached to airborne particles and reduce the spread of other windborne pests (Kimber *et al.* 1999).

9.5 Improvement in pollination services

The value of pollination to agriculture in Australia has been calculated as $1.2 billion per annum (PMSEC 2002) but is under threat, including the loss of native vegetation. Pollination services are provided both by wild, free-living organisms chiefly native bees, but also many butterflies, moths, flies, beetles and wasps, as well as birds and mammals. These native pollinators complement the pollination services by commercially managed bee species (Kremen *et al*. 2007). Conserving and enhancing native vegetation can improve the pollination activity from insects such as native bees (Cunningham *et al* 2002) and provide shelter from wind and heat for domesticated bees.

10. References

Akbari, H. and Konopacki, S. (2005). Calculating energy-saving potentials of heat-island reduction strategies. *Energy Policy, **33**,* 721-756.

Beckett, KP, Freer-Smith, PH, and Taylor, G. (2005) Urban Woodlands: their role in reducing the effects of particulate pollution. *Environmental Pollution* **99**, 347-360.

Bennett, AF, Clarke, R, Stewart, A, Holland, G and Radford, J (2008). Revegetation on farm landscapes. Are there benefits for wildlife? *School of Life and Environmental Sciences*, Deakin University.

Bird, PR (1991). Bad Weather, Shelter and Stock Losses, *Agricultural Science*, **4(4):**18-19.

Bird P R, Lynch, JJ, and Obst, JM (1984). Effect of shelter on plant and animal production. *Animal Production in Australia* **15,** 270-273.

Bird, PR, Bicknell, D, Bluman, PA, Burke, SJA, Leys, JF, Parker, JN, Van der Sommen, FJ, and Voller P. (1992). The role of shelter in Australia for protecting soils, plants and livestock, *Agroforestry Systems* **20**, 59-86.

Bond, S and Taws, N. (2006). Bringing breeding birds back: woodland birds breeding in revegetation patches, *Canberra Bird Notes* **31 (3)**.

Burke, S (1991). The effect of shelterbelts on crop yield at Rutherglen Victoria, *Proceedings of a national conference at Albury: the role of trees in sustainable agriculture*. pp.41-50.

Campbell, CA (1993). Can Australian farming Systems be more Sylvan? *Agro forestry Systems* **22,** 17-24

Chudleigh, P, Prior, J and Simpson, S. (2004). Incorporating native vegetation management into agricultural production systems – *Project AGT10, Report for Land and Water Australia*, Native Vegetation Research and Development Program.

Coutts, AM, Beringer, J, Tapper, NJ (2007). Changing urban climate and CO_2 emissions: implications for the development of policies for sustainable cities. *Urban Policy and Research*. **45**, 123-35.

Cunningham, SA, Fitz Gibbon. F, and Heard, T (2002). The future pollinators for Australian agriculture. *Australian Journal of Agricultural Research*, **53,** 893-900.

Davies, P, Bunn, S, Mosisch, T, Cook, B, and Walshe, T (2007). *Principles for Riparian Land Management.* Canberra: Land and Water Australia.

Eldridge,DJ and Freudenberger, D (2005). Ecosystem wicks: Woodland trees enhance water infiltration in a fragmented agricultural landscape in eastern Australia, *Austral Ecology* **30,** 336-347.

Eriksson, E., Blinge, M. and Lovgren, G. (2005). Life cycle assessment of the road transport sector. *The Science of the Total Environment*. **189/190**, 69-76.

George-Jaeggli B, Meinke, H, Carberry P S, de H N Maia, A, and Voller P (1998) Variations in wheat yields behind windbreaks in Southern Queensland, *Proceedings of 9th Australian Agronomy Conference*, Wagga Wagga, 683-684.

Growth Centres Commission. (2007) *Growth Centres Conservation Plan: Final Exhibition Draft*.

Hammervold, J., Reenass, M. and Bratebo, H. (2009). ETSI Stage 2, *Sub-project 2: Environmental effects – life cycle assessment of bridges*. Norwegian University of Science and Technology. Trondheim, Norway.

Johnson, R (2000). Shadelines: Making money by keeping trees, *Australian Farm Journal Bush*, February pp. 14-15.

Keoleian, G A., Kendall, A., Dettling, J E, Smith, VM., Chandler, RF., Lepech, MD., and Li, VC. (2005). Life cycle modeling of concrete bridge design: Comparison of engineered cementitious composite link slabs and conventional steel expansion joints. *Journal of Infrastructure Systems* **11**, 51-60.

Kimber, S, Bennett, A and Ryan, P (1999). *Revegetation and Wildlife*, School of Ecology and Environment, Deakin University.

Kremen, C, Williams, N., Aizen, M. Gemmill-Herren, B. LeBuhn, G. Minckley, R. Packer, L. Potts, S. Roulston,T. Steffan-Dewenter, I. Va´ zquez, P. Winfree, R. Adams, L. Crone, E. Greenleaf, S. Keitt, T. Maria Klein, A. Regetz, J. and Ricketts, T (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change, *Ecology Letters* **10,** 299-314.

LWRRDC (Land and Water Resources Research and Development Corporation) (1995), *Socio-economic aspects of maintaining native vegetation on agricultural land*, Canberra.

Law, B. and Chidel, M.(2006). Eucalypt plantings on farms: Use by insectivorous bats in south eastern Australia. *Biological Conservation*, **135**, 236-249.

Lockwood, M, Walpole, and Miles, S (2000), *Economics of Remnant Native Vegetation Conservation on Private Property*, Land and Water Resources Research and Development Corporation, Canberra.

Lomov, B, Keith, DA, Britton, DR and Hochuli, DF (2006). Are butterflies and moths useful indicators for restoration monitoring? A pilot study in Sydney's Cumberland Plain Woodland. *Ecological Management and Research* **7(3)**, 204-210

Lomov, B , Keith, DA, Hochuli, D (2009). Linking ecological function to species composition in ecological restoration: Seed removal by ants in recreated woodland, *Austral Ecology* **34,** 751-760.

Lomov, B, Keith, D, Hochuli, D (2010). Pollination and plant reproductive success in restored urban landscapes dominated by a pervasive exotic pollinator, *Landscape and Urban Planning*. **96,** 232-239

Loyn, R, McNabb EG, Macak P, and Noble, P (2007). Eucalypt plantations as habitat for birds on previously cleared in south eastern Australia. *Biological Conservation* **137**, 533.

Mead, DJ (1995) The role of agroforestry in industrialized nations: the southern hemisphere perspective with special emphasis on Australia and New Zealand, *Agroforestry Systems* **31,** 143-156.

Meat and Livestock Australia (2002). *Prograzier Biodiversity Edition*, **19**, Sydney.

Mercer, K, and Griffin. J (2009). *Role of revegetation as habitat for birds: A case study of four revegetation localities in rural South Australia.* Department of Land, Water and Biodiversity Conservation.

Milford, RL and Allwood, J M (2009). Assessing the CO_2 impact of current and future rail track in the UK. *Transportation Research* (Part D) **15**, 61–72.

Moll, J, Dorrough, J, Crosthwaite, J and Straker, A. (2005). Improving native biodiversity management on wool properties in central Victoria – investment analysis of four strategies. A paper presented to a Resource Economics Workshop '*Identifying production and environmental trade-offs at the farm level'*. Rockhampton.

Murray Catchment Management Committee and NSW Land and Water Conservation (1998) VegNotes, Series 4, *Economics of Native Vegetation*.

NSW Legislative Assembly, Standing Committee on Natural Resource Management (Climate Change).(2008). *Climate change and natural resource management in New South Wales* : [report], **54/03**

Polglase, P and Hairsine, P (2003). Maximising the benefits of new tree plantations in the Murray Darling Basin. *A joint statement by CSIRO Forestry and Forest Products and CSIRO Land and Water*

Price, P and Tubman, W (2007) *Principles for riparian lands management.* Canberra: Land and Water Australia.

Prime Minister's Science, Engineering and Innovation Council (2002) *Sustaining Our Natural Systems and Biodiversity*, Eighth Meeting, Canberra

Prior, J and Agtrans Research (2004) *Incorporating Native Vegetation Management into Agricultural Production Systems*, Brisbane

Radford, J, and Bennett, A (2003).Thresholds in landscape parameters: occurrence of the white browed treecreeper *Climacteris affinis* in Vicotria, Australia. *Biological Conservation* **17,** 135-42.

Radford, J, Bennett, A and Cheers, G.(2005) Landscape level thresholds of habitat cover for woodland dependent birds. *Biological Conservation*, **23,** 317-337.

Reid, R and Bird, PR (1990) Shade and Shelter, *Trees for Rural Australia* Chapter 24**,** Inkata Press, Sydney

Ridley,P. and Stacey, C. (2009) Greenhouse cost-benefit analysis for urban road tunnels. *Solutions for a Sustainable Planet 10.* SSEE International Conference Society for Sustainability & Environmental Engineering, Melbourne, Victoria, Australia, November 2009.

Rizwan, AM, Dennis, LYC, Liu, C. (2008). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of Environmental Sciences*, **20,** 120-128.

Rutherfurd, I, Anderson, B and Ladson, A. (2007) *Principles for Riparian Lands Management.* Canberra: Land and Water Australia.

Santero, N.J. and Horvarth, A. (2009). Global warming potential of pavements. *Environmental Research Letters* **4**, 034011

Schofield,N.J (1992). Tree Planting for dryland salinity control in Australia, *Agroforestry Systems* **20,** 1-23

Treloar, G.J., Love, PED. and Crawford, RH (2004). Hybrid life-cycle inventory for road construction and use. *Journal of Construction Engineering and Management*. **130**, 43-49.

Tsitsilas, B, Stuckey,A, Hoffmann, A, Weeks, B and L. J. Thomson ,AC (2006). Shelterbelts in agricultural landscapes suppress invertebrate pests, *Australian journal of Experimental Agriculture* **46,** 1379-1388.

van der Ree, R, Bennett, AF and Gilmore, DC (2003). Gap crossing by gliding marsupials: thresholds for use of isolated woodland patches in an agricultural landscape. *Biological Conservation* **126,** 241-249.

Wakefield SM (1990). Why You Need Trees on your Farm, *Farm Trees* **Series No 1**, Department of Agriculture, Forestry Commission, and Soil Conservation Service of NSW.