The Zero Carbon Australia Land Use report shows how:

- Australia's land use sector can take a lead role in addressing climate change
- Net zero emissions agriculture can be achieved through changes to some agricultural activities and limited revegetation
- Revegetation can provide an alternative revenue stream for farmers
- Forests in SE Australia can sequester 7,500 million tonnes of carbon dioxide if left to recover

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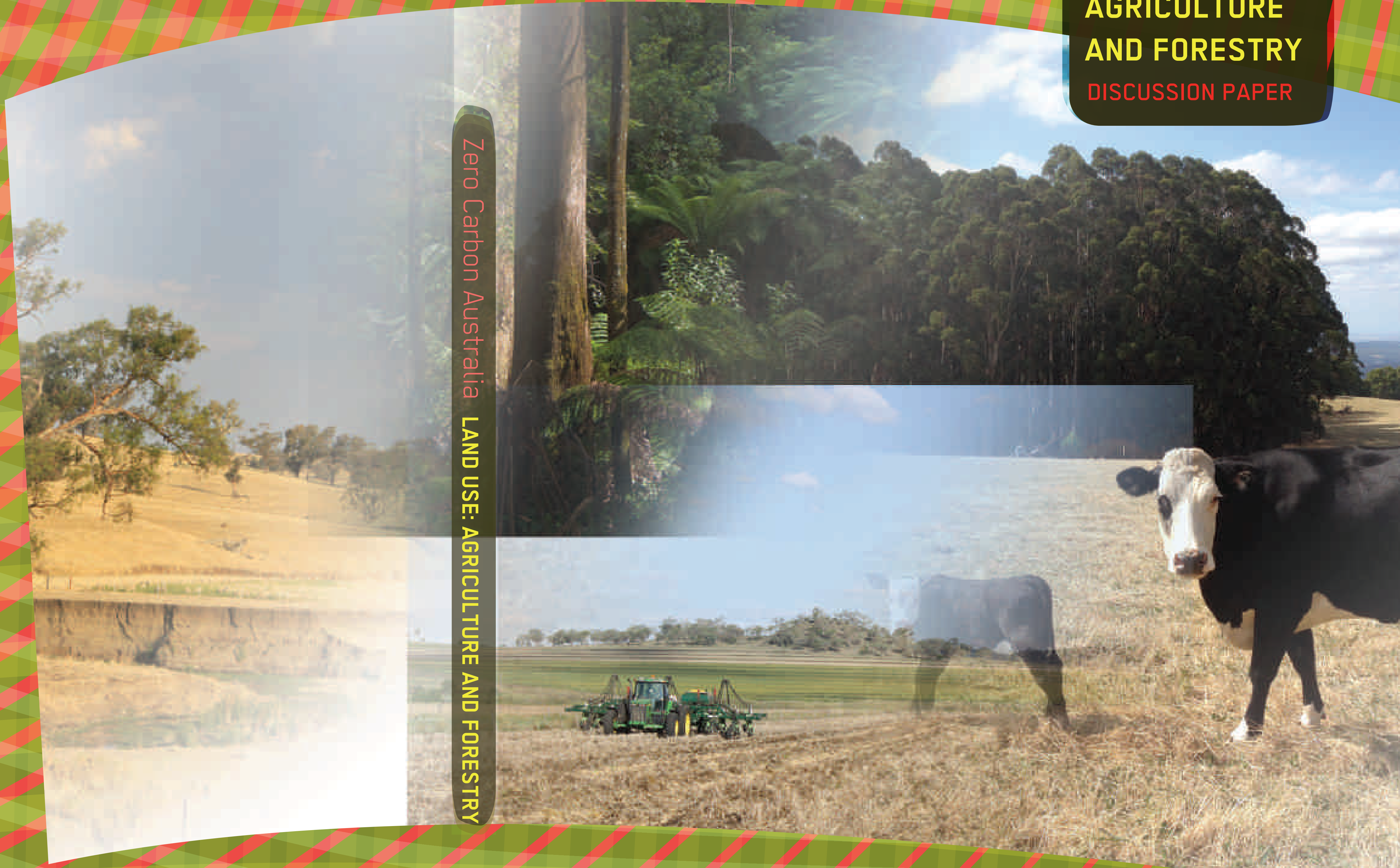
THE UNIVERSITY OF MELBOURNE

beyond ZERO emissions

Zero Carbon Australia LAND USE: AGRICULTURE AND FORESTRY



Zero Carbon Australia

LAND USE: AGRICULTURE AND FORESTRY

DISCUSSION PAPER

THE UNIVERSITY OF MELBOURNE

MELBOURNE SUSTAINABLE SOCIETY INSTITUTE

beyond ZERO emissions

"What we put in the air is crucial; so is what we take out of the air. In the greenhouse era, wise land use is no longer just a good idea; it's a prerequisite for a working planet."

BILL MCKIBBEN, FOUNDER OF 350.ORG AND AUTHOR OF THE END OF NATURE.

"Congratulations on completion of your ZCA Land Use Plan. You provide a model for those of us in other countries."

LESTER R. BROWN, PRESIDENT OF EARTH POLICY INSTITUTE AND AUTHOR OF
FULL PLANET, EMPTY PLATES: THE NEW GEOPOLITICS OF FOOD SCARCITY.

"This land-use report is another important step toward eliminating emissions of pollutants and greenhouse gases and their negative impacts on the environment and human health. The steps outlined should be implemented immediately if we hope to slow global warming and improve air quality for our children and grandchildren."

MARK Z. JACOBSON, PROFESSOR OF CIVIL AND ENVIRONMENTAL ENGINEERING,
AND DIRECTOR OF THE ATMOSPHERE/ENERGY PROGRAM, STANFORD UNIVERSITY.

"The next climate change agreement in Paris, in 2015, must chart a pathway to peak greenhouse gas emissions, ensure a deep de-carbonization of the global economy and achieve a climate neutral world in the second half of this century. How we manage lands and soils will be as critical as how we manage cities and transport to energy and buildings. This timely report shows that ambitious and smart climate action can get us to that zero carbon state at the same time as offering huge opportunities for a profitable transformation towards a truly sustainable future."

CHRISTIANA FIGUERES, EXECUTIVE SECRETARY OF THE UN
FRAMEWORK CONVENTION ON CLIMATE CHANGE.

"The science and knowledge presented in this report contribute to ongoing national and global debate on how the management of land-based biomass production and consumption can be developed towards a higher degree of sustainability across different scales. The report deals with the highly contentious and complex environmental issue of how best to reduce greenhouse gas emissions from agriculture and forestry land uses in Australia; through modelling and exploration of different alternative scenarios, it discusses plausible opportunities toward substantial emissions reductions in the agricultural sector. Undoubtedly many of the proposed interventions require transformational changes in policy and people's behaviour for their successful implementation, including a concerted effort from farmers, rural and urban communities and government."

GRACIELA METTERNICHT, PROFESSOR AND DIRECTOR OF UNSW
AUSTRALIA INSTITUTE OF ENVIRONMENTAL STUDIES.

"The impacts of climate change are increasing and affect our natural land and ocean ecosystems including the Great Barrier Reef. The land use sector makes a significant contribution to Australia's greenhouse gas emissions as well as having an influence on areas such as the Reef. This report highlights the potential for substantial greenhouse gas emissions reductions and carbon sequestration from the land. The report outlines plausible options to both reduce emissions from the land use sector and enhance the utilisation of our land."

OVE HOEGH-GULDBERG PROFESSOR AND DIRECTOR OF UQ GLOBAL CHANGE
INSTITUTE, AUSTRALIAN ACADEMY OF SCIENCE FELLOW, AUSTRALIAN RESEARCH
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Other Beyond Zero Emissions publications include:

Zero Carbon Australia Stationary Energy Plan
Zero Carbon Australia Buildings Plan
Zero Carbon Australia High Speed Rail Report
Laggard to Leader
Repowering Port Augusta

Zero Carbon Australia

Land Use: Agriculture and Forestry

Discussion Paper

Beyond Zero Emissions
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The work we do

Researching Zero Carbon solutions for Australia is a hard job.

The fact is that Beyond Zero Emissions relies on donations from hundreds of donors, both small and large - people like you. We don't get government backing. We are very careful to ensure that our research is independent.

To do the research that needs to be done, to get the word out there, to empower Australians by providing them with scientifically sound facts, all costs money.

Your help will allow us to continue researching our Zero Carbon Australia solutions. And every cent helps.

Who is Beyond Zero Emissions?

Beyond Zero Emissions is a not-for-profit research & education organisation.

We are working to deliver a zero carbon Australia, relying on the support of people like you. To learn more visit our website's Zero Carbon Australia section. This is the fourth Zero Carbon Australia report to be delivered.

What is the Zero Carbon Australia project?

The Zero Carbon Australia (ZCA) project is an exciting initiative of Beyond Zero Emissions and the University of Melbourne's Melbourne Energy Institute and University of Melbourne's Melbourne Sustainable Society Institute. The project is a road map for the transition to a decarbonised Australian economy.

The latest and most credible science tell us such a transition is necessary in order to reverse climate disruption.

The project draws on the enormous wealth of knowledge, experience and expertise within Beyond Zero Emissions and the community to develop a blueprint for a zero carbon future for Australia.

How can you help?

Please go to the Beyond Zero Emissions website to pledge donations or contact us at Beyond Zero Emissions, Suite 10, 288 Brunswick Street, Fitzroy, Vic 3065, or phone +61 (0)3 9415 1301.

The Zero Carbon Australia project

Six ZCA plans will provide a detailed, costed and fully researched road map to a zero carbon economy for Australia. Following seven guiding principles, each plan will use existing technology to find a solution for different sectors of the Australian economy.

Stationary Energy plan

The plan details how a program of renewable energy construction and energy efficiency can meet the future energy needs of the Australian economy.

Buildings plan

The plan details how all existing buildings can reach zero emissions from their operation within ten years. It sets out how Australia can transform its building stock to reduce energy bills, generate renewable energy, add health and comfort to our living spaces, and make our workplaces more productive.

Transport plan

The plan will show how Australia could run a zero fossil fuel passenger and freight transport system. The main focus is on the large-scale roll-out of electric rail and road vehicles, with the application of sustainable bio-fuels where appropriate and necessary.

Industrial Processes plan

The plan will show how our industrial energy requirements can be supplied primarily from 100% renewable grid and investigate replacing fossil fuels with chemical equivalents.

Land Use: Forestry & Agriculture

This is the report you are holding.

Renewable Energy Superpower plan

The Renewable Energy Superpower Plan focuses on Australia's large fossil fuel exports.

ZCA Guiding Principles

1. Australia's energy is provided entirely from renewable sources at the end of the transition period.
2. All technology solutions used are from proven and scaleable technology which is commercially available.
3. The security & reliability of Australia's energy is maintained or enhanced by the transition.
4. Food and water security are maintained or enhanced by the transition.
5. The high living standard currently enjoyed by Australians in maintained or enhanced by the transition.
6. Other environmental indices are maintained or enhanced by the transition.

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[continued overleaf...]

Foreword

Unprecedented global economic growth and improvements in living standards have created societies that are not sustainable: continuing or accelerating on the path we are on will undermine future economic growth and political stability.

A key element among the various changes that we need for our global future is to create low- or zero- carbon societies. This is not an academic pipe-dream, but something that is identified as a time-bound goal among some mainstream political parties, such as by the Liberal Democrats, currently in coalition in government in the United Kingdom, in 2013.

Australian society is unique in that, with large land mass and relatively small population and secondary industry, our land-use generates a relatively high proportion of our current national emissions. Land use is also an enormous opportunity for carbon sequestration, or carbon "sinks". Thus, when Australians devise ways to reduce or eliminate carbon emissions, or perhaps become carbon negative in some future time, we need to pay close attention to our land-use practices. Our farmers and foresters, scientists and policy-makers have an opportunity to lead the world in debating, devising and implementing plans to create zero carbon societies. Our need - because land-use is such an important part of our national economy and identity - and preparedness to lead innovation, have led us to become a global leader in agricultural and environmental science and practice. These characteristics – need and innovativeness - give us the opportunity and capacity to lead land-use change towards a zero carbon society, too.

While it is currently fashionable among some politicians to say we should avoid being a global leader in moving to a low-carbon society, those same leaders and our population generally acknowledge that leadership confers economic benefits, such as accrue from our "clean, green" image in global food markets and downstream revenue from agricultural research.

The first step to change to a zero-carbon land-use sector is to suggest scenarios for change. That is the purpose of this Report. These scenarios provide one evidence-based perspective that should encourage debate, lead to developing plans and policies and to individual land-managers taking action. The Report is not a blueprint for change, a top-down "thou must", but rather a scenario to show that change, based on science and supported by sound economics, is practical. Practical because the changes that are suggested make sense at a local level – changes an individual farmer would sensibly do, when given government support- and fit within an holistic, national accounting of carbon sequestration and emissions. And it's not catastrophic: as Andrew Longmire and his co-authors explain, we can shift to a low-, zero, or even negative- carbon land-use for the continent of Australia without prejudicing food production.

This ZCA Land Use, Forestry & Agriculture Report is an outcome of a joint project between Beyond Zero Emissions and The University of Melbourne's Melbourne Sustainable Society Institute (MSSI). The project, which was made possible by the support of a private donor, is one of a suite of sector-based analyses initiated by BZE and the Melbourne Energy Institute. As indicated earlier, because of the relative size of the land-use sector, it is one of the most important in the suite.

As Professor Ross Garnaut wrote in a recent MSSI book with respect to achieving a sustainable society, "What Australians do over the next few years will have a significant influence on humanity's prospects for handing on the benefits of modern civilization to future generations". Where Australians can make the most impact, is through leadership of change in land-use. This is an opportunity particularly for farmers and foresters and their grower organizations, NGOs concerned with agriculture and the environment, and the political parties that serve them. This report explains why these changes are necessary, where they are best targeted, and how they can make sense at the levels of both local farmers and our nation. It provides a basis for discussion and a scenario that illustrates that leadership towards a zero carbon society is do-able.

Craig J Pearson

Founding Director of the Melbourne Sustainable
Society Institute
Honorary Professor of the University of Melbourne,
the Australian National University, and the Institute for
Governance and Policy Analysis, The University of Canberra.

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Zero Carbon Australia

Land Use: Agriculture and Forestry

Executive Summary

Introduction

This **Zero Carbon Australia *Land Use Report*** outlines research showing how greenhouse gas emissions from land use — agriculture and forestry — can be reduced to zero net emissions. The proposals in this report offer economic opportunities to rural communities as well as resilience to the increasingly severe impacts of climate change.

The land use sector is the second largest source of emissions in Australia and also presents unique opportunities for reducing the severity of climate change. These opportunities include stopping deforestation as well as reemphasis of some areas from grazing to revegetation.

Key findings in the report include:

1. The land use sector can take a lead role in addressing climate change.
2. Australia can drastically reduce its agricultural emissions to around net zero by implementing changes to some agricultural activities and limited revegetation.
3. Revegetation of an overall average of 13% of cleared land can draw down sufficient carbon to balance ongoing emissions from land use activities.
4. The eucalyptus tall open forests of south-east Australia can sequester 7,500 million tonnes of carbon dioxide if allowed to recover from clearfell logging.

The Risk

> *"The adverse impacts of a changing climate are going to have serious effects in agriculture and water sectors. This would have an impact on food security, nutrition, and rural livelihoods."*
>
> WILLIAM SUTTON, WORLD BANK LEAD ECONOMIST (2013)

The land use sector in Australia — agriculture and forestry — is highly exposed to the impacts of climate change. Recent climate projections show that by 2100 global temperatures may increase by 4 – 5 degrees. The climatic changes in the years ahead will have a dramatic impact on our ability to maintain agricultural productivity and the viability of rural communities.

Many farmers are already experiencing a range of economic and client-related challenges in running their farms. Extreme weather events are becoming both more frequent and more intense, resulting in increasingly regular and severe droughts, bushfires and floods.

The Opportunity

Australia's land use sector is in a unique position to mitigate (reduce) climate impacts and take a leading role in addressing climate change. Agriculture and forestry are the only sectors of the Australian economy that can draw carbon dioxide out of the atmosphere by sequestering it in growing plants and in the soil. The agriculture and forestry sectors can mitigate climate impacts on the land, bringing prosperity to rural areas in the process. **The Zero Carbon Australia *Land Use Report*** explores how this can be done.

Current emissions

Emissions in the agriculture and forestry sectors in Australia are high and growing, currently estimated at 15% of our national total before emissions from land clearing are taken into account (***Fig. 0.1***). Sources of emissions include land clearing for agriculture, enteric (intestinal) fermentation from digestive processes in livestock and cropping.

A number of agricultural industries are among the most emissions intensive activities in Australia. Beef production, for example, is more emissions intensive than aluminium and steel production. Emissions from agriculture are even more significant when the impact of activities is calculated over 20 years instead of the more common 100-year accounting approach. When considered from this perspective, agricultural emissions could account for as much as 54% of Australia's total emissions.

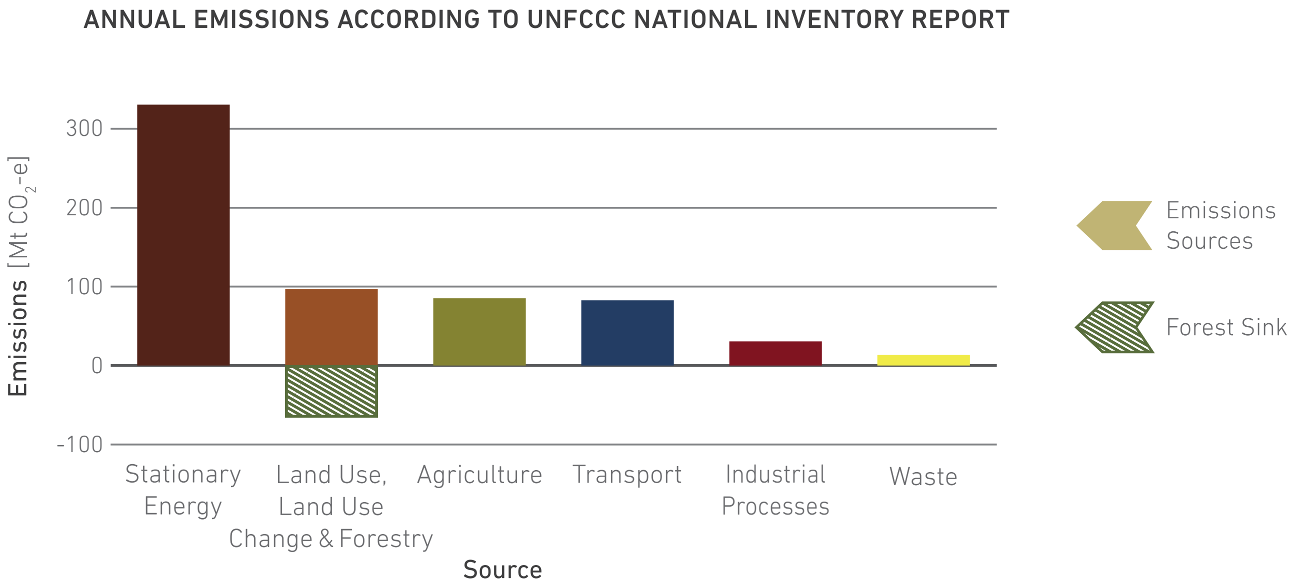


Figure 0.1 Average annual emissions (in million tonnes of carbon dioxide equivalents per year) for six sectors in Australia in 2006-2010 according to the **United Nations Framework Convention on Climate Change (UNFCCC)** ***National Inventory Report***. Under this, the standard breakdown, 'Land Use, Land Use Change and Forestry' and 'Agriculture' are presented separately when in fact the vast majority of land clearing is done for agriculture.

Toward Zero Carbon Emissions Agriculture

Australian farmers are among the most innovative, resilient people in our community and have faced many challenges in the past. These people know their land and have the right to make decisions about how that land is used — they will be a crucial asset as we tackle climate change. Rural Australians also have the tools, equipment, ingenuity and work ethic to get the job done.

Acting to reduce emissions could earn revenue for farmers and land managers, for example through the Carbon Farming Initiative or any future carbon pricing scheme. Our society should work to ensure they are paid a fair day's pay for their efforts in providing not only quality food and fibre but also for sequestering carbon dioxide.

Farmers and other landholders are the best placed to assess, discuss, investigate and implement many of the proposals outlined in this plan. Past and current approaches to reducing agricultural emissions in Australia (e.g. bioenergy), are effective at some scale but are not sufficient to substantially reduce emissions from this sector. To effectively reduce emissions a more innovative and transformational approach is required across the different types of activities we undertake on the land.

A Sequestration Industry

By combining emissions data with vegetation growth potential across geographic regions, we calculated the amount of reforestation required to bring net emissions to zero.

By first minimising emissions with available management and technology, then balancing the remaining emissions in regrowing vegetation, our landscape can sequester and store carbon from the atmosphere in sufficient quantities to bring net regional emissions to zero. This could be achieved by reassigning an overall average of 13% of the cleared land in each subregion to carbon sequestration. Much of this could be done on land less suitable for other uses because of steep slopes or salinity issues.

Case studies were carried out at six farms to gauge farmers' reactions to the prospect of revegetating a portion of the cleared land on their farms, incorporating feedback from farmers.

Reducing emissions from animal agriculture

To substantially reduce carbon emissions, consideration needs to be given to what we produce on the land and also what we eat. Many of these issues are highly contentious and emotive. By necessity the ***Land Use Report*** addresses these issues head-on, while recognising the challenges involved.

The largest single source of land use emissions is land clearing for the expansion of grazing. These emissions can be avoided through the cessation of land clearing and re-clearing in the rangelands of Australia.

Reducing shorter lived emissions with high Global Warming Potentials is a high priority. One such example is methane from enteric fermentation in animals (microbial reactions in the stomachs of ruminants). Reducing these emissions will be highly effective in coming decades, in addition to actions aimed at reducing longer lasting carbon dioxide emissions.

Significant reductions in animal emissions will only be achieved by reducing herd numbers. This is also one of the cheapest methods of climate mitigation. A 20% reduction in ruminant meat production can be achieved without impacting domestic consumption as over half Australia's beef, veal and sheep meat is exported. There is also ample capacity to reduce or replace the amount of animal food products with those sourced from plants.

The economic impacts of reducing animal numbers on farms can be balanced through incentives to revegetate. There is also potential for the reduction of methane and nitrous oxide emissions from agricultural sources using currently available technologies and management. An example is the conversion of methane at piggeries to bioenergy.

Soil carbon, Biochar, Savanna Burning and Tropical Deforestation

There are a range of other actions on the land that are important for reducing emissions.

Use of biochar (charcoal made from plant matter) has the potential to achieve continuous draw-down of carbon dioxide and should be prioritised for research and industry development. Biochar production systems can have a carbon abatement between 2 and 5 times greater than would be possible if the feedstock was burnt as a substitute for fossil fuels. Short rotation woody crops such as Mallee are already being utilised.

Adjustments can also be made to rural land use practices to restore soil carbon stocks. An effective and practicable scheme to monitor soil carbon fluxes should be developed.

Enhanced savanna management and burning methods can make a substantial contribution. Providing incentives for avoided deforestation is also important. The land use sector can not be a sink for emissions from other sectors until it is net zero itself.

The combined effect: bringing land use emissions down

Australia can drastically reduce its agricultural emissions to around net zero, as shown in ***Figure 0.2***. This can be achieved through a combination of the various activities outlined above. The cumulative impact of these measures will reduce agricultural emissions by around 70%. Limited revegetation activity then offsets the remaining emissions to result in a small net positive emissions scenario from this sector.

Further sequestration efforts would bring emissions to beyond net zero. This figure shows the emission reductions possible in the agriculture sector only, which does not include the substantial emission savings available from the forestry sector.

Towards Zero Carbon Emissions Forestry

Large emissions are caused by clearfell logging in forests — Australia's most carbon-dense landscapes. Forest carbon stocks are systematically underestimated by a factor of up to five, and hence their contribution to a stable climate is also undervalued. Clearfell logging also prevents ongoing carbon sequestration in living forests. If allowed to recover, the eucalyptus forests of south-east Australia can sequester 7,500 million tonnes of carbon dioxide.

Disturbance to our tall forests increases the likelihood that fires will be more severe and more frequent; fires too are large sources of carbon emissions. Rehabilitated and older forests are more resilient to the impact of fire.

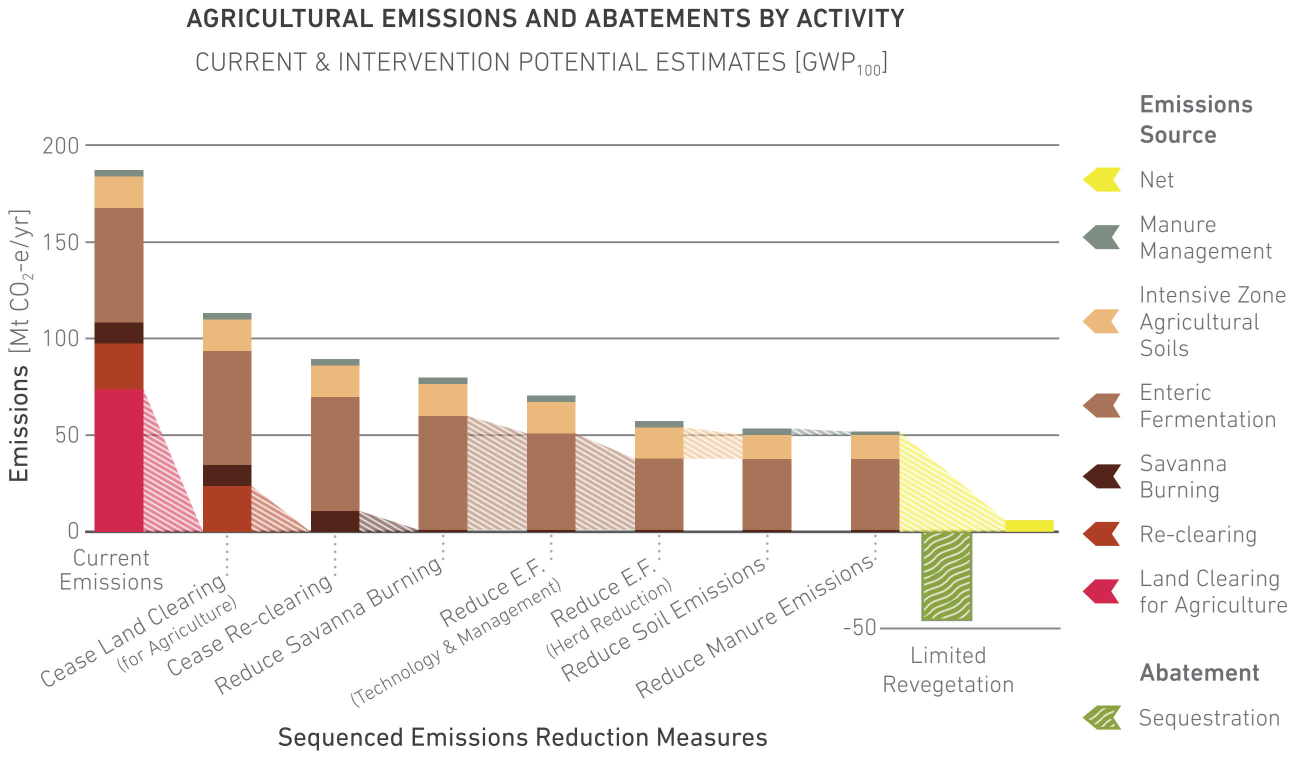


Figure 0.2 Potential reduction in greenhouse gas emissions from changes to agricultural activities.

An expanded reserve network recognising the importance of forests for carbon stocks and sequestration potential is recommended, as well as stopping clearfell logging. This approach can be accompanied by management regimes including risk-spreading strategies and growing wood for high-value specialty products.

Making it happen

It is estimated in this report that a zero carbon agricultural sector can be achieved with restoration of 55 million hectares of Australia's cleared land at an opportunity cost of approximately $5.3 billion per year. However, more work is required to assess the various benefits from revegetation including positive revenue streams from carbon sequestration initiatives such as carbon farming and the costs associated with revegetation, such as fencing and labour.

The cost is in line with that of climate mitigation measures being undertaken by other developed countries. In the longer term, it is far less than the cost of not taking action. Implementation of the proposals in the report requires support and investment from government and the community. This is entirely consistent with instances in the past where the Australian community has assisted the transition of economic activities to become more sustainable, such as in fisheries, water and forest conservation.

Summary

The land use sector is currently one of the largest sources of greenhouse gas emissions in Australia and is critical to transitioning the economy to beyond zero emissions. Forestry and agriculture have unique and powerful potential to address the very problems they face.

The ***Land Use Report*** outlines a range of measures that can substantially reduce emissions and provide opportunities for farmers in building resilience to the impacts of climate change. These measures encompass both agriculture and forestry and address emissions at the scale required to prevent catastrophic climate change.

Farmers and other landholders are instrumental in assisting the move to a zero emissions future, and require support from governments and rural and urban communities.

The report presents challenging issues and will require robust discussion. Engagement with stakeholders is essential.

Part 1:

Introduction to ZCA Land Use Report

Contents

1.0 Introduction

This Zero Carbon Australia Land Use Report was produced by Beyond Zero Emissions in collaboration with the Melbourne Sustainable Society Institute. Its objective is to devise a means of taking rural land use in Australia from its current status as a heavy greenhouse gas emitter to a new state where land use emissions are balanced or exceeded by removals of atmospheric carbon.

The project principles are as follows:

- Only proven, reliable, commercially available technology and methods are used
- Overall food production is maintained or enhanced
- Other environmental indices are maintained or enhanced
- Solutions do not defer costs to future generations

We believe the work has achieved these aims.

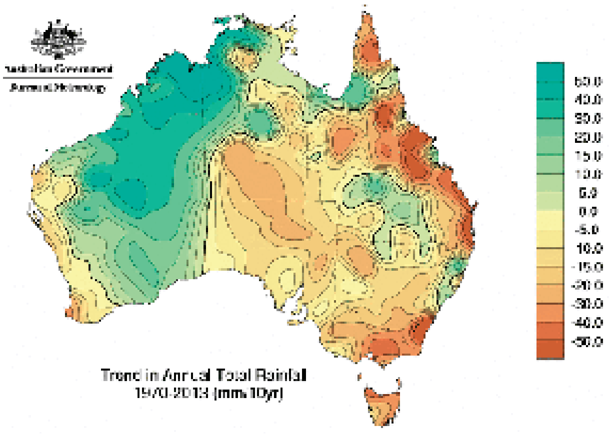


Figure 1.1 Trend in annual total rainfall in Australia 1970 – 2013 [mm/decade].

1.1 The case for change

Climate change, caused by human activities, has brought us more severe storms, floods, droughts, heat waves, inter-annual variability and desertification (e.g.[1 – 3]). Warming thus far of just 0.8°C has produced record lows in Arctic sea ice volumes, melting glaciers and permafrost, widespread record high temperatures and extreme droughts.

Here in Australia, the year 2013 broke many climate records, especially related to heat, and this too bore the mark of human influence.[3] Such extremes are also reflected in longer term observations. For example, the number of record high maximum temperatures per year has increased markedly since the 1990s, after being relatively stable for most of the preceding century.[4] Exceptionally hot years now occur over twice as much area as would be expected from long-term historical observations.[5] Such records reflect overall higher average temperatures. Via increased temperatures and evaporation, climate change has increased the severity of Australian droughts, and this effect is likely to become more pronounced.[5 – 7]

In early 2014, the atmospheric carbon dioxide concentration was slightly below 400 parts per million. This level has not been recorded since well before the Holocene, the period in which human civilisation arose and agriculture was developed. It is well established that the release of greenhouse gases resulting from the human use of fossil fuels and destruction of vegetation has been the primary driver of this increase. It is also accepted that atmospheric greenhouse gas concentrations are driving increases in global average temperatures.[8] Climate change poses severe threats to both natural and human systems, particularly agriculture, and is impacting human health and security.[9 – 11]

Greenhouse gas emissions and their harmful effects are tracking ahead of worst-case scenarios and a large body of literature indicates that this human interference in climate systems has already committed the planet to warming in excess of 2°C relative to pre-industrial average temperatures. Furthermore, in a world where 2°C is surpassed, progress toward and beyond 4°C of warming is almost assured and would lead to major disruption.[12] These mileposts may also be closer than we have so far supposed.[13]

Unless effective action to reduce emissions is taken in the near future, global mean temperature increase relative to the pre-industrial period is likely to exceed 2°C by 2030 – 2040 and to exceed 4° – 5°C by 2080 – 2100.[13] Temperature increases in this range are likely to induce further, possibly uncontrollable warming, through a variety of feedback loops.[12, 14] But progress to date in emissions abatement negotiations does not inspire confidence that a solution is at hand. Indeed emissions have tracked with or ahead of worst-case projections throughout recent years.[15, 16]

Temperature increases exceeding 2°C will result in great risk of rapid, abrupt and irreversible climate change.[17, 18] Indeed the widely-accepted 2°C 'guardrail' target for limitation of warming is of political rather than scientific origin,[19] and analysis of emissions trajectories offers little chance of reaching even the 'safety' offered by these.[16,20,21] The 2°C guardrail itself has been characterised as only delineating 'dangerous' from 'extremely dangerous' climate change,[12] and even to meet this risky target the human race may have to actively remove carbon dioxide from the atmosphere, as well as drastically reducing emissions.[16]

It is imperative that we radically reduce greenhouse emissions in the near future. There are many opportunities for doing this, but here we are concerned with change to human land use patterns, specifically in Australia. This is because humans extract their basic needs from the natural environment via their patterns of land use. We are very successful at obtaining food, fibre and water by manipulating natural systems, a capacity that has been crucial to our success as a species. However landscape-scale change has also been a vehicle for substantial damage to the systems that support life, including the stable climate on which land use activities depend.

1.1.1 Climate change and Australia's rural industries

Supplies of at least two of our basic needs, food and fibre from crops and trees, are dependent on relatively consistent and predictable rates of plant growth. Plant growth in turn depends on climate and its localised manifestation, weather. In many parts of the world, climate change poses serious challenges to agricultural producers on account of their direct reliance on the natural resource base and hence high exposure and sensitivity to the impacts of climate change.[22] Put simply, any human activity that relies on plant growth is susceptible to damage from changing climates and especially to weather extremes.

Australian agriculture and forestry are highly exposed to climatic variability and likely future changes.[23 – 26] Given the natural volatility of our climate, our rural industries may be in a worse position than those of other countries. Modelling indicates great uncertainty but alarming possibilities for the future, with shifting climate regimes likely to affect all aspects of Australian food production.[27] Australian producers are already facing severe impacts, with recent extremes including the widespread Millennium Drought bearing the mark of human influence.[3, 7]

Studies confirm a decades-long drying pattern in agriculturally important regions of Australia, including the east coast and hinterland, most eastern inland areas and southern WA.[5] Many such regions have lost 20 – 50 mm of rainfall per decade since the 1970s (***Fig. 1.1***). Late autumn and winter rainfall has reduced since 1950, especially in south-west Western Australia. This signal is distinct from background variability[4] and affects crucial growing season rain for wheat. South-east Australia has also seen a trend to lower rainfall. These data, from large-scale, systematic meteorological observations and modelling, are in direct agreement with farmers' lived experience. Cereal growers in Victoria's Wimmera, for example, also report that most rainfall has been lost from the growing season.[28, 29] It is likely that conditions for many rural industries will deteriorate further without effective mitigation of climate change.

Average temperatures have trended higher in recent decades, at rates of up to 0.15 – 0.30 over many areas important for agriculture and forestry (***Fig. 1.2, 1.3***), and extreme heat has followed a similar pattern. In isolation from rainfall reductions, warmer conditions can have dramatic effects on agriculture. Increased accumulated heat can reduce the time crops take to mature, allowing plants less time to accumulate biomass and hence lowering yields. Just days or even hours of extreme temperatures during critical periods of growth can crash entire crops. Hot weather can also reduce animal performance, increase animals' drinking water needs and introduce or exacerbate animal welfare issues.[30, 31]

Increased heat is a problem on its own but also drives higher evaporation, which in turn leads to lower grain yields per unit of water supplied, to reduced grain quality and lower pasture availability. Higher evaporation also causes lower soil moisture content and this again can reduce both yields and quality of produce.[32–34] The risk of soil degradation is higher where soil moisture is low, whether on cropland or pasture, and dry soils are less able to sequester and retain carbon.

Lower rainfall of course compounds other effects, and water scarcity caused by reduced rainfall is itself compounded as still lower river flows, a problem especially in irrigation areas. A 10% reduction in rainfall can cause 30% lower stream flows.[32] Modelling based on projected rainfall and evaporation changes has suggested that the Murray-Darling Basin may see flow reductions of 12–35% by 2050.[35] Despite such reduced average stream flows, it is also increasingly likely that intense storms, though irregular and unpredictable, will increase the severity of floods and cause physical damage to landscapes through erosion.

Higher evaporation and reduced rainfall also result in drier, more fire-prone forests and woodlands. This compounds the effects of other disturbance on forest resilience. More frequent and intense fires can shift forests into a compromised state from which they will not recover. Forests constitute a major stock of stable landscape carbon, and they are also an important sink for carbon already in the atmosphere. Their disturbance leads to strong greenhouse emissions and a reduced capacity to sequester carbon. Disturbance of forests also diminishes other ecosystem services. Many of these, such as water supply, are relied upon by both major urban centres and rural users.

Apart from the effects described above, projections more generally indicate greater climatic variability, giving less predictable conditions overall. Also uncertain but of great relevance to rural industries are potential changes to pest and weed distributions.

1.1.2 The need and capacity for change

Any one of the eventualities described above is a difficult prospect for Australian rural industries, but their compound effect is potentially catastrophic. Despite their iconic toughness, adapting to climate-related pressures such as drought and flood has already tested some farmers' and communities' resilience.[36, 37] Distressingly for all of us, there is a direct relationship between drought and ill-health, suicide and other problems in rural Australia.[7, 38, 39]

A recent Bureau of Meteorology / CSIRO assessment of the trigger for declaration of 'exceptional circumstances' due to drought concluded that the current standard of a one-in 20–25 year event is inappropriate under climate change. The report stated that exceptional drought could in future be declared 2–4 times more frequently than it has been in the past.[5] In other words, the cost impact of droughts borne by the broader community is likely to be far greater in coming decades.

Studies suggest relatively high levels of confidence in producers' ability to adapt to future extremes in climate and weather,[40, 41] and this is likely to be reflected in some responsiveness in farming systems. But adaptation to past extremes has often come at the cost of long-term deterioration in the soil condition and carbon content of grazing pastures and other agricultural land.[42] These physical deficits have contributed to a landscape of reduced physical, biological and sometimes social resilience.

There is also a danger that climate change adaptation leads to perverse outcomes for the climate. This may happen, for example, if landholders turn cropland over to pasture. Because they are less sensitive to short periods of low rainfall, grazing animals can lessen financial risk, but emit more greenhouse gas. Another scenario is the abandonment of land when in fact careful management is required for the best climate outcome, such as landscape carbon storage. Yet another potentially perverse outcome, albeit with some sustainability payoff, is the reallocation of land from food growing to biofuels, as has been done in at least one response to lower cereal growing season rainfall in Victoria.[28]

1.1.3 Transformational adaptation

We argue that ongoing adaptation of agriculture and forestry to worsening effects of climate change need to be coupled to a major effort to reduce emissions both from the sectors themselves and the rest of the economy. Other authors also assert that such a response to climate change is needed, because incremental reductions are not sufficient to avert dangerous warming (e.g.[19, 43, 44]). Such an effort would be transformational, long-term and would carry its own risks, but would constitute a proactive and positive response to humankind's most pressing issue.

The decision we face is one between managed disruption and severe, ongoing, uncontrolled disruption of our land use systems. Agriculture has shown it has the wherewithal to adapt, but change on the scale required for a comprehensive response to climate change has never been considered.

Transformational adaptation is perhaps most urgently to be considered in the land use sector, because the sector relies on plants for its productivity, and plants interact with climate. Across the world, agriculture emits 19 – 29% of all greenhouse gases[26] and is the greatest source of shorter lived greenhouse emissions (e.g.[45, 46]). In Australia, when LULUCF (*Land Use, Land Use Change and Forestry*) emissions from deforestation and subsequent soil carbon loss are accounted to agriculture, the sector's contribution is in excess of 30%. This is because land uses are strong emitters of greenhouse gases: CO_2 and CH_4 from biomass burning, CH_4 from enteric fermentation, CO_2 and N_2O from soils.

Land use activities, however, also offer large scale opportunities for both emissions abatement and landscape carbon sequestration.[47 – 49] The vast size of the Australian continent serves to emphasise the magnitude of the opportunity for a strong climate change mitigation effort based on land use practices. Likewise our skilled and knowledgeable rural workforce will be a crucial asset.

Reduction of emissions from agriculture and forestry and landscape sequestration is not a substitute for action in other sectors of the economy. The concept of transformational adaptation can equally be applied to energy generation, transport, our built environments and more, as detailed in other BZE publications.

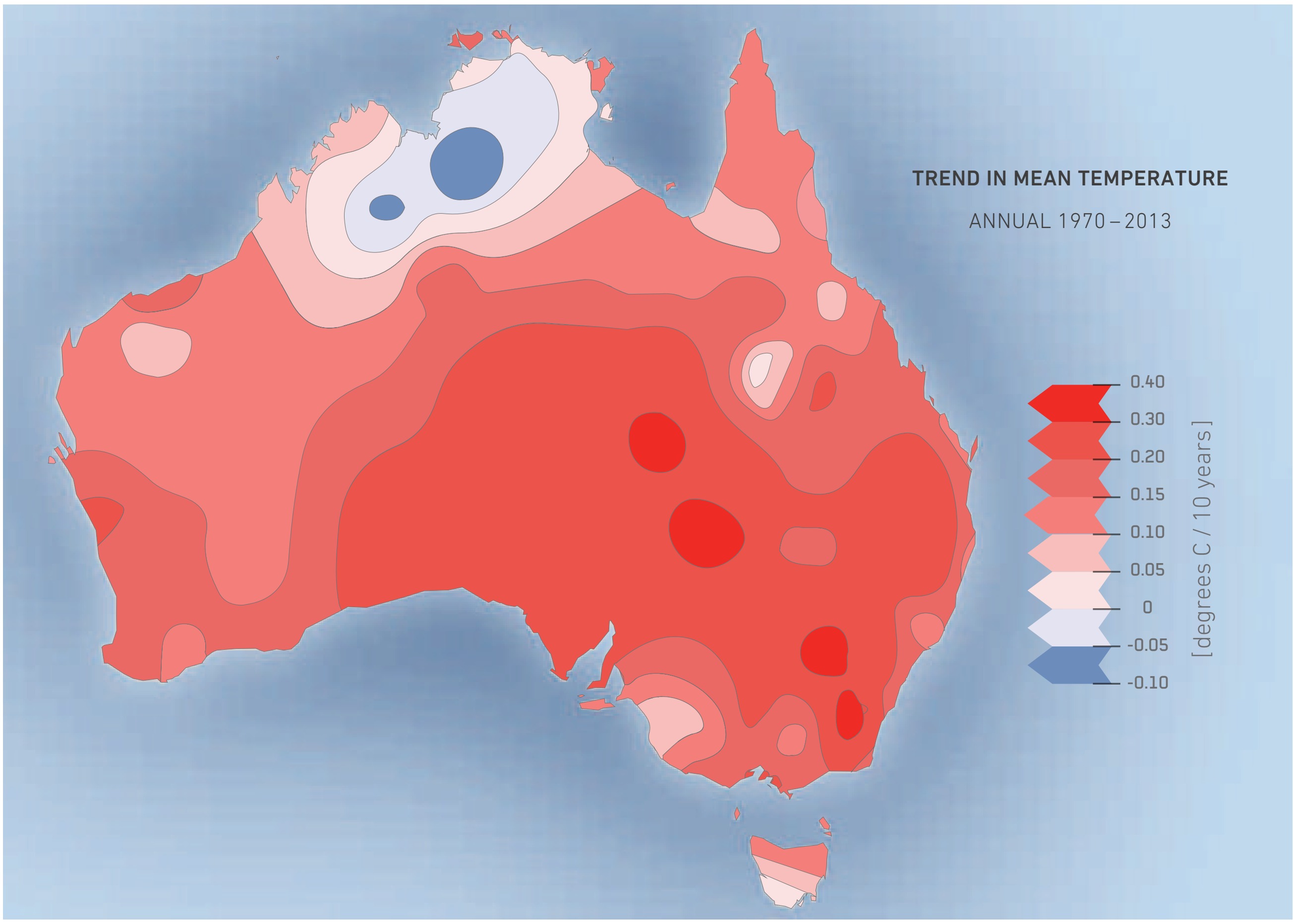


Figure 1.2 Annual average temperature anomaly 1900 – 2013 compared to long-term average 1961 – 1990 [°C] based on Bureau of Meteorology map.

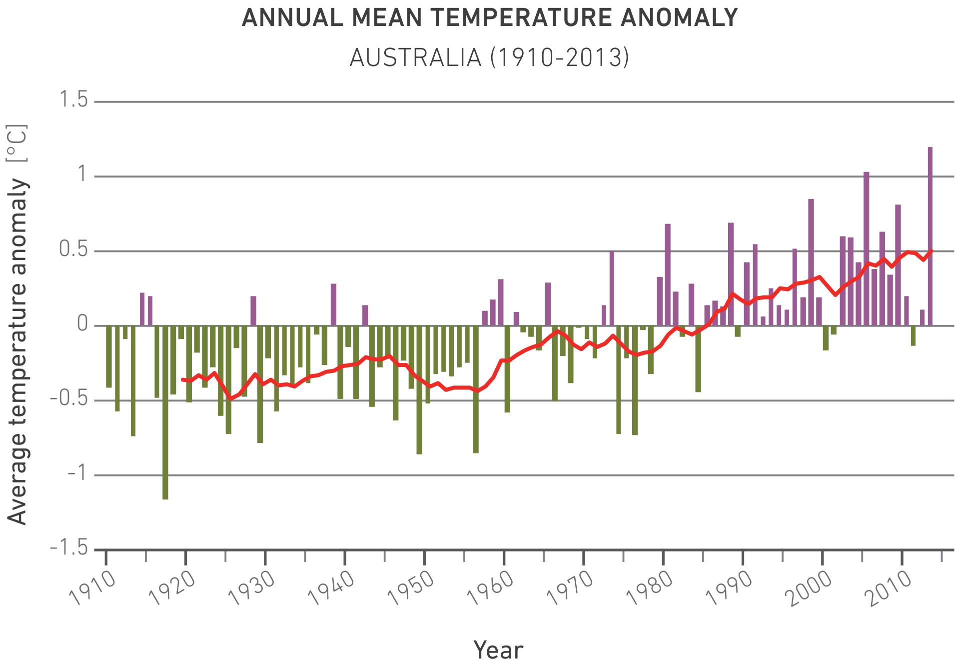
1.2 A shared responsibility

Our agricultural systems and workforce have borne the brunt of climate change to date, and rural livelihoods are further threatened by likely future change. Our farmers supply food to Australians and to millions of others, in the process earning important revenues for our nation. This capacity must be protected. Farmers and graziers know their land and have the right to make decisions about how that land is used, and will be a crucial human resource as we tackle climate change. Rural Australians also have the tools, equipment, ingenuity and work ethic to get the job done.

Rural Australians, however, cannot be asked to shoulder the burden of costs of the large-scale, transformational change we envisage. We hope that this document can provide a basis for city-dwellers to identify the scale of change required as both possible and worth the effort required. We hope that recognition of the massive potential to both reduce emissions from our landscape and to sequester carbon dioxide from the atmosphere will inspire Australians to find a way to facilitate the necessary transformation. Though we are agnostic with respect to the 'how' — whether via carbon pricing or other market mechanisms, carbon trading, public buyouts of land or even a 'green army' of suitably-equipped and motivated people — a number of options are already known to the Australian community.

At the same time, we want to encourage all Australians toward a more comprehensive understanding of the impacts of their own choices on both the rural environments on which we depend, and on the people who live and work outside our cities. Again we hope to inspire a collaborative approach whereby landholders are paid a fair day's pay for the dual essential services of food production and custodianship of the land. In parallel, we hope, recognition of the high cost of inaction will help us all to accept that prudence demands an immediate investment in both research and action. The multiple costs of inaction dwarf those of the interventions we suggest.

Transformational adaptation of Australia's landscape from a large source of greenhouse emissions to a net carbon sink will require us to take a wholistic view of landscapes, their natural features, biological productivity, as well as agricultural and forestry production and emissions. The following chapters offer a framework and practical method as to how this might be achieved — the first time this has been attempted for any continent. We expect that many reasonable, forward-thinking and responsible Australians will respond positively to the clear evidence and sensible suggestions we present. We look forward to dialogue with a wide range of such stakeholders.


ANNUAL MEAN TEMPERATURE ANOMALY

AUSTRALIA (1910-2013)

Figure 1.3 Annual average temperature anomaly (columns) 1900 – 2013 compared to long-term average (red line) 1961 – 1990 [°C].

1.3 Report scope and structure

Part 1

Introduction.

Part 2

Overview of the land uses, agriculture and forestry, considered in this report. Origins, development and current status are outlined.

Part 3

Agriculture is commonly understood to cause about 16 – 20% of Australia's total greenhouse gas emissions. But this figure excludes emissions from the Kyoto Protocol category *Land Use, Land Use Change and Forestry* (LULUCF). We allocate emissions due to land clearing for agriculture, among others, to a more accurate *Agriculture* category. We also assess agricultural emissions according to twenty-year global warming potential, as this measure is more closely aligned with the urgency of action on climate change.

We examine the major types and magnitudes of emissions from land use, as reported in the national inventory. We examine the activities responsible for agricultural emissions, and how emissions can be abated. Emissions from native forest logging are also described and estimated.

Part 4

We inspect the concept of carbon storage in soils, which has attracted attention for its seemingly great potential to contribute to climate change mitigation efforts. Replenishment of soil carbon is certainly good for agriculture, and can make a major contribution to reducing net emissions from land use. The weight of scientific research, however, shows that carbon sequestration in soils is subject to great uncertainties, and that a great deal more research is needed even to establish baselines against which soil carbon stocks can be measured. There is also a substantial risk that carbon stored in soils will be re-emitted. Moreover, any addition to soil carbon should not be conflated with actual reductions in emissions from land use or other sectors.

Other approaches that have been proposed or enacted to reduce emissions from agricultural activities are reviewed. Many are useful, good for business, and have already become part of Australia's rural landscapes; some are not currently feasible on technical or economic grounds but warrant priority research or improved accessibility. Others reduce emissions in sub-sectors of agriculture but do not scale to the needed emissions reductions. The conclusion is that real reductions in emissions from agricultural land use will require substantial changes to the way we do business, including some reductions in animal numbers. The potential to reduce emissions by cessation of clearfell native forest logging is also assessed.

Part 5

We propose limited restoration of native vegetation on a scale commensurate with that of land use emissions coming from the same discrete geographic area, with the objective of achieving zero emissions from agriculture for the whole continent. We use the Interim Biogeographical Regionalisation of Australia (IBRA) to frame spatial modelling of greenhouse emissions, based on animal numbers obtained from government data. To this we add outputs from recognised landscape carbon modelling software to estimate sequestration potential.

This modelling presented in ***Part 5*** demonstrates that emissions from the business-as-usual activities of five important agricultural activities can be offset by carbon sequestration in growing vegetation in the same region, and emissions also reduced. The required changes are quantified in terms of hectares of land retired from production, animal numbers and local economic impacts.

We also quantify the cleared land in each IBRA sub-region according to its susceptibility to salinisation and, on the basis of slope, its relatively lower agricultural usefulness.

We argue that some land is well-suited for revegetation because it is either relatively less valuable already or likely to be entirely lost from agricultural production in the absence of effective intervention. This analysis is offered as an example of how other landscape factors might be taken into consideration in land use decision making, and of the potential for win-win situations.

Part 6

Similar modelling of emissions and sequestration based on actual farm data also assesses the degree of restoration required to achieve a zero emissions scenario on a number of actual farms. These studies highlight a range of possible outcomes, the ease with which some farms could negate their emissions and the difficulty that faces others. Our farm visits also afforded the opportunity to gauge farmers' reactions to our proposals, and many of these are included.

On the basis of our assessments of emissions, their sources and available abatement methods, we lay out a roadmap toward zero emissions land use for the Australian continent. We summarise the interventions necessary, and some of the opportunities that they encompass. Further, we show that this can be done without negative effects on food production.

We also assess short rotation woody crops, grown for conversion to biochar, as a novel industry with the potential for ongoing carbon sequestration, whereby atmospheric greenhouse gas concentrations can actually be reduced. Such ventures and their benefits are already familiar to some Australian farmers and rural communities.

Part 7

Part 7 briefly considers a number of the issues arising from the interventions we propose, such as economic and food production impacts, the requirement to prevent re-emission of landscape carbon and active removal of carbon dioxide from the atmosphere by growing commercially valuable and short rotation tree crops. We canvass examination of the ownership and responsibility for our national response to climate change with regard to land use decisions.

1.4 Further reading

This work focuses on mitigation of the risks posed by climate change through abatement of emissions from the land use sector. It does not give detailed coverage to climate change adaptation, which is already underway to varying extents in Australian rural industries. Climate change adaptation itself is a very complex field, particularly in agriculture, and is well covered elsewhere; we direct interested readers to Rickards (2013[50]) and Stokes and Howden (2010[52]).

We do not attempt to model the effects of climate change on agriculture, beyond those described in this introduction. Readers interested in the effects of more than two degrees of warming on Australian agriculture are directed to, for example, Howden, Schroeter and Crimp (2013[51]), and to the same volume (Christoff (Ed.; 2013[53])) for overviews of the likely effects of unmitigated climate change on biodiversity, marine resources, cities, health and national security.

For more information on the drivers and mechanism of climate change and its link to human activities, we recommend the 2010 Australian Academy of Science publication "The Science of Climate Change: Questions and Answers."[54]

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Part 2:

Overview of Rural Land Use

Contents

2 Introduction

This chapter offers an overview of rural land use in Australia. The history of development and its natural and social drivers are briefly explored, as are the greenhouse emissions and landscape stresses these changes have imposed. The multiple values of rural land use are also described.

Chapter highlights

- Land clearing has made way for world-leading agriculture, and extensive clearing continues. At least 58% of our continent is heavily modified by clearing and/or grazing.
- Land clearing has led to regional climate change, erosion, biodiversity loss as well as immediate and ongoing carbon emissions from plants and soils.
- Logging is now concentrated in eucalyptus open and tall open forests. The major end use for materials extracted from our forests is low-value woodchips for export, while softwood plantations supply 65% of our wood needs.

2.1 Introduction and historical context

2.1.1 Geology, climate and soils dictate rural development

Australia is the smallest, lowest-lying and driest inhabited continent. Our landscape is characterized by a great diversity of plants adapted to aridity, such as the dominant eucalypts, acacias and grasses.[1] The continent has seen minimal volcanic activity or glaciations for many millions of years, meaning that relatively little new material has been deposited onto or eroded from ancient and weathered parent rock. Generally dry conditions have also caused slow soil formation. In combination with long periods of leaching, erosion and some regions of salt deposition, this has left Australian soils relatively infertile.

Fertile soils are present in those areas where volcanic activity has brought basaltic rocks to the surface in the recent geological past (from 30—10 million years ago).[2] Highly productive ecosystems evolved where these areas of richer soil coincided with a relatively benign climate, but in the majority of the continent, the deciduous forests of ancient Gondwana gave way to more arid landscapes as the Australian continent moved slowly northward.[1] Modern Australia comprises a large range of climatic zones, from the tropical north to the arid interior and the cold wet zones of Tasmania and the south-eastern highlands.

Agricultural systems have been adapted to many of Australia's agro-climatic zones (***Section 2.2.1***), with activities and economic returns strongly influenced by rainfall (***Section 5.6***). Cropping occurs across a range of climate zones and soil types, from the summer-dominant rainfall regions of Queensland to the winter-dominant rainfall areas of southern Australia. Livestock grazing extends across the entire continent, from the savannas and open woodlands of the north to cleared pastures of Victoria. Climate variability strongly influences primary production, resulting in large fluctuations in productivity. This is evident in both crop and pasture yields across the continent, which can drop by half in drought years.[3]

Farming in Australia was largely a matter of trial and error during the long period of agricultural expansion.[4] Among other hardships, pioneer farmers encountered regular dry periods and in the early to mid-1800s the first multi-year droughts were recorded. Soil loss and the requirement for high levels of inputs, such as water, manure and fertilisers, which were often difficult to obtain, also hampered agricultural expansion.[5] Neither farming methods nor plant cultivars imported from Europe were particularly well-suited to the Australian environment. A great amount of effort went into clearing large trees from areas to be cropped or intensively grazed.

Modern Australian agriculture is a world leader. Due to our large land mass, innovative and hardworking farmers, investments in agricultural research and the application of fertilisers and pesticides, Australia now produces about twice as much food as we need. Agriculture also earns substantial export income, with food alone earning $19b in 2011 – 12.[6] Our biggest agricultural export earners are grains and oilseeds, meat, and wool, though other products are also prominent.[6]

2.1.2 Rural development as a driver of land clearing

The development of agriculture in Australia resulted in extensive clearing of native vegetation. This was seen as a prerequisite to productive farming as fewer trees meant less competition for sunlight, nutrients and water with crops and pasture grasses, as well as fewer obstacles for farming implements. Most of Australia was (and much still is) crown land, so governments could influence development through lease conditions. The Crown Lands Alienation Act of 1861 opened up land to settlers and threatened eviction if allotments were not cleared. Federal and state governments supported clearing with bounties, tax incentives and other policies. Government scientists advised on herbicides, fire and other clearing methods.[9] These activities continued well into the 20th century, with financial institutions — many of these state entities — making access to farm finance conditional on clearing and draining land.[10] Full tax deductibility of tree clearing costs continued in Tasmania until the mid-1970s and the activity continued at high rates until the 1980s. In Queensland, the requirement for crown land leaseholders to clear their land remained in effect until the 1980s.

Clearing increased with the post-war 'Soldier Settlement Schemes', but mechanisation in the 1960s resulted in broadscale clearing across the state. The 'ball and chain' method of clearing land, involving a large metal ball as an anchor connected to a heavy chain with bull dozers raking the chains to uproot large swaths of vegetation at a pass, was used extensively. This practice continues today.[9]

In the practice of land clearing, cleared vegetation debris was largely heaped into piles and burned. Much of the carbon stored in the cleared vegetation and debris was immediately emitted into the atmosphere. The soil based carbon was released at a slower rate following land clearance for a period extending over decades.[11]

At the time of European settlement, about 30% of the Australian landmass was covered by forest, defined as trees more than 2 m high and with at least 20% crown cover; a further 21% was open woodland and 40% was shrubland.[12] By 2010, forested areas had declined to around 19% of the country, a loss of 38% of the original forests.[12] By 2011, 15% of the continent had been severely modified, a further 43% modified by grazing and 10% by improved pastures (introduced grass species).[13] Modification in this context includes not only tree clearing, but changes to grasslands and shrublands. As agricultural development followed rainfall and fertile soil, these percentages consisted mostly of the highly productive areas and a large proportion of the arable land in Australia (***Fig. 2.1***).

Some vegetation communities have been completely removed from areas of the landscape. The greatest impact has been on eucalypt forests and woodlands, with more than 80% altered,[15] followed by brigalow (*Acacia harpophylla*) communities. The extent of cleared native vegetation and major vegetation types affected are detailed in (***Fig. 2.2***).

2.1.3 Recent land clearing

Queensland has been the site of more than three quarters of Australia's land clearing in recent decades, and both satellite data and ground survey have been used to monitor this activity since the late 1980s.[17] From 1988 to 2009, an average of 410,000 ha was cleared per year in Queensland. Less than 2% of trees cut in this period were used for timber and 93% of the clearing was to establish pasture for livestock grazing (***Fig. 2.3***). Around 60% of vegetation

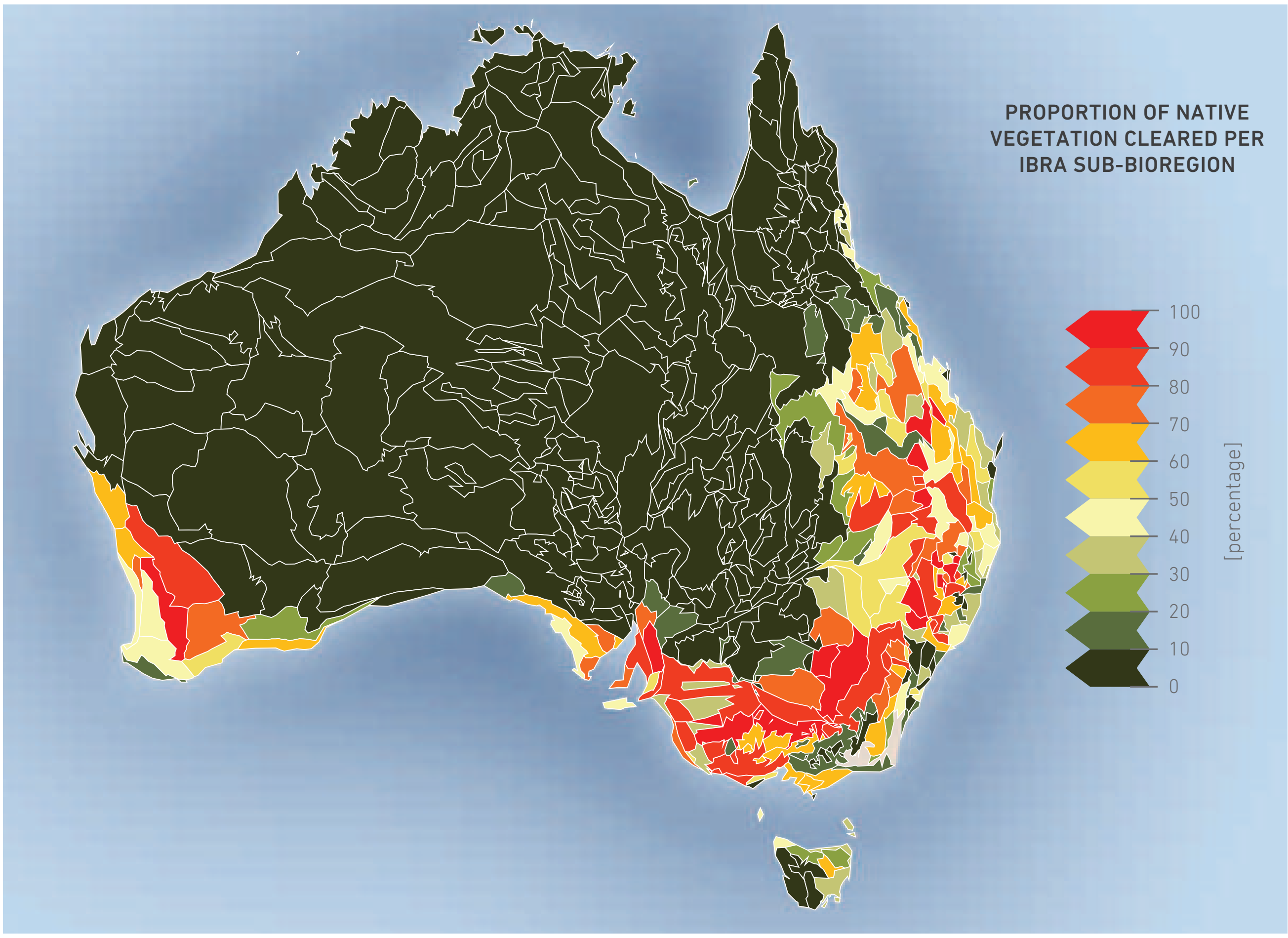

Figure 2.1 Proportion of native vegetation cleared per IBRA sub-bioregion[14].

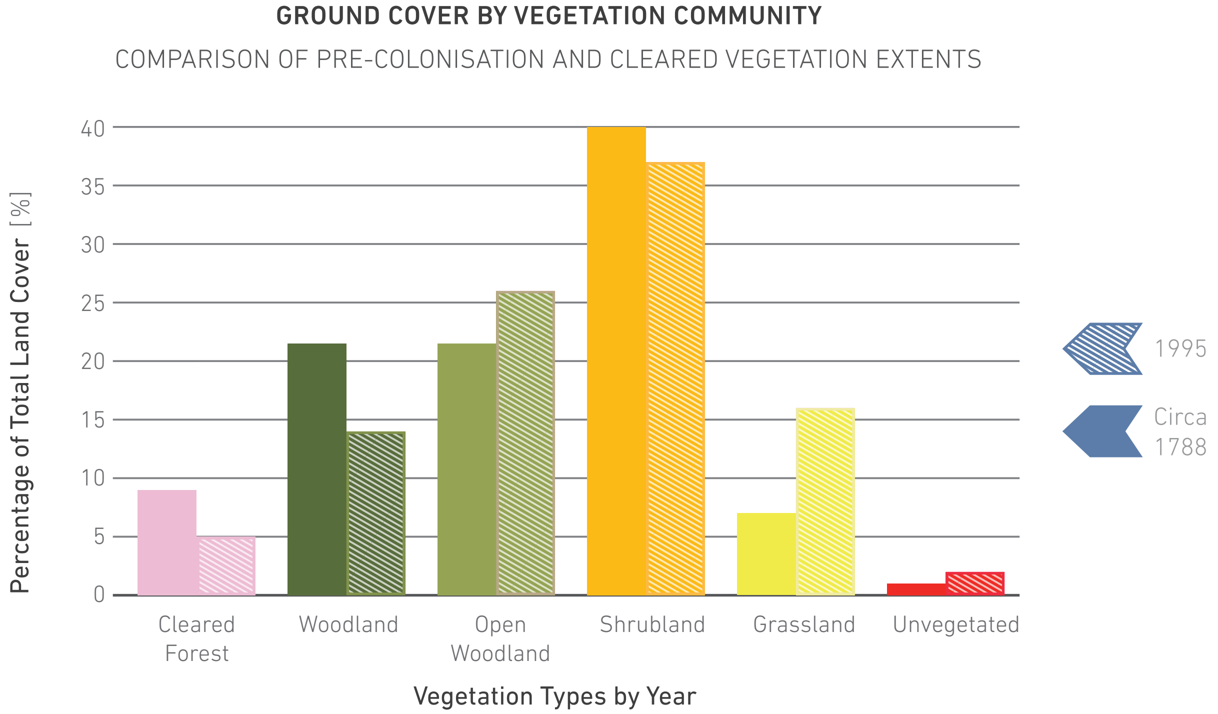

Figure 2.2 Change in major vegetation types up to 1995. 'Forest' is defined as trees taller than 2 m and with a crown cover of 20% or more.[12,16]

cleared was remnant (pre-European) forest. The remaining 40% relates to the re-clearing of woody re-growth from pastures, especially in the brigalow belt, where regrowth is vigorous. In some areas, regrowth is cleared as regularly as every 3 – 6 years.[5]

Since 2006, clearing of listed endangered ecosystems and broad scale clearing of remnant vegetation in Queensland has been deemed unlawful by the Queensland government, but certain exceptions allow it to continue. These exceptions permit clearing for livestock fodder in drought years. 78,000 ha were cleared in 2009 – 2010.[17] In 2013, Queensland again eased its vegetation protection laws.

2.1.4 The effects of widespread clearing

Land clearing has released large amounts of carbon dioxide to the atmosphere, as detailed in ***Part*** 3, but has also had other damaging effects. Agricultural ecosystems now dominate much of Australia's arable land,[7] and this places great pressure on the natural capital on which agriculture itself relies. The loss of vegetation has driven soil degradation and loss, changes to regional climate and biodiversity loss[5, 8] as well as emitting vast amounts of carbon to the atmosphere.

2.1.4.1 Soil loss and degradation

Agriculture and widespread clearing of native vegetation are recognised as the most important cause of land degradation over more than half of the Australian continent.[5,18,19] This reduces soil organic carbon levels, alters fertility and structure and promotes erosion by wind and water. When vegetation is removed, the ground surface is exposed to sunlight, and is more susceptible to drying. The loss of cover also exposes soil to the physical impact of raindrops, and increases runoff at the expense of infiltration, factors which exacerbate erosion. Wind speeds at ground level also increase when the three-dimensional structure of vegetation is removed, and this also promotes drying and erosion.

Cultivation and the introduction of hard-hooved production animals to vast swathes of the country also changed the structure of our soils, making soils more susceptible to erosive loss and compounding the effects

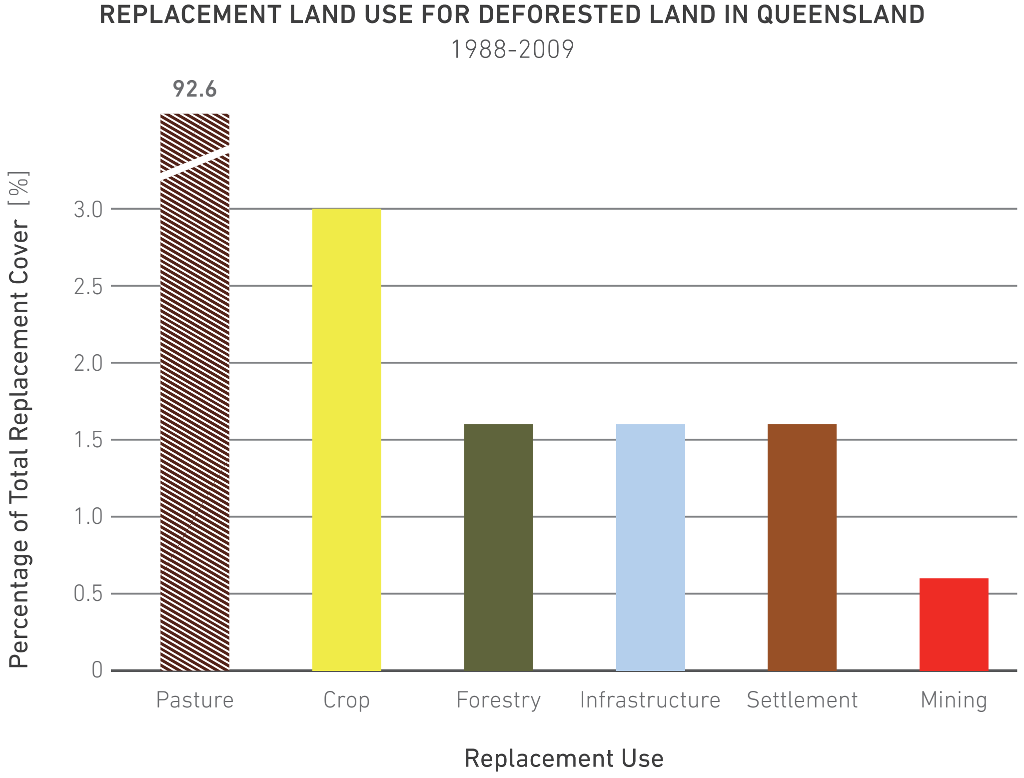

Figure 2.3 Queensland deforestation by replacement land use, 1988–2009.[17]

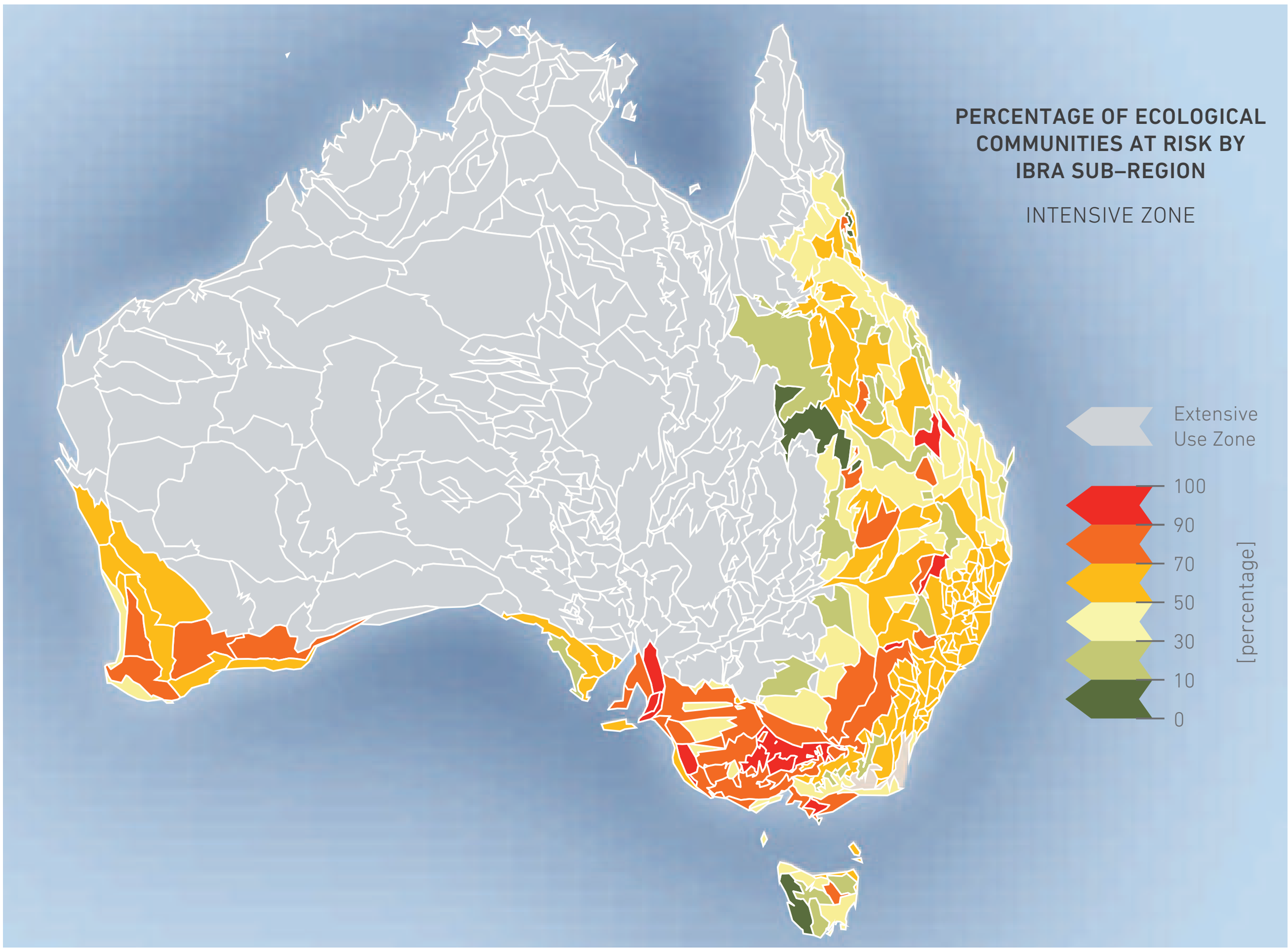

Figure 2.4 Percentage of ecological communities at risk in the intensive land use zone[24] by IBRA sub-region.

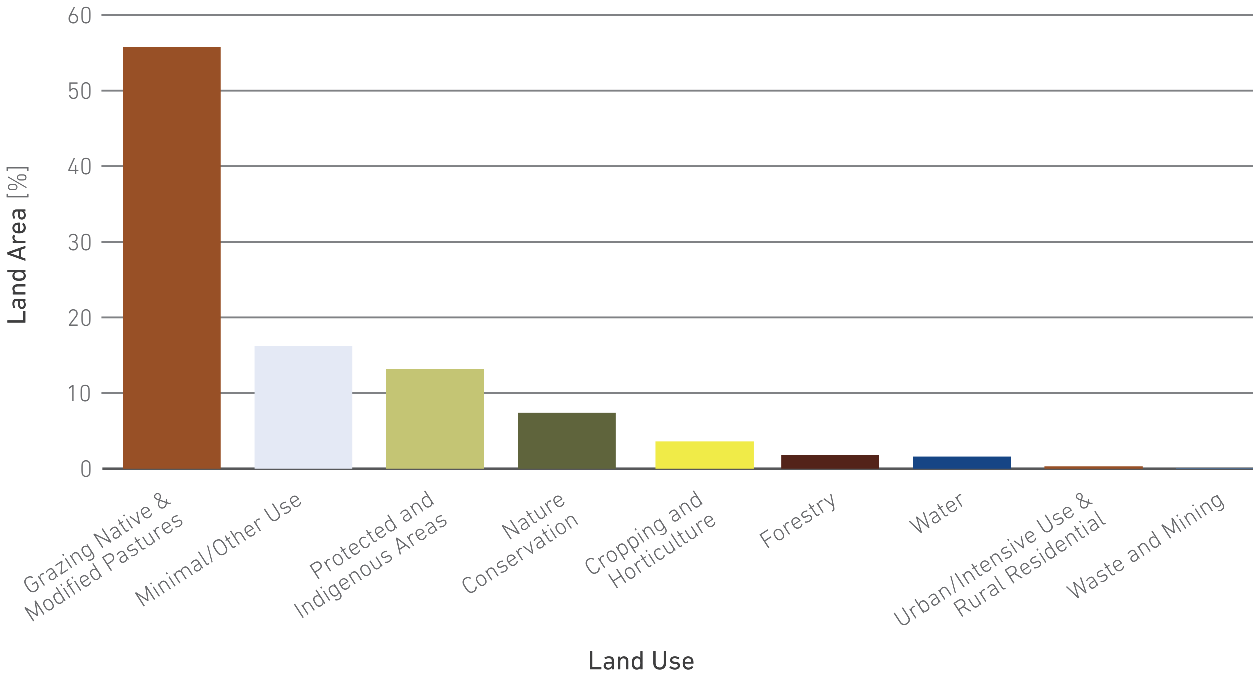

Figure 2.5 Land use in Australia (Australian Collaborative Land Use and Management Program[14])

of clearing itself.[20, 21] The damage caused by introduced feral herbivores, such as rabbits, goats and camels, also contributed heavily to soil loss. Forestry activities and changes to drainage patterns due to the construction of roads, railways and fences have often promoted erosion, both directly through vegetation removal and via changes to water flows. Erosion gullies are a reminder of this ongoing problem. Soil loss and soil carbon loss are covered in more detail in ***Part 4.1*** (*pp 74–76*).

2.1.4.2 Biodiversity loss

Since colonisation Australia has seen more biodiversity loss than any other continent and this rate is still one of the highest globally.[22] Land use change (mainly deforestation) and grazing pressure are the major threats to biodiversity, and causes stress to a range of ecological communities across the continent (***Fig. 2.4***). These are easily visualised as Interim Biogeographical Regionalisation of Australia (IBRA23) sub-regions, described in ***Section 5.2***.

2.1.4.3 Regional climate effects

Tree clearing has made eastern and south-western Australia hotter, and eastern Australia drier than would otherwise occur with global climate change.[8] Decreased rainfall due to tree clearing has been evident in Queensland, New South Wales and southwest Western Australia since the 1950s. Other impacts of tree clearing include regional climate change, greater variability of rainfall, more droughts and more severe floods;[25, 26] more extreme wildfires[27, 28] and greater risk of salinisation.[29, 30] Forest and woodland removal and modification have therefore reduced the resilience of rural landscapes to the impacts of climate change.

Table 2.1 Rural land use by area and gross and export values, 2011 – 12[32].

Activity	Gross Value of Production	Export Value	Land Use Area (Mha)
All crops	$27.6b	$21.7b	26.5
Grains & Oilseeds (wheat)	$12.8b ($7.5b)	$11.1b ($6.4b)	20 (13.5)
Cotton	$2.8b	$2.7b	0.6
Sugar Cane	$1.1b	$1.7b	0.37
Horticulture	$8.4b	$1.7b	-
All meat	$13.7b	$6.8b	-
Beef Cattle	$7.9b	$4.9b	429
Sheep + wool	$5.0b	$4.9b	
Dairy	$b	$2.3b	
Fodder	$1.5b	–	1.7
Forest products	$3.2b	$2.2b	1.4

2.2 Current rural land use

Although the gross value of the combined agriculture, forestry and fishery industries is just 2% of Australia's GDP, the land-based extent of agriculture and forestry occupies around 60% of the continent. This vast spatial extent underlines the potential for rural industries to contribute to an effective national climate change mitigation strategy.

2.2.1 Agriculture

Agriculture dominates our use of the land. Cropping and horticulture occupy about 4% and livestock graze native or modified pastures on almost 56% of the continent (*Fig. 2.5*).[14]

In 2010 – 11, agricultural industries employed 306,700 people in 134,000 businesses.[31] *Table 2.1* shows gross and export values of a range of rural land use industries, as well as the area they occupy. Agriculture is a major contributor to our greenhouse emissions profile, as detailed in subsequent chapters.

2.2.1.1 Grazing

Cattle and sheep grazing is the dominant land use in Australia, occupying 56% of the country. Australia produces 4% of the world's beef, making us the world's 8th biggest producer, and we export 62% of total production.[32, 33] We also produce 8% of the world's sheep meat, of which 45% of lamb and 79% of mutton is exported.[34] Australia's sheep flock built steadily after wool prices reached their peak in 1950—51, reaching a maximum of around 170 million head in the 1960s,[4] but numbers are now down to less than half of that total (*Table 2.2*). Large properties in northern Australia account for most of the grazing extent, largely for beef as detailed below, but grazing is widespread across the continent and has substantially altered native vegetation in many areas (*Fig. 2.6*).

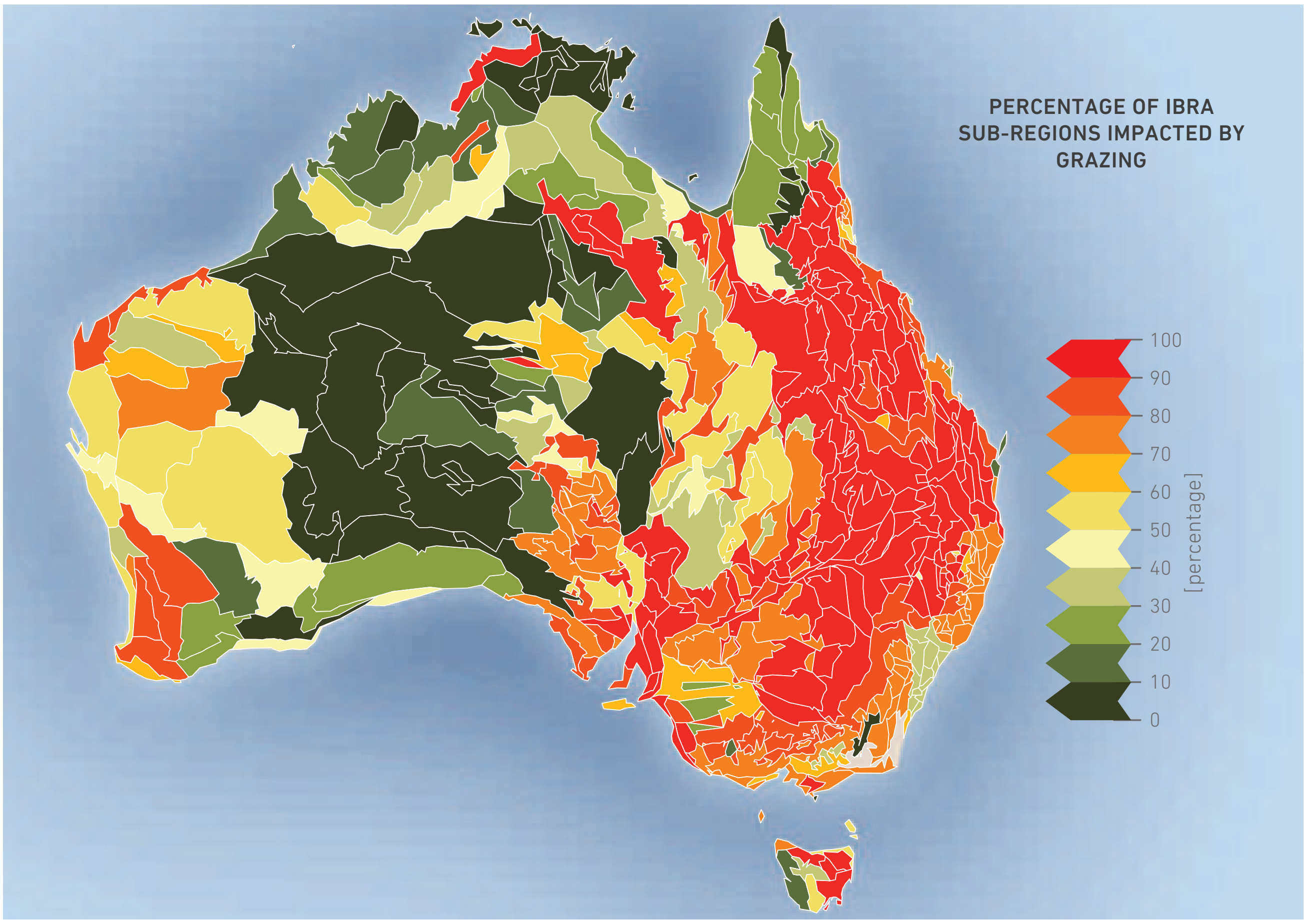

Figure 2.6 Percentage of IBRA sub-regions impacted by grazing.

Table 2.2 Grazed livestock herd size, 2011 – 12[32].

Animals	Herd size 2011 – 12 [million]	Notes
Beef cattle	28.5	7.9 million slaughtered in 2011
Dairy cattle	2.7	
Sheep	74.5	
Goats	1.8	
Camels	1	(feral, not livestock)

Beef

Beef production directly employs 47,000 people and another 18,000 in the mixed beef-sheep industry, while meat processing (all meats) employs another 18,000 people. Northern and southern beef industries are markedly different, and are discussed separately below.

Most meat exports are lower value 'manufacturing beef', mostly frozen, for the food service sector and the hamburger market, from northern *Bos indicus* cattle. Smaller amounts of higher value *Bos taurus* beef are exported, usually chilled.[35] About 600,000 beef cattle are exported live each year.

Northern Australia

Northern herds (Queensland, Northern Territory and northern Western Australia), which occupy three quarters of all beef grazing land, produce 70% of the country's beef. About 500,000 cattle are exported live and 70% of all beef produced from northern herds is exported.[36] Northern properties are predominantly crown land leasehold, leased by pastoral corporations. Such corporate producers, while numbering less than 1% of producers, have large holdings and account for 11% of total cattle sales and 29% of live export cattle.[36] Queensland is Australia's main producer and exporter, supplying nearly 50% of Australia's export beef, worth about $3.4b/yr. A very significant proportion of Australia's grazing land is controlled by offshore interests.

The distribution of cattle breeds varies with climate. In the hot, arid centre and tropical north of Australia the Brahman *Bos indicus* breed is favoured, along with crosses such as Santa Gertrudis, Droughtmaster and Braford. The Brahman breeds are also more resistant to pests and better able to tolerate tropical C4 grasses.[37] Stocking rates for cattle vary markedly, depending on pasture condition and growth, and

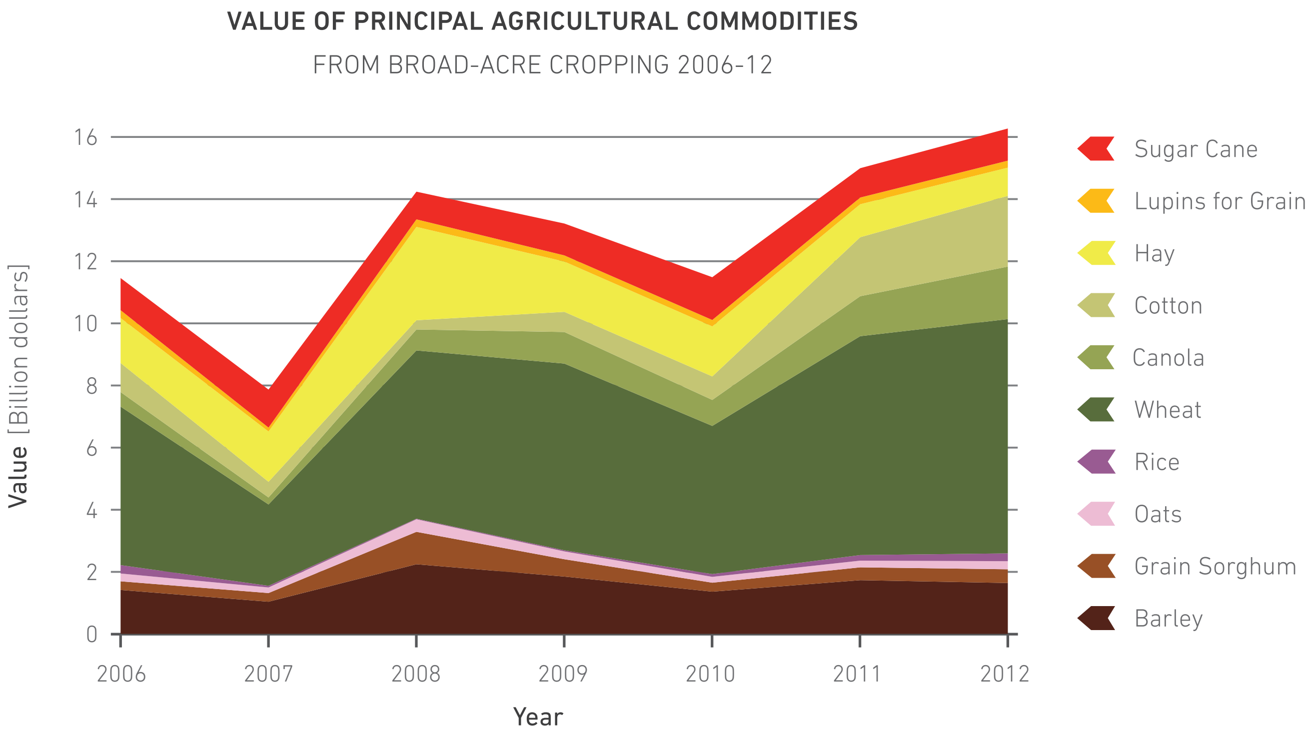

Figure 2.7 Value of principal agricultural commodities from broadacre cropping 2006 – 2012[40].

range from one animal per hectare on improved pasture in good condition, to one animal per three hectares on good native pastures, to one animal per 50 hectares on the least productive pastures.[4]

Southern Australia

Southern producers (NSW, Victoria, South Australia, Tasmania and southern Western Australia) often run cattle and sheep and grow grain crops, particularly in the wheat/ sheep belt of New South Wales. South of the Tropic of Capricorn, the European *Bos taurus* breeds are more suited to these climates, with Angus and Hereford breeds most popular. Other breeds include Charolais, Murray Grey and Shorthorn.

About a quarter of Australian beef cattle are 'finished' in feedlots for about 50 – 120 days, delivering faster weight gain and producing more marketable beef. Prior to this, cattle are weaned at 8 – 10 months then raised on grass until 12 – 28 months of age, weighing 280 – 350kg, when they enter a feedlot.[35] Feedlots are mostly situated in grain growing regions in southern Queensland (60%), and NSW.

Sheep

Sheep are suited to cooler, drier climates, but are grazed on properties from the south of Tasmania as far north as the 20°S latitude, mostly away from the humidity of the coast. Stocking rates for sheep vary from 0.5 – 2 head/ hectare on good native pastures to about 8 – 10 head/ha on quality improved pastures4.

In 2011 – 12, Australia produced 539,000 tonnes of sheep meat and is the largest exporter of mutton and second largest exporter of lamb (behind New Zealand), and the largest exporter of live sheep (2.3 million were exported to the Middle East in 2012). Sheep are run on nearly 44,000 farms, a third of all Australian farms.

Dairy

Dairy cattle are grazed on pastures in higher rainfall regions with more productive pastures. Climatic conditions and natural resources of south-eastern Australia are generally favourable for dairy farming, and Victoria and Tasmania account for 73% of the milk production in Australia. The rainfed pastures of Gippsland and Western Victoria and the irrigated Murray-Darling Riverina are highly productive, and most farms in this region are pasture-based systems where 70—75% of the feed component comes from grazing.[38] Australia's 1.63 million dairy cows each produce around 16 litres of milk per day. Cows are predominantly Holstein Friesians.

Table 2.3 Australian crop production 2011–13[40]

	Area Planted ['000 ha]		Yield [t/ha]		Production [Mt]	
Winter crops	2011—12	2012—13	2011—12	2012—13	2011—12	2012—13
Wheat	13,902	13,243	2.15	1.67	29.905	22.079
Barley	3,718	3,680	2.21	1.84	8.221	6.761
Canola	2,461	2,970	1.39	1.31	3.427	3.898
Chickpeas	456	564	1.48	1.27	0.673	0.713
Faba beans	151	203	1.77	1.86	0.268	0.377
Field peas	249	281	1.38	1.14	0.342	0.320
Lentils	173	164	1.67	1.12	0.288	0.184
Lupins	689	450	1.42	1.02	0.982	0.459
Oats	731	668	1.73	1.57	1.262	1.048
Triticale	145	258	1.97	1.66	0.285	0.429
Summer crops						
Grain sorghum	659	565	3.40	3.05	2.239	1.721
Cottonseed	600	442	2.82	3.17	1.694	1.403
Cotton lint	600	440	2.00	2.24	1.198	0.992
Rice (paddy)	103	116	8.91	10.01	0.919	1.160
Corn (maize)	70	81	6.47	6.13	0.380	0.451
Sunflower	40	28	1.17	1.19	0.047	0.034
Sugar*		397		93.35		37.128

* data for sugar are from ABS (200842) for the year 2006 - 07.

Figure 2.8

2.2.1.2 Cropping

Crops grown in Australia include cereals, oilseeds, sugar cane, legumes, hops, cotton, hay and silage and horticultural crops. Some gross values of production are shown in ***Figure** 2.7*. Our analysis of greenhouse emissions in ***Part 5*** is limited to four cereal crops — wheat, barley, oats and triticale, covering 80% of winter cropping by area[39] — and sugar cane. Other crops are presented here for context. Two-thirds of crop production for domestic markets and all fodder production are consumed as animal feed.

Cropping is defined by three broad agro-ecological regions: Northern — having dominant subtropical and summer rainfall; Southeastern — with seasonally uniform to winter-dominant rainfall; and Western/Southern — with Mediterranean-type dominant winter rainfall. The northern region has summer cereal production (primarily sorghum and maize) with smaller areas of summer-growing pulses (peanuts, mung beans) and oilseeds (sunflower, safflower). The northern region is the source of most premium hard high protein wheat, and supplies large amounts of feed grain to southern Queensland beef feedlots.

Grains

The South-East Australian wheat belt, where rainfall is winter-dominant, produces the bulk of Australia's cereals, often in rotations that include grazing. Small areas of highly-productive summer cereal crops are also produced under irrigation in the Murray-Darling region of south-eastern Australia. Crop compositions across the south-eastern and southern region and the Western Australian wheatbelt regions are broadly similar with the exceptions of triticale in the south-east produced mainly as feed for dairy cattle and greater production of lupins in WA. Overall crop production for 2011 to 2013 is given in ***Table 2.3***.

Australia produces about 35 million tonnes [Mt] of grain each year (***Table 2.3***). Wheat is the dominant crop in terms of area sown and total production, with barley a distant second. Grain export volumes depend on production, which is dramatically reduced in drought years. Wheat also dominates Australia's grain exports by value and quantity, and as much as 70—90% of the crop is exported in years of high production (***Fig. 2.9***). However, the majority of Australian-produced chickpeas, barley, canola and field

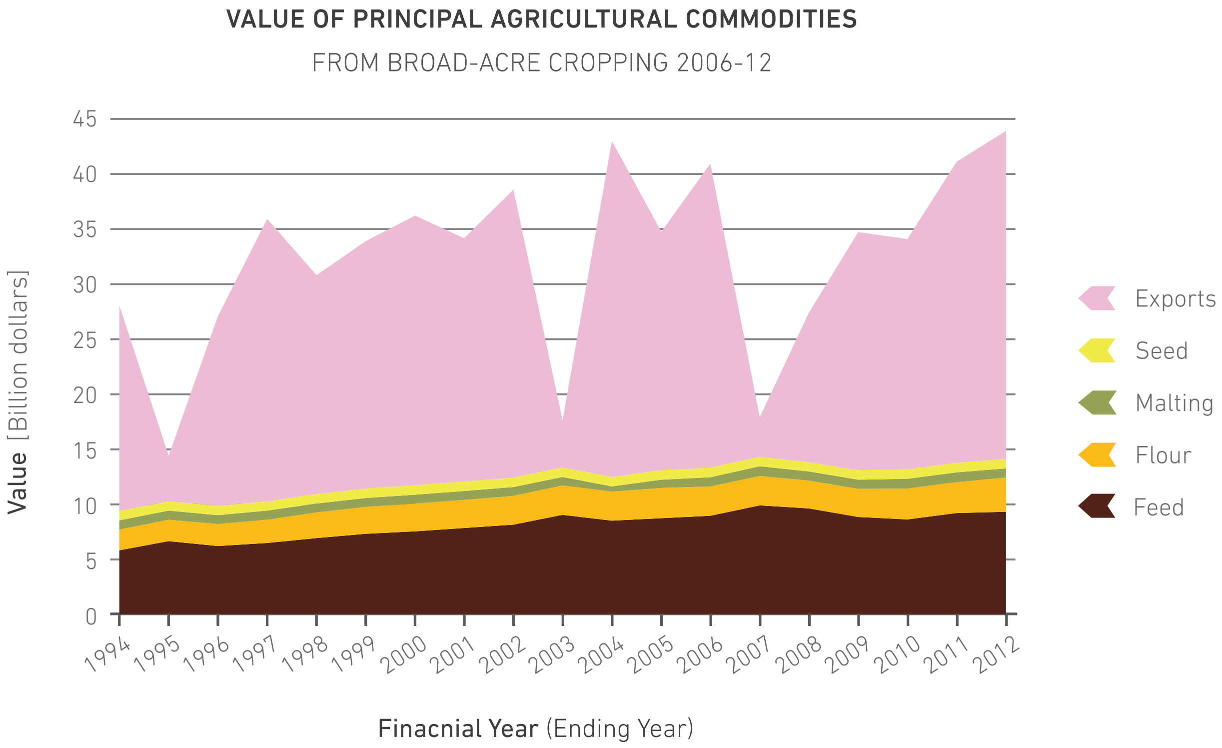

Figure 2.9 **Value and end-usage of grains produced in Australia[43].**

peas are also exported, along with some lupins, grain sorghum, oats and corn.

Domestic consumption is very consistent: 66—68% goes to animal feed, 20% to flour production and the remainder to malt, seed and ethanol production. Feed for beef and dairy cattle, sheep, pigs and poultry amounted to an average of 9.265 Mt/year for the period 2006—2012.[42] Nationally, concentrate feeds for the beef and dairy industries may consume as much as half of all grain sold as stockfeed.[42] Feedlots in the southern Queensland grain growing region are the greatest single consumer of feed (≈3—3.5 Mt), followed by Victorian dairy farms and NSW feedlots. Wheat, barley and sorghum are the main feed grains. Coarse grains sorghum and triticale are dedicated feed grains and are supplemented by soy, cotton and canola seed meal in stockfeed manufacture. The use of other grains for stockfeed is determined by relative prices. Usually, feedlots are considered a reliable though low-value market for grains that often do not meet human food market standards.

Grain milling, malting and brewing industries earn $6.6 billion annually and also supply the feed compounding industry that in turn supplies Australia's $14.6 billon intensive animal production sector for beef, dairy, pork and poultry production. Wheat is also the most-consumed domestic grain, with around 2.5—3 Mt milled annually. NSW is the major flour milling state with 62% of flour production. Around 1 Mt of barley is used in malt production each year, but this uses less than 1 Mt of the 7 Mt of barley produced; around two-thirds of total production is for stockfeed. Grain end-usage and export quantities for 1993—2011 are given in ***Figure 2.9***.

Sugar cane

Sugar cane is an important commercial crop, grown along the north-east tropical and sub-tropical high rainfall coastal floodplains. All but 10% of this crop is grown in Queensland, and 80% of sugar produced is exported.[43]

Much cane is grown on fertile coastal soils. Pre-harvest cane fires were commonplace up until the past decade or so, but now 80% of farms have adopted green harvesting and green trash blanketing.[44] Due to high fertiliser application rates, high rainfall and proximity to waterways and coastal estuaries, sugar cane has caused substantial nitrogen and phosphorous pollution.[44] In some areas, disturbance of waterlogged coastal soils has resulted in acid sulphate release. Sugar cropping, particularly on acid sulphate soils, is a strong source of both methane and nitrous oxide, powerful greenhouse gases.[45]

Table 2.4 Broadacre crops in Australia, 2006 – 07 (Longmire unpubl.; data from ABS (2008)42).

Use	Commodity	Area [ha]	Area (% of total cropped)
Non-feed	Wheat-oats-barley	17,778,766	72.1
	Rice	102,130	0.4
	Oilseeds	1,091,328	4.4
	Non-cereal broadacre	1,705,929	6.9
	Cotton	327,240	1.3
	Sugar	397,746	1.6
	Other	129,783	0.5
	Total non-feed	21,532,922	87.3
Feed	Triticale	391,788	1.6
	Sorghum for grain	766,679	3.1
	Maize for grain	67,212	0.3
	Hay	1,914,517	7.8
	Total feed	3,140,196	12.7
Total		24,673,118	100

Other cropping

Australian horticulture produces a wide variety of fruit, vegetables, nuts, flowers, turf and nursery products from mainly small scale family owned farms. However, it still has the third largest agricultural gross value of production and employs 63,000 directly and another 9,800 in fruit and vegetable processing.[46] Major crops in order of their value are fruit and nuts, vegetables and nursery, flower and turf production. Most vegetables are grown close to urban centres to minimise transport costs, although large wholesalers and buyers such as supermarkets have nation-wide transport systems. Due to their proximity to expanding urban areas, farmers have come under strong pressure from urban development. Productive horticultural areas have been subsumed by the spread of urban areas, a process that is largely irreversible.

Major vegetable crops are potatoes ($600 million; by far the largest in area and value of production) and tomatoes. Fruit varieties include exotic tropical fruits and stonefruits grown in temperate regions. Bananas, valued at nearly $500 million, are the largest single fruit crop, followed by apples and oranges. Grapes for winemaking, drying and table use had a gross value of production of $1.1 billion, grown. Grapes are grown largely in winter rainfall zones of South Australia (≈50% of the national harvest), and other southern regions.

Cotton is grown in New South Wales (60% of production) and Queensland, away from the coast, in the Murray-Darling catchment where irrigation water is available. Due to heavy reliance on irrigation, cotton harvests vary considerably: gross value of production in 2009 – 10 was $754 million, up from $227 million in 2007 – 08 (a drought year). Although the main product is cotton lint, oil is extracted from the seeds and kernels are crushed for stock feed.

Fodder crops

Fodder crops are not directly covered in our analysis of greenhouse gas emissions from agriculture, but are planted over large areas. Pasture grasses, cereal, lucerne, clover and vetches are planted, as well as other varieties. Around 38,000 properties make hay each year, with a production value similar to that of barley, sugar and poultry. Yearly hay production is 4—7 Mt, mostly in Victoria (39% of production) and in NSW, with dairy production the single largest domestic user of fodder, followed by beef producers, the horse industry and feedlots. However, the largest market for fodder is export.[46]

Silage production (fodder cut and stored green) amounted to 2.5—3.8 Mt from about 10,000 farms.[46] Fodder can be stored for several years: these crops supply feed in the dry season or in winter, therefore demand for fodder in drought years is high, creating a useful income for those properties not affected by drought. Typically, 20—40% of feedlot ration is roughage from fodder.

Of the total area planted to broadacre crops in 2006 – 07, 12.7% was dedicated to the production of commodities neither for human consumption nor forming part of a crop rotation with the objective of producing food for people (***Table 2.4***).[47]

Table 2.4 gives a conservative estimate of the land dedicated to animal feeds, as e.g. all oilseed production is counted as for human consumption when in fact many such crops are grown as a disease break in cropping systems whose primary objective is to cultivate cereals. One such crop, canola, accounted for almost 90% of all oilseeds by area in 2006 – 2007.[41] In reality, a significant proportion of other cereals, for example wheat, oats and barley, are also destined for the stockfeed market as detailed above. Crops planted largely or exclusively for nitrogen supplement are also included as 'non-feed' crops. In contrast, some maize is destined for human consumption.

2.2.2 Forestry

2.2.2.1 Extent of Australia's Forests

Forests cover around 149 million hectares or nearly 20 percent of the continent. They are mostly dominated by the eucalypt species, comprising of 79%50. The Eucalypts are extensive and feature a diversity of sub-species, from the low woodland ironbarks (*Eucalyptus jensenii*) in the Kimberley region of north-west Australia through to the tall and wet mountain ash (*Eucalyptus regnans Muell.*) dominated forests of south east Australia. They span distinctive climate zones, from the tropics in northern Australia, to the alpine regions of south-east Australia, through to the arid semi-deserts of Central Australia.[49] Over all, there are about 500 – 700 species of eucalyptus trees recognised.[50] Interspersed with the coverage of *Eucalyptus* dominated forest are other forest types. These include closed rainforests, which are in themselves diverse, consisting of tropical rainforests in far north Queensland through to the closed cool temperate rainforests of Victoria and Tasmania.[49] These mostly occupy fire protected refugia in the landscape.[51] There are 1.82 million hectares of plantations, mostly comprising 1.0 million hectares of pine (softwood) and 0.81 million hectares of eucalypt (hardwood), an increase of 12% over the 1.63 million hectares reported in 2003.[48]

2.2.2.2 Concentration of Forestry and Logging across Australia's Forests

Forestry and logging activities have been mostly concentrated in the rainforest, eucalyptus open and tall open forest major vegetation groups (MVGs) throughout Australia (***Table 2.5***).[52, 53] These MVGs have been considered valuable for logging owing to the relative tall trees that comprise their dominant canopy. The eucalyptus tall open forest MVG is considered the most valued, where the trees are over 30 metres tall and can reach heights of 100m. They include the tallest tree species in Australia and the tallest flowering plant in the world, *Eucalyptus regnans* (mountain ash).[54] These species were particularly exploited from the 1920s onward to supply timber for the housing boom following the Second World War.[55] The development of the pulp and paper industry and the technical utilisation of eucalyptus trees for pulp production also rapidly expanded around this time, particularly in Victoria and Tasmania.[53] Other species considered valuable by the logging industry include *E. delegatensis* (alpine ash), *E. diversicolor* (karri) and *E. nitens* (shining gum).[56, 57] Eucalyptus tall open forest is restricted the wetter areas of eastern Australia, which extend from the margins of the rainforests of northern Queensland through to Tasmania and the south-west of Western Australia. They are often located in mountainous areas.[54] A comparatively small 14% of these forests was cleared for agriculture.

Logging has also been conducted, though to a lesser extent, throughout the eucalyptus open forest MVG. This group contains trees with heights from 10m to 30m and they are widespread along the subcoastal plains and foothills and ranges of the Great Dividing Range in eastern Australia and the subcoastal ranges of the south-west of Western Australia.[54] Species valued by the logging industry found within this vegetation group include *E. obliqua* (messmate), *E. maculata* (spotted gum) and *E. marginata* (jarrah).[57] These species were used in housing and construction, but were also increasingly used for export woodchipping supplying the Japanese paper manufacturing market following the late 1960s.[52] Their relative proximity to coastal ports made them viable for such exploitation.[53] In comparison to the eucalyptus tall open forests, nearly a third of the eucalyptus open forest was cleared for grazing and agriculture in the major agricultural zones of eastern Australia and the south-west of Western Australia.[54] Unregulated timber-getting in these forests during the 19th Century resulted in large areas of land becoming rapidly degraded, prompting Australian governments to establish forestry agencies to regulate such activities.[58] Logging currently occurs in remaining forest outside the formal reserve system.[48]

Historically, large areas of rainforest were exploited for timber. This was particularly evident throughout northern and eastern Queensland and north east New South Wales.[53] The rainforest (and vine thicket) MVG consist of closed forests characterised by dense foliage and a large diversity of plant species. They are mostly confined to the wetter areas or climatic refugia in eastern Australia.[54] They are highly diverse in range and floristic composition, particularly in northern Australia.[59] The southern rainforests are distinct from their northern counterparts, in that they are dominated by fewer species, notably *Nothofagus cunninghamii* (myrtle beech) and *Atherosperma moschatum* (southern sassafras).

Table 2.5 Major Vegetation Groups (MVG) with pre-European settlement (1750) extent, current extent, difference and percent change. Shaded cells indicate where forestry and logging have been primarily concentrated (Source: NVIS 1999)56.

Major Vegetation Group	1750 Extent (ha)	Current Extent [ha]	Difference (Loss) [ha]	Reduction
Rainforest and vine thickets	5,345,323	3,522,837	1,822,486	34%
Eucalyptus tall open forest	4,079,488	3,527,019	552,469	14%
Eucalyptus open forest	39,407,442	27,162,932	12,244,510	31%
Eucalyptus low open forest	491,235	404,423	86,812	18%
Eucalyptus woodlands	136,163,314	89,215,913	46,947,401	34%
Acacia forests and woodlands	49,469,613	40,834,623	8,634,990	17%
Callitris forests and woodlands	4,029,270	3,230,619	798,651	20%
Casuarina forests and woodlands	16,622,023	14,921,788	1,700,235	10%
Melaleuca forests and woodlands	10,583,534	9,934,040	649,494	6%
Other forests and woodlands	8,067,916	7,230,977	836,939	10%
Eucalyptus open woodlands	49,788,513	45,790,258	3,998,255	8%
Tropical Eucalyptus woodlands/grasslands	11,523,374	11,219,993	303,381	3%
Acacia open woodlands	32,077,375	31,384,612	692,763	2%
Mallee woodlands and shrublands	38,725,742	27,162,678	11,563,064	30%
Low closed forest and tall closed shrubland	2,584,785	1,630,435	954,350	37%
Acacia shrublands	86,538,636	85,070,746	1,467,890	2%
Other shrublands	15,759,842	12,350,619	3,409,223	22%
Heath	928,682	808,647	120,035	13%
Tussock grasslands	55,977,625	52,580,174	3,397,451	6%
Hummock grasslands	136,765,618	136,636,169	129,449	0%
Other grasslands, herblands, sedgelands and rushlands	6,807,973	6,486,146	321,827	5%
Chenopod shrublands, samphire shrubs and forblands	44,716,538	43,680,155	1,036,383	2%
Mangroves	1,011,440	962,964	48,476	5%
Total	757,465,301	655,748,767	101,716,534	13%

Rainforests also occur in drier environments, such as those in the semi-arid tropics of Northern Territory and the Kimberley region of Western Australia.[51, 54] Rainforests were cleared extensively during the nineteenth and early twentieth centuries for high value timbers, dairying, tobacco, sugar cane and other agricultural production.[54] Over a third of Australia's rainforest cover has been cleared (***Table 2.5***). Specific tree species were targeted, such as red cedar, where nearly all accessible trees were cut.[60] The introduction of state forestry agencies during the 1920s brought regulation of timber getting in these forest types.

In more recent times, increasing environmental awareness and the modern environment movement targeted rainforest logging and advocated for the protection of rainforests, particularly in Australia.[53] The Terania Creek protests in north east New South Wales rainforest and those against development in the wet tropics of far north Queensland during the late 1970s and early 1980s drew national attention and saw the reduction and demise of widespread logging in rainforests across Australia.[61 – 63] Most current logging occurs in the eucalyptus tall open forests and eucalyptus open forests.

The Australian logging industry extensively sources from the plantation estate, which consists of two million hectares. Of this, 977,000 ha have been planted with hardwood species, such as *E. globulus* (tasmanian blue gum) and *E. nitens* (shining gum), and over one million hectares planted with softwood species, including *Pinus radiata* (radiata pine) and *Araucaria cunninghamii* (hoop pine).[48] The plantation estate was established in part to supply builders with preferred softwood species over the then unfamiliar eucalyptus species.[63] Concerns over wood shortages increased the drive to establish plantations.[64] Since the late 1990s, increased rates of plantation establishment occurred as a result of the Managed Investment Schemes (MIS) from an area estimated at 1.3 million hectares in 1998 to 2.0 million hectares in 2009, mainly to hardwood eucalypts.[65]

The majority of wood grown in Australia is sourced from the country's plantation estate, totalling around 65 percent of the total. Details of these volumes are presented in ***Figure 2.10***. Of this, around 82% of volume is sourced from the softwood plantation sector (14 million m^3). The greater proportion of this is for sawlog. In contrast, the hardwood plantation sector primarily produces pulp logs for woodchip export.[39]

The native forest hardwood is, by volume, dominated by the woodchip sector (63% of volume logged), and with the majority of this exported.[39] Although covering a much

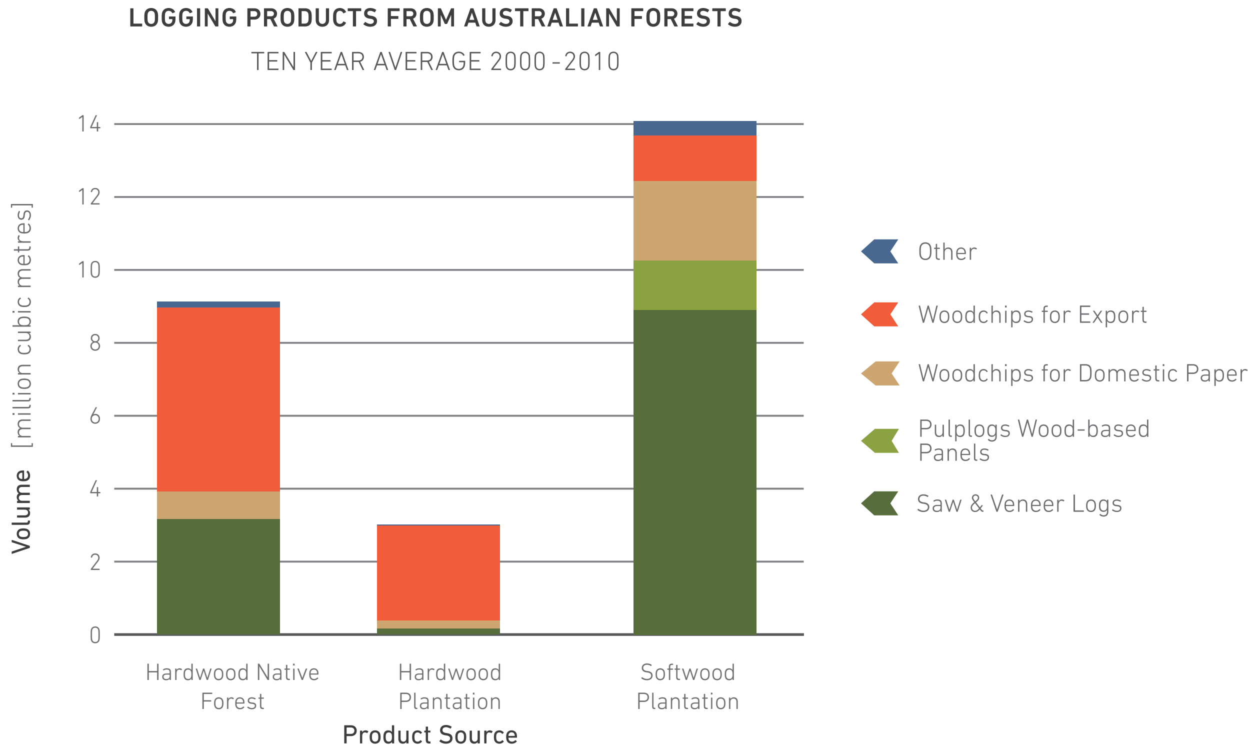

Figure 2.10 Logs produced in Australia's native forests and plantations 2000-10. (Source: ABARES 2012)32

larger area than the plantation estate, native forests yield lower volumes. This is largely because plant selection and breeding combine with more intensive management techniques in plantations to produce higher yields. However, logging practices in native forests have intensified over the past 40 years. Clark (2004[66]) argues that the drivers behind this were for the native forest sector to remain competitive with the plantation sector. This resulted in mature and old forests being clearfell logged (where all standing trees are removed, merchantable logs taken and remaining forest debris burnt to create an ash bed) and the forest landscape shifted to a continual 'regrowth' phase. This has been accompanied by shortened logging rotations and the application of plantation management techniques, such as commercial thinning, to increase wood yields.

2.2.2.3 Contention and change concerning Australia's forest management practices

This intensification of logging drew considerable public controversy, particularly in the states of Western Australia, New South Wales, Victoria and Tasmania.[53] The Routley's *The Fight for the Forests*[67] questioned the wood production ideology of Australian forest management and heralded the beginning of a changing perspective on forest conservation.[68] Successive governments, both at the federal and state levels, have attempted to resolve the conflict over forest management. The most ambitious and costly attempt was the Regional Forest Agreement (RFA) process, initiated by the Keating Government under its National Forest Policy Statement.[69] The outcome was to provide industry with resource security and provide for a 'Comprehensive, Adequate and Representative' (CAR) reserve system across Australia's forest estate. It sought to protect:

- 15% of the pre-1750 distribution of each forest type;
- 60% of the existing distribution of each forest type, if it was vulnerable;
- 60% of the existing old-growth forest;
- 90% or more of high-quality wilderness forests;
- all remaining occurrences of rare and endangered forest ecosystems (including rare, old-growth forests).

The process resulted in the transfer of more than 2 million hectares of forest from the broad tenure category of multiple-use public forest to nature conservation reserves.[48] However, the RFAs resulted in the further intensification of logging operations in non-reserved areas. This was evident in the state of Tasmania, where up to 85,000 hectares of native eucalyptus forest was to be cleared for exotic plantations of radiata pine and fast growing eucalypts.[64] Furthermore, the adequacy of the reserve system under the RFAs was questioned. Williams *et al.* (2007[70]) stated that:

> *…..the RFAs do not provide a comprehensive coverage of the native forest estate as there are important areas that have not been assessed. Further, within the regions where RFAs were undertaken, many important conservation needs have not been adequately addressed. For example, several biologically significant ecosystems and species have not been adequately protected, many additions to the conservation reserve network have not been determined using the best available scientific techniques, and the efficacy of a number of forestry management prescriptions remains to be determined. The implications of these limitations for biodiversity conservation may be amplified since government quotas on wood-chipping were removed on signing of an RFA. Hence, the potential for the intensification of wood-chipping in these regions on public and private lands has significantly increased. (p55)*

The majority of native forest logging is conducted by state owned corporations. These include VicForests, Forests NSW, Forest Products DAFF (Queensland), Forest Products Commission Western Australia and Forestry Tasmania. Collectively, they manage nearly 9 million hectares of native forest and small areas of plantation throughout Australia.[71] Although it is often argued that sawlogs drive these state owned enterprises (e.g.[72]), pulplogs dominate volume output. Volume output for VicForests, the state owned corporation of the Victorian government, changed with the logging and sale of logs from Victorian public native forests.[73] Since its inception in 2004, VicForests has averaged 68% of its output as pulp-log. In contrast, the state owned corporation charged with the logging and sale of logs from government-owned plantations in South Australia has almost the inverse sawlog/pulplog ratio, with around 38% of its output pulp-logs.[74] These volumes are detailed in ***Figure 2.11***.

This falls within the overall trend of the Australian wood products industry becoming highly commodified.[66] It has made Australia a net exporter of low value products, particularly its relatively large volume surplus of wood chips. It is an importer of value added products. While considerably less in volume, the value of those imports has resulted in Australia sustaining a trade deficit average of nearly $A 2 billion for 2000 – 10 (***Table 2.6***).

The expansion of woodchipping , particularly in the native forest sector, has resulted in remote areas of forest becoming accessible, where under an exclusive sawlog regime, they were deemed uneconomic to log. Since the expansion, large areas of forest have been opened up to clearfell logging, which drives on the model of attaining maximum yield for the least amount of labour.[66] Large volumes of low value product are produced, and have now become the driver of the industry. This was recently expressed in the Victorian Auditor General Office's (VAGO) report into VicForests, Victoria's state owned logging enterprise. Where it stated:

> *While sawlog sales drive VicForests' operations, VicForests and the industry could not operate financially without complementary pulp log sales.*[75]

The impact of the commoditisation of native forests has resulted in large areas of native forest undergoing transformation, where the impact of clearfell logging results in the creation of homogenous and uniform stands of young trees.[76] This alters the functioning of these forests and results in a reduction of their carbon stock.[77] This is further explored in ***Parts 3 & 4***.

Table 2.6 Summary of trade flow for Australian Forest and Wood products, average volumes 2000 – 10.

	Imports	Exports	Difference
Wood [x1000 m^3]	1,133.2	1,761.1	+627.9
Paper and Woodchips [x1000 t)	2,034.8	7,033.7	+4,998.9
Value [$A]	4,144.1	2,205.0	-1,939.1

Figure 2.11 Wood volumes of sawlogs and pulplogs for VicForests and Forestry South Australia 2005-2013.

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Part 3

Greenhouse Emissions from Rural Land Use

Contents

3.0 Introduction

This chapter explores the greenhouse gases arising from agriculture and forestry. To do this, we first describe emissions as they are reported under different protocols, each of these a part of the National Inventory Report (NIR).[1] We explain why current reporting conventions underestimate the land use sector's total emissions. We then break the agriculture sector into sub-sectors, and identify the emissions from each as reported according to UNFCCC guidelines. Finally we describe how national inventories, by UNFCCC convention, omit short lived emissions and discuss the importance of these emissions and how they mostly arise from agriculture.

Chapter highlights

- The national inventory records agriculture as emitting 85.3 Mt CO_2-e/yr but this quantity doubles when emissions from land clearing for agriculture are included. The revised total, almost 190 Mt CO_2-e/yr, is 33% of emissions from the whole economy.
- Within the agriculture sector, annual emissions from clearing (73.9 Mt CO_2-e/yr) and subsequent soil carbon loss (24.2 Mt CO_2-e/yr) exceed even those from enteric fermentation (56.2 Mt CO_2-e/yr). Current emissions from clearing in Queensland alone are estimated at 56 Mt CO_2-e/yr, 10% of national emissions from all sources.
- Crop emissions are minor in comparison to land clearing and enteric fermentation.
- Clearfell logging is applied to Australia's most carbon-dense landscapes, causing large emissions and preventing ongoing carbon sequestration in living forests.
- Forest carbon stocks are systematically underestimated by a factor of up to five which undervalues their contribution to a stable climate.
- Logging in the Victorian Central Highlands alone may have caused the emission of 57 Mt CO_2 since the practice was begun.

3.1 How are land use emissions counted?

Australia reports greenhouse emissions under a number of different protocols; two are described below. Emissions from agriculture are not easy to find in the NIR, the assessment most commonly referred to, because those listed under the Agriculture category are far from comprehensive. Other emissions are obscured by accounting methods. Alternative official methods of dividing the economy into emissions sectors are also explored. We describe where other emissions caused by agriculture are reported, and attribute these to agriculture.

3.1.1 Standard emissions reporting in the National Inventory Report

Australians would be most familiar with the national inventory breakdown in ***Figure 3.1***, showing *Agriculture* as the source of around 15% of national emissions.[1] This is the standard, most easily recognised breakdown and identifies Stationary Energy (including coal and gas fired electricity generation, and gas heat production) as the prime source of emissions in Australia, suggesting that fossil fuels are the prime target for mitigation. Indeed this understanding of Australia's national greenhouse emissions profile was the basis of Beyond Zero Emissions' previous work on the stationary energy sector.[2]

Net emissions are reported for ***Land Use, Land Use Change and Forestry*** (LULUCF), obscuring deforestation emissions as discussed below.

3.1.2 Where to find agricultural emissions in the National Inventory Report

Emissions resulting directly from agriculture are provided in the NIR under three sectors: ***Agriculture***, ***Land Use, Land Use Change and Forestry*** (LULUCF) and ***Energy*** (***Table 3.1***.).

The LULUCF sector reports net emissions from grassland, cropland and forest land. This sector contains large sinks due to forest growth, as well as large emissions due to

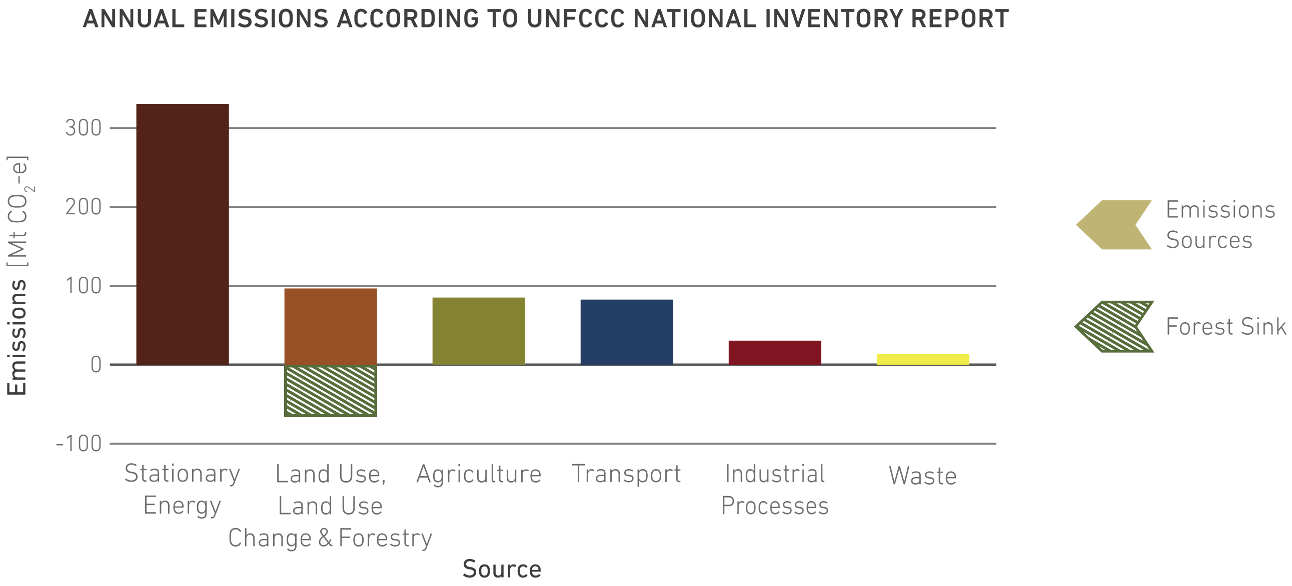

Figure 3.1 Australian average annual emissions 2006-2010 by UNFCCC sector (Mt CO_2-e/yr).

deforestation and subsequent soil carbon loss, plus a number of other minor sources. For 2006 – 2010, average net LULUCF emissions amounted to 14.7 Mt CO_2-e, whereas 113.5 Mt CO_2-e in emissions were generated. In other words, forest sinks offset 99 Mt CO_2-e in emissions from other agricultural and land uses, effectively hiding these emissions from scrutiny.

Clearing to make way for pasture and crops is effectively an agricultural activity, so we attribute the associated emissions to the agriculture sector for the purpose of our analysis. Natural forest growth, though it is claimed as an offset against LULUCF emissions as described above, is in contrast not an agricultural activity and therefore should be counted as distinct. Agricultural emissions (mostly from

Table 3.1 Average annual emissions (2006 – 2010) from agricultural production, their attribution to National Inventory Report sectors and magnitudes.

Sector	Categories	Greenhouse Gases	NIR Total* [Mt CO_2-e]
Agriculture	Enteric Fermentation Manure Management Rice Cultivation Prescribed burning of savannas Field burning of agricultural residues	CH_4, N_2O, NO_x, CO, NMVOC†	85.3
Land Use, Land Use Change & Forestry (LULUCF)	Land Clearing to Cropland Land Clearing to Grassland Agricultural Liming N_2O from soil disturbance	CO_2, CH_4, N_2O, NO_x, CO, NMVOC	99.6
Energy	On-farm Energy	CO_2, CH_4, N_2O, NO_x, CO, NMVOC	4.6

* Agriculture includes no CO_2 emissions, but CO_2 emissions from cropland and grassland appear under LULUCF

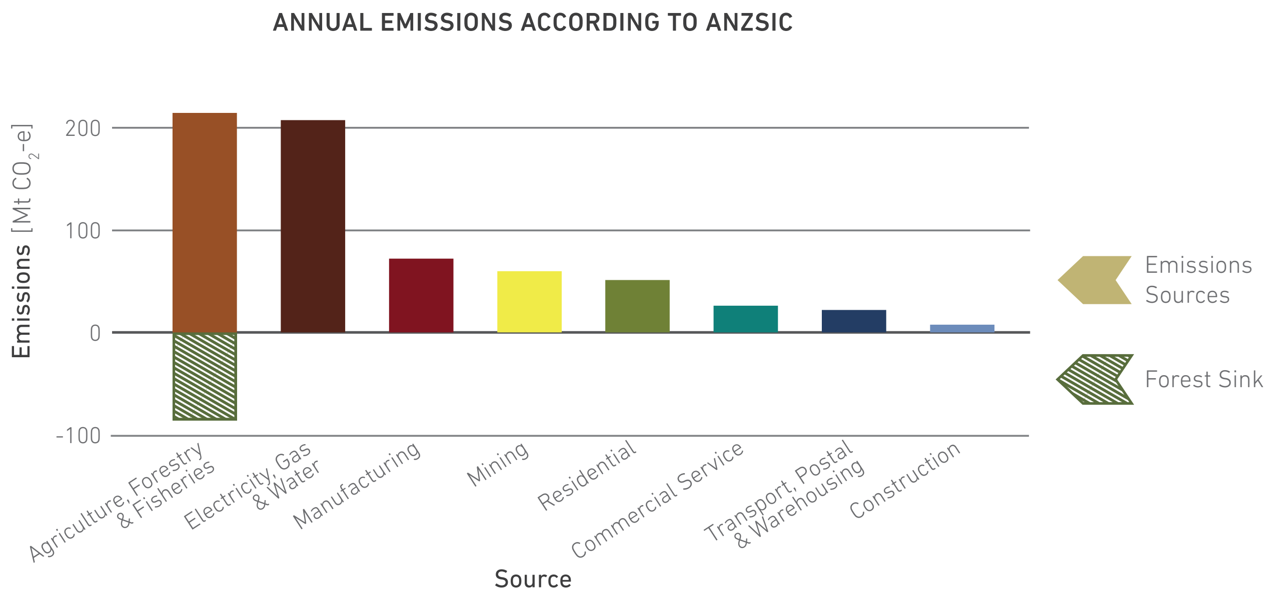

Figure 3.2 Average annual emissions 2006–2010 by ANZSIC sector (Mt CO_2-e/yr), with Forestry carbon sinks shown separately from Agriculture and Fisheries.

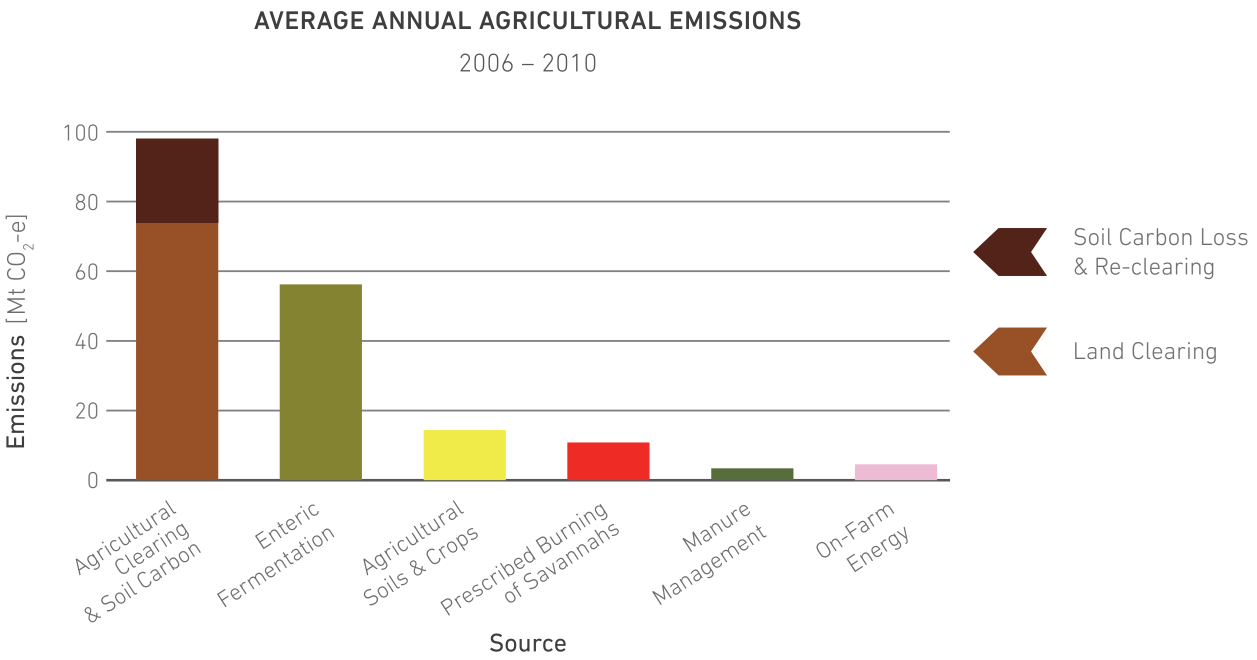

Figure 3.3 Agricultural emissions (Mt CO_2-e/yr). Agricultural Clearing & Soil Carbon emissions are recorded under LULUCF, and Agricultural Soils & Crops includes direct soil emissions (predominantly from manure and synthetic fertilisers), field burning of agricultural residues, liming, rice cultivation and soil disturbance.

clearing) reported under LULUCF exceed those in the ***Agriculture*** sector.

Greenhouse emissions from agricultural production include CH_4 and N_2O emissions from grazed pastures reported in ***Prescribed Burning of Savannas***, and CO_2, CH_4 and N_2O from grassland emissions (including deforestation to grassland and subsequent loss of soil carbon). Similarly the emissions sub-categories ***Cropland, Field Burning of***

Agricultural Residues and ***Agricultural Lime*** are directly related to cropping so have been aggregated (***Table 3.1***)

Total emissions attributable to Australian agricultural production amount to 189.5 Mt CO_2-e, or 33% of average total national emissions for 2006 – 2010. This total includes emissions from deforestation for agriculture, cropland and pasture soils, pasture maintenance fires, and from on-farm energy use but excludes off-farm transport, processing and waste generated in the sector. Our attribution of these emissions to agriculture, and the resultant expanded contribution of agriculture to the national total emissions, is in agreement with a 2005 study by Foran and colleagues. into the economic, social and environmental impacts of Australian industries. This study found that a comparable aggregation of agricultural production and processing produced 33% of national emissions.[3]

3.1.3 Emissions by ANZSIC sector

The NIR also provides emissions data according to the Australian and New Zealand Standard Industry Classifications (ANZSIC), a categorisation of industries used by the Australian Bureau of Statistics. Agricultural emissions in the LULUCF sector can be shown in relation to this protocol, and this is a useful exercise for the purpose of comparison.

As is the case under the UNFCCC's LULUCF category, emissions reported for agriculture under ANZSIC are net of negative emissions from forestry sinks. Forest growth provided an average sink of 84.9 Mt CO_2-e, or -15% of national emissions from 2006 – 2010. A clearer picture of emissions from agricultural industries can be gained by subtracting negative emissions due to forest growth sinks from the ***Agriculture, Forestry and Fisheries*** sector (fisheries are a very minor source of emissions).

By removing this artefact of net accounting, the agriculture sector of ***Agriculture, Forestry and Fisheries*** is identified as the largest component source (***Fig. 3.2***), with agricultural deforestation contributing the largest amount. While tree-planting and forest growth in plantation forests is certainly a human-caused carbon sink, natural forest growth is not an agricultural activity, and therefore should be not included in assessments of agricultural emissions. Plantation forestry and harvested wood products together provide a much smaller sink of approximately 0.4% of national emissions (around 2 Mt CO_2-e), and are not shown here.

3.2 Emissions from agricultural activities

Here we take a comprehensive view of agricultural activities, according to UNFCCC reporting standards. We add agricultural deforestation and subsequent soil carbon emissions reported under LULUCF to other emissions reported under ***Agriculture*** as described above. When these are aggregated, the total for agriculture is 189.5 Mt CO_2-e/yr. This includes 4.6 Mt CO_2-e/yr for on-farm energy, which however is not further considered in this study. Including emissions from clearing for pasture, enteric fermentation, prescribed burning of savannas, and manure, livestock production generates a total of 152.8 Mt CO_2-e/yr, or 83% of all agricultural emissions.

All of the data presented below come from the NIR, and all are available to the public. Except where we report otherwise, an average of emissions from 2006 – 2010 has been used to smooth interannual variability. Henceforth we discuss emissions in order of their size: agricultural clearing and subsequent soil carbon loss, enteric fermentation, agricultural soil emissions, savanna burning and manure management (***Fig. 3.3***). Subsequent sections describe the next-level components of each source, its component gases and the specific activities or processes that emit them.

Our category ***Agricultural Clearing & Soil Carbon*** includes LULUCF categories ***Forest Land Converted to Grassland*** and ***Forest Land Converted to Cropland*** as well as emissions from grassland and cropland soils caused by the removal of vegetation (***Fig. 3.3***). Even though clearing has declined in recent years this remains the largest agricultural emission. A description of the former extent of native forests and brief history of land clearing appears in ***Section 2.1***.

3.2.1 Emissions from agricultural clearing and soil carbon

Emissions from land clearing for agriculture averaged 73.9 Mt CO_2-e/yr for the period 2006 – 2010 (***Fig. 3.4***). This was a reduction from the 1990 – 2010 average of 83.8 Mt CO_2-e/yr (***Fig. 3.5***). From 2006 – 2010, 79% of clearing was for grazing and the remainder for cropping. Soil carbon loss from all cleared land (***Grassland Remaining Grassland***) totalled 24.2 Mt CO_2-e/yr (***Fig. 3.4***). By

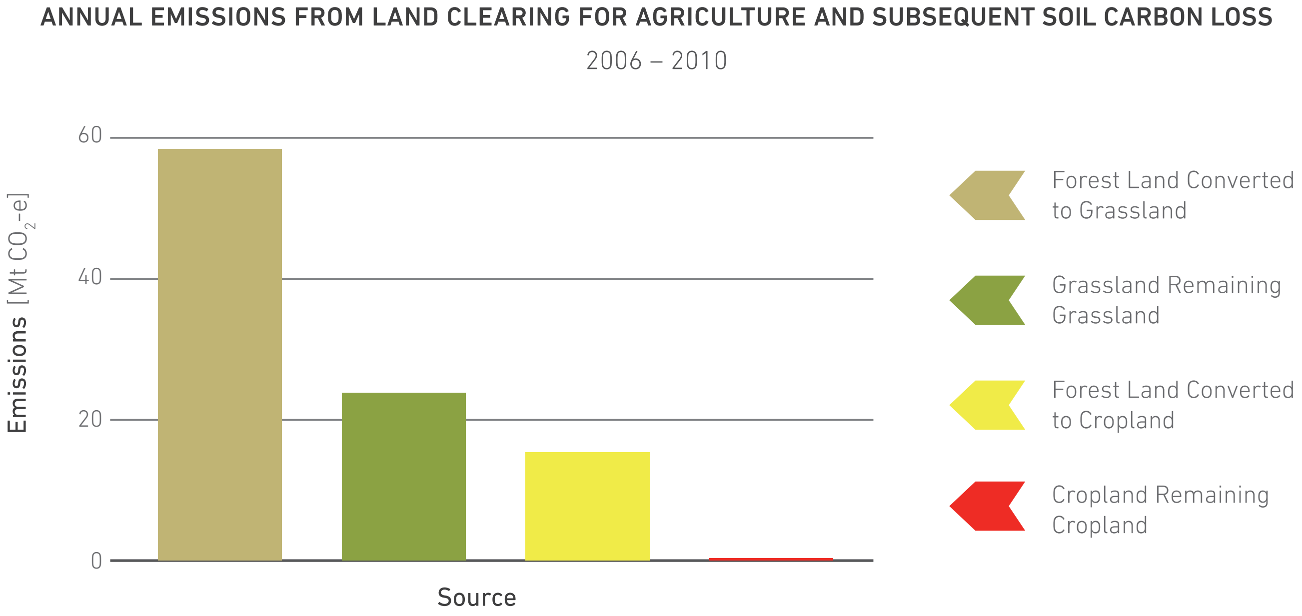

Figure 3.4 Average annual emissions from land clearing for agriculture (Mt CO_2-e/yr).

comparison, Australia's ten biggest coal-fired power stations had combined average emissions of 181.6 Mt CO_2-e/yr for 2006 – 2010.

Deforestation emits CO_2, CH_4 and N_2O from loss of both above and below ground biomass, and as a result of changed soil processes. Emissions from new clearing for pasture and crops are reported under LULUCF as ***Forest Land Converted to Grassland***, and ***Forest Land Converted to Cropland*** respectively. Re-clearing of native woody vegetation and soil emissions caused by and subsequent to clearing are reported under ***Grassland Remaining Grassland*** and ***Cropland Remaining Cropland***. Annual variation of plants and litter is excluded.

The decrease in national deforestation emissions since 1990 that was predicted as an offset for other sectors' emissions, sometimes called the Kyoto "Australia Clause" is evident in ***Figure 3.5***. While deforestation laws have slowed clearing, this is still a significant emissions source. In 2010, agricultural deforestation emissions amounted to 56 Mt CO_2-e or 9.6% of national emissions.

Approximately three quarters of Australia's recent tree clearing occurred in Queensland, and 65% of 2010 emissions due to clearing and subsequent soil carbon loss came from this state (***Fig. 3.6***). Queensland has published detailed reports on deforestation showing an annual average of 415,000 ha of woodland or forest has been cleared since the late 1980s. 60% of this total was 'remnant' (old growth), with the remainder re-clearing of woody regrowth on pasture cleared in recent decades; 93% was for grazing pasture (***Fig. 2.5* p 24**).[4]

Using the same data, Raison and colleagues (2009) estimated emissions from Queensland clearing as averaging 36 Mt CO_2-e/yr over two years in the mid-2000s, though the authors noted that earlier years had seen much higher rates.[5] This estimate covers carbon in trees only, and excludes soil carbon losses. If clearing in Queensland was causing 65% of Australia's deforestation emissions at the time, this indicates a national total of about 56 Mt CO_2-e, or almost 10% of national emissions. Data from the NIR accord with this estimate (***Fig. 3. 6***).

For both cropland and grassland emissions as reported in the NIR, the Department of Climate Change and Energy Efficiency (DCCEE) and its successor custodian of the NIR, the Department of the Environment, use the mass balance, process-based ecosystem model FullCAM. This software models emissions, reporting all carbon pools including living biomass, dead organic matter and soil.[6] The modelling conducted for this study also uses FullCAM to estimate the sequestration potential of land, though emissions from conversion to cropland are excluded from our modelling of agricultural emissions (see ***Part 5* p 103**).

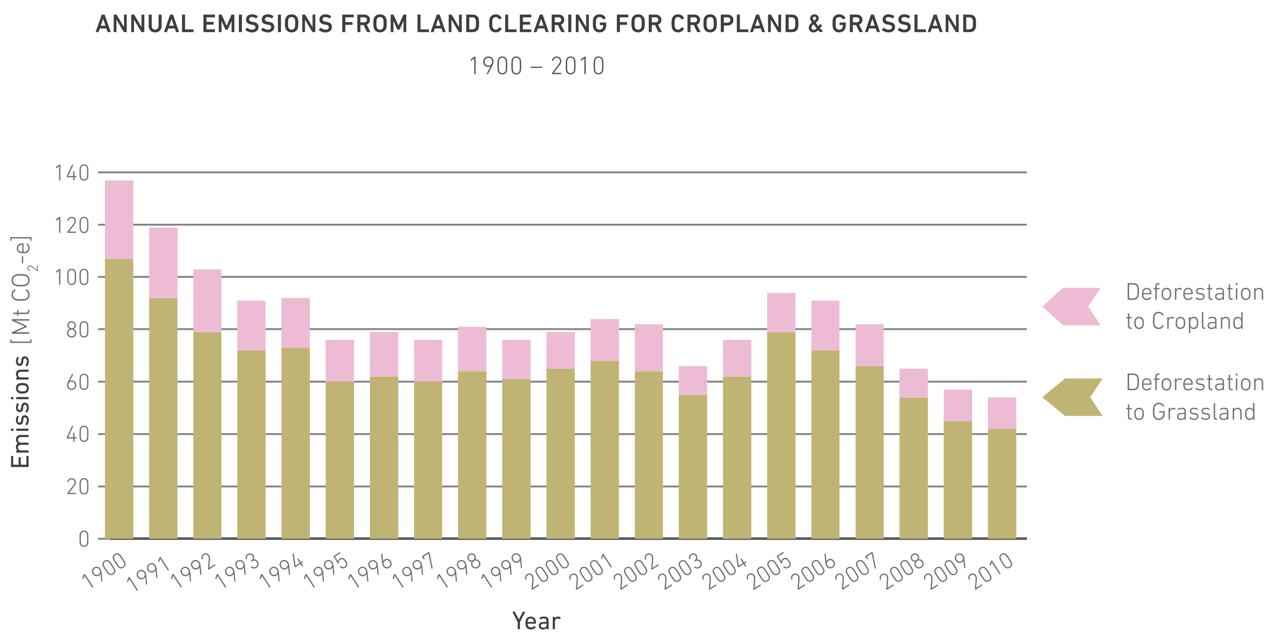

Figure 3.5 Average annual land clearing emissions 1990 – 2010, including LULUCF categories. Does not include soil carbon loss following clearing.

3.2.1.1 Forest land converted to grassland

Average annual emissions from this LULUCF category, which are all from deforestation to grazing pasture, were 58.5 Mt CO_2-e/yr for 2006 – 2010. This accounts for 30.8% of the total emissions for agriculture.

3.2.1.2 Re-clearing and soil carbon emissions from cleared land

Average annual emissions from this source, which includes ***Grassland Remaining Grassland*** and ***Cropland Remaining Cropland***, were 23.8 Mt CO_2-e/yr for 2006 – 2010. This was 12.8% of the national total for agriculture.

This category also includes so-called 'non-forest clearing', which according to NIR definitions covers sparse woodlands and shrublands. These communities carry very significant amounts of landscape carbon and cover vast areas of inland Australia.

3.2.1.3 Forest land converted to cropland

Average annual emissions from this source for 2006 – 2010 were 15.4 Mt CO_2-e/yr, or or 8% of the national total for agriculture.

Emissions from the ***Grassland Remaining Grassland*** sub-category are caused by loss of soil carbon in the years following deforestation, grazing intensity, annual grass cover variability, burning, natural wildfire, variations due to shrub and grass transitions and variations in soil carbon. As described above, carbon sinks from grassland returning naturally to forest land (including forest re-growth on grazing pastures) are not included in this assessment as they do not result from agricultural activity and are not considered to be anthropogenic, unlike forest plantings or plantation forestry.

3.2.1.4 Uncounted emissions from soil erosion

Although not captured in the national GHG inventory, soil carbon losses from Australia's agricultural land due to wind and water erosion are greatly accelerated by the removal and disturbance of vegetation. Soil organic

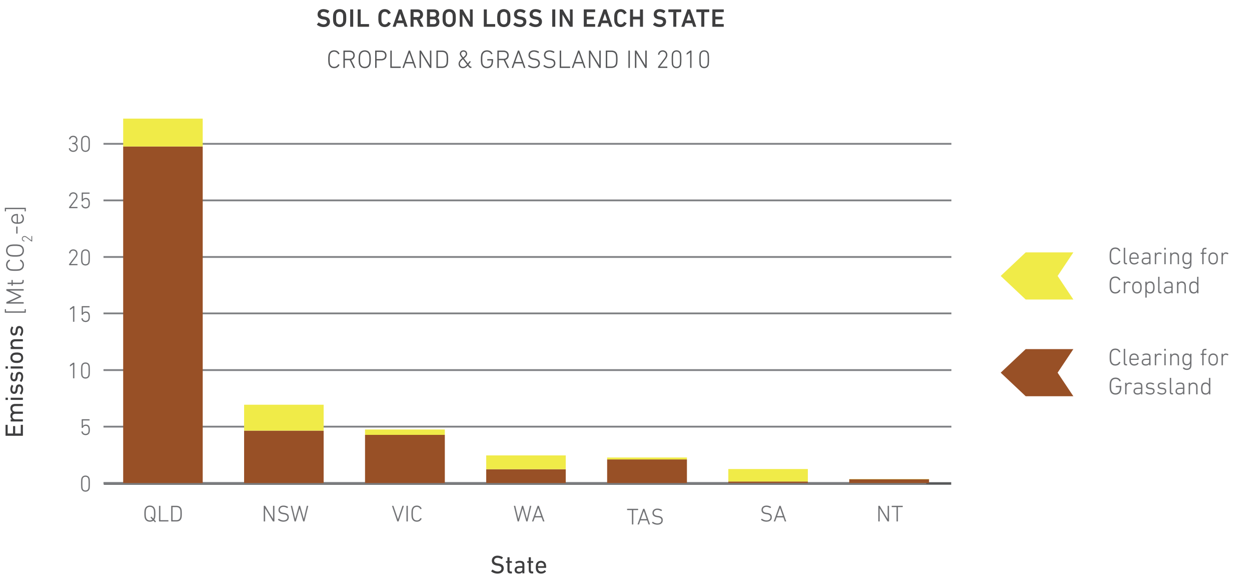

Figure 3.6 Emissions from agricultural clearing for cropland and grassland in each state (Mt CO_2-e/yr).

carbon loss on Australia's rangelands has been estimated at 5.6 t C/ha/yr. At the continental scale, 80% of these emissions, or 6.2 Mt CO_2-e/yr comes from rangeland grazing areas.[7] This study also conservatively estimates total emissions from rangeland deforestation and land degradation to be 117 Mt CO_2-e/yr, noting that where higher resolution data are available, emission estimates were considerably higher than the estimate presented. This compares with the national inventory value for this source of 82.8 Mt CO_2-e/yr as described above.

Worldwide, the loss of soil carbon through deforestation and soil degradation is estimated to have emitted 78,000 Mt CO_2-e since 1850,[8] and Australian soils have lost a major proportion of their original carbon content. In ***Section 4.1*** we analyse the capacity of Australia's soils to recover some of their lost carbon.

3.2.2 Emissions from enteric fermentation

Methane (CH_4) from enteric fermentation (EF) contributes 56.2 Mt CO_2-e/yr, 30% of all agricultural emissions or more than 10% of total national emissions under standard NIR reporting. This equates to 48% of total national CH_4 emissions. Enteric fermentation is therefore an important target for mitigation, as the grazing industries have recognised.[9, 10] The emission of methane from livestock also represents a loss of 6 – 10% of the energy ingested by ruminant livestock and therefore a significant loss of grazing system efficiency.[10 – 12]

Ruminant species including cattle, buffalo, sheep, goats and camels produce methane as part of their normal digestive processes. Enteric fermentation is performed by methanogenic organisms in the foregut or rumen of cattle, sheep and other animals, and converts fibrous feed into products that can be digested and utilised by the host animal. Ruminant animals are uniquely able to process low-quality fodder, and owe this capacity to EF. Methane is mostly absorbed into the blood before release through the lungs,[11] with smaller amounts eliminated by belching or deposited in manure.

Methane production varies between animal species and individuals, and is influenced by the production system type, quality and quantity of feed, animal body weight, age and amount of exercise. Animal nutrition, in particular the level and quality of feed intake, are the primary influences on the amount of methane produced. Higher levels of feed intake generally result in the production of more methane, while feed quality improvements can reduce CH_4 production. The biochemistry of rumen fermentation, and the composition of the microbial population of the rumen, in turn influenced by diet, are also important. Enteric methane arises from many sources, but the rangeland beef herd is by far the largest contributor (***Fig. 3.7***).

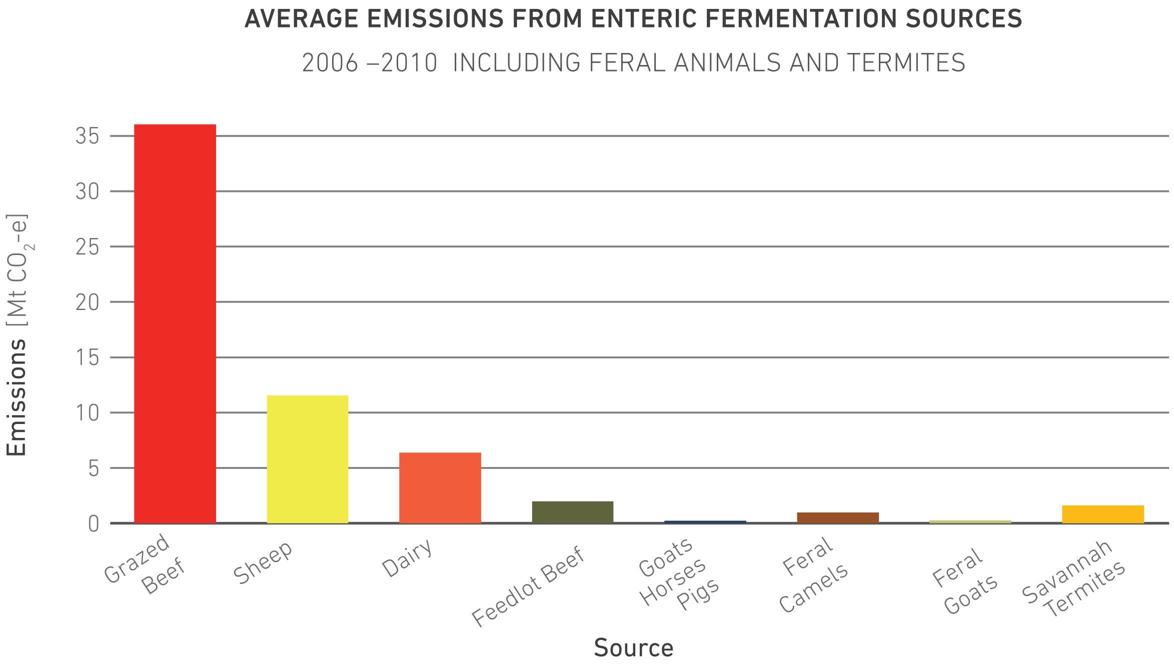

Figure 3.7 National enteric fermentation emissions (Mt CO_2-e/yr). Feral animals and termites are excluded from the national inventory.

Methane from feral camels and goats is not included in the national inventory, but contributes around 2.2% of the anthropogenic total.[13] Savanna termite emissions are also excluded, but for comparison these amount to 2.8% of total EF caused by human activities.

3.2.2.1 Grazing sheep and cattle

Beef cattle and sheep grazing on pastures contribute 81% of the EF total. Cattle, and to a lesser extent sheep, are large animals, take a long time to mature and reproduce slowly. For these reasons, they have large maintenance energy requirements, meaning they have to eat a lot just to remain alive. Beef herds[14] and individual cattle use about 50% – 75% of their dietary intake for maintenance.[15]

Cattle grazed on northern rangelands emit more methane than their southern counterparts[16] both in total and per unit of product. Northern herds make up 70% of Australia's beef cattle, and are typically ***Bos indicus*** breeds feeding on tropical C4 grasses, factors that contribute to their heavy emissions. Northern grazing properties are also far larger in area, due to their low carrying capacity, and their seasonality of rainfall drives greater extremes of forage growth. This again drives higher EF (and lower methane efficiency per unit of product) due predominantly to animals' high energy expenditure on movement and low forage digestibility.

Northern beef production also drives land clearing and savanna burning for pasture maintenance. Emissions from northern beef production therefore include approximately 47 Mt CO_2-e (deforestation), 26 Mt CO_2-e (enteric fermentation), and 10 Mt CO_2-e (prescribed burning of savannas) — a total of 83 Mt CO_2-e, 43% of agricultural emissions or 14% of the national total. The suppression of woody regrowth by grazing pressure also prevents landscape sequestration of carbon over vast tracts of the continent.

3.2.2.2 Dairy

Dairy cattle produce around 6.1 Mt CO_2-e/yr of methane from EF, which is 10% of total EF emissions and 3% of the total from agriculture. One analysis of total dairy emissions in Australia estimated 9.3 Mt CO_2-e,[17] including methane (CH_4) from enteric fermentation and manure, and nitrous oxide (N_2O) from both manure and nitrogen fertilisers.[18]

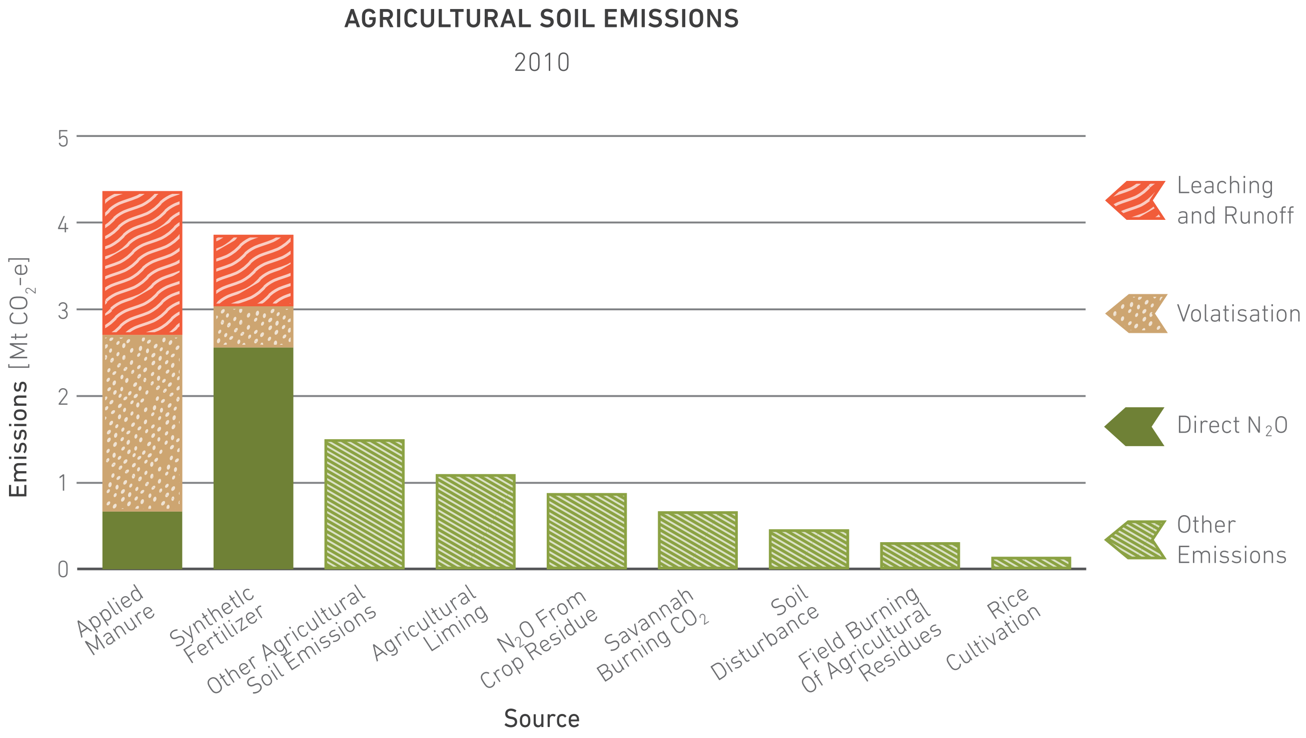

Figure 3.8 Agricultural soil emissions from various sources (Mt CO_2-e/yr).

3.2.2.3 Beef feedlots

Beef cattle in feedlots contribute 2 Mt CO_2-e/yr, or 3.5% of total annual average EF emissions from 2006 – 2010. This equates to just 1% of total emissions from agriculture for the same period.

3.2.3 Emissions from agricultural crops and soils

Emissions in the category ***Agricultural Soils*** averaged 16.4 Mt CO_2-e/yr for 2006 – 2010. A breakdown of 2010 emissions is shown in ***Figure 3.8***. Most soil emissions are the potent GHG nitrous oxide (N_2O). Although anthropogenic emissions of N_2O are much lower than carbon dioxide or methane, its global warming potential over 100 years is 310 times that of carbon dioxide, and 21 times that of methane.[19] It is a major contributor to the depletion of the ozone layer.[20]

N_2O emissions from agricultural soils increased 5.6% between 1990 and 2009, but declined by 1.9% from 2008 – 2009.[22] Greater use of nitrogenous fertilisers was the main reason for the increase, along with emissions from the manure of intensively managed livestock.[21] Synthetic nitrogen fertiliser use in Australia has increased by a factor of 2.5 since 1990.[22]

The major emission sources are manure applied to crops and excreted on grazed land (33% of the 2006 – 2010 average), followed by applied synthetic fertiliser (29%). Nitrogen leaching and runoff is dominated (≈65%) by cattle and sheep manure with a further significant contribution from nitrogenous fertilisers.

Many farmers plant legumes for their ability to provide nitrogen subsidies to crops, and these cause around 5% of total agricultural soil emissions. Other more minor emissions attributable to cropping include those from ***Agricultural Lime Application***, ***Soil Disturbance*** and ***Field Burning of Agricultural Residues***, all LULUCF categories. Methane from Australian rice cultivation amounts to just 0.15 Mt CO_2-e/yr (***Fig. 3.8***).

3.2.3.1 Soil emissions from animal production

These soil emissions are 100% nitrous oxide (N_2O) and result from urine and faeces voided in pasture, range and paddock as well as animal manure applied to crops and pasture. Emissions from this source averaged approximately 5.4 Mt CO_2-e for 2006 – 2010 and therefore equate to less than 3% of all agricultural emissions.

3.2.3.2 Soil emissions from synthetic fertilisers

This is a minor emission by national scales: 3.9 Mt CO_2-e in 2010, or 2% of the total for agriculture. Included are emissions from irrigated and non-irrigated pastures and crops; the largest single line-item is non-irrigated pastures, at 0.85 Mt CO_2-e in 2010, 0.3% of the national total for agriculture. Non-irrigated crops emitted 0.46 Mt CO_2-e in 2010.

When fertiliser is applied to cropland, nitrogen not taken up by plants remains available to soil microorganisms. This leads to the release of nitrous oxide, largely through denitrification. This process emits N_2O and ammonia, and release rates increase with higher temperatures and soil moisture.

Fertiliser application rates and emissions rates vary, but in Australia most fertiliser is used on cereal crops. Our largest crop, wheat, commonly accesses only 40% of applied nitrogen,[23] so fertiliser is significantly over-applied. Sugar cane, which is grown in hot, moist conditions and typically receives large amounts of nitrogen fertiliser, is also a significant source of N_2O emissions.[24, 25] Sugar receives up to 8% of all nitrogen fertiliser applied nationwide despite the very limited spatial extent of this crop[26] and caused 14% of N_2O emissions from fertiliser in 2010. Sugar also produced about 5% of gaseous emissions due to crop residues, emitting around four times as much per unit of area as wheat.

3.2.3.3 Pre-farm emissions from fertilisers

Pre-farm emissions from fertilisers are not directly attributable to the agriculture sector, and are hard to quantify with certainty because they depend on the product type, its country of origin and specific production process. Nevertheless they are significant because fertilisers are used in such large quantities across Australia's agricultural landscapes. Greenhouse emissions from the production of nitrogenous fertilisers most commonly applied in Australia are in the range 2 – 3.5 t CO_2-e per tonne of product (see appendices), and more than 4 Mt CO_2-e were emitted during the production of fertilisers used here.

3.2.4 Emissions from biomass burning

3.2.4.1 Prescribed burning of savannas

Prescribed burning of Australia's tropical and sub-tropical savannas each year is a large source of CH_4 and N_2O, and from 2006 – 2010 emitted on average 10.85 Mt CO_2-e/yr, or 5.7% of total agricultural emissions. Prescribed burning of Australia's tropical and sub-tropical savannas is a large source of CO_2, CH_4 and N_2O, and is by far the largest source of short term gas carbon monoxide (CO).[27]

Large amounts of dry vegetation and severe fire weather often combine to cause extensive fires late in the northern dry season, and these fires emit 60% of the total from savanna burning. Though not all fires on Australia's northern savannas are prescribed burning, only those fires lit by humans are recorded in the NIR. The NIR assumes that these fires would occur naturally if they were not set. The NIR defines savanna to include all grassland ecosystem types that experience burning in Australia, including grasslands, savanna and open woodland.

In area, over 90% of fires in Australia occur in northern arid, semi-humid and humid zones in these grassland ecosystems, in the dry season (winter/spring).[28] Between 2006 and 2010, an average of 46 million hectares (Mha; approximately twice the size of Victoria) of savanna and open woodland was burnt each year for pasture maintenance and to inhibit woody regrowth, mostly in the northern half of the country.[16] In many regions, burning is annual: The 2010 National Inventory Report states that remote sensing showed fires in consecutive years in 55% of pixels (100 ha/pixel), and 83% of pixels experienced another fire in two years or less. This fire frequency is far higher than would naturally occur (***Fig. 3.9***).

Savanna fire is set to establish or maintain pasture for grazing cattle. Fire suppresses sapling growth, removes unpalatable dead grass and stimulates the growth of 'green pick'. Fire is also used to support conservation goals, by removing fuel load to reduce wildfire intensity.[30] The Tropical Savannas Research Centre promotes annual burning for these purposes and to promote the growth of introduced pasture grasses. Fire and grazing pressure combined are very effective at inhibiting woody regrowth (***Fig. 3.10***).

There is strong evidence that almost all grassland/savanna/woodland fire is human-caused. In northern Australia where 90% by area of fire occurs, most lightning strikes happen in the wet season. Russell-Smith and colleagues (2007) found little lightning activity during the northern Australian burning season, indicating that there was no link between fire and lightning strike.[28] This evidence contradicts the view of DCCEE and its predecessor the Department of Climate Change that savanna fires are predominantly natural and would occur anyway if not lit.[31] In contrast, the Esplin Enquiry into the 2002 – 03 Victorian bushfires concluded that most of these were started by lightning.[32]

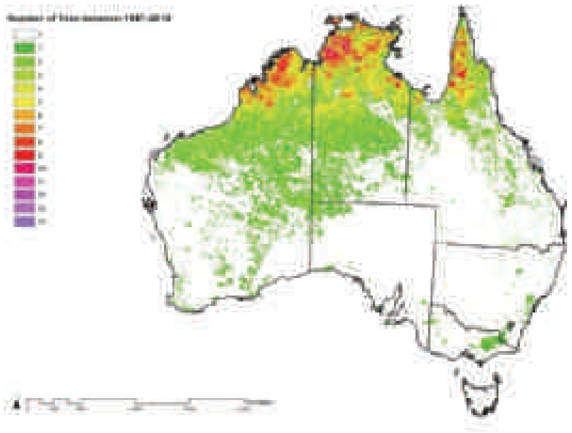

Figure 3.9 Fire frequency on Australia's northern savannas, 1997 – 2010[30]. Source: generated using data sourced from North Australia Fire Information, www.firenorth.org.au.

The albedo (reflectivity) of savanna is strongly reduced by burning, photosynthesis shuts down when tree leaves are scorched and evapotranspiration also drops strongly. These factors drive atmospheric and water cycle changes, and cause increased heating of the ground surface. Altered surface energy balance in turn affects convection and even regional scale circulation such as the tropical monsoon.[33]

3.2.4.2 Burning of crop residues

Crop residue burning emitted an average of 0.31 Mt CO_2-e for the years 2006 – 2010. Although CO_2 emissions are not included in the NIR because it is assumed this is re-sequestered in the next growing season, crop residue burning releases other GHGs: CH_4, N_2O, CO, NO_x and NMVOCs, as well as black carbon. Residue burning includes grain stubbles and burning of sugar cane before harvest.

3.2.5 Manure management emissions

Piggeries, beef feedlots, dairy and beef grazing, and to a lesser extent sheep, also contribute to Australia's total carbon footprint through GHGs emitted from manure — largely methane (CH_4) and nitrous oxide (N_2O). Manure management emissions totalled around 3.3 Mt CO_2-e/yr in 2010 (***Fig. 3.11***). Piggeries were the largest single contributor (1.1 Mt CO_2-e/yr).

Though manure management emissions are small in comparison to those from deforestation, enteric

Figure 3.10 Effectiveness of fire and grazing exclusion in inhibiting woody re-growth in the Northern Territory. 20-year exclusion upper-left, 10-year exclusion upper-right.

fermentation and agricultural soils, they warrant attention because in many cases the methane component is amenable to capture and reuse for energy generation.

3.2.6 Fugitive emissions from extractive land uses

Agriculture is not the only major source of methane: assessment of short-term climate forcers draws attention to their other sources, which may either not appear in national inventories or may be underreported. In Australia, fugitive emissions from fossil fuel extraction are the second largest source of methane, amounting to 60% of that from enteric fermentation of ruminant animals.[27] Fugitive emissions as reported are dominated by coal mining, where coal bed methane is directly emitted when coal seams are excavated, but significant fugitive emissions also emanate from fossil gas extraction.

Extraction techniques employed in coal seam gas (CSG) 'fracking' are intended to release gas over a wide area, but diffuse soil emissions are not reported.[27] If they were comprehensively measured, these emissions would increase significantly. Field measurement of fugitive methane vented from tight gas extraction in Utah, USA has shown that 6.2 – 11.7% of production is vented to the atmosphere.[34]

In Australia, this proportion is given as 1.3 – 4.38% of total extractions.[35] It is therefore likely that fugitive methane emissions from 'unconventional gas' activities are very significantly higher than is currently recognised in national accounts.

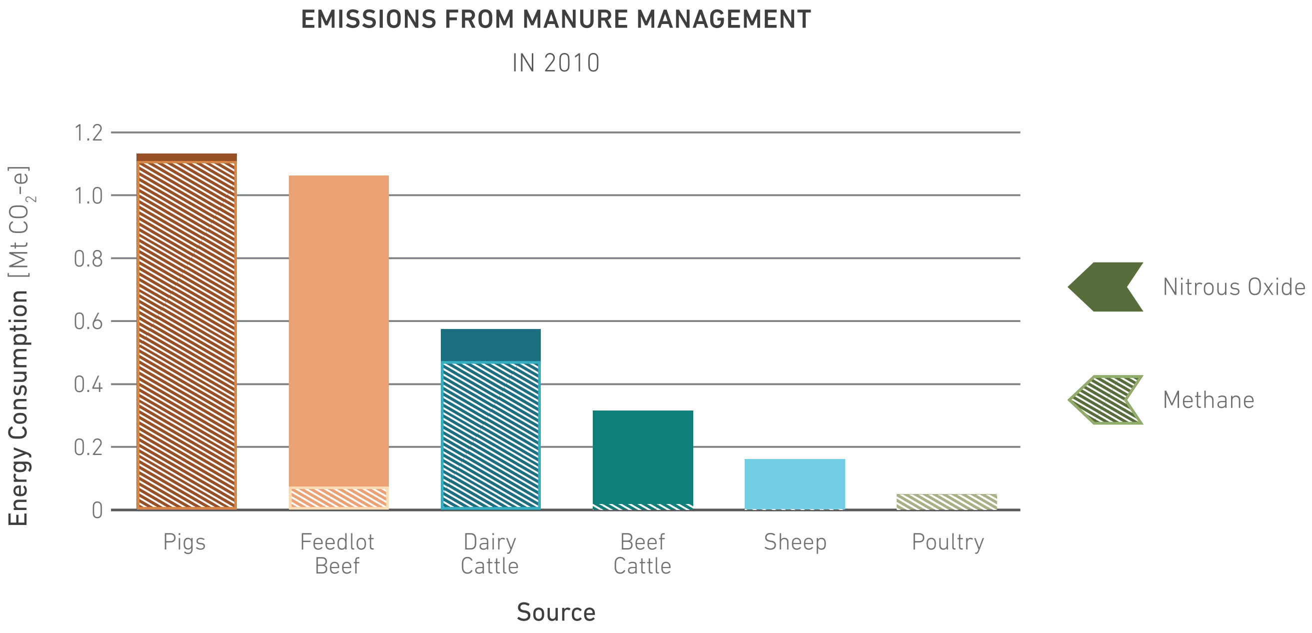

Figure 3.11 Manure management emissions 2010 (Mt CO_2-e/yr).

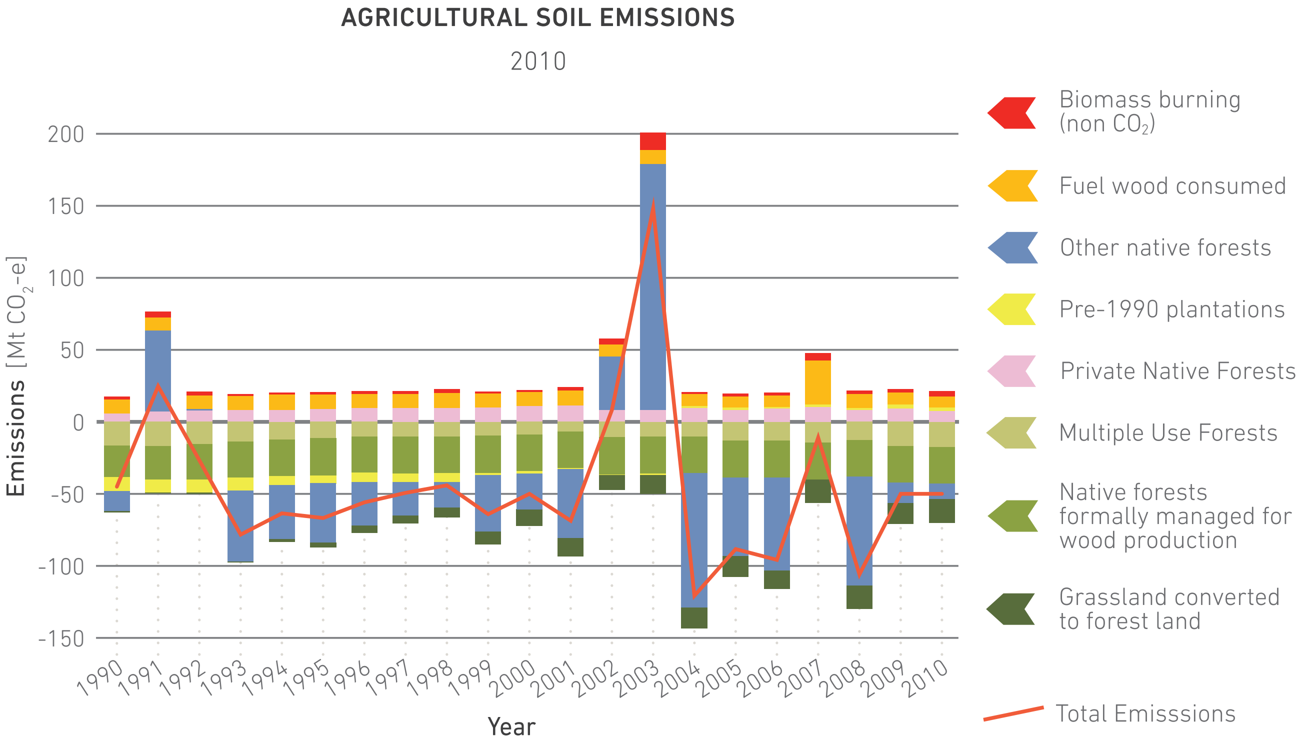

Figure 3.12 Net emissions from forest land (Mt CO_2-e/yr) at GWP_{100}.[1]

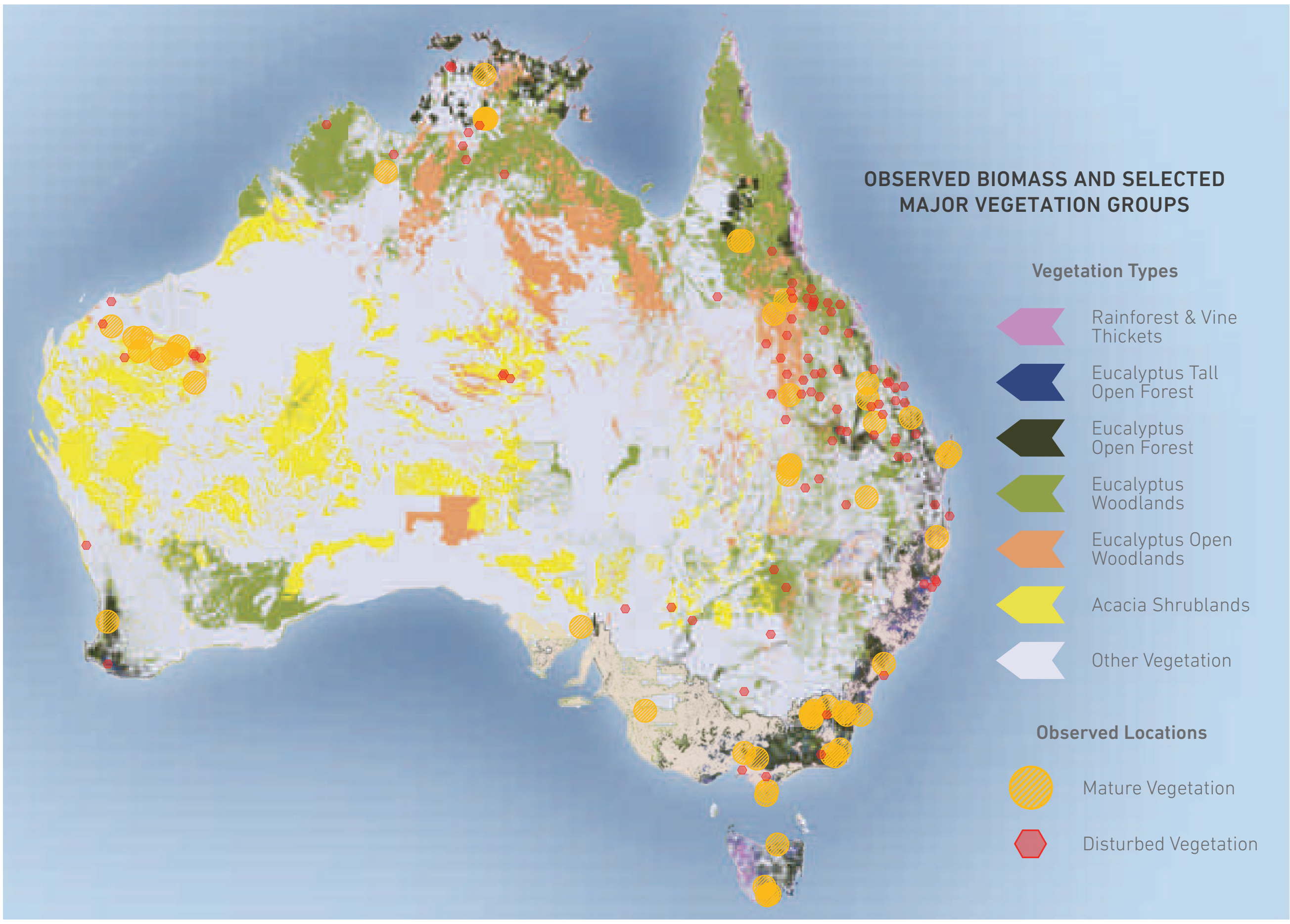

Figure 3.13 Location of observed biomass points and selected Major Vegetation Groups.[42]

3.3 Emissions from native forest management

3.3.1 Standing Carbon estimates

This section addresses emissions and removals of carbon from plantations, logged native forests and other native forests according to the National Inventory Report (NIR) 2010.[1] The total carbon accounted for in land deemed 'forested' under the National Carbon Accounting System (NCAS) is estimated at around 10,548 Mt (***Table 3.2***). The vast majority (99.1%) of this carbon is held in native vegetation. The major vegetation group (MVG) containing the most ecosystem carbon is eucalyptus open forest; this and other major MVGs are detailed in ***Table 3.2***.

3.3.2 Carbon exchanges between the ecosystems and atmosphere

According to the NIR, forest lands have been accumulating carbon stock at an average rate of approximately 12 Mt of carbon per year. However, the flow of carbon between native vegetation and the atmosphere has been variable, with some years showing net emissions, while the remainder show net sequestration (***Fig. 3.12***). The key drivers of emissions variability in forest lands are annual logging rates, the age classes of the forests, climate variability and wildfires.

The categories considered carbon sinks are inclusive of 'multiple use forests', 'native forests formally managed for wood production', 'pre-1990 plantations', 'other native forests' and grassland converted to forest land (i.e. plantations and environmental plantings). Fires are

Table 3.2 Estimate of current carbon stock for selected Major Vegetation Groups (megatonnes of dry matter; MtDM).[36]

Major Vegetation Group	Above Ground Biomass [Mt DM]	Root Biomass [Mt DM]	Forest Floor Biomass [Mt DM]	Total Biomass [Mt DM]	Total Carbon [Mt DM]	Percent of Total
Rainforest and Vine Thickets	844	84	403	1,331	599	5.7
Eucalyptus Tall Open Forest	670	94	429	1,193	537	5.1
Eucalyptus Open Forest	4,091	1,841	1,853	7,785	3,503	33.2
Eucalyptus Low Open Forest	35	16	14	64	29	0.3
Eucalyptus Woodland	3,206	1,315	851	5,372	2,417	22.9
Tropical Eucalyptus Woodland/Grassland	1,242	509	378	2,130	958	9.1
Acacia Forest and Woodland	445	200	300	945	425	4.0
Callitris Forest and Woodland	66	30	24	119	54	0.5
Casuarina Forest and Woodland	33	15	24	72	32	0.3
Melaleuca Forest and Woodland	311	140	76	526	237	2.2
Mallee Woodland and Shrubland	311	298	73	682	307	2.9
Low Closed Forest & Closed Shrubland	60	57	4	121	54	0.5
Other Forest and Woodlands	1,512	916	477	2,905	1,307	12.4
Total Native Forest	12,824	5,515	4,905	23,244	10,460	99.1
Softwood Plantation	82	57	3	142	71	0.7
Hardwood Plantation	23	9	1	33	17	0.2
Total Plantation	105	66	4	176	88	0.9
Total Forest	12,929	5,581	4,909	23,420	10,548	100

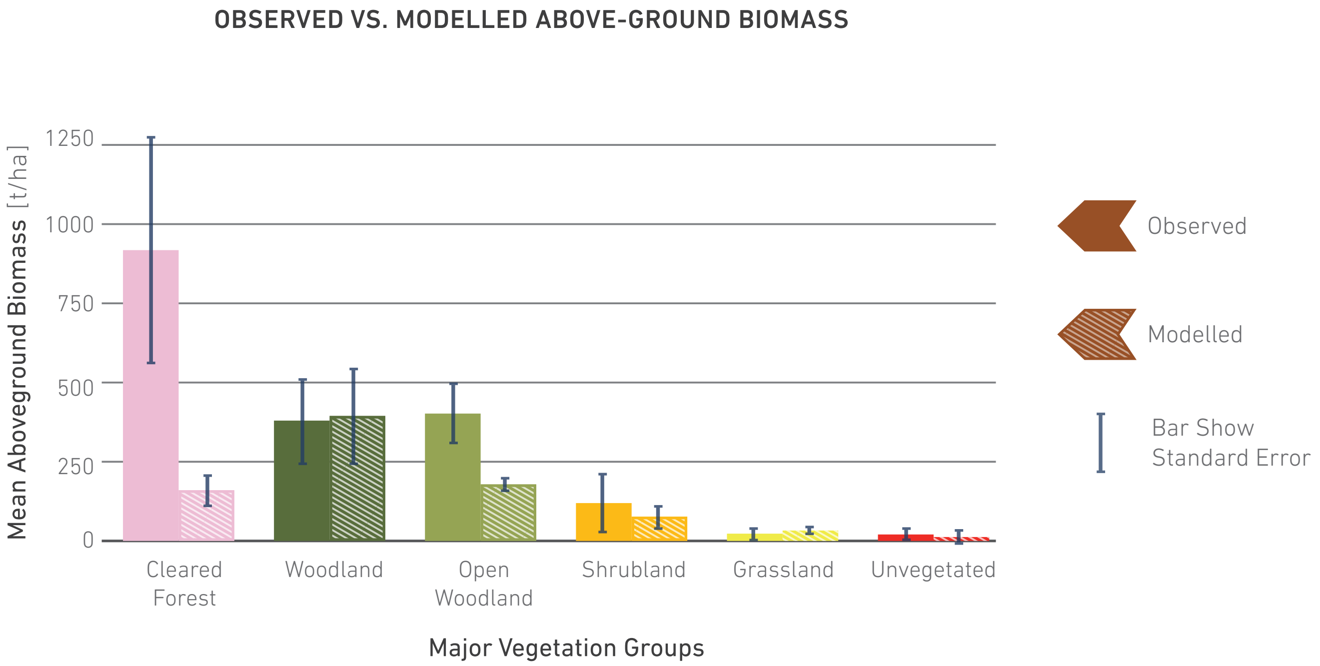

Figure 3.14 Comparison of observed above-ground biomass with modelled above-ground biomass for sample sites across the Major Vegetation Groups.

considered to be the major source of emissions. These estimates are generated through the FullCAM modeling software, which uses age-based growth data, modeling of dead organic matter accumulation and incorporates the effects of differing silvicultural treatments on the creation and management of harvest residues. Empirical data inputs constrain FullCAM to an accurate reflection of field data.[21]

3.3.3 Estimating above ground biomass across Australia

FullCAM requires an estimate of the assumed initial biomass of mature forests to estimate emissions resulting from the first time clearing events. This is referred to as the maximum potential biomass, which is the highest above ground biomass value that the model will assign to any forest area and it is an average of the range of measured biomasses (field) for a range of forest disturbances. The distribution of maximum potential biomass is detailed in ***Figure 3.13***.

The assumed initial above ground biomass is calculated based on a regression model of the relationship between a Forest Productivity Index (FPI) and measured biomass taken from sample sites. The observed biomass measurements include all forest conditions, except those with visible evidence of recent disturbance, such as clearing, harvest or fire since 1970. To model the spatial and temporal patterns of forest growth, a simplified form of the 3-PG model[37] was used to provide relative indices of growth potential on a monthly basis since 1970.

Through regression analysis, Richards and Brack (2004[38]) determined a correlation ($p < 0.01$, $r^2 = 0.68$) between sampled observed above ground biomass sites and the FPI. They used a square root transformation of both the dependent and independent variables to meet the assumptions of normality and homogeneity:

$$M = \left(6.011 \cdot \sqrt{P} - 5.291\right)^2 \qquad (1)$$

Where P is the average FPI and M is the above ground biomass in tonnes of dry matter per hectare.

This represents the above ground biomass that vegetation growth will generally approach.[38]

The biomass and carbon yield estimates of FullCAM have been shown to underestimate the total carbon stock of a number of forest types, particularly in south eastern Australia. Keith *et al.* (2010[39]) argue that carbon stocks of natural eucalypt forests throughout this region are greater than the NCAS estimates. They explain that the low NCAS estimates most likely reflect the fact that the model was developed for the purpose of assessing carbon stocks in afforestation and reforestation projects under the Kyoto protocol, not necessarily for determining the carbon stock of mature and old forests exceeding 100 years of age. The focus is mostly on younger forests that are influenced by human land use activity.

3.3.4 Comparing biomass across forest types and land use histories

This study tested the validity of the FullCAM estimates by comparing the modelled maximum above ground biomass estimate used in the model with observed above ground estimates published in peer reviewed and other scientific literature. The literature review obtained data for 297 sites across Australia from over 70 individual studies and summaries. These sites were grouped according to the MVG to which they were spatially aligned.[40] The study focused on data reported on mature and undisturbed sites. A number of the published studies provided disturbance history and vegetation age (and lack of recent disturbance) was determined.

For the studies that did not provide such detail, the spatial location of the site was matched with the 'Vegetation Assets, States and Transitions' (VAST) spatial dataset.[41] This provides a breakdown of areas mapped as 1) residual; 2) modified; 3) transformed; 4) replaced; or 5) removed. The residual category indicated an absence of recent disturbance, particularly with regard to logging and clearing, because the structure, composition and regenerative capacity of the land are considered intact. The selection of sample sites was further narrowed to those occurring multiple times and across a range of areas within MVGs. This process resulted in data taken from 80 sites being used across five MVGs (rainforest and vine thickets; eucalyptus tall open forest; eucalyptus open forest; eucalyptus woodlands; and acacia woodlands). The sites and MVGs sampled are detailed in ***Figure 3.13***.

Observed above ground biomass from each site was compared with its corresponding modelled estimate using an Analysis of Variance (ANOVA), carried out in SPSS (α=0.05; ***Table 3.3***). Statistically significant differences between observed above ground biomass and modelled estimates were identified post-hoc with the most conservative Sheffe's test, based on the F- ratio statistic.[43] The results of this analysis suggest that the true mean value of both eucalyptus open forests and eucalyptus tall open forests is significantly higher than the modelled value (***Fig 3.14***).

The modelled estimates were found to be statistically similar to observed values in the rainforests and vine thickets, eucalyptus woodlands, eucalyptus open woodlands and acacia shrublands MVGs. However, differences of statistical significance were noted for all sites in eucalyptus tall open forest and eucalyptus open forest MVGs. In both of these groups, the modelled estimate grossly underestimates the actual above ground biomass observed from these sites. According to the observations, the eucalyptus tall open forest features the highest yield in above ground biomass, with a mean of 918 t/ha. This compares with the modelled mean of 160 t/ha for the same sites.

Likewise, the model underestimates above ground biomass for eucalyptus open forest, where the observed mean is 402 t/ha and the modelled mean is 178 t/ha. This presents a problem when estimating the carbon flows of native forests subjected to logging, because logging is mostly concentrated in these two vegetation groups and any disturbance to these forests may result in higher emissions than what FullCAM estimates.

To determine the overall potential loss of carbon from these forests through disturbance, this study compared the above ground biomass value of mature and undisturbed sites with those that had experienced disturbance. In total, there were 156 sites that were noted as disturbed across the six MVGs. An ANOVA was used to test for differences in mean biomass between undisturbed and disturbed sites. A statistically significant difference was noted for eucalyptus tall open forest, where the disturbed mean for the range of sites is 285 t/ha, which is considerably less than the mean of 918 t/ha for the undisturbed mature forest (***Fig. 3.15*** and ***Table 3.4***). No other forest type showed a statistically significant difference between mature and disturbed sites.

A possible reason for the difference being significant in the eucalyptus tall open forest and not the other forest types may reside in intensive logging practices, such as clearfell logging, being concentrated in this forest type. This can be seen in the eucalyptus tall open forests of the Central Highlands of Victoria, north and east of Melbourne. Overall,

Table 3.3 Analysis of Variance comparing observed mature above ground biomass with modelled above ground biomass at maturity (tonnes of dry matter; t DM). Shading indicates significant differences (α = 0.05). Eucalyptus open forest and eucalyptus tall open forest results reveal statistically significant differences between observed and modelled above ground biomass estimates.

Major Vegetation Group	Mean difference [t DM]	Std. Error [t DM]	Significance	95% Confidence Interval [t DM]	
				Lower Bound	Upper Bound
Acacia shrublands	9.3	97.84	1.000	-432.47	451.22
Eucalyptus open forest	224.00	42.20	0.005	33.42	414.59
Eucalyptus tall open forest	757.87	97.84	0.000	316.02	1199.72
Eucalyptus open woodlands	-10.26	112.98	1.000	-520.46	499.94
Eucalyptus woodlands	45.63	87.51	1.000	-349.57	440.83
Rainforest and vine thickets	-16.32	123.76	1.000	-575.22	542.58

Table 3.4 Analysis of Variance comparing observed mature above ground biomass with observed disturbed above ground biomass (t/ha) (shaded cells are significant at α = 0.05). Eucalyptus tall open forest results reveal statistically significant declines in above ground biomass (t/ha) from undisturbed to disturbed sites.

Major Vegetation Group	Mean Difference [t DM]	Standard Error	Significance	95% Confidence Interval [t DM]	
				Lower Bound	Upper Bound
Acacia shrublands	11.50	98.91	1.000	-432.46	455.45
Eucalyptus open forest	34.18	44.23	1.000	-164.35	232.71
Eucalyptus tall open forest	632.07	84.30	0.000	253.66	1010.47
Eucalyptus open woodlands	-15.50	97.65	1.000	-453.79	422.80
Eucalyptus woodlands	51.09	71.89	1.000	-271.59	373.78
Rainforest and vine thickets	61.31	174.46	1.000	-721.75	844.37

Table 3.5 Breakdown of logging clearfell coupes in the Central Highlands from 1940 – 2011 (shaded values detail eucalyptus tall open forest) (Source: DSE 2011[44])

Major Vegetation Group	Species	Area (ha)	Percent of Total
Eucalytpus Tall Open Forest	Alpine Ash	9,193	13%
Eucalytpus Tall Open Forest	Mountain Ash	38,769	57%
Eucalytpus Tall Open Forest	Shining Gum	373	1%
Eucalyptus Open Forest	Alpine Mixed species.	29	0%
Eucalyptus Open Forest	Foothill Mixed species.	15,740	23%
Eucalyptus Open Forest	Foothill Mixed species.	193	0%
Eucalyptus Open Forest	Mountain Mixed species.	3,237	5%
Eucalyptus Open Forest	Mountain Mixed species.	116	0%
Unknown	Unknown	714	1%
Total		68,414	100%

COMPARISON OF ABOVE-GROUND BIOMASS OF MATURE VS. DISTURBED VEGETATION

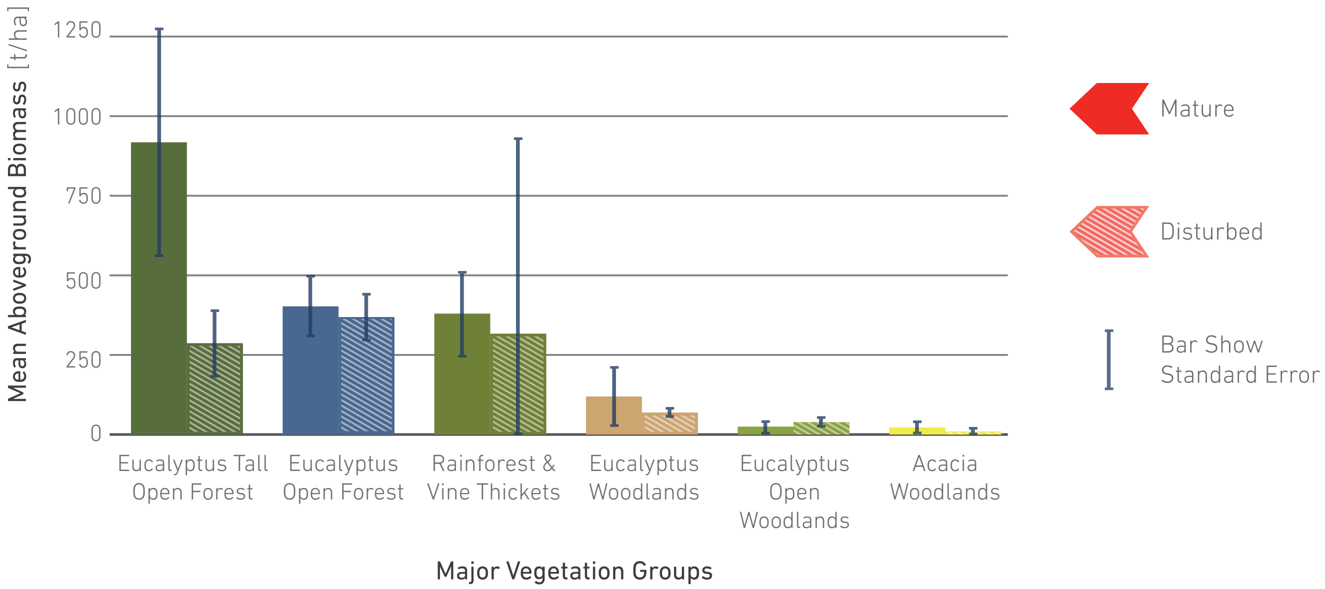

Figure 3.15 Observed above-ground biomass comparison between mature and disturbed categories of Major Vegetation Groups.

around 70% of forest logged is within the eucalyptus tall open forest group (*Table 3.5*).

With the inclusion of proposed logging, the overall amount of eucalyptus tall open forest clearfell logging is 30% (*Table 3.6*). This concentration is the result of these forests being commercially preferred by the sawn timber and woodchip industries. This overall concentration of logging has reduced the age class and structure from complex and heterogeneous stands to young and homogenous even aged stands.[45] It has been widely assumed that Mountain Ash forests are largely dominated by even-aged stands, resulting from fire regimes that impose stand replacing perturbations across the landscape.[46, 47] This has formed the silvicultural basis for clearfell logging in Mountain Ash forest, where the majority of trees are removed and the remaining debris burnt to create a receptive seed bed,[48 – 50] and resulting in even-aged stands in logged areas.[45] This in turn has reduced overall standing biomass and, therefore the carbon stock of these forests.[39, 51]

Table 3.6 Summary of eucalyptus tall open forest clearfell logged and area within 100 m of cutover edge.

Land type	Area [ha]	Percent of total [%]
Clearfell logged	48,334	22
Proposed clearfell logging	14,958	8
Total clearfell logging	54,100	30
Forest in reserve	52,284	29
Total forest area	178,539	100

The trend of declining carbon stock in these forests can be observed across the sample sites of the study, which compared the undisturbed and disturbed sites to the disturbed and undisturbed sites of the other MVGs. In *Table 3.7*, the mature eucalyptus tall open forest is compared with the other MVGs in their respective mature age classes. The mature eucalyptus tall open forest features a significantly greater mass of above ground biomass than the other MVGs. When comparing the disturbed eucalyptus tall open forest to the other MVGs in their disturbed states, the above ground biomass of the eucalyptus tall open

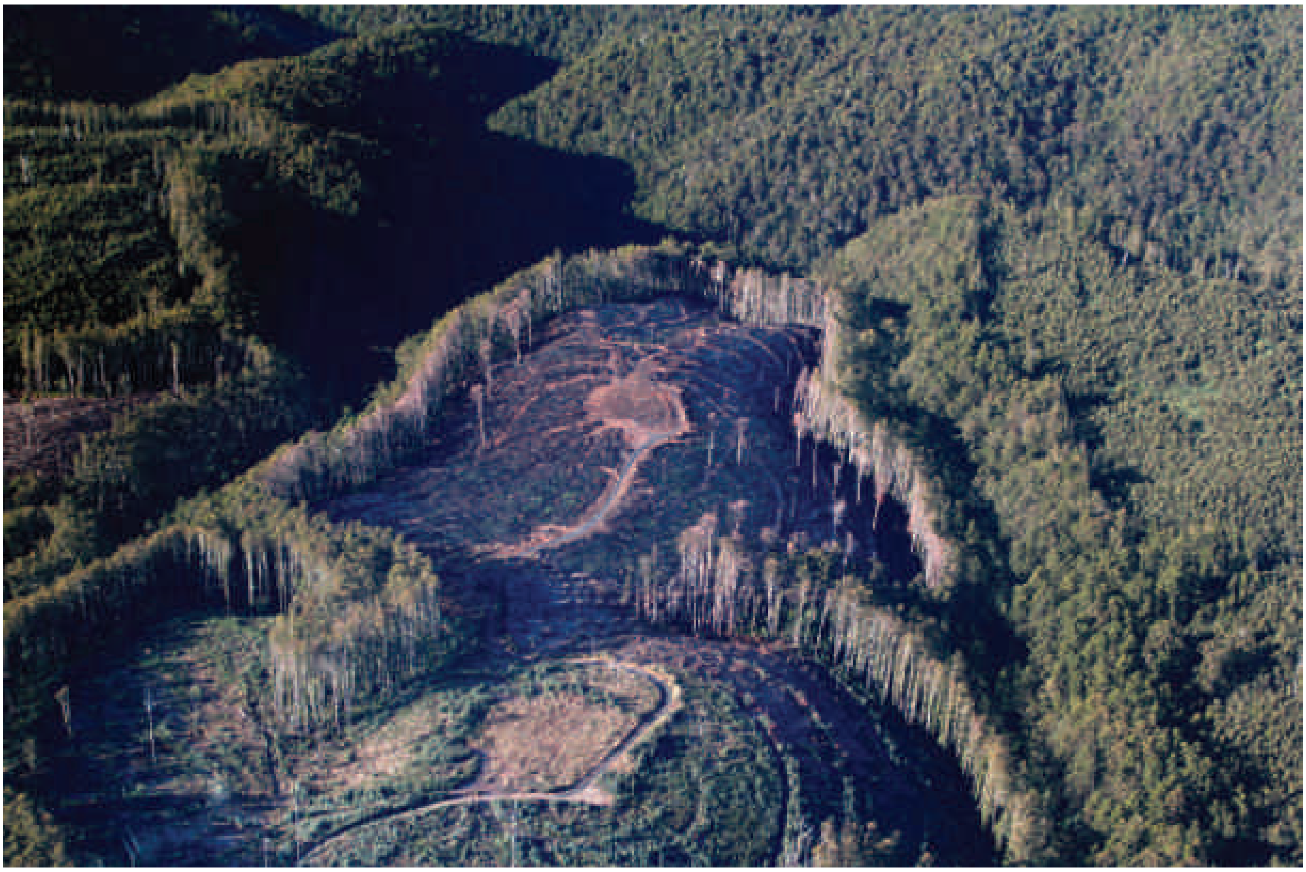

Figure 3.16 Central Highlands of Victoria showing the imact of industrial clearfell logging. Past and planned logging is mostly concentrated within the Eucalyptus Tall Open Forest Major Vegetation Group.

Table 3.7 Analysis of Variance comparing Mature Eucalyptus Tall Open Forest against listed mature MVGs with P-value (all MVGs are significant at the 95% confidence interval. P<0.05).

Major Vegetation Group	Mean Difference [t DM]	Standard Error	Significance	95% Confidence Interval [t DM]	
				Lower Bound	Upper Bound
Acacia shrublands	896.66	104.26	0.00	428.69	1364.63
Eucalyptus open forest	515.77	80.29	0.00	155.40	876.14
Eucalyptus open woodlands	895.68	112.61	0.00	390.21	1401.14
Eucalyptus woodlands	798.80	98.91	0.00	354.84	1242.75
Rainforest and vine thickets	540.99	118.87	0.04	7.42	1074.55

forest is no longer significantly different, but similar to the majority (***Table 3.8***). The disturbed mean of 285 t/ha renders it less than the disturbed above ground biomass of eucalyptus open forest.

To convert these changes into CO_2 emissions, the study partitioned the biomass and carbon fractions for each tree component, as detailed in the NIR. The carbon content of each tree component can vary and each component was calculated by dividing the weight for total above-ground carbon into its respective components, and multiplying it by the respective carbon fraction of each above-ground tree component (***Table 3.9***).

The mean carbon stock of above ground biomass in undisturbed eucalyptus tall open forest is 467 t C/ha. The disturbed carbon stock decreases to 145 t C/ha, with a difference of 322 t C/ha. In the Central Highlands of Victoria, a total of 48,334 hectares of eucalyptus tall open forest has been clearfell logged between the years 1931 and 2011.[44] A multiplication of the mean difference with the area logged equates to a loss of above ground carbon equaling 15.5 Mt C, therefore equating to historic emissions of over 57 Mt CO_2 in the region since clearfell logging was first implemented during the 1930s.

3.3.5 Forest fire

Fires are recognised as a major source of greenhouse gas emissions from forested land throughout Australia.[1] While fires are widespread throughout the Australian continent, they can be particularly intense in the southern forests of Australia.[53] In the state of Victoria, modelling has estimated that around 70 Mt of CO_2 have been emitted into the atmosphere from fires over the period 1999 – 2009.[54] The largest pulses of CO_2 occurred during the 2003 Alpine fires and 2007 Great Divide fires, where 1.3 million and 1.2 million ha were impacted, respectively.[55, 56] The fires of 2009 were comparatively smaller in both the area impacted and the emissions released, but burned forests with higher densities of standing carbon.[51] Estimates of the emissions from this event were approximately 50 – 70 C t/ha.[56] According Williams *et al.* (2012[56]), it will take around 20 years for these forests to recover the carbon lost in the fire event. Based on the infrequency of historic fires in these forests, this is below the current return frequency of fires for these forests, which are between 50 – 200 years.[45]

Table 3.8 Analysis of Variance comparing disturbed Eucalyptus Tall Open Forest against listed disturbed MVGs with P-value (All MVGs are no longer significant at the 95% confidence interval P<0.05).

Major Vegetation Group	Mean Difference [t DM]	Standard Error	Significance	95% Confidence Interval [t DM] Lower Bound	95% Confidence Interval [t DM] Upper Bound
Acacia shrublands	276.09	77.59	0.32	-72.18	624.35
Eucalyptus open forest	-82.12	51.16	0.99	-311.76	147.52
Eucalyptus open woodlands	248.11	62.93	0.17	-34.37	530.60
Eucalyptus woodlands	217.82	49.93	0.07	-6.27	441.92
Rainforest and vine thickets	-29.77	153.01	1.00	-716.56	657.02

Table 3.9 Calculations for mean historic emissions from clearfell logging of above ground biomass in eucalyptus tall open forests in the Central Highlands of Victoria.

Description	Stems	Branches	Bark	Leaves	Total
Fraction of total biomass to above ground tree components	0.55	0.12	0.09	0.03	0.8
Fraction of above ground biomass to each tree component	0.69	0.15	0.13	0.04	1
Carbon Fraction of biomass for each tree component	0.52	0.47	0.49	0.52	-
Volume (tC ha^{-1}) for each tree component in undisturbed forest (above ground biomass at 918 t ha^{-1})	328	65	56	18	467
Volume (tC ha^{-1}) for each tree component in disturbed forest (above ground biomass at 285 t ha^{-1})	102	20	17	6	145
Difference (tC ha^{-1}) for each tree component between disturbed and undisturbed forests (difference at 633 t ha^{-1})	226	45	39	12	322

Table 3.10 Average annual emissions from agriculture and forestry 2006–2010 (Gg/yr) including both 'long-lived' and 'short-lived' greenhouse gases[16].

Average agricultural and forestry yearly 2006–2010 emissions		Greenhouse Gas Species (Gg/yr) (1 Mt = 1,000 Gg)					
		'Long-lived' greenhouse gases (included in National Inventory totals)			'Short-lived' greenhouse gases (excluded from National Inventory totals)		
	Sector & Category	Carbon Dioxide O_2	Methane CH_4	Nitrous Oxide N_2O	Nitrogen Oxides NO_x	Carbon Monoxide CO	Non-Methane Volatile Organic Compounds NMVOCs
Agriculture	Enteric Fermentation	*	2,676	0	0	0	0
	Manure Management	*	87	5	0	0	0
	Rice Cultivation	*	7	0	0	0	0
	Agricultural Soils	*		46	0	0	0
	Prescribed Burning of Savannas	*	390	9	553	15	896
	Field Burning of Agricultural Residues	*	10	0	18	400	23
LULUCF	Cropland / Deforestation	15,397	25	1	19	753	91
	Grassland / Deforestation	78,883	59	1	45	1,753	212
	Forest Land	-65,413 (net sink)	101	2	76	2,964	358
Energy	On-farm Energy	4,559	1	0	85	3	11

* CO_2 from Agriculture activities is not reported as sequestration is deemed to offset emissions from year to year.

3.4 Long- and short-lived emissions from agriculture

This section outlines the human-caused emissions from agriculture and forestry, their impact and lifetime. Short-lived emissions, excluded from national inventories by UNFCCC convention, come mostly from agriculture. The impact of these is described along with implications of including or excluding them from the national inventory.

Here we use the term 'emissions' to describe both greenhouse gases and aerosols arising from human activity that cause warming or cooling. For completeness, ***Table 3.10*** lists all greenhouse gases emitted by agricultural and forestry activity over the period 2006 – 2010. A breakdown of how these emissions arise from land use activities is given in earlier sections of ***Part 3***.

3.4.1 Long-lived greenhouse gases

As required and defined by UNFCCC conventions, Australia reports long-lived gas emissions carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as well as industrial emissions of hydrofluorocarbons and halocarbons (not discussed here, but equal to approximately 1.2% of total national greenhouse emissions in 2010). CO_2 emissions are not reported under the *Agriculture* sector, because losses of carbon from plant harvest or fire are assumed to be balanced by plant growth from year to year. However, agricultural activities included in the LULUCF sector do include CO_2 emissions, the single greatest source being from deforestation (described and further quantified in ***Section 3.2.1*** **p 45**).

The majority of methane comes from enteric fermentation, with further significant amounts of this gas from prescribed burning of savanna. Deforestation for agriculture is a major carbon monoxide (CO) source, and the single largest source of N_2O is agricultural soils (mostly from nitrogenous fertiliser).

Table 3.11 Emission-based global radiative forcing (RF) since 1750 showing the components included and excluded in UNFCCC GHG accounting rules (adapted from Forster *et al*. 2007, Table 2.13[57]).

Emissions	Component Species	Included in UNFCCC accounting	Atmospheric lifetime	Global RF since 1750 (W/m^2)	Proportion of *net* global RF from all emissions since 1750 (2.86 W/m^2)
Long-lived gases	CO_2	Y	100 – 1000 yrs	1.56	55%
	CH_4	Y	12 yrs	0.86	30%
	Halocarbons	Y	600 – 3500 yrs	0.36	13%
	N_2O	Y	100 yrs	0.16	6%
	HFCs	Y	1.4 – 270 yrs	0.02	1%
Short-lived gases	CO/VOC	N	Days – to – weeks	0.27	9%
	NO_x	N	Days – to – weeks	-0.21	-7%
Aerosols	Black Carbon	N	3 – 8 days	0.44	15%
	Sulphates	N	Days – to – weeks	-0.4	-14%
	Organic Carbon	N	Days – to – weeks	-0.19	-7%
Tropospheric Ozone (produced from CH_4, CO, NO_x, NMVOC emissions)	O_3 (T)*	N*	4 – 18 days	0.39*	14%*

*Not an emission, included for comparison only. Radiative forcing from CH_4 and CO includes that caused by O_3 (T).

3.4.2 Short-lived greenhouse emissions

Depending on their properties, emissions can last in the atmosphere from millennia (e.g. CO_2) to a few days (e.g. black carbon), but only the long-lived gases are included in UNFCCC accounting conventions. Short-lived greenhouse emissions, which last just days or weeks in the atmosphere, have significant long-term impact. Ignoring short-term greenhouse gases therefore causes significant under-reporting. Cooling emissions (from nitrogen oxides (NO_x), sulphates and organic carbon) are also excluded from inventories by convention, but have important effects. Sulphates, the strongest cooling emission, originate from fossil fuel combustion and partially offset warming from the co-emitted CO_2.

Table 3.11 lists the lifetime and warming impact of global emissions since 1750. Despite remaining in the atmosphere for just 4 to 18 days, tropospheric ozone alone has caused 14% of warming since 1750, making it the third most important greenhouse gas. The combined radiative forcing from CO and tropospheric ozone (O_3 (T)) has caused 19% of human-caused warming since 1750.[57] Tropospheric ozone gas is not emitted — it is formed in a photochemical reaction between carbon monoxide (CO), nitrogen oxides (NO_x) and volatile organic compounds (VOCs) including methane.[58] The most effective means of reducing O_3 (T) is to reduce CH_4, which drives half of anthropogenic ozone production,[58] as well as reducing emissions of its other precursor gases.

Short-lived greenhouse gases and precursors of O_3 (T) are predominantly from agriculture (***Fig 3.17***). Cooling emissions (nitrogen oxides (NO_x) and sulphates (SO_2)) are predominantly from industrial sources, a factor that emphasises agriculture's relative greenhouse impact. Although CO emitted by industry is a key component of urban smog, most CO is emitted from biomass burning.[17]

Production of O_3 precursors, particularly CH_4, is widespread across the continent, but most of Australia's CO and a large proportion of NMVOC emissions come from ***Prescribed Burning of Savannas***, an activity that occurs mostly in the northern dry season, between autumn and spring. Southern Australia experiences open fire in summer and autumn. Much of the Australian continent is under the influence of mid-latitude weather systems, which mix northern and southern air masses.[59] For this reason, ozone produced in northern Australia has a warming effect on the

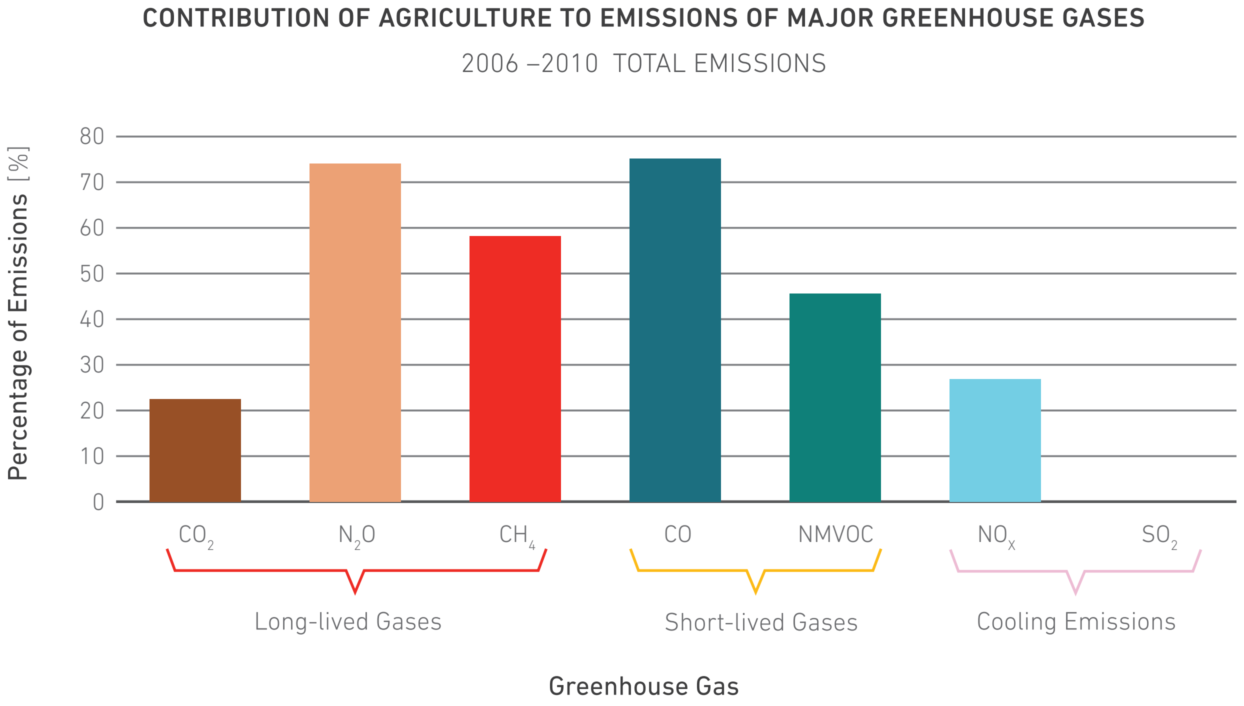

Figure 3.17 Contribution of agriculture to emissions of named gases from all other sectors ('other'), including precursors of tropospheric ozone, CH_4, NO_x, CO and NMVOCs. NO_x and SO_2 are cooling emissions.

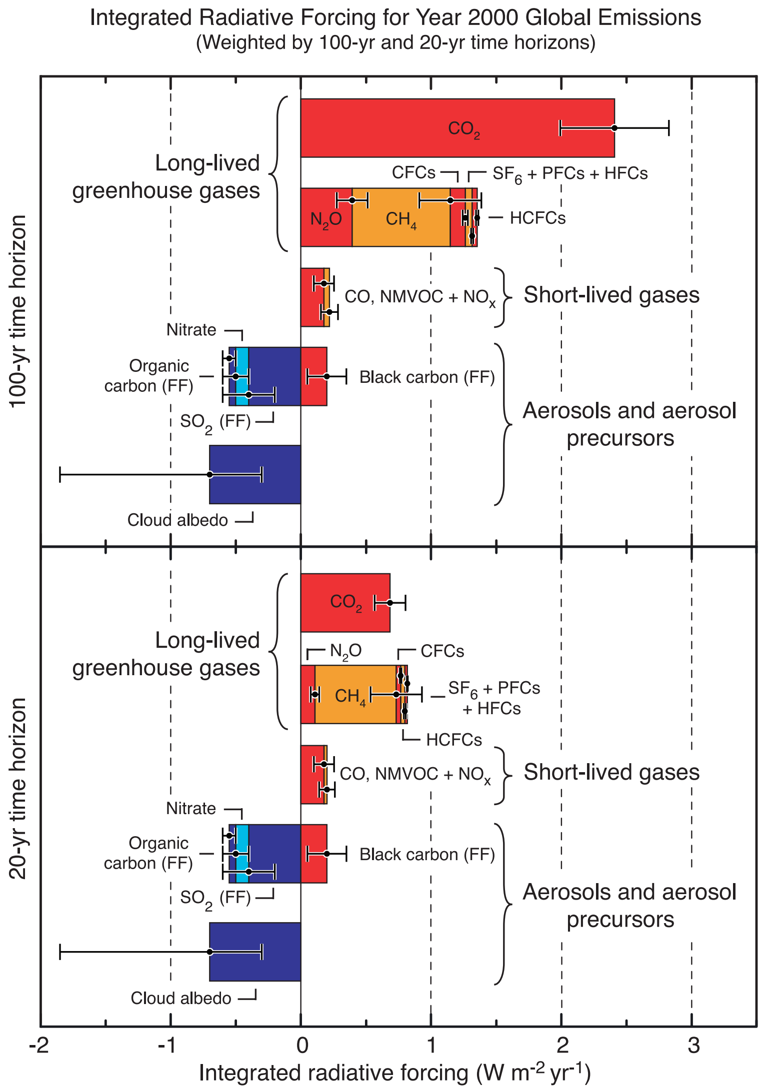

Figure 3.18 Integrated 20-year time horizons of year 2000 greenhouse emissions (IPCC Fourth Assessment Report,[71] Fig. 2.22)

regional to continental scale.[60, 61] It is therefore appropriate to include O_3 (T) in Australian emissions inventories, even though this short-lived gas is excluded under UNFCCC convention. Other studies have confirmed the validity of including short-lived ozone precursors when assessing regional (continental and sub-continental) warming impact.[61]

At atmospheric concentrations above 40 ppb, a level regularly recorded in Australia,[62] tropospheric ozone also harms plants, reduces crop yields and slows forests' sequestration of atmospheric carbon.[63, 64] Wheat, rice, soybean and maize are all negatively impacted at these ozone concentrations, and crop damage is predicted to increase.[65] This places further pressure on agricultural systems already impacted by climate change and other challenges.

3.4.2.1 Black carbon

Black carbon (BC, also known as soot) is produced from incomplete combustion of biomass, and lasts a few days in the atmosphere. Globally, BC is responsible for 1.1 W/m^2 of radiative forcing (***Table 3.11***).[66] The human-caused part of this radiative forcing is 0.71 W/m^2, making BC the second greatest warming emission after CO_2. Globally[67] and in Australia,[28, 67] most BC comes from savanna burning (grassland and woodland fires). However, aerosols co-emitted with BC from open biomass burning may have a cooling effect, offsetting direct warming from BC. Data on Australian emissions of BC and co-emitted aerosols is lacking, therefore the effects of these emissions is unknown, although it may potentially be a significant contributor to short-lived forcing. Because BC has caused 15% of human-caused warming, our understanding of this significant emission nationally would benefit from further research.

3.4.3 Measuring short term global warming impact

Emission metrics are used to compare warming caused by the various greenhouse gases. The UNFCCC-agreed metric is the Global Warming Potential (GWP), which measures the total radiative forcing (warming) of greenhouse gases for a given period after emission, compared to that of CO_2 over the same period. The typical period over which warming from different gases is compared is an arbitrarily chosen 100 years (GWP_{100}).[68]

One problem with this approach is that the atmospheric lifetimes of different emissions vary widely, from days to centuries (***Table 3.11***). Adoption of GWP_{100} is appropriate for N_2O (which lasts about 100 years) for a warming target 100 years hence, but is highly inappropriate for methane, because methane lasts only about 12 years in the atmosphere. 100-year framing is questionable for CO_2, which has a decay rate such that 1,000 years after a CO_2 emission pulse, one fifth of that gas still remains in the atmosphere. GWP_{100} is even less appropriate for comparing emissions that last only days or weeks. Institutionalisation of accounting based on GWP_{100} has framed discussion and locked common understanding into a narrow focus on CO_2 and hence fossil fuel combustion products.

Continual improvement in atmospheric science, models and experimental results gives more accurate metric values for individual emissions. For example, the IPCC 4th Assessment in 2007 updated its GWP_{100} value for methane from 21 to 25 to account for methane's role in O_3 (T) formation.[57] Australia will use this new value in its 2013 inventory, to be published in 2015. The Fifth IPCC Assessment Report is expected to publish new GWP's for methane as 84 (GWP_{20}) and 28 (GWP_{100}), respectively. Although IPCC guidelines have yet to adopt GWPs that account for interactions between gases and aerosols,[57] these are considered in recent NASA models[70] (***Table 3.12***).

Emission metrics are debated, with criticism levelled at their limitations in comparing different emission lifetimes, and their inability to account for policy options such as price ratios or policy targets.[72, 73] However, now that dangerous climate change guardrails are rapidly approaching (in present and coming decades, rather than centuries), new metrics are being proposed that account for more immediate policy targets or critical thresholds

Table 3.12 Recent revisions of Global Warming Potentials (GWP).

Greenhouse Emissions	Atmospheric Lifetime	GWP_{20}	GWP_{100}
Carbon Dioxide (CO_2)	100 – 1000 years	1	1
Methane (CH_4)	12 years	72 [70] 84* 100 [69]	21 [57] 25 [70] 28* 33 [69]
Nitrous Oxide (N_2O)	100 years	289 [70] 264*	310 [69] 265*
Tropospheric Ozone precursors			
Carbon Monoxide (CO)	4 – 18 days	19 [69]	5 [69]
Nitrogen Oxides (NO_x)	Days	None assigned	None assigned
NMVOCs	Weeks	None assigned	None assigned
Black carbon	3 – 8 days	2900 [71]	830 [71]

*Values published in the 2013 IPCC 5th Assessment Climate Change 2013: The Physical Science Basis.

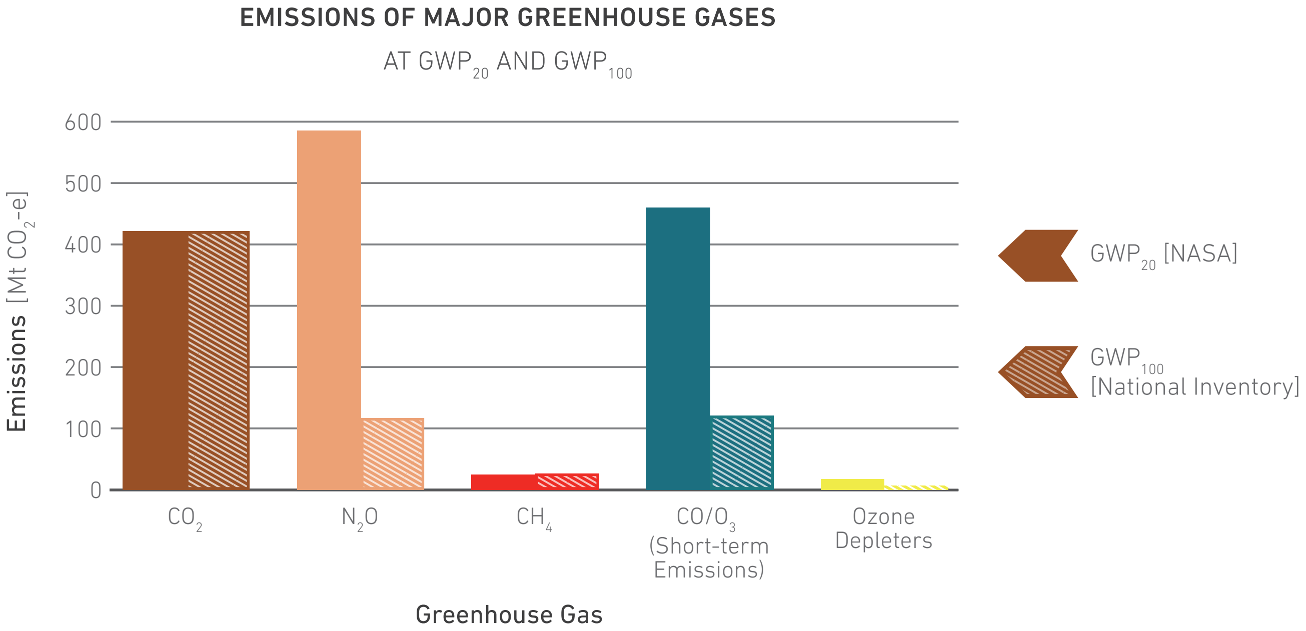

Figure 3.19 Average 2006 – 2010 emissions of long- and short-term gases, comparing 20-year global warming potentials derived by NASA[70] and 100-year Global Warming Potentials from the NIR, as per Table 3.12.

such as temperature rise.[72–76] These metrics allow for a 'countdown' as the stabilisation target year approaches - for example a target of 2°C global warming cap by the year 2060. In the case of GWP, the value would be calculated based on a countdown to the year by which emissions would need to be stabilised in order to attain the target. In such accounting, GWP_{20} would be used when 20 years out from the target year, then GWP_{19} the following year and so on.

As urgency increases in the years leading up to the target year, the metric values used to compare gases tend to converge as the target approaches. This means that choice of metric is far less important than the time remaining to reach the target.[77] New insights emerge when this approach is used. For example, for a year 2060 target, reducing global methane emissions by 46% would have the same impact as entirely stopping CO_2 emissions.[78]

Adopting a metric that measures the impact of gases against a stabilisation target year gives a unifying framework for comparing gases, as well as a means of assessing policy options that balance the relative impact of each gas. Our use of GWP_{20} for the modelling presented in ***Part 5*** could therefore be considered a proxy for comparing the warming impact of greenhouse gases emitted this year against a stabilisation target 20 years hence (2034). This timeframe is consistent with current projections that suggest that the level of 'safe' warming will be exceeded within 20 – 30 years and that, without strong and timely action, increases in global mean surface temperature of 4°C or more are possible.[79–81]

It is useful to reconsider our understanding of the global warming impact of each emissions source over time periods other than the 100-year standard. The IPCC 4th Assessment compares integrated radiative forcing (RF; warming) from year 2000 global emissions over the commonly used timeframes of 20 years and 100 years (***Fig. 3.11***). Accounting for warming over 100 years emphasises the importance of CO_2 and diminishes the relative importance of shorter-term emissions. Conversely, 20 year accounting shows that the combined integrated RF from CH_4 and O_3 (T) is greater than CO_2 over that time (***Fig. 3.19***). In other words, for the 20 years following these year 2000 emissions, CH_4 and O_3 (T) together have a greater warming impact than CO_2.

Agriculture produces the bulk of short-term gases, as well as the most methane, and therefore offers unique possibilities for climate change mitigation. Given this, and the need to adopt emissions reduction targets that result

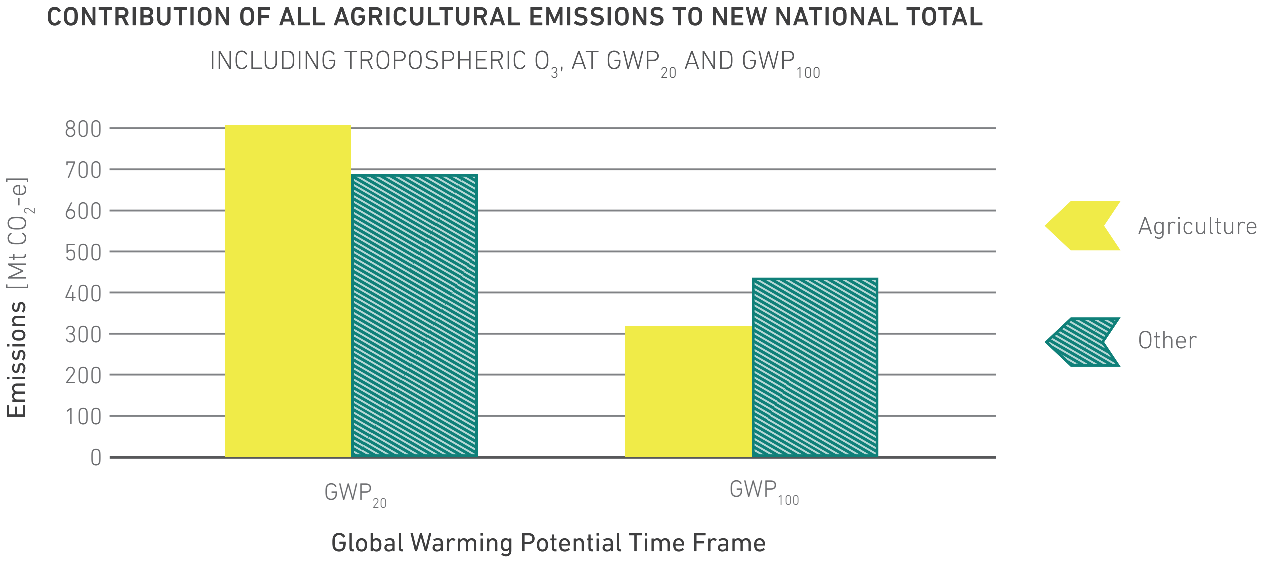

Figure 3.20 Average 2006 – 2010 emissions of both long- and short-term gases, showing contribution of all agricultural emissions to the new national total, including short-term gases CO and O_3 (T), with 20- and 100-year global warming potentials (GWP) shown in Table 3.12.

in stabilisation targets in coming decades, this is a strong argument to adopt GWP_{20} when comparing emissions. This approach is adopted in ***Part 5***, where agricultural emissions are modelled on both 100- and 20-year global warming potentials, although our modelling does not consider tropospheric ozone precursors.

3.4.4 Including short term emissions in the national inventory

When short-term emissions are added to the national greenhouse gas inventory, and the impact of all emissions is assessed over 20 years rather than 100 years, powerful emissions abatement options become evident. In the following analyses, short-lived emissions are attributed to agriculture as detailed above, and emphasise the importance of rural land use in the climate problem. We use the GWP_{20} values from Shindell *et al.* (2009[70]; ***Table 3.12***).

Using standard UNFCCC GWP_{100} accounting, but including short-term emissions, average 2006-2010 total national emissions (including LULUCF) increase by 121 Mt CO_2-e/yr, from 567 Mt CO_2-e/yr as given in the NIR, to 689 Mt CO_2-e/yr (***Fig. 3.20***). This means that UNFCCC accounting conventions cause Australia and other nations to under-report emissions. In Australia's case, national emissions are understated by 21% in standard UNFCCC 100-year accounting.

When warming is instead assessed at GWP_{20}, and short-term gases are included, total national emissions more than double from 689 Mt CO2-e/yr to 1,497 Mt CO2-e/yr (***Fig 3.20***). Under this accounting, the summed global warming impact from methane and short-term gases rises to 70% of the national total for those emissions classes. This in turn emphasises cuts to short-term emissions as a powerful tool for mitigation of warming in coming decades.

3.4.5 Agriculture is key to short term warming

The inclusion of warming from short-term gases brings agriculture to the fore as a heavy-emitting sector. At either GWP_{100} (where agriculture emits 319 Mt CO_2-e/yr, 42% of total emissions) or at GWP_{20} (where agriculture emits 803 Mt CO_2-e/yr, 54% of national emissions), agriculture emits more than any other single sector (***Fig. 3.20***).

Grouping emissions into: Enteric Fermentation plus Manure Management; Prescribed Burning of Savannas; Deforestation and soil carbon loss on Grasslands (pasture land); and Total Crop Emissions (including deforestation for crops) illustrates emission sources (***Fig 3.21***).

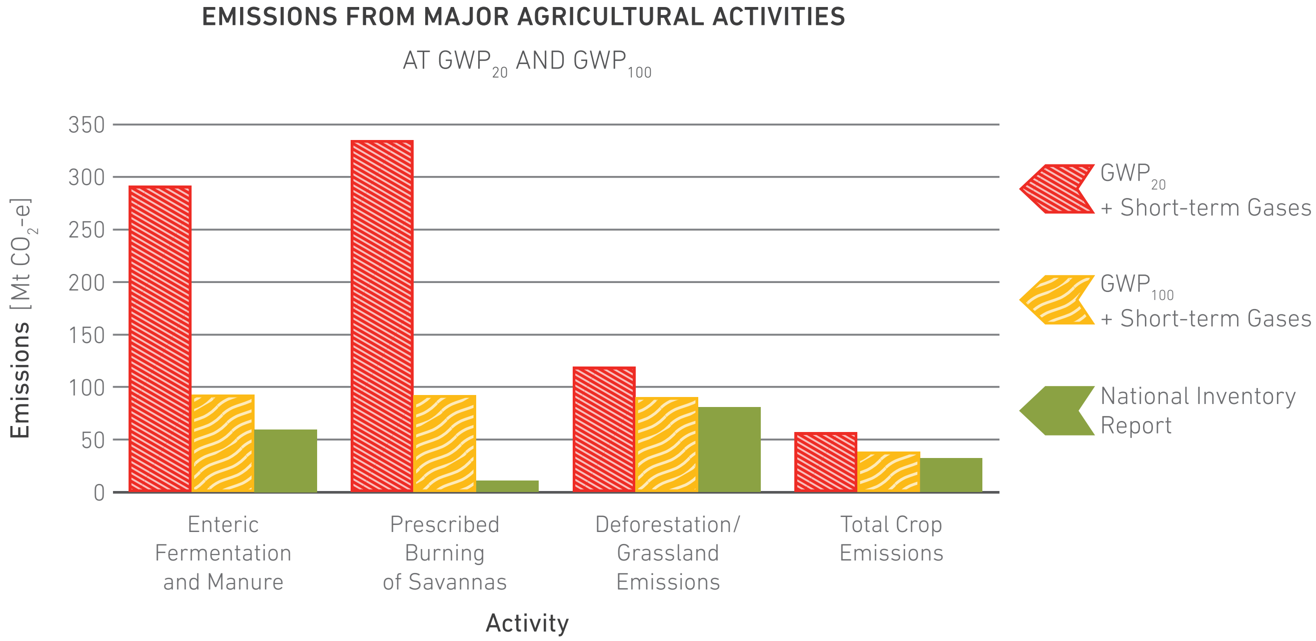

Figure 3.21 Grouping of agricultural emissions (2006 – 2010; Mt CO_2-e/yr) by agricultural activity.

Understanding that agricultural emissions have the greatest warming impact of any sector when assessed over 20 years and when short term gases are included provides truly transformational climate change mitigation opportunities.

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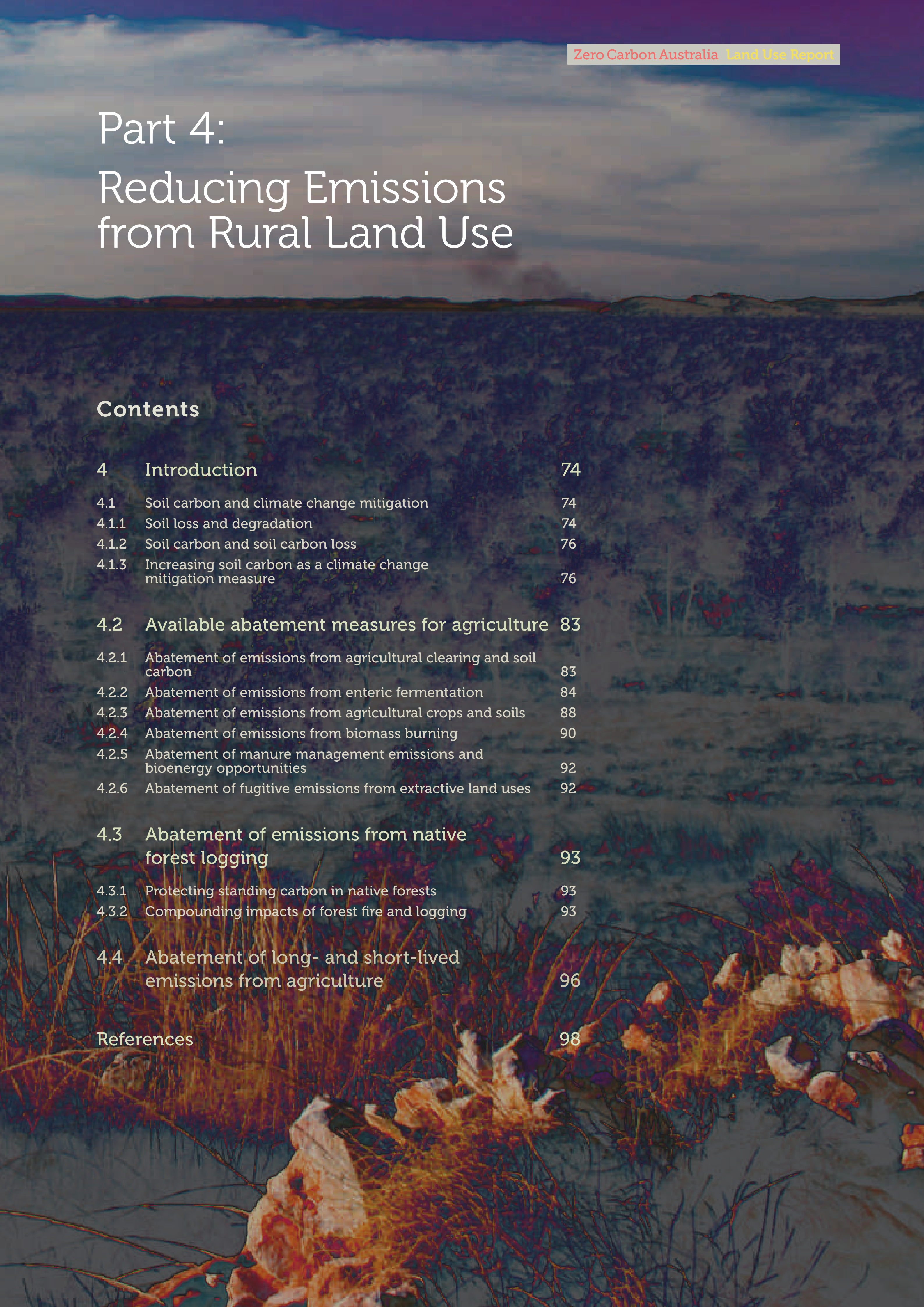

Part 4:

Reducing Emissions from Rural Land Use

Contents

4.0 Introduction

This chapter first analyses the climate change mitigation available through an increase in soil carbon levels on agricultural land, a concept discussed widely in recent times because of its political appeal and the apparent though illusory ease with which ongoing emissions could be offset through sequestration in soils. We demonstrate that though soil has potential to absorb very large amounts of carbon this potential appears to be more limited than hoped, and would be unlikely to offset emissions from agriculture alone, far less those from the wider economy.

We then describe currently available technological, management and other methods for reducing greenhouse emissions from heavy-emitting industries and sectors. A number of these methods are already in use or have been tried and withdrawn for political reasons despite their proven effectiveness. Others are implementable but uneconomic, while still others require further development but may become available in the future.

Chapter highlights

- The science of soil carbon is beset with variability and uncertainty. The potential to mitigate climate change by improving soil carbon stocks is limited.
- Changed policy and practice with regard to agricultural land clearing can prevent emissions on the order of 100 Mt CO_2-e/yr.
- Beef cattle and sheep cause around 80% of all enteric fermentation methane emissions. Options to reduce these are of very limited applicability to rangeland animals but may be useful in more intensive operations.
- A total reduction of up to 20% in other enteric methane emissions may be possible with existing techniques, but this falls well short of needed emissions reductions.
- Large emissions from clearfell native forest logging can be avoided. Allowed to recover from disturbance, the eucalyptus forests of south-eastern Australia can sequester 7,500 Mt CO_2.
- Disturbance of our tall forests increases the likelihood that fires will be severe and cause tree death. The combined effects of fire and human disturbance can drive forests into to a permanently compromised state.

4.1 Soil carbon and climate change mitigation

4.1.1 Soil loss and degradation

Healthy soils sustain plant and animal life in both natural and managed environments; they hold water, store carbon and cycle nutrients. But globally, topsoil disappears at a rate of around 1% per year, and at least 40% of arable land is degraded as a result of human activity.[1] The rate of soil loss is 10 to 100 times that of new soil development[2]: soil simply does not regenerate on human timescales.

Soil can be displaced by wind or water, chemically or physically degraded in situ, or be subject to a combination of these effects. These processes are invariably accelerated by human activities, notably agriculture because of its great extent and direct manipulation of soils. Soil degradation and erosion imply the loss of soil organic matter and the depletion of nutrients and substrate vital for plant growth, and also a reduced capacity to capture carbon. The carbon in soils is emitted to the atmosphere when it is disturbed by human activity or natural processes.

Australian soils were already ancient, weathered and nutrient-poor at colonisation; they are an asset we can ill afford to lose or further degrade. Agricultural production, beginning with deforestation, has accelerated soil loss in Australia.[3, 4] Our continent now loses 50 to 150 million tonnes (Mt) of soil each year as dust[5] alone and probably comparable quantities as waterborne sediment. Cultivation, bare fallowing, and the associated drying of soil and loss of soil structure have played a large part in these losses, as have both production animals and ferals such as rabbits. Inflexible pasture management practices and the use of imported feed to maintain high animal stocking rates long into periods of drought have also contributed.

Historical records from throughout the twentieth century indicate episodes of red snow, rain or mud in New Zealand when soil removed from the Australian continent was redeposited.[6] Massive amounts of topsoil are still periodically lost in wind storms that carry soil to our eastern cities and the ocean beyond (***Fig. 4.1*** to source). Recent research indicates that wind-blown components of the Australian soil may be transported as far as sub-Antarctic islands[7] and Antarctica itself.[8] As well as being a source of carbon emissions, eroded dust can both directly increase atmospheric heat capture through absorption and light scattering, and lead to decreased heating through its role in cloud formation.

Losses of soil to water erosion are also significant, though less well documented for the continent as a whole. Around 14 Mt of soil are deposited into the Great Barrier Reef (GBR) lagoon each year, a rate around 3 to 4 times higher than that before the land was cleared.[9] The rate of sedimentation to the GBR has increased up to tenfold since European colonisation,[10] and the greatest increase has been from intensively-grazed catchments;[11] a 2013 Queensland Government report estimated that more than 75% of total sediment in the Fitzroy and Burdekin rivers was soil lost from grazing land.[12]

As well as removing the most nutrient- and carbon-rich topsoil from the landscape, erosion can physically destroy productive areas. Erosion by wind is an important aspect of desertification, as productive soils are stripped from the land or desert soils are deposited on farmland. Erosion gullies are common in rural Australia and like wind storms provide visual evidence of ongoing and irreversible soil loss.

Soil loss also has negative effects on inland and inshore waters. High sediment loads reduce light penetration into water bodies, causing changes to plant life and therefore shifts in riverine ecology. This affects ecosystem function, amenity and can have great economic impacts. Higher nutrient loads in waters receiving erosive runoff also alter the balance of species, favouring algae and increasing the risk of toxic blooms. High sediment loads change channel dynamics, and faster runoff from bare earth also means less water is retained in landscapes. Subsequent deposition of soil removed by water erosion also causes damage to infrastructure, for example causing dams to become unserviceable.

However, modelling suggests that even a minimal change to land use practices, achieving only a 10% increase in ground cover in tributary catchments, could reduce sediment loads by up to 17% at the mouth of the Burdekin River.[11] Because 70% of water-borne sediment discharged to the GBR lagoon arises from only 20% of its catchment, changes to reduce soil loss could be targeted and would not necessarily require wholesale changes to land use patterns.[9] Such changes could take the form of improved grazing management, especially reduced cattle numbers and exclusion of animals from some areas such that soil cover was maintained, combined with active or passive revegetation.

Figure 4.1 Red dust storm Photo: Daniel Boud boudist.com.

4.1.2 Soil carbon and soil carbon loss

Soil carbon exists as living biomass — plant roots and other soil organisms — and as non-living organic matter. Plants grow by absorbing CO_2 from the atmosphere, thus converting gaseous carbon to less reactive, solid forms. Carbon from roots, leaf and debris fall and crop residues is transported into the soil by the activities of animals, fungi and microbes. Some carbon comes into soils via symbiotic fungi which feed on carbon from plant roots in exchange for nutrients supplied to the plants. Carbon imported to soils by these pathways provides the energy for soil life.

The Earth's soils hold around 2500 GT of carbon, twice as much as the atmosphere,[13] and as such are an important component of the carbon cycle. Levels of soil organic carbon (SOC) are an important indicator of the functional health of soils, with higher levels of SOC an important characteristic of fertile soil. Depending how they are managed, soils can sequester or emit carbon. Soil carbon levels in Australia and globally have declined as a result of human activity, notably agriculture. Losses can be rapid or sustained, but regaining SOC takes time.[14]

The SOC content of Australian soils appropriated for agriculture declined by at least 39%[15] and up to 60%[14,16] between 1860 and modern times. Direct SOC losses continue for 20 to 100 years after woodlands and forests are converted to cropland or grassland for agricultural use.[17] Post-clearance management practices also strongly influence soil carbon levels. Long term SOC depletion in Australian soils is largely due to grazing pressure,[18] and a reduction of this pressure can prevent rangeland SOC loss.[19] However where SOC is depleted by cultivation in areas of higher rainfall, conversion from crop to pasture can also slow carbon losses.[16]

Because of its small particle size and relatively lower density, the SOC fraction of soils is selectively lost to wind erosion[20]; hence the most valuable portion of soil is simply blown away more easily. A 2013 analysis of the quantity and sources of carbon emitted when soil is lost to wind erosion in Australia reveals total annual emissions of 5.38 Mt CO_2-e/yr.[22] These emissions are not captured in national greenhouse accounting, despite the fact they are approximately equal to direct emissions from agricultural soils.[21] Rangeland grazing land is the source of 4.92 Mt CO_2-e/yr, or 84% of these emissions due to SOC loss.[22] This significant contribution from rangelands is due in part to the great area of grazing in Australia, and also to inflexible pasture management practices as described above.

4.1.3 Increasing soil carbon as a climate change mitigation measure

Because their carbon stocks are depleted, agricultural soils can conceptually offer large potential for carbon sequestration.[23, 24] Several public documents comment on our soils' capacity to absorb carbon and thereby provide a cost-effective sink for atmospheric carbon. This mechanism has been promoted for its potential to offset greenhouse gas emissions from economic sectors outside land use. To date publications that have considered soil carbon for its offset potential include The *Garnaut Review* and updates, the report of the Wentworth Group of concerned scientists, the Australian Labor Party's *Carbon Farming Initiative* (CFI) and the Australian Liberal/National Parties' *Direct Action Plan*.[25–28] These documents rightly observe that increases in soil carbon will also improve the nutrient cycling and water holding capacity of soils, and so improve conditions for agriculture.

Here we discuss the potential of soil carbon increases to act as an "emissions abatement" or offset measure, offering context from the scientific literature to political proposals that manipulation of soil carbon can form a major part of Australia's policy response to climate change. Though increasing soil carbon is a worthwhile objective, the development of climate change mitigation strategies based on soil carbon will be far from straightforward.

In general, any increase in plant growth should translate to increases in SOC stocks, though this is not universally found.[14] According to this basic assumption, however, any intervention that increases plant production has the potential to increase SOC also. This means that fertiliser, irrigation or other methods designed to increase yields can increase SOC, as can land use changes such as shifts from cropping to pasture, or retirement and revegetation of agricultural land. The science of soil carbon is a complex field, and many variables influence stocks, rates of change and permanence of soil carbon (***Fig. 4.2***).

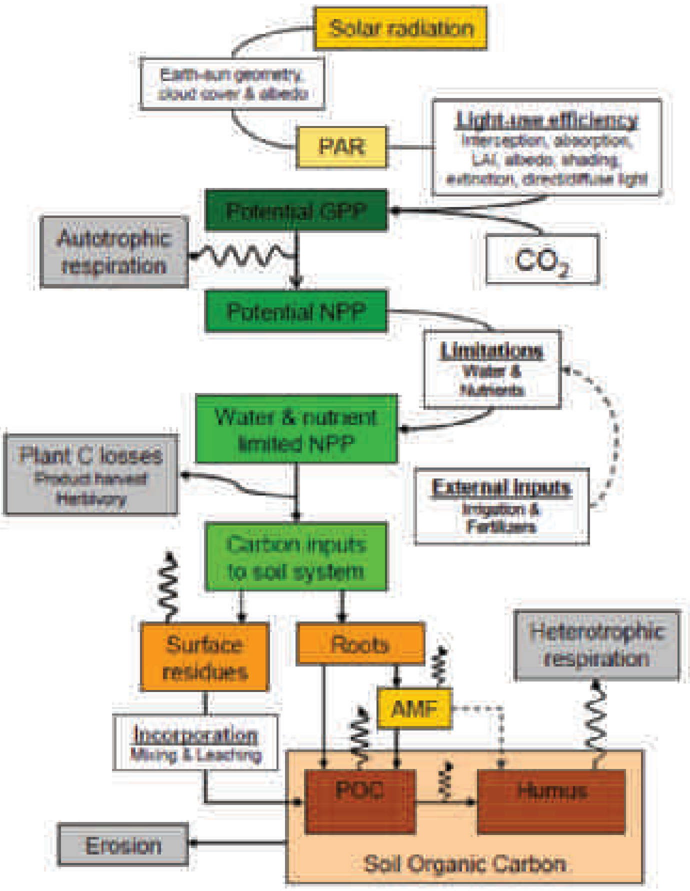

Figure 4.2 Carbon (C) flow in agroecosystems. White boxes represent limitations to C capture, grey boxes represent C losses, squiggly lines represent emissions of CO_2 to the atmosphere. Some C enters the soil as organic compounds excreted by roots and Arbuscular Mycorrhizal Fungi (AMF) if these are present. Carbon from plant shoots (above ground, including crop residues) may be introduced to the soil by the activities of animals or tillage or dissolved in water leached through residues. Most C enters the soil as particulate organic C (POC), relatively large pieces of plant matter. A portion of the total carbon entering soil is transformed into humus, and the remainder is re-mineralised to CO_2 and emitted to the atmosphere during respiration (adapted from Sanderman *et al*. (2010), p. 6 [14]).

A number of farming techniques adopted widely over past decades have been analysed for their potential to influence soil carbon levels. This section offers a brief summary of some such techniques and of recent findings with respect to storing carbon, particularly in Australian agricultural soils. Many experts highlight the difficulty of reversing soil carbon lost as a result of agricultural activities, and the slow rate of improvement if reversal is achieved. The many variables inherent in farming systems, including spatial and temporal variations in soil type and climate, make for a complex story with respect to the potential to increase soil organic carbon (SOC). There are also difficulties around both soil carbon accounting and the economic feasibility of proposed programs to sequester carbon in soils, each briefly addressed below. Finally, the retention and ultimate fate of carbon in soils interacts with local climate. For example, increases in temperature and soil moisture can increase plant growth and possibly sequestration, but can also increase microbial activity and hence losses of soil carbon through respiration.

4.1.3.1 Methods of influencing carbon stocks on agricultural land

Sequestration of carbon in soils implies the removal of CO_2 from the atmosphere by growing plants, and the storage of this carbon in long-lived sinks from which it will not be re-emitted in the short term. However as detailed above, large quantities of soil organic carbon (SOC) have been lost from agricultural soils in Australia and elsewhere. Many types of management can influence stocks of SOC, either by reducing losses or increasing gains. A number of these are briefly discussed in the following paragraphs.

Conventional or intensive tillage is used to control weeds, turn in crop stubble and for seed bed preparation, and may involve complete inversion of upper soil layers and several tractor passes per crop. Such methods are a primary cause of sustained SOC declines when virgin land is cultivated.[16, 29] Though conventional tillage introduces plant residues into deeper soil layers, it also stimulates soil carbon emissions. This happens when deeper soil is fragmented and exposed to air, allowing aerobic microorganisms to increase their activity, and because carbon and moisture introduced by soil inversion improves conditions for some microbes and hence increases respiration emissions.

Several forms of less intensive, so-called conservation tillage are practiced. These range from a simple reduction in plowing to zero-till with direct drilling of seed through stubble from the previous year's crop. These methods achieve savings in fuel and labour inputs as well as reducing soil compaction, erosion and nutrient loss. Improvements in soil structure and function compared to intensive till also motivate the growing uptake of conservation tillage methods. No-till farming is now used by around 90% of farms in many regions, and few farmers who adopt the conservation practice ever revert to previous methods.[30] The advantages of reduced tillage are greatest when combined with stubble retention, which provides a source of organic matter, reduces erosion and helps to retain soil moisture.

In general, results show that the less cropping soils are disturbed, the better the result for soil carbon. No-till cropping may have the potential to store or retain 75% more SOC than conservation tillage across Australia's south-eastern wheatbelt.[31] Such results, however, do not necessarily indicate actual increases in SOC levels, as explained below. In recognition of the influence of tillage, incentives for further uptake of minimum-till methods, including assistance to invest in appropriate equipment, are a part of the carbon farming initiative (CFI).

Though they can increase SOC, both fertilisers and irrigation can also foster its decomposition by microbes and hence loss from soil, leading to a trade-off and further uncertainty.[32] Variation of crop rotation regimes,[33] crop residue retention, increased use of fertilisers, importation of bulk organic matter and revegetation to woodland are among other techniques shown to improve soil carbon levels. Deep-rooted cereal crops, which are more resistant to drought than standard varieties,[34] have also been proposed as a mechanism for increasing soil carbon stocks in dryland agriculture. Some of these techniques are used in conjunction with conservation tillage, while others require further development. Conversion of cropland to pasture may offer better C sequestration than no-till,[16, 31, 35] though this effect has not been found consistently[33] and increases in methane emissions would have to be considered (see below).

Conservation tillage, residue retention and maintenance of soil cover in turn also encourage the presence of a healthy soil microorganism community, including microscopic fungal networks that exist in symbiosis with most agricultural plants and improve plants' capacity to forage for water and nutrients. Symbiotic mycorrhizal fungi also consume 20—30% of host plants' total production.[36] By drawing this carbon into the soil matrix, they also provide energy to soil microbial communities, which in turn boost nutrient processing. The substance left in the soil, a protein called glomalin, persists for long periods contributing to soil structure[37] and to long-term carbon sequestration (Smith and Read pp607-609[38]).

Alternative farming methods

Some innovative farming methods may have potential to increase SOC relative to traditional farming, and deserve serious attention for their capacity to supply commercial quantities of food with reduced inputs and environmental impacts. A small sample of these is presented below.

Pasture cropping (PC), a zero-till technique that involves direct sowing of winter cereal crops into mixed-species, especially native perennial pastures, has gained significant popularity among farmers. As well as year-round ground cover and hence lower erosion, pasture cropping can permit reduced fertiliser and herbicide use and the satisfaction of producing both cereals and grazing products on the same piece of land.[39] Integration of production activities with conservation of native grasslands is also a motivation,[40] and improvements in soil structure and nutrient cycling have been observed.[40, 41] Though cereal yields are lower with pasture cropping, the diversified income stream and reduced input costs can bring higher average returns.[39,41,42] Pasture cropping also allows more responsive cropping, because no preparation is required prior to seeding. Farmers can decide late in the season whether and what to sow, lowering risk as fewer resources are committed.

Pasture cropping has been linked with higher SOC levels in the top 10cm of soil than observed in otherwise equivalent holdings.[40] Long-term monitoring will be needed to quantify the degree of carbon sequestration available from PC, and other alternative agricultural techniques, and these are currently lacking. However, the lower levels of nitrogen needed in these systems should be directly reflected in lower soil emissions.

Some studies have questioned the future viability of PC if climate change brings more frequent dry years, or a decrease in available moisture, because of competition between pasture and crop plants.[42] However this competition may not be problematic, as pasture and crop species are generally active at different seasons. Mid- to long-term improvements in SOC relative to degraded soils — a reported doubling in some instances — as well as better soil structure, should improve water holding capacity, and this has also been observed under PC.[43] Shading of the soil surface and the wind protection offered by pasture herbage should also reduce water loss.

Rotational grazing is an alternative pasture management whereby grazing animals are rotated through a series of paddocks at high stocking rates and graze each heavily before being moved to the next. Paddocks are rested for relatively long periods, allowing vegetation to regrow. Though results are variable, such management can confer benefits to grazing systems. Rotational grazing has often been shown to increase herbage growth, permitting higher stocking rates and better productivity (e.g.[44–48]), though other trials have recorded no such benefit (e.g.[49, 50]).

Greater pasture growth should translate to higher soil carbon levels, as more photosynthate becomes available for import to soils, so any pasture management that improves herbage levels should be good for soil carbon. Significantly greater SOC levels relative to comparable conventionally-grazed pasture have been recorded on rotationally-grazed land.[51, 52] Higher cation exchange capacity, an aspect of soil fertility closely related to SOC levels, has also been recorded in soils under cell grazing than in otherwise equivalent soils where cell grazing is not practiced.[46, 51] See the Appendices for a more comprehensive description and assessment of rotational grazing.

Organic and other low-input agriculture can potentially play a role in reducing emissions or sequestering carbon in soils. Though European[53, 54] and North American[55] studies have confirmed significant SOC increases associated with organic agriculture, large scale, long-term studies of this nature are absent for Australia. However, because chemical weed control is off-limits to organic and biodynamic producers, weeds must be destroyed mechanically. This reintroduces the SOC deficits caused by conventional tillage.

The 2010 CSIRO Sustainable Agriculture Flagship report *Soil Carbon Sequestration Potential: A review for Australian Agriculture*[14] considered the potential impact of a number of management or land use options, and we recommend this report as further reading on the subject. Only two of the interventions included in the review offered both high potential for SOC increases and high confidence of this estimate. These were the direct addition of imported organic matter to mixed cropping / grazing systems and the retirement and revegetation of agricultural land.

4.1.3.2 How much carbon could we store in soils?

Though increases in soil carbon are without doubt helpful from the climate perspective, on its own soil does not offer a panacea. Recent Australian studies have directly addressed this issue. The potential soil carbon gains presented in these studies, even if realised as material and permanent additions to SOC, would fall far short of offsetting current emissions from land use, far less compensating for past emissions of soil carbon or abating emissions more broadly.

A recent meta-analysis of 56 studies on a range of Australian soil types and management regimes between 1984 and 2012 compared SOC benefits from residue retention, conservation tillage, conversion to pasture and nitrogen fertilisation.[16] Each appeared to offer some SOC benefit relative to control treatments out to 20 years. However, the magnitude of SOC increases was quite small (7—13%) and was limited to the upper 10cm of the soil profile. An international meta-analysis, covering a range of crop and soil types, suggests that a change from conventional to no-till methods produced modest average SOC increases to twenty years of only 2—3% in temperate regions.[29] Even a hypothetical full adoption of the suite of management changes considered by Lam *et al.* (2013[16]) across all of Australia's 100 MHa of cleared agricultural land would account for less than 10% of Australia's total 2011 national greenhouse emissions.

Modelling has found that the maximum sequestration in the top 30cm of Australia's southern wheatbelt soils, with 100% adoption of no-till cultivation over 20 years, would amount to 68.328 Mt CO_2-e/year.[31] This would offset just 0.6% of the 2011 national total even when emissions reductions from the lower on-farm fuel use and animal numbers often associated with conservation tillage are included. Extrapolated to all of Australia's agricultural land — much of which is either not cropped, is already under conservation tillage, or for other reasons would not be available for such a management change — this total would offset perhaps 3% of 2011 national emissions. Any advantage for national emissions accounts would again be conditional on actual and permanent sequestration rather than a simple slowing of agricultural emissions.

It is also useful to compare the abatement proposed in political documents to the magnitude of Australia's emissions. In 2013, the Federal Liberal / National Parties' Direct Action Plan claimed the potential to deliver a "once in a century soil replenishment" by sequestering or avoiding the emission of 140 Mt.CO_2/year by 2020, 84 Mt.CO_2/year of this in soils.[27] This quantum of soil-based sequestration would amount to about 15% of annual national emissions. The Australian Labor Party instead claimed that the CFI would result in the sequestration of "around 460 million tonnes of carbon pollution" Australian soils and landscapes to 2050.[28] Assuming that mass of CO_2 is meant, this is around 11.8 Mt.CO_2/year, or around 2% of total emissions in 2011.

4.1.3.3 Measuring SOC change and permanence

Unresolved difficulties and knowledge gaps relating to both soil carbon measurement and the stability of carbon in soil lead to concerns regarding rates of sequestration and permanence. Where baseline SOC levels have been recorded at all, there is often uncertainty over whether these reflect a steady state or ongoing decline. For this reason, whether or not higher relative SOC levels observed in response to interventions represent actual removal of atmospheric CO_2 remains questionable. Australian and international studies have shown that SOC is often higher only relative to control treatments where soil carbon loss is ongoing,[17] and in such cases the relative advantage represents only a slower rate of soil carbon emissions. Long-term monitoring is required to ascertain the status of baseline SOC.

Nor can it be assumed that carbon stored in agricultural soils will remain there long-term. Regardless of the change to management that leads to SOC gains, organic matter is mostly accumulated in the top 10cm of soil, the layer most susceptible to SOC loss.[14, 16, 33] The positive effect may also be largely limited to the first ten years after implementation,[16] with significant rates of sequestration lasting only up to several decades.[57] Management changes that are effective under some climates and soil conditions may not work in others. For example, research shows that Soil C increases 20 years after a change to minimum till were significant in well-watered areas but not in arid areas.[29] Furthermore, there is evidence that SOC gained by zero-till methods can be released by a single plough pass.[58]

4.1.3.4 Trade-offs and limitations

Attention must be paid to the net emissions balance of changes to farming methods. This is especially true where animals are introduced to a system. Carbon inputs to soil may or may not be greater in pasture as compared to cropping,[16, 31, 35] and SOC benefits of conversion may be evident only after several decades. Emission of enteric methane and nitrous oxide passed by grazing animals may negate the direct carbon benefit.

The same caution applies to nitrous oxide and pre-farm emissions associated with fertiliser use. The capacity of soils to sequester and retain carbon is influenced by soil nitrogen levels.[59, 60] Many Australian agricultural soils are nitrogen-poor and would therefore require inputs of N-fertiliser to increase and maintain higher SOC levels. Further, if plants can obtain their nutrients with relative ease, for example from fertiliser or other amendments, they invest fewer resources in their roots. Fertiliser application to promote shoot growth can therefore leave roots underdeveloped and

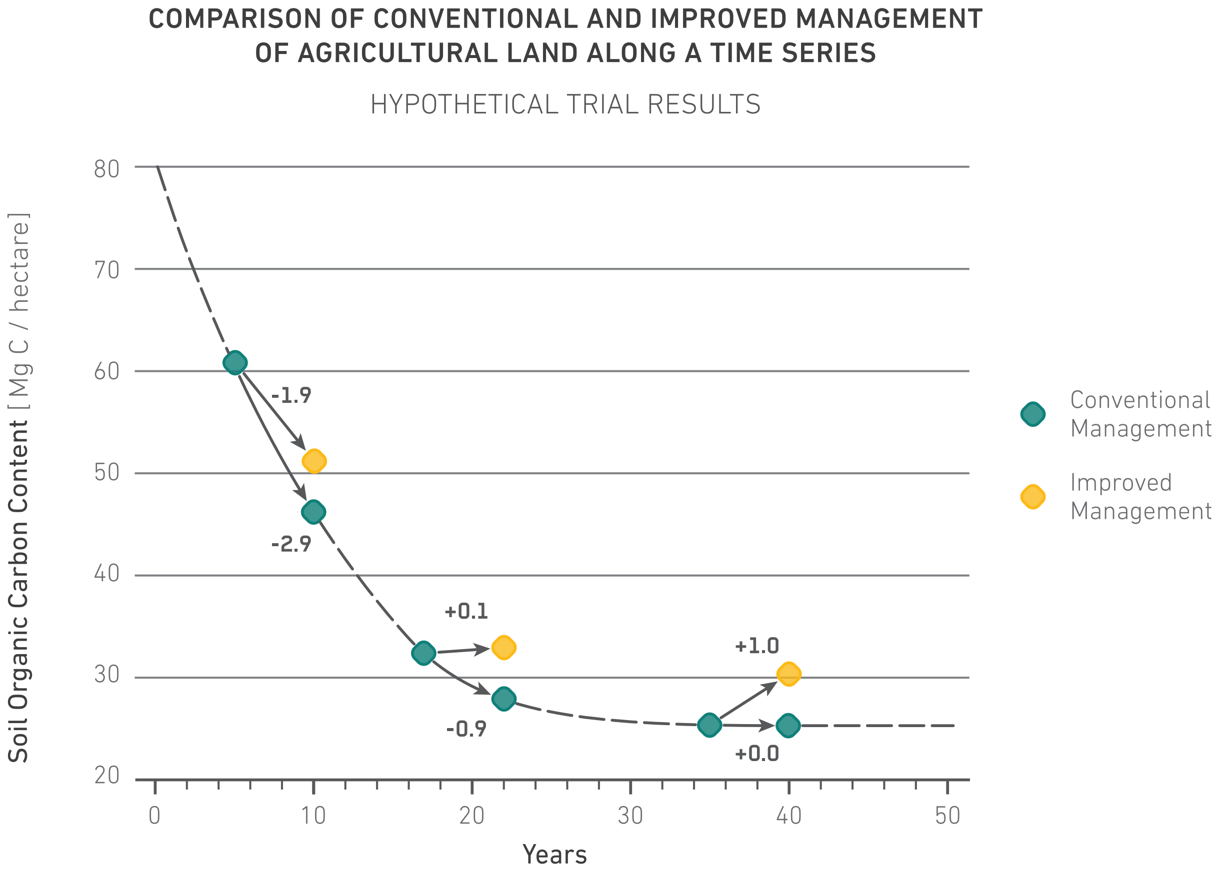

Figure 4.3 Soil carbon levels under two management treatments. All three results show the same relative difference (5 t C/ha over a five-year period). Adapted from Sanderman and Baldock 2010[56].

result in lower below-ground biomass, reducing the carbon imported to soils.

Consideration of the emissions embodied in N fertilisers during production and transport, though these emissions are accounted for in a distinct sector of the economy and may be realised outside Australia, also cautions against a presumption of net sequestration if fertilisers are used. Improvements in SOC may be also overwhelmed by other emissions released during the process, for example, of importing bulk organic matter to farmland. Comprehensive lifecycle analysis is needed to assess this balance.

The absolute carbon capacity of soil, and ecosystems more generally, also is finite; landscapes can only store the same quantity of carbon as was emitted from them as a result of their conversion for past uses.[61] Even complete revegetation of land cannot compensate for emissions resulting from the land uses themselves. Of course, a return to pre-development landscape carbon stocks is unachievable from the perspective of competition for land, though increases in farmland SOC stocks could enhance global food security.[62] But humans' ability to influence landscape carbon stocks is also limited by economic, social and political factors, and changes to the environment have also reduced its absolute capacity to regain carbon historically lost.

4.1.3.5 Is the storage of carbon in soils economically feasible?

The accounting and economics of soil carbon sequestration also remain unresolved. Though the CFI has made inroads to driving some emissions mitigation measures, it is unlikely to engender management practices specifically aimed at increased soil C. A carbon price of $A36 per tonne of carbon dioxide would be needed to make viable any of the changed practices considered by Lam *et al.* (2013) if they were undertaken for the purpose of carbon sequestration.[16] Changes to management involving increased nitrogen inputs were rendered unprofitable as input costs overwhelmed potential payment, even under the provisions of the CFI (\$24.15/t CO_2-e in 2013),[63] and would be at further disadvantage at lower trading prices for carbon.

According to 2010 economic modelling, at an arguably realistic carbon price of \$50/t.CO_2-e, less than 10% of the 18.64 Mt CO_2-e total carbon storage potential in the southern Australian grain-producing region would tapped by adoption of no-till farming.[31] Even at \$200/t CO_2-e, these authors suggest only 19—33% of this potential would be realised, despite the fact that their model assumed that SOC gains were permanent. In mid-2013 the prospect of a carbon price on the order of \$20/t CO_2-e once again faded, with the government foreshadowing that from 2014 the Australian price would be linked to the European carbon price. More recent developments have diminished yet again this prospect. A much higher price than that currently mooted in Australia would be needed to motivate change to farming practices aimed at sequestering large amounts of carbon.

4.1.3.6 Great potential, great uncertainty, no climate panacea

The sheer size of global soil carbon stocks, and their depleted status, indicates their capacity to sequester large amounts of CO_2, and so offer a large-scale climate change mitigation option. Tapping this potential is of great importance both because it will remove carbon from the atmosphere, and because it can improve food security through improvement of agricultural soils.[23, 64] What is less clear however is that storage of carbon in soil is permanent or can happen at a scale and rate commensurate to the immediacy of the climate problem. It is dangerous to assume that soil carbon alone has the capacity to mitigate climate change.

The human capacity to influence soil carbon may saturate far earlier than the biogeochemical capacity of soil to store carbon. In fact, as Mackey *et al.* (2013) make clear, the global capacity to sequester carbon in landscapes is several times smaller than the amount of carbon that would be released if emissions from fossil fuel use continued unabated. This confirms landscape carbon sequestration as a sink for ongoing emissions in other parts of the economy as a logical fallacy.

Rural land use — agriculture and forestry — cannot offset emissions from other sectors until these activities are themselves emissions-neutral. While carbon sequestered in landscapes does come out of the atmosphere, such removals now and in the foreseeable future remain putative and in any case would be swamped by land use emissions.

Just as measured relative improvements in soil carbon status may reflect only a slowed loss, even verified increases in soil carbon would constitute only a slight slowing of emissions from agriculture, all else being equal. Instead what is required is a rapid and verified decrease in emissions, with sustained and growing cuts in coming decades to bring land use to zero net carbon emissions.

The sequestration of carbon in agricultural soils does not constitute a material reduction in emissions. Improvement of soil carbon stocks constitutes at best the replacement of legacy carbon emissions from soil, and must not be used as a trick of accountancy to 'offset' ongoing emissions from fossil fuel use. Such expediency would betray future generations of Australians. In order to reduce atmospheric carbon dioxide stocks to a safe level, a sustained net annual sequestration of carbon in our landscapes — in soils and vegetation — will need to be additional to cuts in fossil fuel extraction and combustion. We are currently far from this scenario.

4.2 Available abatement measures for agriculture

With deforestation and prescribed burning attributed to agriculture, total agricultural emissions averaged 189.5 Mt CO_2-e/yr in the period 2006 – 2010, or around 33% of Australia's total net emissions. Here we examine approaches for reducing emissions from the activities producing the bulk of these emissions. We discuss targets for emissions abatement in order of their potential for mitigation on the basis of average 2006 – 2010 emissions (***Section 3.2***).

4.2.1 Abatement of emissions from agricultural clearing and soil carbon

Land clearing emissions for 2006 – 2010 were significantly lower than long-term average from this source (***Fig. 3.5*** **p 47**). This suggests that appropriate policy can reduce land-clearing emissions. Much has been made of the concept of increasing soil carbon stocks as an offset for emissions from other sectors of the economy (***Section 4.1*** **p 74**), but these emissions can be strongly mitigated by restrictions to clearing.

4.2.1.1 Forest land converted to grassland

Though emissions from deforestation and subsequent soil carbon loss have reduced in the twenty years to 2010, they have large potential for further reduction and are targetted in the *Carbon Farming Initiative* (CFI). The CFI has noted shortcomings and faces an uncertain future, but could frame a concerted effort toward substantial bio-sequestration by ensuring financial rewards for retaining and maintaining forests and woodlands exceeded those for grazing activities.

Ceasing deforestation for pasture would reduce national emissions by 58.4 Mt CO_2-e, 31% of average 2006 – 2010 agricultural emissions.

4.2.1.2 Re-clearing and soil carbon emissions from cleared land

Emissions from *Grassland remaining Grassland* are captured here and include those from re-clearing and soil carbon loss after clearing. The component of this caused by clearing and burning regrowth vegetation can be avoided simply by ceasing the practice. Graziers in some regions commit significant time and resources re-clearing woody re-growth and 'weeds' that invade pastures, and some would gladly turn these areas over to biosequestration if there were financial incentives.

A significant component of emissions from the *Grassland remaining Grassland* sub-category are these losses are in the form of soil carbon (see also ***Section 4.2.1.4*** **p 83**). These emissions are committed and the best way of reducing them is to re-grow the woodlands or forests that until recently grew on them.

Based on the 2006 – 2010 average, potential avoided emissions total 24.2 Mt CO_2-e/yr.

4.2.1.3 Forest land converted to cropland

Cessation of clearing for crops to the extent this was conducted in the 2006 – 2010 period would reduce national emissions by 15.4 Mt CO_2-e, 8% of the national total for agriculture.

4.2.1.4 Uncounted emissions from soil erosion

The vast majority of soil carbon emissions due to wind erosion come from the rangelands. Remediation of these would come about by revegetating parts of the rangelands, and by reducing and closely managing grazing pressure to prevent the incidence of bare soils. As discussed in ***Section 4.1.1***, revegetation can be closely targeted to slow erosion by water, but a more generalised approach will be needed for wind erosion. Wind erosion from cropped lands can be lessened by maintaining ground cover year-round, retaining stubbles, avoiding fallowing, practicing conservation tillage, maintaining or establishing windbreak vegetation, and by other management approaches that

Figure 4.4 Options for reducing production of methane from enteric fermentation (Eckard *et al*. 2010[66]).

maintain soil moisture and structure. Many of these methods are also good for soil carbon, and are treated in ***Section 4.1.3***.

4.2.2 Abatement of emissions from enteric fermentation

Emissions from enteric fermentation (EF) averaged 56.2 Mt.CO_2-e from 2006 – 2010. Enteric fermentation contributed 48% of total national methane (CH_4) emissions. Beef cattle grazing on pastures contribute 62% of total EF emissions, sheep 18%, dairy cattle 11% and beef feedlots 3.5% (***Fig. 3.7* p 49**). Methane from all other enteric sources, including feral camels, which are not included in the national inventory, is equivalent to around 5% of human-caused EF. Emissions from EF represent a loss of efficiency in grazing animals and systems,[65 – 68] so a great deal of research has gone into methods of reducing them and limited improvements in methane efficiency (ME) have followed.

Enteric fermentation can to varying degrees be controlled by interventions at the system, animal, diet and rumen levels. Different interventions may suit dairying, beef and / or sheep grazing operations. Gains made through one approach may be additive, neutral or counteract improvements made in others, and many interventions require further research.[66, 69] Many are diet-dependent, and some are applicable in certain geographical or climatic zones but not others. Some measures are impractical in combination with other farming operations, while others face market acceptability or cost limitations.

Methane abatement options show some promise for lot-fed cattle and temperate grazing systems, where animals are relatively closely controlled. However most options are unsuited to tropical and sub-tropical extensive grazing systems where most of Australia's beef is produced.[66]

Some methane reducing treatments have corollary benefits, either in terms of their potential to abate emissions of other GHGs, or in other respects. For example, the addition of tannins to ruminant diets with the aim of methane abatement also reduces the level of volatile nitrogen in urine, which would translate to lower N_2O emissions from soils and manure management, especially in intensive applications.[70]

We describe below options for abatement in order of the quantity of greenhouse emissions by source. For this purpose, sheep are grouped with grazed beef as EF abatement possibilities are similar for these two groups.

A range of available approaches, their effects on methane production and their current feasibility for implementation are summarised in ***Figure 4.4*** and ***Table 4.1***.

Genotypic changes to herds, achieved by selectively breeding for attributes such as fast growth, low methane production and efficient feed conversion, offer the best opportunity to reduce emissions in the medium term. These may be compatible with the other economic objectives of graziers, though implementation may take years to decades. On temperate pastures, a concerted effort to reduce methane emissions from grazing livestock may deliver emissions reductions of up to 20% in the short term.

Management strategies include provision of higher quality fodder such as more digestible temperate perennial

Table 4.1 Interventions with potential to reduce emissions of methane from enteric fermentation in Australia, with assessment of their likely impact.

Intervention	Description	Potential methane reduction	References
Animal Level			
Breeding for improved animal genotype	Inclusion of low methane production among criteria for breeding.	10—20%	66
System Level			
Concentration of animals into feedlots	Earlier finishing gives lower lifecycle emissions.	Up to 38%	66,71,72
Rotational grazing	Animals are rotated through paddocks to maintain high grazing pressure for limited periods.	22%	69,73
Reduce maintenance consumption	Reduce number of unproductive animals in herds.	10%	66
Decrease heifer replacement rate	Improve the fertility of dairy cows to meet milk quotas and maintain herd size	15%	74
Rumen Level			
Vaccination with antibiotics or other agents	Destruction of rumen methanogens.	Unknown	66
Monensin (antibiotic)	CH_4 suppression short-lived, controversial use in meat/milk production.	25—30%	65,75
Promotion of or inoculation with acetogens	Chemical diversion of H_2 from methane to acetate, an energy source for animals.	Unknown	69,76,77
Defaunation	Removal of methanogens by destruction of protozoa. Uncertain effectiveness in vivo.	50%	78
Diet Level			
Grains / concentrates	Optimising feed intake levels, quality and digestibility of feed. Usually involves intensification (feedlotting).	23—38%	71,72,79
Feeding of legumes or alternative forage crops.	Lower fibre content gives a faster rate of passage through rumen	Unknown	66,75
Grinding and pelletising of forages.	Increased rate of passage through rumen.	20—40%.	69
Fats / oils	Emissions effects may be additive to those of high-concentrate diets.	Up to 52%, 10—25% likely	69,75
Synthetic additives	Eg. Bromochloromethane, chloroform. Strong methanogenesis inhibitors. Unlikely to gain public acceptance.	Up to 91%	66
Enzymes	Potential for future — equivalent enzymes currently used in industrial food and fibre.	9—28%	66,75
Yeast cultures	In development.	Unknown	80
Dicarboxylic acids	Expensive to produce; high doses required; needs work to commercialise.	Up to 23%	69,77
Nitrate	Further study required but demonstrated reductions in methane production.	16%	69,81
Plant secondary compounds.	Tannins, Saponins, Nisin	10—29%	66,70,82

ryegrass/white clover pastures, which can reduce methane because of their lower fibre content and faster rate of passage from an animal's rumen. Rotational grazing can also increase methane efficiency (the quantity of CH_4 produced per unit of product(e.g.[69, 73]), although this has not been found consistently.[83]

Because they increase the efficiency of conversion of pasture into animal products, methane efficiency (ME) improvements are generally sympathetic with graziers' objectives. As product volumes dictate farm income as much as product quality however, faster turnoff of beef cattle tends to see larger numbers produced in a given period. In this situation, any gain in ME is lost when net emissions are counted. For per-animal reductions in CH_4 production to be translated across the national herd, net farm incomes would need to be maintained despite higher costs and stable or reducing animal numbers.

But profitable farming will already have driven many farmers and graziers to optimise their use of accessible techniques, such as breeding, herd management and feeding for efficient conversion, and the options for further substantial reductions in greenhouse gas emissions by the same means are limited. The current slow uptake of breeding specifically for low methane production, added expense, limited availability and low public acceptance of intensive feedlots, rumen manipulation, synthetic feed additives and antibiotics all impede large reductions in enteric methane emissions.

Garnaut (2008) estimated a potential reduction to EF emissions of ≈30%, based either on the use of anti-methanogenic technologies for grazing livestock, or on a one-third reduction in the national ruminant herd.[84] By comparison, the UK dairy sector targets GHG emissions reductions of 20—30% by 2020, a target that may be more achievable since most UK dairy cows are already lot fed. Without a large-scale structural change, we estimate that a reduction in total enteric fermentation emissions of perhaps 5—20% is possible in the short to medium term and would require very significant investments.

4.2.2.1 Grazing sheep and cattle

To make an impact on national emissions, technical solutions to reduce EF must apply to grazing cattle and sheep, as distinct from dairy or feedlot animals, because these make up 81% of total EF emissions.

Increased productivity in beef herds means faster live weight gain, giving faster turn-off rates for beef cattle and better profitability.[71, 72] Smaller animals have lower physiological maintenance requirements, and younger animals grow more quickly. Breeding for small size, reducing the age at which cows reproduce, and slaughtering cattle at a younger age are management methods that take advantage of these physiological factors to improve grazing system productivity.[66, 69] Animal breeding for attributes such as fast growth, low methane production and efficient feed conversion has also been effective, but even marginal improvements in ME through herd or flock structure may take many generations of progeny to effect, or conflict with other priorities.

Improvements in forage quality can be effective in improving ME but may be difficult or impossible to implement, especially where animals graze mixed or unimproved native pastures. *Leucaena leucocephala* is a perennial legume often planted in tropical and subtropical rotational grazing systems and favoured because it produces large quantities of fodder and is resilient to heavy grazing.

Heavy consumption of leucaena can be toxic to grazing animals and if not controlled by periodic heavy grazing or slashing the plant itself can become a problematic and prolific weed. Non-native species, including leucaena and many of the staple grasses of the pastoral industry, particularly buffel grass (*Cenchrus ciliarus*), are also strongly implicated in biodiversity loss and increased wildfire intensity.[85]

Like some other plants, leucaena promotes fast weight gain in cattle and provides fodder long into the dry season, both of which give grazing system efficiencies. Leucaena can also directly reduce EF methane production, an effect attributed to its tannin content[86] and well known in other animals and grazing systems.[70, 87, 88] Added to the diet of forage-feeding sheep, tannins from the black wattle (*Acacia mearnsii*), have also been shown to reduce EF methane and nitrogen excreted in urine,[82] which could reduce N_2O emissions.

Though they may offer marginally better herd performance than native pastures, especially on rangelands, these system-level efficiencies are not to scale with the methane emissions problem. Legume pasture and fodder plants also fix nitrogen, and can cause nitrous oxide emissions large enough to offset any gains from grazing system efficiency.[89]

Hormone growth promotants are in widespread use in Australia's northern rangelands[90] and allow cattle to maximise use of seasonally available pasture. These substances can accelerate muscle gain by 10—30% but may also reduce eating quality. In terms of greenhouse emissions, this accelerated growth can improve the ME of rangeland beef. Market acceptability of hormones, antibiotics and other substances in human food chains is also in question at least in the domestic market, such that one of Australia's major supermarket chains excludes hormone-treated beef from its range.

Grazing sheep or cattle are often integral to mixed farming in the intensive zone and can be an efficient addition to the productive capacity of farms, for example by grazing crop residues or pasture grown to take advantage of residual soil moisture in irrigated crops. However, most of our cattle — and all of those on the rangelands — fall outside this category. While some of the methods described above offer potential to reduce EF emissions, most feasibly in the intensive agricultural zone, reducing animal numbers is the quickest and most effective method of reducing farm greenhouse emissions. Studies conducted on the Australian rangelands also conclude that exclusion of grazing animals and managed regeneration of woody vegetation can lead to the capture of large quantities of carbon in the landscape, as well as improving water infiltration and retention;[91-94] further discussion of soil carbon appears in ***Section 4.1***.

A number of studies have considered the potential of reduced herd sizes to contribute to reduced methane emissions as part of broader initiatives to reduce the climate and environmental impacts of rangeland grazing, and that such changes would also lead to landscape carbon sequestration (e.g.[94-96]). Witt and colleagues (2011[93]) estimated that cessation of grazing on 50% of the Mulga Lands IBRA region could sequester 11.6—14 Mt CO_2-e/yr, independent of reduced methane emissions, noting that all other herbivores would also need to be controlled to obtain such a benefit. Because of the complex dynamics of landscape carbon, estimates of sequestration vary greatly and are all approximate, especially when applied over large areas.[97] Nevertheless because the areas are so large, restoration of both arid and tropical rangelands degraded by grazing offers large sequestration potential. This has been estimated, albeit with a large uncertainty factor, at 120 Mt CO_2-e/yr over an assumed 40 years before saturation.[97]

4.2.2.2 Dairy

Dairy methane efficiency gains are achieved by increasing the amount of milk produced per unit of methane emitted, without milk quality losses, so are in agreement with broader objectives. As in other grazing activities, this means that many steps have already been taken, both in research and in practice. Possible interventions at the animal and herd levels include increasing the proportion of their lives during which cows lactate, and making cows live longer. Concentrate feeds, pelletisation and feed grinding are described below for feedlots, but are equally applicable and often used in dairies. Dietary supplements are another viable option for dairying, although many currently face cost barriers.

Decreasing the heifer replacement rate by improving the fertility of dairy cows can be effective in mitigating GHG emissions, as well as allowing dairies to meet milk quotas and maintain herd size. Emissions are avoided by minimising the number of non-productive animals in productive systems.[98] Based on simulated results from dairy farms in the Waikato region of New Zealand, changing the annual heifer replacement rate from 22% to 15% had the potential to achieve about 5% reduction in EF emission per unit of farm area, and improved breeding can also contribute to better ME.[74] Herd efficiency measures would also be expected to decrease emissions of nitrous oxide from urine and dung.

Research into dietary supplements is ongoing and results promising. Martin and colleagues (2010[99]) indicate that lipids rich in fatty acids, such as sunflower seed, linseed and coconut oil, can eliminate methane emissions in dairy cows. The fatty acids oleic, linoleic and linolenic acids enhance the production of propionic acid in a cow's rumen, depressing CH_4 generation. However, excess lipids can also lower cows' dry matter intake and reduce milk production. A 10—25% decrease in CH_4 can be achieved with a recommended maximum 6—7% of dietary lipids.[75]

In an experiment on dairy cows in Victoria, methane production was reduced by supplementing feed with agricultural and food processing by-products containing vegetable fats, with little effect on milk quality. Each of brewer's grains, hominy meal and canola brought reductions in methane emitted per litre of milk.[100] Grape marc, the residue left after crushing for winemaking, also reduces dairy cow methane production,[101] though this is likely an effect of tannins rather than of fats.

All of these are by-products of the processing of agricultural products and hence do not compete for arable land with products for human use. They should also be easily and cheaply available, and as the authors point out, any greenhouse emissions inherent in their production would have been produced anyway, regardless of the fate of the by-products. Tannins have also shown promise with respect to improving dairy ME in field trials, though with some reduction in milk production,[70] and in general responses to dietary tannins are mixed.[99]

Dairy herds are relatively amenable to interventions aimed at reducing emissions per unit produced, and many measures already implemented for productivity have also improved the industry's greenhouse position. This means however that much of the low-hanging fruit has already been harvested; further increases in ME will require increased investment of both funds and research efforts, and would benefit from incentivisation. The whole dairy industry, however, contributes only a small proportion of Australia's agricultural methane, so has limited capacity to influence overall national emissions.

4.2.2.3 Beef feedlots

About a quarter of Australian cattle are 'finished' in feedlots for 50—120 days, delivering faster weight gain and more marketable beef. Cattle are weaned at 8—10 months then raised on grass until 12—28 months of age, when they enter feedlots. Total feedlot enteric fermentation emissions are just 3.5% of the national total from EF, so interventions to reduce feedlot methane emissions, while more effective than grazing interventions, have little impact on total emissions.

Dietary interventions are feasible in situations where animals are contained and are most effective when animals do not have access to pasture (i.e. in feedlots). Grinding, pelletisation and optimisation of diets for maximum digestibility are common. Feed additives, including lipids (discussed above) and other plant compounds may also offer scope for reducing feedlot methane emissions, provided appropriate substances were available in very large quantities.

Some argue that lot feeding can improve ME as compared to pasture finishing, because of the effect of slaughtering animals at the earliest possible age; living shorter lives, the animals emit less methane (also less methane per day of life). Other research, however, indicates that well-managed pastures can accrue significant amounts of soil carbon, sufficient to partially offset methane emissions. If soil carbon is included in GHG analysis, pasture finishing can produce lower net emissions than feedlots, and without the potentially conflicting animal welfare outcomes.[72]

The net impact on total EF emissions of increased use of feedlots would depend on the particular management regime they replaced. Without a price on carbon emissions, a large scale move to feedlots is unlikely due to their higher costs, and a public perception of animal welfare problems has also made lot feeding a less attractive option. Inputs to feedlots — concentrate feeds and grains, as well as unprocessed but transported fodder — entail their own pre-, on- and post-farm emissions, and any comparison of the relative benefits of cattle raising methods must take these factors into consideration.

4.2.3 Abatement of emissions from agricultural crops and soils

Soil emissions averaged 16.4 Mt CO_2-e/yr for 2006-2010 (*Fig. 3.7* **p 49**). The two major categories which it is feasible for humans to influence are those from animal manure and synthetic fertilisers. Though not specifically addressed below, nitrogen leaching and runoff are largely a result of animal production (⅔) and nitrogen fertilisers (⅓) and would be reduced proportionately with their sources. Nitrogen runoff and leaching would also respond to mitigation methods as per ***Section 4.2.3.1 & 4.2.3.2.*** Other major categories are not easily influenced.

4.2.3.1 Soil emissions from animal production

We assume that these emissions will be reduced proportionately with the lower animal numbers proposed in ***Parts 5 & 6***. See below for discussion of urease inhibitors' potential to reduce N_2O emissions from fertiliers and animal husbandry.

4.2.3.2 Soil emissions from synthetic fertilisers

Large quantities of nitrogen are applied in Australia. In 2010, 1.2 million tonnes of urea, the most commonly used nitrogenous fertiliser were applied,[102] but opportunities exist for reducing this quantity.

Driven by increasing prices as well as concerns for soil and waterway health, many farmers are expert at deciding when to apply fertiliser, and in what amount. These decisions are made with respect to rainfall and stages of crop growth. Precision agriculture, where measured amounts of fertiliser are delivered to plants on the basis of plant requirements, can also improve the efficiency of fertiliser use. Delivery of fertiliser with irrigation water, sometimes directly into the root zone, is common in horticultural operations and orchards, and allows precisely measured dosing with minimal waste.

The efficiency of fertiliser nitrogen in Australian agriculture can be improved through the use of enhanced efficiency fertilisers. These fall into three categories: controlled release fertilisers, urease inhibitors, and nitrification inhibitors.[103] A large number of substances have shown promising results in the laboratory and in small field trials, but are not available commercially. The quantification and mitigation of nitrous oxide emissions from the use of fertiliser nitrogen in Australia is an area of ongoing research, and as more data becomes available, the effectiveness of different products in different environments will become clearer.[104] See also Appendix A.7 for more detail on enhanced efficiency fertilisers.

When used appropriately, controlled release fertilisers can match the release of nitrogen with the plants' requirements, increasing nitrogen use efficiency and maintaining or increasing yield and quality.[103] Accurate nitrogen release pattern (to match crop uptake) can be achieved using polyolefin-coated urea, and computer simulations can be used to select the best fertiliser for the crop, temperature and conditions.[105]

Urease inhibitors slow the mineralisation of urea so that more of the nitrogen applied can move into the soil for uptake by plants. They are likely to be most effective where ammonia emissions are a problem. This mostly occurs where urease is highly active in the soil, and when large amounts of urea are applied directly to the soil surface, as in the dairy industry and other intensive animal agriculture.[103] High levels of urease activity also occur where there are high levels of organic matter such as sugarcane trash. Ammonia emissions are likely to indirectly increase nitrous oxide emissions where ammonia deposition occurs.

Nitrification inhibitors can cut N_2O losses from grazing and cropping operations by delaying the conversion of ammonium, from fertilisers or manure, to nitrate. Dicyandiamide (DCD) can be used to minimise the N_2O emitted from fertilsers, urine and manure. Research by the Primary Industries Climate Challenge Centre (PICCC) on dairy farms across south-eastern Australia showed that DCD reduced N_2O emissions by 35% in spring and 45% in autumn,[106] though results vary with soil type and temperature.[107, 108] The extra cost of DCD currently makes widespread application uneconomic,[108] but this could change with carbon pricing of agricultural emissions.

Retention of nutrients in fields is another important technique for improving the effectiveness of fertilisers applied to crops, and allows lower application rates. Nutrient retention often involves earthworks or ploughing designed to prevent, intercept or slow surface flows. Contour and riparian tree plantings are also employed to intercept water and the nutrients it carries. Maintenance of viable soil microbe and fungi communities also prevents nutrient loss.[109, 110]

Numerous farming techniques known to improve nutrient cycling are already widely practiced and include reduced tillage, stubble retention, and avoidance of bare fallowing, and these can allow reduced application of fertiliser. These methods also encourage mycorrhizal fungi which, in symbiosis with plants, bring carbon into the soil, and improve nutrient processing. Mycorrhizal fungi also make a major contribution to soil structure, life, water transport and carbon levels (Smith and Read 2008 p. 618[38]).

4.2.3.3 Pre-farm emissions from fertilisers

Though these emissions occur off-farm and mostly beyond our shores, so rightly are not recognised as an agricultural emission, on-farm action can reduce them significantly. Reductions in fertiliser usage rates means less energy consumed in their production, transport and application, as well lower N_2O emissions.

4.2.4 Abatement of emissions from biomass burning

4.2.4.1 Prescribed burning of savannas

Current approaches to emissions from savanna burning are based on the assessment of the former Department of Climate Change and Energy Efficiency (DCCEE) that natural wildfires would replace intentionally lit savanna fires if the latter were reduced in frequency or extent.[111] This position was based on largely anecdotal evidence that Aboriginal 'firestick farming' was extensively practiced prior to colonisation. Instead substantial expert opinion supports the conclusion that these emissions, categorised under Prescribed burning of Savannas, are anthropogenic. There is also evidence that savanna fires are far more widespread and frequent than would naturally occur. The DCCEE worldview deemphasises the potential for careful policy settings to reduce savanna burning and hence to abate emissions from this source.

Although 'firestick farming' — deliberate and systematic burning of vegetation for cultural reasons and to maintain the hunting and food-gathering values of land — was probably used extensively by Aboriginal people prior to colonisation, there is now strong evidence that burning by Indigenous peoples was far less significant than that seen since the arrival of Europeans.

Mooney and colleagues (2011[112]) studied 70,000 years of fire represented in sedimentary charcoal records from 223 sites across Australasia. Dense charcoal deposits correlated strongly with warmer climatic periods, but no change in fire regimes was associated with the arrival of aboriginal people around 40 – 60,000 years ago. Biomass burning instead reached its maximum in the last 200 years, coincident with European settlement.

This increase in burning associated with European colonisation of the continent was even more marked when Australian sites only were analysed (*Fig. 4.5*). Other authors support this finding with evidence from specific regions. Banks (1989[113]) finds a five-fold increase in fire frequency in the Australian Alps, concurrent with the large-scale introduction of sheep grazing in that region. Lacey (2009[114]) also argues that burning by Aboriginal populations in southern Australia was far less widespread and less frequent than today's pasture management or fuel reduction fires.

The World Wide Lightning Location Network locates lighting ground strikes to a positional accuracy of 1 – 2km. Russell-Smith and colleagues (2007) compared these with satellite fire data for the years 1997 – 2004. This work showed that 90% of Australia's fires occur in the tropical and sub-tropical savannas during the dry season when lightning strikes are rare or absent.[115] A very weak relationship between lightning strike and fire activity in Australia's north led the authors to conclude that most landscape fires in northern Australian savannas are anthropogenic.

The same study also found that the likelihood of dry season fire in any one place was not strongly related to rainfall and vegetation growth in the wet season immediately prior and instead correlated more strongly to burning in the prior years. This does not support the hypothesis that fuel reduction burning as currently practiced is effective in reducing wildfire, but appears to confirm the strong human influence on savanna fire frequency. It does not follow, therefore, that emissions from natural fires would replace those from prescribed burning for pasture as claimed by DCC.[111] Hence we include emissions from savanna burning in our list of emissions from agriculture.

The frequency of extensive, intense fires late in the dry season is also higher than would naturally occur, or than would occur under traditional land management.[116] These burns, which take place when the landscape has dried out under the intense heat of the northern dry and are often driven by severe weather conditions, contribute around two thirds of emissions from savanna burning according to the NIR. The Carbon Farming Initiative has targeted savanna burning for emissions abatement, and has approved projects burning early in the dry season, based on the evidence that late dry season fires produce twice the emissions of early fires.[117] However reduction of the area burnt each year is a more effective mitigation strategy.

In traditional times, fires were kept small and burning progressed from dry uplands early in the season toward moister gullies and floodplains as these dried out.[116] This is likely to reflect past practices over much of Australia's tropical savannas. These burning patterns are thought to have reduced the susceptibility of the savannas to extensive and intense fire, while the practices imported with European colonisation have had the opposite effect.[115, 116]

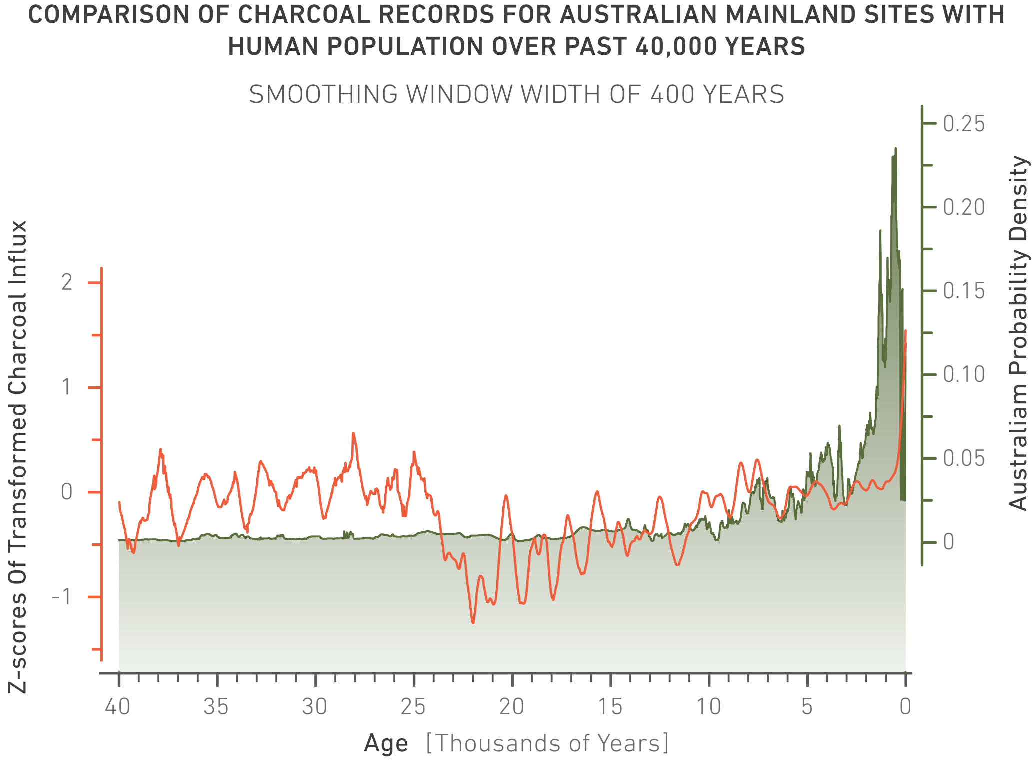

Figure 4.5 Charcoal records for Australian mainland sites over the last 40,000 years compared with human population (green curve), adapted from Mooney *et al*. (2011[112]).

Other factors also suggest a reduction in savanna burning. There is mounting evidence that fire negatively impacts biodiversity, species mix, soil erosion and greenhouse gas emissions.[118] The current practice of high frequency pasture fires is also modifying ecosystems in northern and central Australia.[119]

Abatement of fire in Australia's tropics has been heavily debated over decades but the West Arnhem Land Fire Abatement (WALFA) project has recently achieved minor verified emissions reductions[120] from dry season burning across 28 Mha of biodiverse savanna in the Northern Territory. Funded as an emissions offset project by a fossil fuel processing facility, the project funds Aboriginal traditional owners to engage in traditional land management activities, burning early in the dry season to prevent more intense wildfire later in the year. The WALFA project initially aimed to prevent the emission of 100,000 t CO_2-e/yr, but in its first three years has exceeded this target by an average of 50%. The project also provides part-year employment for 30 people.[120]

Though in the context of the national greenhouse inventory the abatement achieved by the WALFA project are modest, they indicate the potential for far greater emissions reduction if such programs were instituted across entire 190 Mha of Australia's tropical savanna. Garnaut (2008[84]) estimated that a 50% reduction in emissions from savanna burning was practical, while work by CSIRO has estimated that a 90% reduction from current levels is potentially achievable.[121] Heckbert and colleagues (2008[122] p.22) proposed that one full-time equivalent job would be created in Indigenous communities for each 7500 t CO_2-e of emissions abated on indigenous-held land.

4.2.4.2 Burning of crop residues

Increasingly, burning is being replaced by stubble retention, which reduces erosion, aids nutrient cycling and soil moisture retention, and can lead to improved soil carbon levels. In this commonplace practice, stubble is grazed some weeks after harvest and the next crop is sown by drilling though the remaining vegetation. Firing of sugar cane has also become less common with the introduction of green cane mechanical harvesting, and cane crops are now more commonly burnt once every three or four years at the end of the sowing/ratoon cycle. In some situations, fire is used to reduce the prevalence of pest animals and weeds, so cannot be avoided completely.

4.2.5 Abatement of manure management emissions and bioenergy opportunities

Piggeries and dairies produce relatively large amounts of methane from slurries kept in anaerobic conditions, whereas beef feedlots produce high levels of nitrous oxide, predominantly from cattle urine. Management practices that may have the potential to reduce emissions from livestock waste include storage pond management, manure management, feed management and feed waste reduction, and these methods have been captured in the CFI.

Enclosing waste storage lagoons allows methane capture for flaring or for on-farm energy, and aerating and de-watering inhibits anaerobic decomposition. Water and solids from the pond bottom can be removed for use as fertiliser. Under the Carbon Farming Initiative, piggery and dairy operators can earn carbon credits by capturing or destroying methane-rich biogas from effluent lagoons. A small number of piggeries have already adopted technologies to capture and convert methane to energy for on-farm use and sometimes export. Victoria's Berrybank farm began capturing methane from pig slurries in the 1990's and today generates a significant proportion of its large on-farm electricity requirements. Solid by-products are sold off-farm as potting mix, introducing a profitable line item to the business, and have entirely displaced imported fertiliser for the farm's cropping activities.

There is potential to capture and use methane from dairy feedlots in a similar manner, with milk refrigeration requirements providing a ready demand for electricity generated from wastes. One large dairy in the NSW Riverina has calculated that the approximate $1m infrastructure cost would be returned within ten years, based on avoided electricity costs alone, but notes that the up-front price is a barrier to entry.[123] Because most dairy cows spend much of their time grazing pastures, a lower proportion of their manure is amenable to capture than that from pigs.

Cattle feedlot manure management can minimise emissions by minimising manure stockpiles. The timely distribution of manure on crops and pastures can both promote biological processes and minimise anaerobic activity and therefore emissions from stockpiles. Although feedlot manures applied to crops and pastures can increase N_2O emissions for the same reasons as fertilisers do, research shows that emissions are significantly lower when they are mixed and applied with composted green waste.[124] Of approximately 1,000,000 tonnes of manure produced in Australia's feedlots each year, nitrogen makes up about 25,000 tonnes.[124]

For dairy farming, increasing dietary carbohydrate energy content can reduce N_2O from manure. This is because with better carbohydrate availability more dietary protein is converted into milk protein, rather than being excreted as ammonia in urine and dung.[125]

4.2.6 Abatement of fugitive emissions from extractive land uses

Extractive land uses such as coal and gas mining are often in conflict with productive uses. This conflict arises because of the spatial footprint of mines, interference with groundwater and other concerns. Fugitive methane emissions from fossil fuel extraction produced 28% of the national total for methane in 2010, and the full scale of these emissions is probably not recorded because of outdated measurement methods and the recent expansion of coal seam gas exploration.

The heavy climate impact of methane, and especially its high global warming potential over the twenty-year period, are described elsewhere in this report. A focus on methane, with the objective of ceasing both fugitive and combustion emissions, could be a useful approach for primary producers who need to defend their land against incursion by extractive industries. Continued extraction and combustion of fossil fuels is incompatible with climate security, itself a crucial asset for agriculture.

4.3 Abatement of emissions from native forest logging

4.3.1 Protecting standing carbon in native forests

As discussed in Part 3, clearfell logging runs down the carbon stock of the eucalyptus tall open forests, the most carbon-rich of Australia's major vegetation groups. These observations agree with those of Keith *et al.* (2010[126]) and Mackey *et al.* (2008[127]) for tall wet forests throughout south-east Australia. They argued that the carbon content of 14.5 million hectares of these forests was 40% below capacity, based on previous assessments.[129]

The forests contained around 9,000 Mt of ecosystem-based carbon, equivalent to 33,000 Mt CO_2. Around 44% of the area has not been logged and is considered to be at carbon carrying capacity. They determined that the remaining 56% of the area had been logged and was below carbon carrying capacity. The carbon sequestration potential of the logged forests is 2,000 Mt Carbon, equivalent to 7,500 Mt CO_2.

In addition to avoiding the logging emissions discussed in Part 3, this large sequestration potential would provide for significant drawdown in the process of recovery from human disturbance. However, historic anthropogenic disturbance can interact with natural disturbance regimes, and impacts can be amplified and compromise the resilience of these ecosystems to persist into the future. A case study on the impacts of fires on these forests is provided below.

4.3.2 Compounding impacts of forest fire and logging

Forest fires are a major source of greenhouse gas emissions from forested areas. Fires do not act in isolation, but are compounded by multiple variables, such as weather, fuel and topography. The following section provides a summary of the relationships between land use and fire severity. The summary provided here forms the preliminary stages of a more comprehensive analysis, which will be published separately in 2014 with separate results.

In line with previous sections, this study focuses on the impact of the February 2009 fires on the eucalyptus tall open forest major vegetation group.[130] Large areas of this forest type were impacted by the fires when the forest fire danger index (FFDI) was extreme and beyond.[131] Forest fires are often at their most intense and spread most rapidly when the FFDI is in the extreme category.[132, 133] It is often at these times that eucalyptus tall open forest (inclusive of montane ash forest) sustain fires that scorch or burn the canopy, killing the trees.[134] These forests are of interest to our study because they yield the highest volumes of carbon[127, 135] and frequent and severe fires can impact on the capacity for these forests to act as large carbon stocks in the landscape.[136]

In terms of area impact, the two of the most significant fires were the fires referred to as the Kilmore East and Murrindindi fires, which impacted 255,300 hectares (***Fig. 4.6***). The majority of eucalyptus tall open forests impacted by fire during February 2009 were part of these fires. Our study used spatial datasets outlining the extent of the eucalyptus tall open forest major vegetation group, along with logging history,[138] modeled old growth extent,[139] slope and aspect, obtained through the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) database Digital Elevation Model (DEM)[140] and generated in ArcGIS 10.[141]

The impact of the fire on forest vegetation was determined using Landsat Level 4 – 5 TM data, obtained for the study area for 22 January 2009, the latest cloud-free product prior to the fires, and data for the 16 February 2009, the earliest cloud-free product following the fires. Both datasets were captured at roughly the same time of day (GMT 23:53:31 and GMT 23:49:09, respectively). The pre-fire dataset was taken with a sun elevation of 43.64 degrees and sun azimuth of 59.02 degrees; and the post-fire dataset was taken with a sun elevation of 45.97 degrees and sun azimuth of 65.42 degrees. A Normalised Difference Vegetation Index (NDVI) was generated using the red (R) and near infrared (NIR) bandwidths of the datasets. The NVDI was computed for both the pre-fire and post fire images. The NVDI was calculated by the following equation[142]:

$$NDVI = \frac{NIR - R}{NIR + R} \qquad (1)$$

NDVI values range from -1 to +1, where low values indicate little photosynthetic vegetation and high values indicate high amounts of vegetation. Areas impacted by the fire

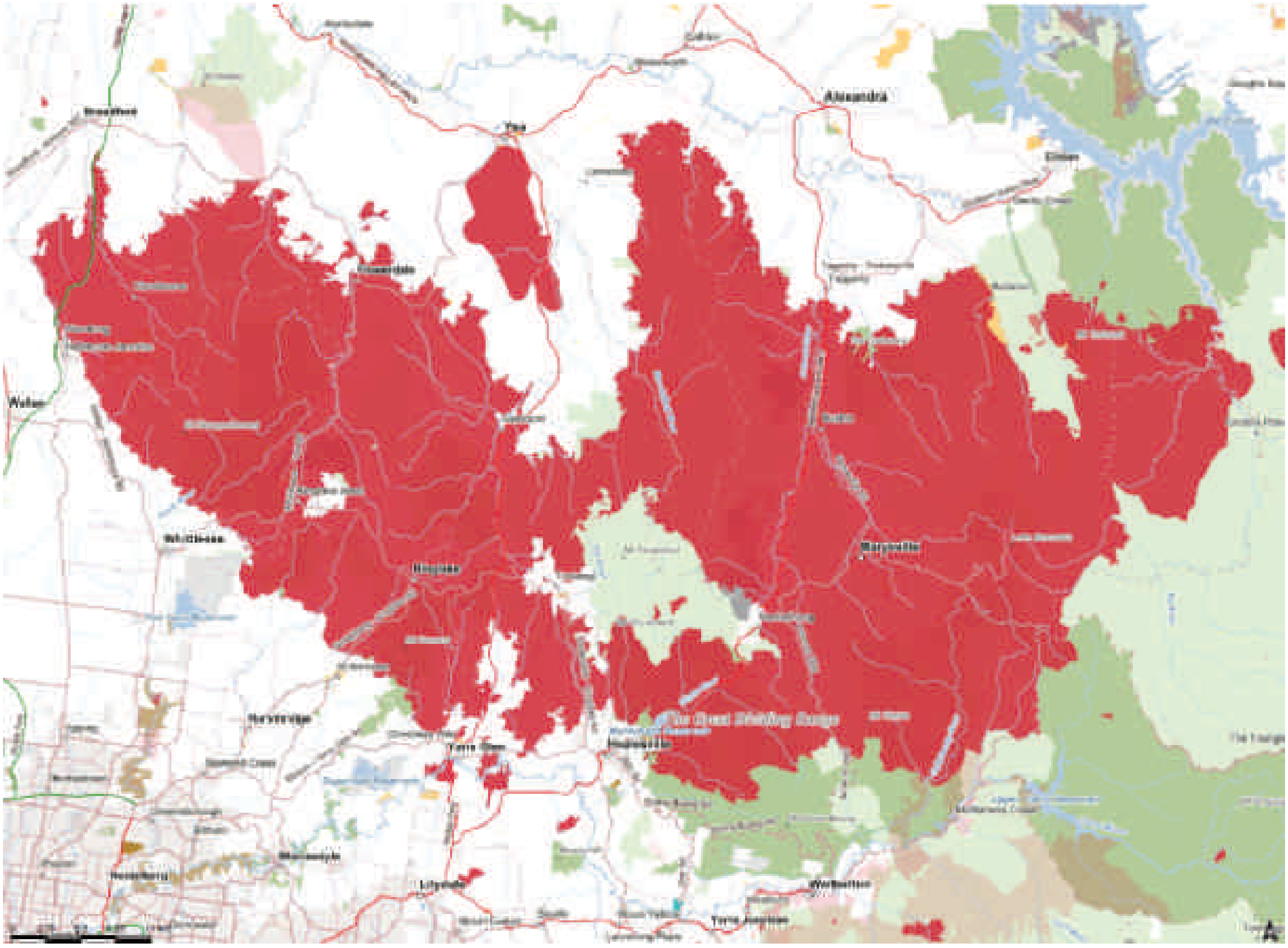

Figure 4.6 Extent of February 2009 fires north east of Melbourne (Source: DSE 2011[138]).

when the FFDI was 50 (extreme) and above were identified following reports from the Bushfires Royal Commission detailing fire progression. A polygon boundary was drawn around the area of eucalyptus tall open forest within the extreme fire weather impact zone. A difference image was calculated, following the methods outlined in Chafer *et al.* (2004[143]):

$$NDVI_{diff} = NDVI_{prefire} - NDVI_{postfire} \quad (2)$$

In the resultant image, values less than -0.11 were assumed to be unburnt. The remaining pixels values ranged from -0.11 to +1.7 and were identified as the presence of vegetation sustaining degrees of impact from the fire. The variation of $NDVI_{diff}$ for a large area of eucalyptus tall open forest (an area south of Marysville) is featured in ***Figure 4.7***. Field verification usually accompanies the NDVI computation and observed data are compared to the NDVI to generate a fire severity map, outlining fire severity classes.[143] However, it was beyond the scope of this study to carry out field work to obtain this data. Fire severity data analysis, obtained through field observation and NDVI computation, will be further published in a separate publication.

The $NDVI_{diff}$ was overlaid onto datasets containing slope and aspect, vegetation disturbance history and age. Vegetation age for eucalyptus tall open forest was categorised following the breakdowns of Ashton (1975[145]; ***Table 4.2***). Stand age on logged sites was obtained from historical logging datasets[138] and the age of stands within modeled old growth areas was assumed to be approximately 300 years (inferred from Mackey 2002[134]). The data was gridded into hectares and corresponding arranged for an ANOVA.[146] Fire weather was considered a consistent variable over the burn period and as having a close relationship with fire behaviour.[147, 148] The run of the analysis under consistent fire weather conditions allowed

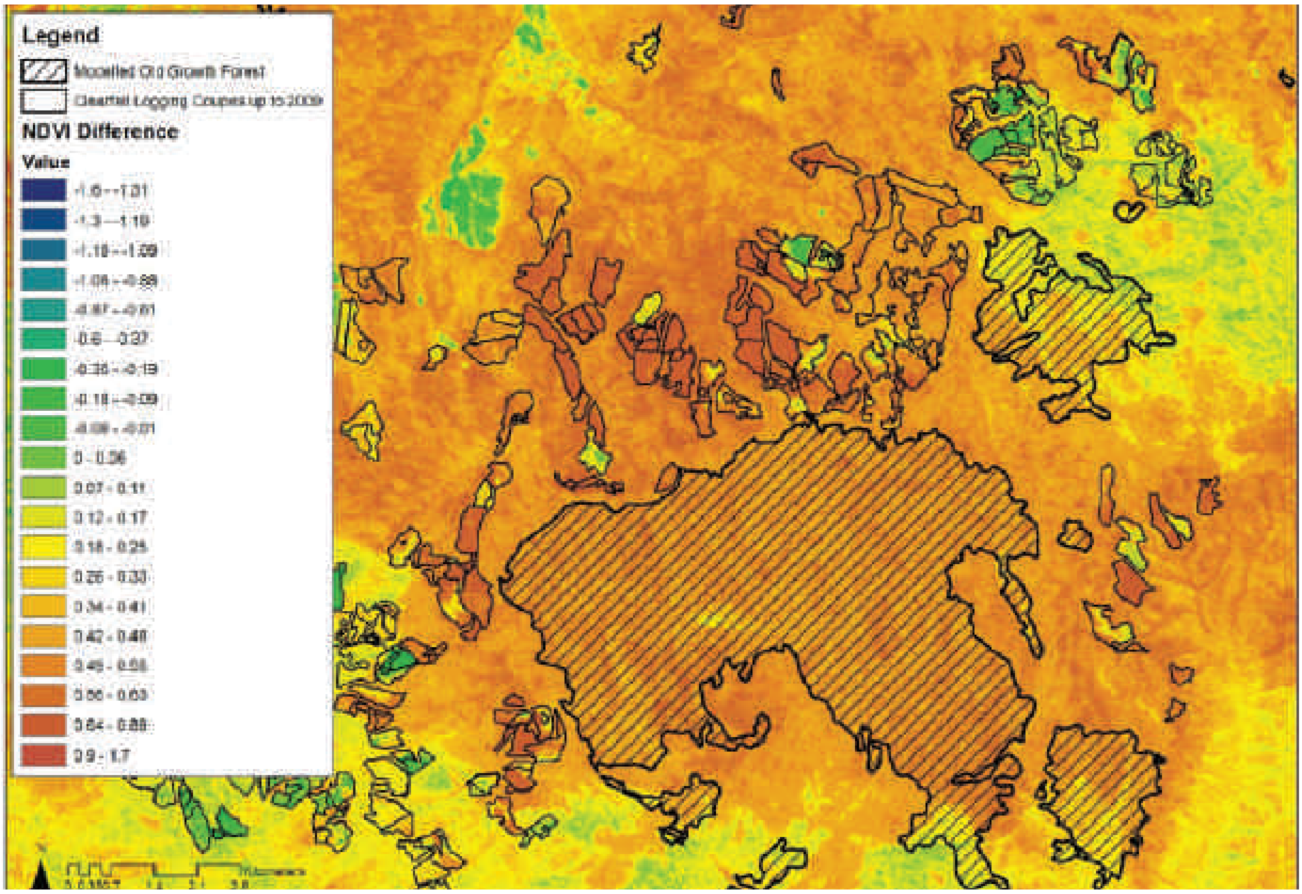

Figure 4.7 Normalised Difference Vegetation Index Difference map of a section of eucalyptus tall open forest impacted by the February 2009 fires (south of Marysville) with extent of modeled old growth forest (lined) and clearfell logged areas. (Data sources: USGS 2012[144], DSE 2005[139])

detection of any other informing variables, such as stand age, slope and aspect (*Fig. 4.8*).

The influence of slope and aspect showed no significant influence ($\alpha=0.05$). However, statistical significance was detected for the correlation between age category and NVDI$_{diff}$. This is indicative of stand age influencing the severity of the fire impact on vegetation (*Fig. 4.8*). However, field verification is required to ascertain fire severity impacts.[143]

This brief analysis shows the significant and compounding effects clearfell logging can have on eucalyptus tall open forests. Clearfell logging is currently applied up to 98% of

Table 4.2 Stages used in the description of eucalyptus tall open forest for the Central Highlands of Victoria (based on Ashton 1975[145]; 1976[149])

Stage	Height [m]	Density [stems/ha]	Approximate age [yr]
Seedling	0.02 – 3	-	0 – 4
Thicket	5 – 8	205,000	5 – 6
Sapling	9 – 12	17,400	7 – 14
Pole	15 – 35	1,915 – 1,205	15 – 30
Spar	45 – 60	227 – 126	40 – 80
Mature	60 – 100	82 – 47	100 – 300
Overmature	30 – 60	-	300 – >400

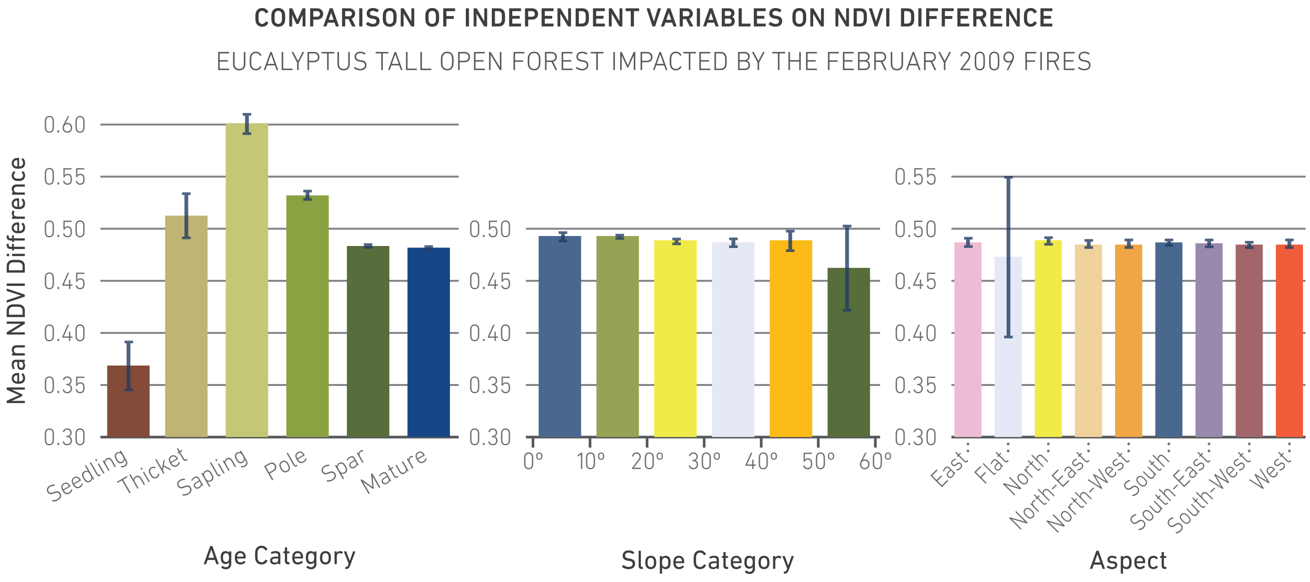

Figure 4.8 NDVI Difference of forest at different ages, slopes, aspects. Error bars 95% confidence interval.

areas logged in this vegetation group.[150] It has also reduced the overall stand age to younger age classes.[134] This may increase the probability of canopy fires occurring across the landscape where clearfell logging has been widely implemented and possibly alter the fire regime that would occur in the absence of such disturbance.

This presents a number of concerns to the current forest management paradigm. First, the survival of trees is greatly diminished where a crown fire occurs. This contributes to the loss of recruitment trees that could serve as habitat or potential future habitat.[151] Second, Mountain Ash trees only start to produce seed at around 20 years of age.[152] If large areas of the eucalyptus tall open forest has its stand age reduced to a younger age class, and these trees in turn are killed in a fire, the capacity of this ecosystem to recover after fire is greatly diminished. Third, these factors combined move the eucalyptus tall open forest ecosystem into a landscape trap.

Lindenmayer *et al.* (2011[136]) define this phenomenon as where entire landscapes are shifted into a state in which major functional and ecological attributes are compromised. This arises through a combination of altered spatial characteristics of a landscape coupled with synergistic interactions among multiple human and natural disturbances. These factors drive entire landscapes into an undesirable and potentially irreversible state.

4.4 Abatement of long- and short-lived emissions from agriculture

If short-lived emissions black carbon (BC), carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), as well as the tropospheric ozone that arises from CO and methane emissions (described in ***Section 3.4***) are added to national inventory emissions figures for agriculture using standard 100-year accounting, average 2006 – 2010 agricultural emissions rise by 68% and national emissions by 21%. If 20-year global warming potentials are used, a reasonable step given the urgency of emissions reduction, the difference is even more striking: average 2006 – 2010 agricultural emissions increase by 260%.

Because it is the greatest source of short-term emissions, agriculture is uniquely placed to offer immediate and radical abatement to Australia's overall emissions. The understanding that agriculture produces more than half of Australia's annual emissions when 20 year GWPs are used and short-term gases are included prompts reassessment of policy options to avert dangerous global warming in coming decades.

Abatement of short-lived emissions offers high impact and immediate climate change mitigation opportunities, both in terms of total warming, and because their short term effect means abatement has a quick payoff. Such action is the most effective means of slowing global warming in the near term, and has the potential to both partially offset 'committed' warming from CO_2 already emitted and to limit warming to the widely-accepted — though not scientific — 2°C guardrail.[153]

40% cuts in methane could delay climate change by 15 years.[154] For a target year of 2050, reducing CH_4 emissions by 46% can be as effective as entirely stopping CO_2 emissions.[155] The Climate and Clean Air Coalition of countries, with the United Nations Environment Program (UNEP), are therefore pursuing urgent abatement of methane, tropospheric ozone and BC.

Warming from Australian agricultural emissions over the next 20 years will be greater than warming from all fossil fuel emissions. When short term gases are fully accounted, transformational mitigation opportunities are revealed. Rangeland grazing, with associated deforestation, enteric fermentation and savanna burning, produces 49% of national emissions when accounted over 20 years. These activities can be curtailed as described above to effect immediate emissions abatement.

4.5 References

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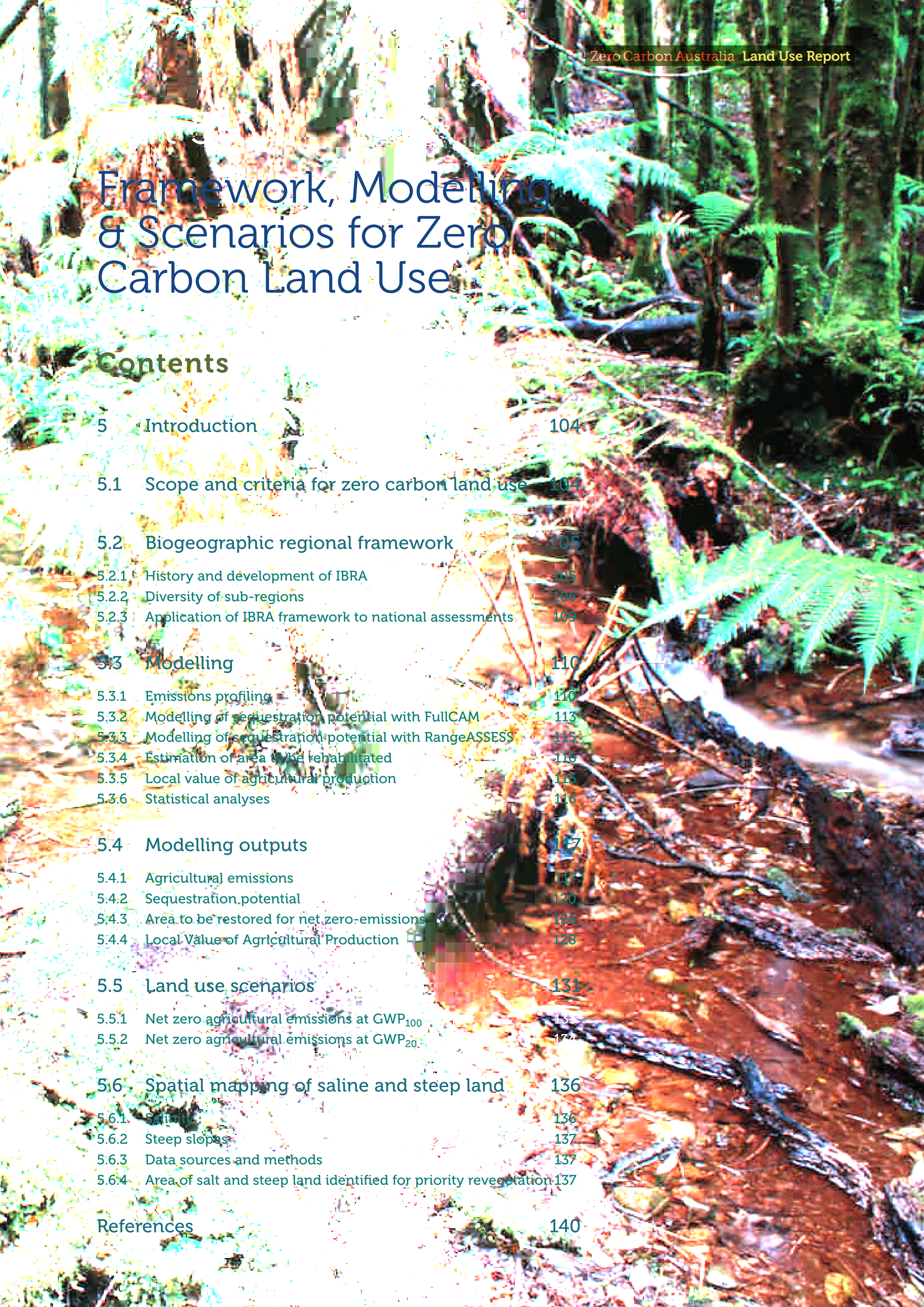


Framework, Modelling & Scenarios for Zero Carbon Land Use

Contents

5 Introduction

We introduce the Interim Biogeographical Regionalisation of Australia (IBRA) as the spatial framework for our analysis of agricultural greenhouse emissions and sequestration potential.

We then detail the methods employed during our spatial modelling, including the industries we included, our separation of productive landscapes into intensive and extensive zones and results.

Part highlights:

- Geographical areas with high emissions also generally have higher landscape carbon sequestration potential as well as greater economic returns per hectare.
- Zero carbon agriculture can be achieved with restoration of 55 Mha of Australia's cleared land, at an opportunity cost of $5.3b/yr. This would avoid 24% of agricultural emissions, by reducing ruminant animal numbers, and offset the rest in growing vegetation.
- There is potential to minimise opportunity costs and even generate double benefits by prioritising revegetation of steep slopes and salt land. Almost 8 Mha fit both of these descriptions.

5.1 Scope and criteria for zero carbon land use

In order to stabilise and eventually reduce atmospheric greenhouse gas concentrations, all economic sectors will eventually need to bring their emissions to zero. The land use sector is currently the only sector of the economy theoretically capable of removing large amounts of CO_2 from the atmosphere, by sequestration in growing vegetation and hence in the landscape. But in order to offset emissions from other sectors which do not have any capacity to bring about negative emissions, land use must first become carbon neutral itself.

Our objective therefore was to establish whether annual greenhouse emissions from business-as-usual agriculture can be abated or offset by sequestration of atmospheric carbon in growing vegetation without undue disruption to agriculture.

We modelled emissions from a subset of Australian agriculture based on government data for animal numbers and crop extents, and other inputs. Sequestration potential was compared with emissions for each of 300 regions where significant agricultural activities are conducted. Given that sequestration in vegetation would require the retirement and reassignment of some agricultural land to this purpose, we also estimated the economic impact of such a change in land use patterns, in terms of opportunity cost.

We structured the work around regions within which physical and biological parameters that drive plant growth, and hence influence agriculture, are similar. This was appropriate to the continental scale of the overall project. Though indicative of the overall size, density and location of emissions, this approach also allowed us to propose a situation where land use decisions are made on a regional basis, without implicating particular properties or industries.

5.2 Biogeographic regional framework

The Zero Carbon Australia Land Use plan employs the Interim Biogeographical Regionalisation of Australia (IBRA) to structure and simulate scenarios for sector emission profiles and potential carbon sequestration through environmental plantings. IBRA classifies Australia's landscapes into 89 large geographically distinct bioregions based on common climate, geology, landform, native vegetation and species information. These are further subdivided into 419 sub-regions, which are defined by more localised and homogenous geomorphological units in each bioregion[1] (*Figures 5.1, 5.2*).

5.2.1 History and development of IBRA

The IBRA framework was first developed in 1993-94 by the Australian states and territories under the coordination of the Commonwealth Government through Environment Australia.[2] It was first established as a basis for developing priorities in the development of a National Reserves system. IBRA represents a landscape approach to classifying the Australian land surface. It combined specialist knowledge, along with regional and continental scale data on climate, geomorphology, landform, lithology and characteristic flora and fauna to delineate specific bioregions, which were ascribed the term 'biogeographic regions'. However, the developers of IBRA acknowledged the paucity of the biophysical data used in some areas of the continent and that new information could modify understanding of specific bioregions. This resulted in the biogeographical

Fig 5.1 IBRA Biogeographical regions.[1] Regions are here differentiated by random colours.

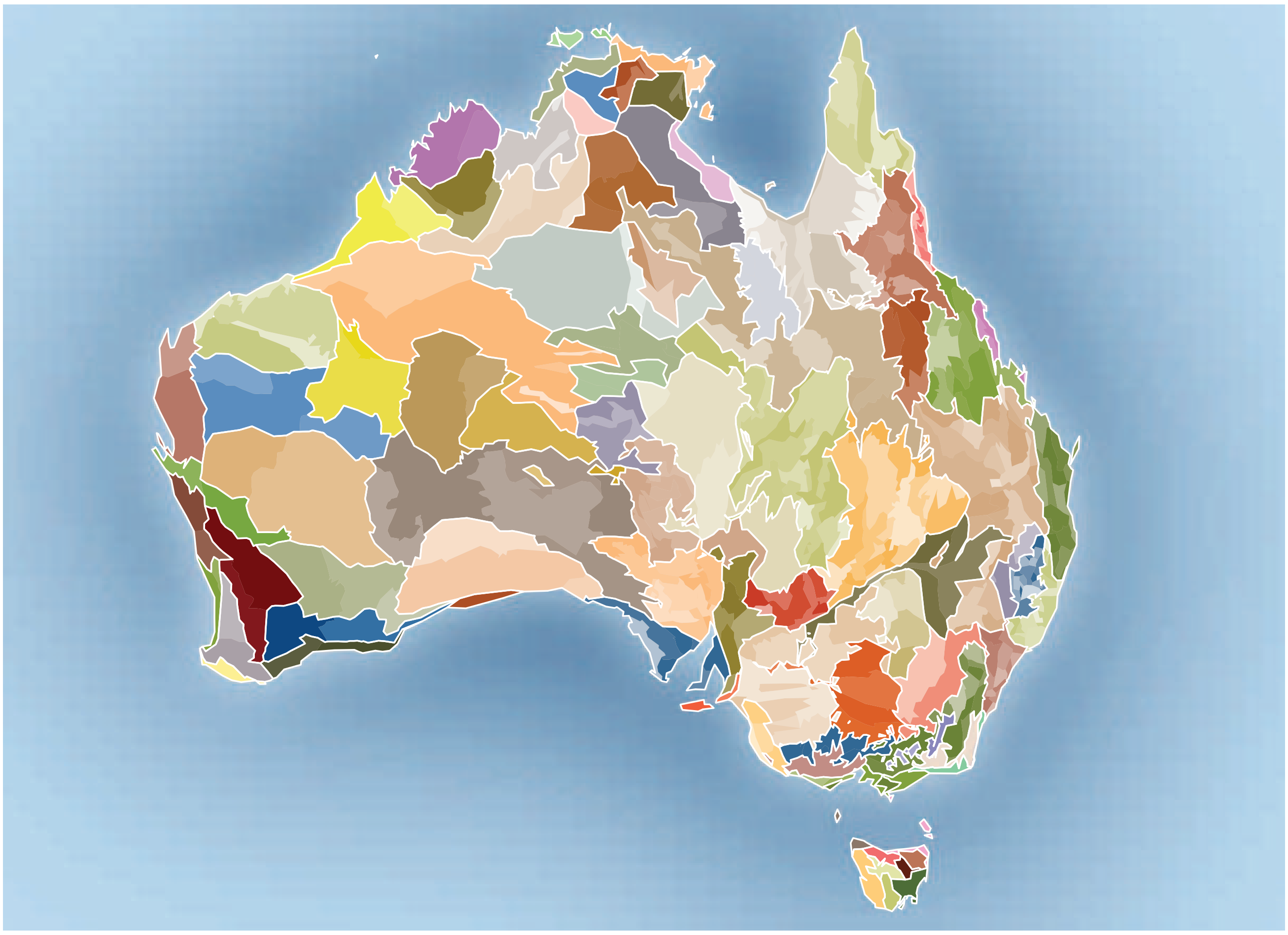


Figure 5.2 IBRA Biogeographical sub-regions.[1] Sub-regions are here differentiated by random colours.

Regionalisation framework being listed as 'interim'.[2] The IBRA framework has subsequently been used in the National Land and Water Resources Audit, including its biodiversity assessment and landscape health assessment.[3, 4]

5.2.2 Diversity of sub-regions

The large number of IBRA bioregions and sub-regions across Australian is driven by our continent's great diversity. According to Steffen *et al.* (2009[5]), this diversity is attributable to a number of factors, which contribute to a high degree of distinctiveness between specific areas and zones of the Australian landmass:

- The Australian continent broke free of the Gondwanan landmass between 45 million to 180 million years ago and has remained isolated from other land masses, which has resulted in a high degree of endemism across Australia's flora and fauna.
- The northward drift of the Australian continent has placed it within the dry mid-30 degree latitudes, where most of the world's great deserts are located. This drift has transformed the landmass, rendering it more arid and favouring organisms able to adapt to drier conditions.
- Most of Australia escaped continental ice sheeting during the series of ice ages of the Pleistocene epoch, which has resulted in Australia having some of the oldest and most nutrient poor soils in the world. The adaption of Australia's biota to these geological conditions has rendered them distinctive in comparison to other parts of the world that have undergone extensive glaciation.
- Australia is located at the confluence of several major oceans, which has resulted in the continent

Figure 5.3 **Mountainous coastal terrain of the Wet Tropics Bioregion.** Photo: Chris Taylor

experiencing a high degree of variability in climate. Such variability includes extremes in temperature and precipitation that result from large oceanic influences from tropical to sub-Antarctic latitudes.

- Less than 5% of the Australian landmass is more than 600m above sea level. The absence of topographic barriers in the form of high mountain ranges may have allowed for the dispersal of species across large areas of land.

It is these distinctions that the IBRA framework seeks to define by delineating bioregions and sub-regions.

Figure 5.4 **IBRA Bioregion Wet Tropics showing sub-region boundaries over satellite imagery.**[1, 6]

5.2.2.1 Example of IBRA division: The Wet Tropics bioregion and its component sub-bioregions

The Wet Tropics Bioregion of Far North Queensland and its surrounding bioregions exemplify some of this diversity and its drivers (IBRA bioregion code 'WET'; ***Figs. 5.3, 5.4***). A large proportion of the Wet Tropics Bioregion is dominated by rainforest (dark green), while the western periphery of the bioregion reveals a rapid transition from rainforest to Eucalyptus woodland (light green and brown). This transition forms the boundary of the Wet Tropics IBRA bioregion to the adjoining bioregions, including the Einasleigh uplands ('EIU').

The presence of rainforest in this bioregion has been attributed to a number of factors. One is the relative absence of fire in comparison to other areas in the Australian landscape. According to Bowman (2000), specific environmental conditions, such as topography, create refugia in which rainforest can be protected from fire.[7] In the Wet Tropics, rugged mountain terrain and high rainfall provide suitable refugia in which this vegetation community resides, and form defining features in the description of the IBRA Wet Tropics Bioregion:

> *… dominated by rugged rainforested mountains, [...] also includes extensive plateau areas along its western margin, as well as low lying coastal plains. The most extensive lowlands are in the south, associated with the floodplains of the Tully and Herbert Rivers. Most of the bioregion drains to the Coral Sea from small coastal catchments, but higher western areas drain in the south into the Burdekin River, and in the north into tributaries of the Mitchell River. The region contains […] tropical rainforest, plus beach scrub, tall open forest, open forest, mangrove and Melaleuca woodland communities (Environment Australia 2000, p. 24)*[2].

However, attributes within the Wet Tropics bioregion are not uniform. Coastal plains form a distinctive topographical feature in comparison with the surrounding mountainous terrain (***Fig. 5.4, 5.5***). As the coastal plains were conducive to intensive cropping, especially of sugar, they were heavily cleared following European settlement. The surrounding mountainous terrain was not suitable for intensive agriculture and remained forested.

Figure 5.5 **Coastal Plains of the Wet Tropics Bioregion contrasted with mountainous terrain in the background**
(Photo: Chris Taylor)

Such contrasts form the delineation of the sub-regions within the Wet Tropics bioregion. For example, the Herbert sub-region in the south of the Wet Tropics bioregion contains:

> *.... the delta of the Herbert River and the piedmont fans associated with the coastal escarpment between the Cardwell Range and Bluewater Creek. This sub-region receives the lowest rainfall of any of the Wet Tropics coastal lowlands and its floodplains are dominated by woodlands. Small areas of dunes occur along its seaward margin and there are a large number of short estuaries with extensive mangrove communities backed by salt plains (Wet Tropics Management Authority 2009, p. 98).*[8]

In contrast, the Daintree-Bloomfield sub-region in the north has been described as being:

> *....a complex sub-region which includes the Carbine, Windsor and Big Tablelands, Mt Finnigan, and the Thornton, McDowall and Black Trevethan Ranges which are all sharply defined granite batholiths that have resisted erosion more than the surrounding sediments which comprise the basins of the Daintree and Bloomfield Rivers. This sub-region also includes a narrow coastal plain. (Wet Tropics Management Authority 2009, p. 100).*[8]

This is one example of how the IBRA framework delineates and distinguishes environmental attributes from one sub-region to another. Such diversity between sub-regions is evident throughout the Australian continent. In the identification of this diversity, each sub-region can be considered as a unit of land within similar environmental attributes and constraints. They also could be viewed as containing similar land use practices, where the sub-regions containing the coastal plains of the Wet Tropics bioregion have mostly been cleared of their native vegetation cover to make way for intensive sugar cane cropping.

5.2.3 Application of IBRA framework to national assessments

The uniformity of environmental patterns across each IBRA sub-region has proven useful in National land health assessments, which include the National Land and Water Resources Audit. In his 'Landscape Health in Australia: A rapid assessment of the relative condition of Australia's bioregions and sub-regions', Morgan (2001[4]) has primarily used the IBRA sub-regions to structure his reporting on the landscape health across Australia, which include the assessment of Continental Stress. In this case, each sub-region was allocated a continental stress rating, based on environmental factors, including native vegetation extent, salinity, changed hydrological conditions, number of threatened species, grazing pressure and invasive weed spread. In the report 'Australian Terrestrial Biodiversity Assessment 2002', Sattler and Creighton (2002[3]) used the IBRA sub-regions to assess the condition of wetlands and riparian zones, threatened ecosystems and species, birds, mammals, vegetation, reserves, biodiversity conservation across the wider landscape and regional biodiversity management.

It is in this context that the IBRA sub-regions are viewed as an appropriate framework for the Zero Carbon Land Use project. Each sub-region is considered to define environmental parameters that would delineate the scope and extent of proposed changes in land use practices. For modelling of sequestration potential, we separate the sub-regions into zones according to the proportion of pre-European vegetation cleared (***Part*** **5.3.1.5**).

Table 5.1 Nitrogen application rates and emissions factors (EF). The proportion of applied Nitrogen (N) that volatilises as nitrogen dioxide (N_2O) used to calculate soil emissions are also given. Adapted from Longmire *et al*. 2014.[16]

Sample Local Area	Av. Annual Rainfall (AAR) [mm]	Agricultural activities captured	kg.N/ha/y (cropping)	Emissions Factor: N_2O/N [%]
Westonia (WA)	325	Cereals, sheep	9[a]	0.085[b]
Orroroo (SA)	366	Cereals, sheep, beef	9[a]	0.085[b]
Wongan (WA)	389	Cereals, sheep	28[c]	0.085[b]
Cobar (NSW)	402	Cereals, sheep, beef	0[c]	0.085[b]
Forbes (NSW)	489	Cereals, sheep, beef, dairy	28[c]	0.085[b]
Corangamite (Vic)	621	Dairy, sheep, beef	50[c]	0.085[b]
S. Grampians (Vic)	622	Sheep, beef	50[c]	0.085[b]
Cabonne (NSW)	937	Sheep, beef, cereals	50[c]	0.085[b]
Kiama (NSW)	1254	Dairy, beef	n/a	n/a
Cardwell (Qld)	2129	Sugar, beef	130[d]	3[d]

(a) Michael Wurst (pers. comm.) for Orroroo/Carrieton; (b) Barker - Reid *et al*. (2005[17]); (c) Geoffrey Minchin (pers. comm.); (d) Thorburn *et al*. (2010[18]). Emissions from dairy pasture were calculated on the basis of 104kg.N/ha/y (DPI Vic 2008[19]) and an EF of 0.4 (DCCEE 2012[20]). Full SLA names are Westonia (S), Orroroo/Carrieton (DC), Wongan-Ballidu (S), Cobar (A), Forbes (A), Corangamite (S) – North, S. Grampians (S), Cabonne (A), Kiama (A), Cardwell (S).[14].

5.3 Modelling

Our objective was to present an outcome where business-as-usual (BAU) annual emissions from agriculture in each of 300 IBRA sub-regions were more than offset by sequestration of atmospheric carbon in growing vegetation in each sub-region, as modelled over 87 years from 2015. To this end we first computed BAU emissions, based on government data on crop extents and animal distribution. We then modelled carbon accrual in previously cleared landscape sinks using FullCAM for extensively cleared areas and RangeASSESS for rangelands. Results for emissions and sequestration potential, each expressed as tonnes of carbon dioxide equivalents per hectare per year (t CO_2-e/ha/yr) were combined to give a proportion of each IBRA sub-region to be rehabilitated to achieve net zero emissions, as detailed below. Animal numbers were notionally reduced in the same proportion as the reduction in grazed area, allowing for a reduction in total emissions in addition to landscape sequestration, and permitting a net zero outcome. The results of our modelling are reported in ***Part* 5.5** and **5.6.**

Concurrent with our independent development of these methods, a study by Eady and colleagues (2011[9]) assessed emissions based on farm-gate lifecycle analysis of beef produced on two Queensland beef properties, including modelling animal emissions with the Greenhouse Accounting Framework calculators[10] and FullCAM[11] to model the sequestration potential of the same properties. These were used to find the percentage of the holding that would need to be revegetated to balance emissions. While the Eady study was more comprehensive with respect to the emissions and other inputs associated with animal products from the properties considered, we include emissions from a greater range of agricultural activities and extend the geographical scope to the whole Australian continent.

5.3.1 Emissions profiling

Emissions from agriculture were computed for cereal and sugar cropping, sheep, beef and dairy operations, ensuring coverage of activities occupying large areas and / or producing large amounts of greenhouse gases (GHG). In 2012, the activities we consider in this study produced more than 71 megatonnes of carbon dioxide equivalent gases (Mt CO_2-e), or 84.4% of the total for agriculture as given in the National Greenhouse Gas Inventory[12] at

100-year global warming potential (GWP_{100}; see also our discussion of GWP below and in ***Section 3.4.3***). These activities and the areas they occupy also represent the vast bulk of both land cleared for agriculture and the uncleared but highly modified rangeland in Australia.

Data on agricultural activities is not available for IBRA regions or sub-regions, but the Australian Bureau of Statistics (ABS) publishes publicly-accessible information gathered during 5-yearly censuses of agricultural activities. We used data at statistical local areas (SLA) level, the smallest and most explicit unit for which ABS data are collated, from the 2006 Agricultural Census.[13] Farming system data was obtained from the Australian Bureau of Statistics (ABS) Agricultural Census 2006.[14]

Ten sample SLAs were selected to represent a cross-section of Australian farming systems and rainfall regimes. Nine of the areas included at least some cropping, and all included grazing animals; eight included beef, eight sheep and three dairy (***Table 5.1***). Each SLA was treated as though it were a single farm, and annual emissions calculated for each of the agricultural activities listed above where present. Greenhouse emissions from agricultural activities were profiled using the Farm Greenhouse Accounting Framework (GAF) calculators developed by Eckard *et al.* (2008[15]). Emissions from electricity and fossil fuel use due to agricultural activities were excluded.

The GAF calculators for grains (G-GAF; also used for sugar), sheep (S-GAF), beef (B-GAF) and dairy (D-GAF) employed reflect UNFCCC accounting protocols and 100-year global warming potential (GWP_{100}). With adjustments to the calculators, we also used them to calculate annual emissions in a twenty-year GWP (GWP_{20}). This matters because of the urgency of action on climate change and because the strong warming impact of methane over its 12-year atmospheric lifetime is not captured in accounting that considers only the 100-year timeframe. Global warming potentials used are given in ***Table 5.2***. Note that GAF agricultural emissions calculators do not include emissions from deforestation for agricultural activities nor from prescribed burning of savannas. These emissions are described in ***Part 3.1*** and options for their abatement explored in ***Part 4.1***.

Table 5.3 Annual emissions from representative on-farm agricultural activities as used to compute total emissions per IBRA sub-region, with data from other sources for comparison.

Activity	Emissions [$t.CO_2$-e/head/yr]		Emissions [$t.CO_2$-e/ha/yr]		Published emissions estimates for comparison [$t.CO_2$-e/head/yr, GWP_{100}]	Published emissions estimates for comparison [$t.CO_2$-e/ha/yr, GWP_{100}]	Reference
	GWP_{100}	GWP_{20}	GWP_{100}	GWP_{20}			
Dairy	3.305	9.572	-	-	1.94 – 2.09*	-	21
					4.20 – 6.45	6.35 – 13.10	22
Beef	1.378	4.508	-	-	1.38*	-	23
					1.93		9
					1.70		9
					1.21 – 1.38		24
					1.26 – 2.25*		25
Sheep	0.161	0.500	-	-	0.139 – 0.151*	-	21
					0.097*		26
					0.287 – 0.316*		27
Cereals	-	-	0.106	0.102	-	0.034	28
						0.062 – 0.084	17
Sugar	-	-	2.489	2.376	-	2.294 – 22.351	29

*consider methane only

Table 5.2 Global warming potentials of agricultural emissions as used in modelling. All GWP data reflects that used by DCCEE for the National Inventory Report (2010).

Emission	GWP_{100}	GWP_{20}
CO_2	1	1
CH_4	23	72
N_2O	310	296

5.3.1.1 Crops

It was not possible to model emissions from all crops nationwide. Instead we limited the study to wheat, oats, barley, triticale and sugar and entered ABS data for extents and yields of these crops directly to the GAF calculators. Fertiliser application rates vary widely between specific agricultural activities and expected crop yields, and can drive marked variations in emissions of nitrous oxide, a powerful GHG. Where applicable to the SLAs and crop types studied, published fertiliser application rates and emissions factors for nitrous oxide from fertiliser application were used. Further nitrogen application rates obtained from expert sources including Catchment Management Authorities, Departments of Agriculture and Primary Industries, peak agriculture bodies and fertiliser suppliers allowed us to refine our estimates (*Table 5.1*).

Crop residues were modelled as unburned in all cases, though some field burning remains a feature of Australian agriculture for reasons including weed and pest management. Field burning of all agricultural residues nevertheless emits less than 0.5% of all emissions from agriculture under standard, 100-year UNFCCC accounting,[12] though the climate forcing effect of soot is not recognised under current UNFCCC protocols (see *Part 3.4.2.1*).

5.3.1.2 Animals

The GAF calculators for sheep, beef and dairy were used to derive emissions from animal agriculture for each of the sample areas. Livestock numbers for all ten SLA's were taken from the 2006 ABS Agriculture Census, re-categorized to National Inventory Report definitions.[20] Nitrogen fertiliser application rates are an important source of emissions in dairy systems so were included as a D-GAF input. An N application rate of 104kg.N/ha/year[19] was adopted for dairy pasture, though expert opinion advised that as much as 250kg.N/ha/year is applied by some producers. Nitrous oxide emissions from such heavy applications of fertiliser can be prodigious, especially when applied to naturally moist or irrigated pasture, typical for dairying.

5.3.1.3 Agreement with published literature

Our emissions estimates for both cropping and grazing as used in the continent-wide analysis are in close agreement with those published (*Table 5.3*). Furthermore the total national emissions from enteric fermentation that we derive by multiplying these per-head data by the number of beef, sheep and dairy animals in the included IBRA sub-regions agree to within 5% of the 2006-2010 average from this source as published in the national inventory report.

5.3.1.4 Areas & conversion to IBRA sub-regions

The ABS Agricultural Census 2006 provided data for area under specific crops but not for areas grazed. Our results for SLAs therefore contain per-hectare emissions from cropping, but per-head information for grazing animals.

We consulted both the Dynamic Land Cover Dataset (DLCD)[30] and the Australian Collaborative Land Use and Management Program (ACLUMP)[31] to quantify and spatially locate areas classified as rainfed and irrigated crops, sugar cane or pasture. To convert our results from SLAs to IBRA sub-regions, the grand mean of emissions density (t CO_2-e/ha) from cereals was multiplied by the area of each sub-region identified in ACLUMP / DLCD as regularly planted to these crops. The emissions density of sugar cane plantations was multiplied by the area under sugar in each sub-region according to ACLUMP, which represents better than DLCD the actual cropped areas as viewed on remote-sensed images.[6] The sum of these products represents total emissions from cropping in each IBRA sub-region. Mean annual emissions (t CO_2-e/head) from animals in the sample SLAs were applied to the total flock and herd sizes in each IBRA sub-region as calculated from ABS data. Emissions from animals were smoothed over the entire area of cleared land in each IBRA sub-region in the intensive zone.

Agricultural emissions were treated as uniform across all cleared land so identified in each IBRA sub-region, giving resolution appropriate to a study at continental scale, though in practice activities and therefore emissions are highly variable. Our adoption of these data for areas provides both consistency and conservatism. Revegetation was modelled in FullCAM for a sample of cleared land within each IBRA sub-region, whereas the activities whose emissions were modelled occupy less area than this, as they are a subset of total agricultural activity. Emissions are therefore distributed over a wider area than they actually occupy. Hence although emissions in t CO_2-e/ha are underestimated, total emissions per sub-region are accurate. Areas to be revegetated under our scenarios are based on the latter measure (see ***Part* 5.6.1** and ***Part* 5.6.2** below).

5.3.1.5 Intensive and extensive zones

We classify 154 sub-regions where vegetation has been cleared from ≥20% of the total sub-region area as subject to intensive agriculture. It is in these areas that most of Australia's crops are planted, and where dairying and mixed farming enterprises operate. Another 146 sub-regions where ≥20% of land has been cleared or significantly modified by grazing of native vegetation make up the extensive zone, where agricultural activity is largely limited to rangeland grazing of sheep and / or beef cattle.

5.3.1.6 Excluded IBRA sub-regions

300 of Australia's 419 IBRA sub-regions are included in this study; those considered are listed in the appendices. Those that have undergone minimal clearing or modification of native vegetation, or where agricultural activity is absent or minimal, do not appear. Some sub-regions that have been extensively cleared are unlikely to provide opportunities for revegetation, so are also excluded. Sub-regions in this category include those with extensive urban development. Offshore islands are also excluded from our analysis.

5.3.2 Modelling of sequestration potential with FullCAM

The terrestrial ecosystem model implemented within Australia's National Inventory System is the Full Carbon Accounting Model (FullCAM), which is a carbon ecosystem model that calculates greenhouse gas emissions and removals in both forest and agricultural lands using a mass balance approach to carbon cycling. As the most significant emissions and removals of greenhouse gases in the land sector occur with transitions between forest and agricultural land use, the model fully integrates agricultural and forestry modelling.[31]

FullCAM is designed as a model for tracking the greenhouse gas emissions and carbon stock changes associated with land use and land use management. It is an integrated carbon accounting model for estimating and predicting all biomass, litter and soil carbon pools in forest and agricultural systems. In addition to this, FullCAM accounts for changes in major greenhouse gases, nitrogen cycling and human-induced land use practices.[11]

FullCAM was developed under the National Carbon Accounting System (NCAS) to integrate data on land cover change, land use and management, climate, plant productivity and soil carbon over time. This was intended to provide an account of the changing stock of carbon in Australia's land systems since 1970.[11]

FullCAM combines a suite of verifiable component models, including:

- CAMFor - for forest systems;
- CAMAg - for cropping and grazing systems;
- 3PG - for forest growth;
- GENDEC - for microbial decomposition; and
- RothC - for agricultural soil carbon.

FullCAM calculates the carbon and nitrogen flows associated with:

1. Forests - including the wood products made from wood harvested from the forest. It calculates the carbon in the trees, debris, mulch, soils, and wood products, and the carbon and nitrogen exchanged with the atmosphere, due to thinnings, multiple rotations, fertilization and fires.

2. Agricultural systems - which can be cropped or grazed systems. It calculates the carbon and nitrogen in the plants, debris, mulch, soil, and products, and the carbon and nitrogen exchanged with the atmosphere, while including the effects of harvest, plowing, fire, herbicides, fertilization and grazing.
3. Afforestation and reforestation systems - which are represented and modelled as transitions from agricultural systems to forests.
4. Deforestation systems - which are represented and modelled as transitions from forests to agricultural systems.
5. Mixed (e.g. agroforestry) systems - assorted combinations of the systems above.

Under the Commonwealth Government's 'Carbon Farming Initiative', a project must consist of the establishment and maintenance of a planting in an area, for the five years prior of a planting, to have either: a) been used for grazing, pasture management, cropping, nature conservation, settlement or not used for any purpose; b) has been non-forested land;

> *'environmental planting', which refers to a planting of species that are native to the local area of the planting and are sourced from seeds that are from within the natural distribution of the species and are appropriate to the biophysical characteristics of the project area. An environmental planting may be a mix of trees, shrubs, and understorey species which reflects the structure and composition of the local native vegetation community. It may consist of single tree species if monocultures naturally occur in the local area where the project is being established.*[32]

5.3.2.1 Our application of FullCAM

FullCAM is a point-based tool, where spatial coordinates and site-specific information, including initial clearing and subsequent land use activities, are needed for each simulation. We obtained information on vegetation cover prior to initial clearing from the National Vegetation Inventory System (NVIS; 2012) dataset.[33] We obtained the approximate date of clearing from the *Atlas of Australian Resources Vol. 6 Vegetation*.[33]

FullCAM modelling was undertaken for each of the 154 IBRA sub-regions in the intensive zone. Our FullCAM simulations were applied to land classified in either DLCD[30] or ACLUMP[31] as rainfed and irrigated crops, pasture or sugar cane, categories which indicate both historical removal of forest or woodland, and current land use activity. We chose between these datasets on the basis of how well they reflected the actual extent of cleared area and crops as revealed in remote-sensed images (Google Earth and ArcGIS 10 basemap[6]). Large discrepancies between DLCD and ACLUMP were identified, especially in Queensland.

The total area of cleared land thus determined for each sub-region was divided by three and three corresponding points selected at random for FullCAM modelling. Three separate model runs were conducted for each IBRA sub-region, allowing for variation in pre-clearance vegetation type and extent (after NVIS 2012), post-clearance land use and other variables embedded in the FullCAM software. Model results were combined into a single 'estate' predicting sequestration in units of t.C/ha before conversion to t CO_2-e/ha as used in all subsequent calculations. We assumed a total revegetation of cleared land within each SLA, and a planting year of 2015, modelling growth of mixed environmental plantings (native forest, woodland or shrubland) in each IBRA sub-region to 2100, a model run of 87 years. This is to say we modelled three sample cleared hectares in each IBRA sub-region, and took an average across these as representative of the areas' sequestration potential. Mean annual increments of carbon accrual (t CO_2/ha/year) were determined for each sub-region by dividing end-of-run total into 87 years.

Our use of the 'mixed environmental planting' parameter in FullCAM permitted a conservative estimate of per-hectare and therefore annual rates of vegetation growth and hence carbon sequestration.

Keith and colleagues[34] report that site data used in the National Carbon Accounting System (NCAS) are mostly based on regrowth forests and plantations and hence underestimate the longer term carbon carrying capacity of sites. Mackey *et al.* (2008) suggest however, that NCAS, which feeds into FullCAM, is appropriate for the younger age classes of vegetation for which it was calibrated.[37] This supports our use of FullCAM to simulate growth of active or passive revegetation to the year 2100 for our scenarios.

5.3.3 Modelling of sequestration potential with RangeASSESS

RangeASSESS is a computer program for exploration of potential impacts of changes in livestock and other grazing regimes, changes in fire frequency and changes in woody plant management or establishment on carbon stocks in Australian rangelands.[36] It is based on ASSESS (A system for Selecting Suitable Sites), which is a user-friendly interface to the full functionality of the grid module for manipulating raster data in ArcGIS. RangeASSESS allows users to simulate changes in the management of different rangeland zones across northern and central Australia. The carbon stores in vegetation and soil are adjusted according to the modelled vegetation states.[37] RangeASSESS is spatially calibrated around 12 vegetation zones:

- Semi-arid woodlands
- Chenopod shrublands
- Mallee
- Mitchell-Dicanthium
- Northern tallgrass
- Hummock grasslands
- Hummock woodlands
- Central arid woodlands
- Arid mulga
- Eastern tallgrass
- Midgrass
- Cracking clay

These zones are represented in a simplified conceptual state and transition model. Vegetation states are defined by significant change in biomass and soil carbon. Relatively undisturbed biomass and soil carbon is described by a continental 1km data set produced from simulations with the Vegetation Assets States Transitions (VAST) model. These spatial data layers are overlaid with other layers that estimate feral animal distributions, livestock density, woody weed distribution, climate and fire impact. The impact of climate variability refers to the relationships between the Southern Oscillation Index (SOI) and the Interdecadal Pacific Oscillation (IPO), combined with rangeland production and degradation. This relationship identifies 6 year types associated with the values of the IPO and SOI, which results in decreases or increases in growth potential of rangelands. The model uses the frequency of occurrence or year types and the percentage change in grassland growth to create a multiplier for carbon sequestration over 50 years.[37]

5.3.3.1 Our application of RangeASSESS

The RangeASSESS model features five primary steps to generate a simulation. The first is the selection of vegetation zones, listed in the preceding section. As our analysis covers the extent of rangeland grazing across Australia, all featured vegetation zones were selected. The next step was to select recovery and degradation rates. Given that the scale of our modelling was continental, we resorted to the generic default values. The third step was to adjust management scenarios, which features parameters of cattle and sheep stocking densities, grazing feral animal population, rabbit population and kangaroo numbers. There are further parameters covering changes in fire susceptible and resistant weeds and the introduction of prescribed burning.

We chose to run two scenarios under this third step, one a representation of the current context, consisting of 100% stocking of cattle and sheep, along with 100% pressure exerted by feral animals, rabbits and kangaroos. We assumed that prescribed burning is no longer extensively practiced due to the cessation of traditional indigenous land burns following European occupation.[38] We also assumed no change in fire susceptible and resistant weeds. The other scenario represented a context where all cattle and sheep had been removed, the feral animal and rabbit populations had been halved due to more effective pest control measures and in which prescribed burning, as carried out by indigenous rangers, was re-introduced into the landscape. The fourth step involved climate variability. This involved choosing years that represented historic variations of the SOI and IPO. We ran multiple simulations of climate variability to represent the climate between 1980 and 2000. The fifth and final step was the carbon model run, which produced spatial maps and spreadsheets of our scenarios.

We reconstructed the 12 vegetation zones in ArcGIS 10 and extracted those areas that had been defined as 'grazing natural vegetation' under the Australian Collaborative Land Use and Management Program (ACLUMP).[31] Other areas were defined as native title and conservation and we assumed little to no extensive grazing on those land tenures. We then linked our data cubes to the areas defined as grazing natural vegetation. We ran a zonal statistical analysis over these areas, arranging our modeled data around the IBRA framework. We did this for our current scenario and the scenario involving the total removal of livestock and re-introduction of prescribed indigenous burning. As per our FullCAM analysis, this method provided us with the necessary output to process our land use scenarios for the rangelands where livestock grazing is practised, which consisted of the annual change in carbon dioxide between current use and removal of livestock/re-introduction of prescribed burning.

5.3.4 Estimation of area to be rehabilitated

Once BAU emissions (t CO_2-e/ha) and sequestration potential (t CO_2/ha) were estimated for cleared land, we applied the following arithmetic to arrive at a proportion of each IBRA sub-region that would need to be revegetated or restored in order to arrive at net zero carbon emissions over a period of 100 years:

$$P = \frac{E}{E+S} \qquad (2)$$

Where **P** is the proportion of cleared land in a sub-region to be revegetated, **E** denotes the greenhouse gas emissions from current agricultural activities (t CO_2-e/ha) and **S** is the sequestration potential of revegetation (t CO_2/ha).[16] **E+S** is hereafter referred to as the net carbon benefit (**NCB**) of conversion of a hectare of land from current use to carbon farming. **P** was calculated using both GWP_{100} and GWP_{20}, for application in our two scenarios (***Part 5.5, 5.6***).

This approach assumes that revegetated land is removed from production, and that the source of emissions is reduced in the same proportion. In some cases, this will result in a reduced local output of agricultural products, especially emissions-intensive ones. We demonstrate, however, that capacity exists in Australia's national agricultural system to absorb this level of change. Outcomes for food production are covered in ***Part 7.1*** .

5.3.5 Local value of agricultural production

By way of estimating the financial opportunity cost of reallocating land to carbon sequestration, we have mapped the Local Value of Agricultural Production (LVAP) to IBRA sub-regions. Our LVAP reflects the ABS' estimates of the value of agricultural commodities in their Value of Agricultural Commodities Produced (VACP) series. This measure is described by the ABS as "the value of agricultural commodities at the point of production".[39] LVAP is therefore an appropriate, if approximate metric for the opportunity cost for agriculture of land use change toward activities designed to sequester atmospheric CO_2. Reassignment of some areas from their current use may incur no opportunity costs, or may be sympathetic with other aims.

Local value data for all broadacre cropping and grazing activities were taken from the 2006 ABS Agriculture Census and assumed to be uniform across all areas cleared for agriculture or grazed in a given IBRA sub-region (with caveats as for ***Part 5.4.1.4***). As such we present mean LVAP (\$/ha) for cleared or grazed land in each sub-region. The values of all grazing animal products, including meat, milk and wool were included in our total LVAP, as were those of all broadacre crops, while emissions analysis was limited to cereals and sugar.

5.3.6 Statistical analyses

Rainfall is an important driver of biological production, and influences per-hectare emissions, sequestration potential, and the economic value of farming enterprises, the basis of our scenarios in ***Part 5.6.1*** and ***Part 5.6.2.*** We apply statistical analyses to these links in order to demonstrate the strength of influence of a single intuitively-understood natural phenomenon to the more abstract concepts of emissions, sequestration and farm incomes. While many other environmental variables, including soil types, evaporation rates and topography, also influence agricultural activities, data for rainfall is easily interpreted. Rainfall is also the strongest driver of plant productivity for which data is both readily available and applicable at continental scale.

The results of our modelling are described in ***Part* 5.5**, and employ standard UNFCCC global warming potentials for 100- and 20-year timeframes. Results for regression analysis of AAR against mean annual agricultural emissions, sequestration potential, net carbon benefit of conversion and local value of agricultural production per hectare of cleared land per sub-bioregion are given in ***Table* 4.2**. For each regression analysis, raw data for both average rainfall and response variables were log transformed to remove heteroscedasticity. Statistical analyses were conducted in the R software environment for statistical computing.[40]

5.4 Modelling outputs

5.4.1 Agricultural emissions

Agricultural emissions are highest in the intensive zone where physical parameters including climate and soil types generally permit high levels of biological activity. Such areas, where average annual rainfall (**AAR**) is relatively high, are concentrated along Australia's south and east coasts and coastal hinterland regions (***Fig.* 5.6**). These regions generally support high-value agricultural activities. The most greenhouse-intensive sub-regions emit up to 3.57 t CO_2-e per hectare of cleared land, but more than 75% of intensively-farmed sub-regions produce on average less than 1 t CO_2-e/ha/yr on the basis of GWP_{100}. These include most farming areas on the western slopes of the Great Dividing Range and the dryland cropping areas in the plains of NSW, Victoria, South Australia and WA.

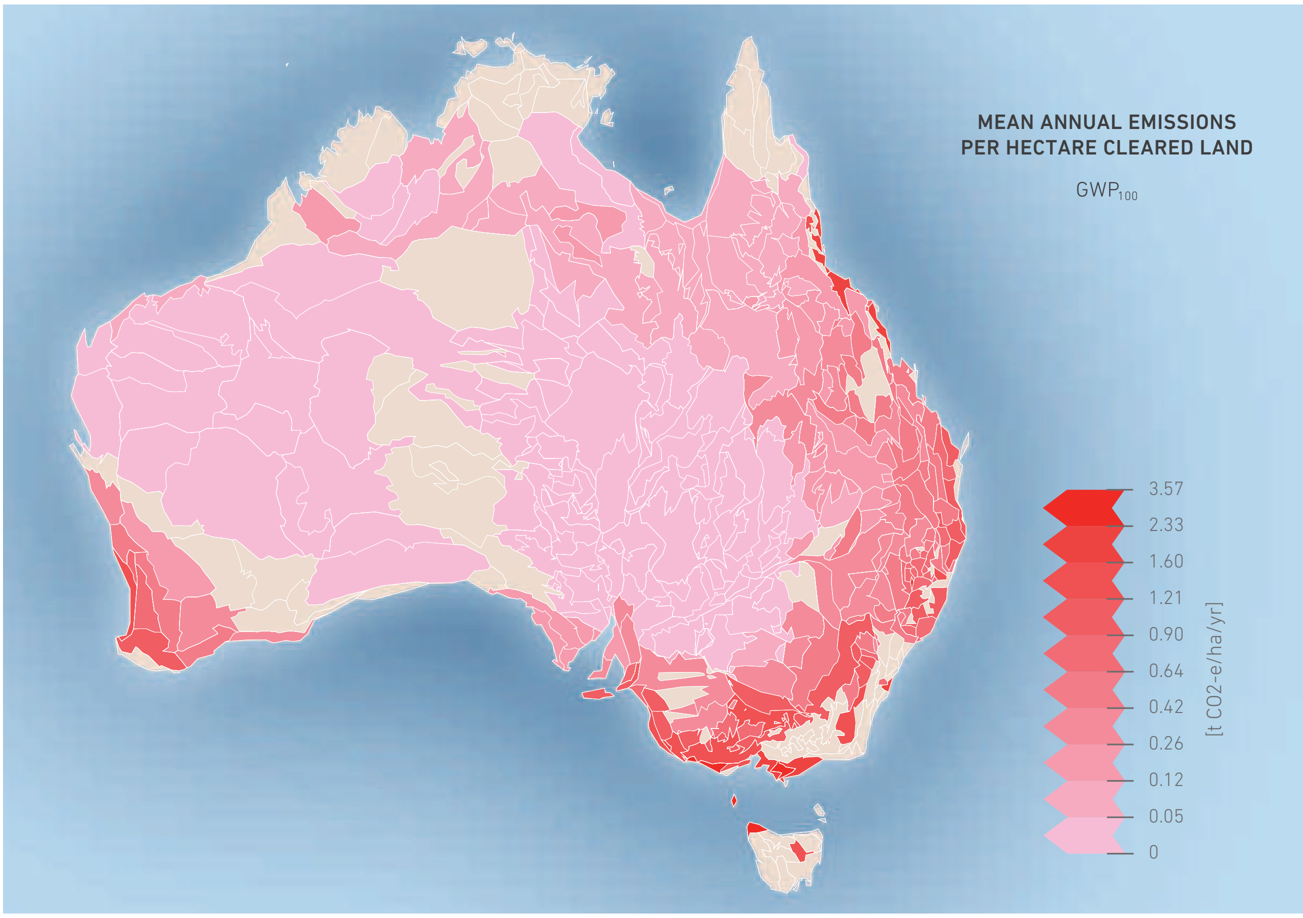


Figure 5.6 Intensive and extensive zones in 300 IBRA sub-bioregions.

In the extensive zone, where agriculture is largely limited to livestock grazing on native or mixed pastures, lower animal densities result in lower emissions per hectare, though areas under these activities are large. Rangeland emissions fall in the range 0—0.31 t CO_2-e/ha/yr and 85% of sub-regions emit less than 0.1 t CO_2-e/ha/yr, reflecting the low grazing animal stocking rates possible. A summary of emissions density is presented in ***Table 5.4***, and is mapped for GWP_{100} only in ***Figure 5.6***. Emissions measured at GWP_{20} (not shown) show a very similar spatial distribution.

Table 5.4 Quartile and median measures of emissions for intensive and extensive agricultural zones for 100-year and 20-year global warming potentials.

Quartile	Emissions [t CO_2-e/ha/yr]			
	Intensive		Extensive	
	GWP_{100}	GWP_{20}	GWP_{100}	GWP_{20}
Q1	0.301	1.154	0.014	0.046
Median	0.567	1.832	0.022	0.072
Q3	0.953	2.745	0.063	0.201

Statistically significant correlation between average annual rainfall and agricultural emissions was demonstrated in both intensive and extensive zones (***Table 5.5, Fig. 5.7***). Rainfall variability explains around 42% of variability in greenhouse emissions per hectare in the intensive zone and 55% of emissions variability in the extensive zone, according to r^2 values. This may reflect the greater variety

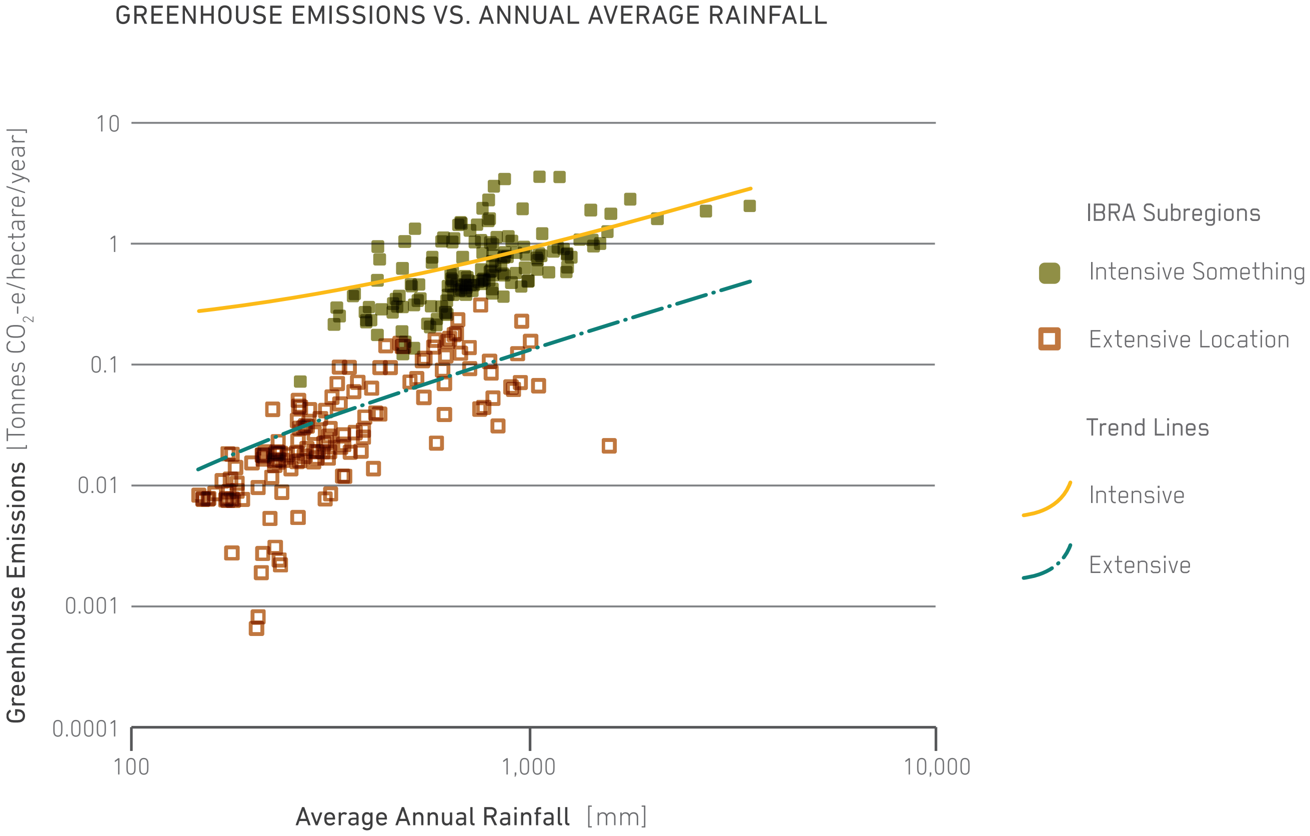


Figure 5.7 Mean annual greenhouse emissions at GWP_{100} (t CO_2-e/ha/yr) from agriculture on cleared land in intensive ($n=154$, $b=1.1147$, $t_{152}=10.54$, $p<<0.01$, $r^2=0.4221$) and extensive zones ($n=146$, $b=1.6629$, $t_{144}=13.18$, $p<<0.01$, $r^2=0.5467$), against average annual rainfall.

Table 5.5 Regression analysis results for average annual rainfall (AAR) [mm] against emissions [t CO_2-e/ha/yr, GWP_{100}], sequestration potential [t CO_2/ha/yr], net carbon benefit [t CO_2-e/ha/yr] and local value of agricultural production (LVAP) [$/ha/yr].

	AAR vs.	b	t(152)	p	r2
Intensive zone	Emissions	1.1147	10.54	<<0.01	0.4221
	Sequestration potential	1.2240	14.44	<<0.01	0.5782
	Net Carbon Benefit	1.2057	15.69	<<0.01	0.6183
	Local Value Agri. Production	0.5934	3.395	<0.01	0.0705
	AAR vs.	**b**	**t(144)**	**p**	**r2**
Extensive zone	Emissions	1.6629	13.18	<<0.01	0.5467
	Sequestration potential	1.3635	7.878	<<0.01	0.3012
	Net Carbon Benefit	1.4600	10.19	<<0.01	0.4189
	Local Value Agri. Production	1.3697	9.846	<0.01	0.4024

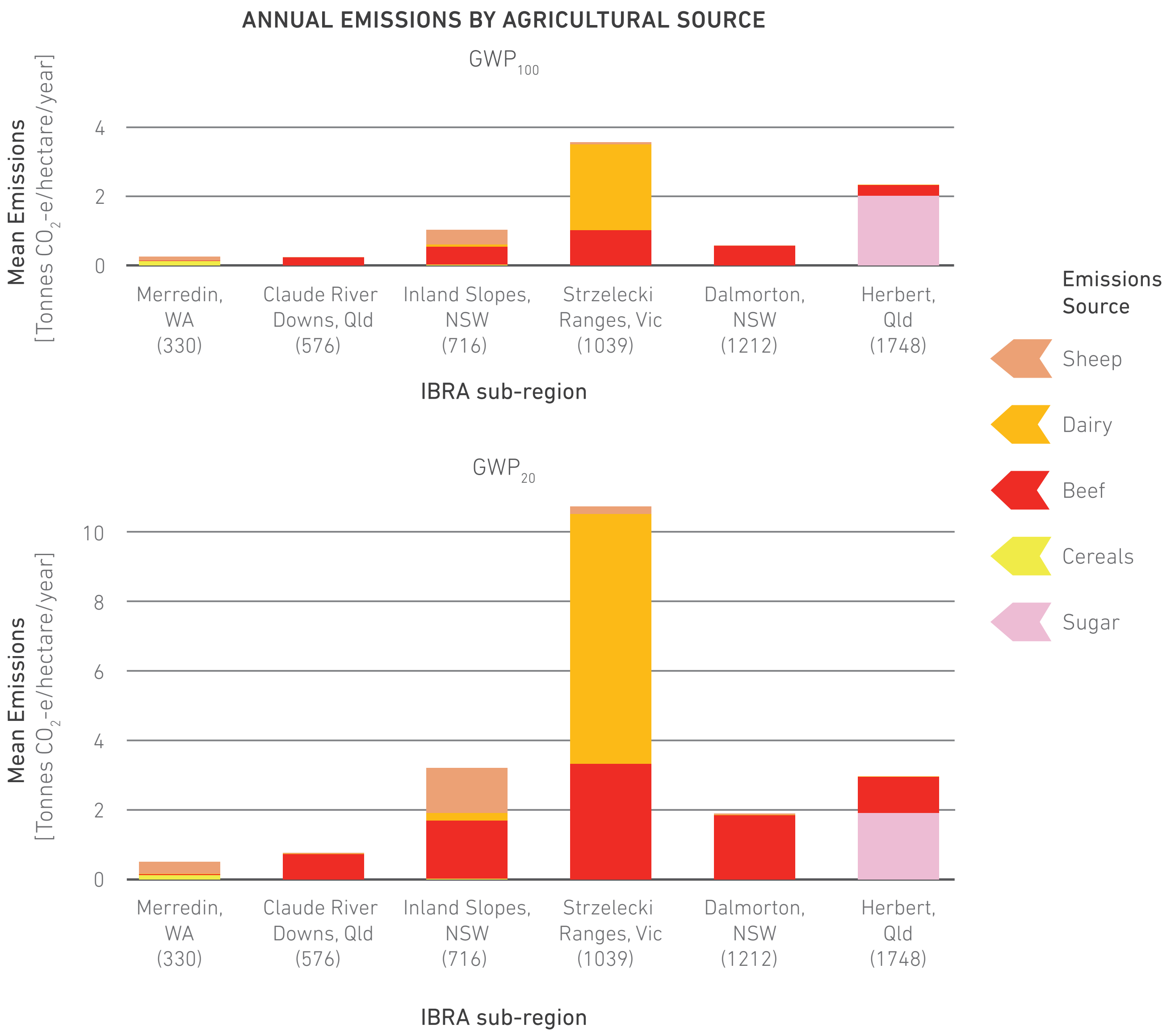


Figure 5.8 Annual emissions from agricultural sources in each of six sample IBRA sub-regions in the intensive agricultural zone. Numbers in parentheses are average annual rainfall (mm).

Table 5.6 Details of Interim Biogeographical Regionalisation of Australia (IBRA) version 7 sub-regions presented as examples in this analysis.

Sub-region code	Average annual rainfall (AAR) [mm]	Sub-region name	Region name	State
AVW01	330	Merredin	Avon Wheatbelt	WA
BBS12	576	Claude River Downs	Brigalow Belt South	Qld
NSS01	716	Inland Slopes	NSW South Western Slopes	NSW
SEH04	1039	Strzelecki Ranges	South Eastern Highlands	Vic
NNC03	1212	Dalmorton	NSW North Coast	NSW
WET01	1748	Herbert	Wet Tropics	Qld

of agricultural industries and associated greater variability in greenhouse gas emission intensity in the intensive zone, driven by a greater range of both natural and social factors than are at play in the rangelands (see ***Part 5.5.4***).

Results for regression analysis of each modelled or computed parameter against AAR are presented in ***Table 5.5***.

Six IBRA sub-regions, representing a spectrum of rainfall regimes, biological and agricultural productivity across the intensive agricultural zone, are presented by way of summarising our results in greater detail than is discernible from statistical summaries or maps (***Table 5.4***). The six example sub-regions are given in ***Table 5.6*** and are hereafter listed in order of average annual rainfall. While it is possible to define emissions per hectare of different crop types, these cannot be directly attributed for each grazing industry because of difficulties demarcating areas occupied by beef, sheep and dairy. Nevertheless the relative contribution of each industry to the overall emissions density of each IBRA sub-region shows clearly which industries emit most heavily, and which are less greenhouse-intensive (***Fig. 5.8***).

Differences in global warming potential over different timeframes drive changes in emissions profiles both of sub-regions and individual activities. The GWP_{20} of methane is approximately three times as great as GWP_{100} for this gas. For N_2O the proportional difference between GWP_{100} and GWP_{20} is much smaller; in fact this gas has slightly more warming potential over 100 years than over 20, the opposite of methane. Because CO_2 is the gas to which other emissions are compared, by definition there is no change in its warming value with changes of timeframe. See ***Table 5.2***, ***Part 5.3.1*** for GWPs used in our modelling.

Cereal emissions emit more nitrous oxide (N_2O) than methane, and animal populations in the wheatbelt are sparse, so there is little change to total emissions with a change from GWP_{100} to GWP_{20} in areas where cropping is the dominant activity. The West-Australian sub-region Merredin, in the Avon Wheatbelt (AVW01), demonstrates this well (***Fig 5.8***). Tropical sub-region Herbert (WET01), with beef grazing and sugar cane the predominant industries, also sees little change in overall magnitude of emissions with a change from GWP_{100} to GWP_{20}. However a change in weighting is seen in Herbert, with emissions from the relatively smaller area under beef cattle increasing over twenty years while those from sugar decrease somewhat because they comprise a large nitrous oxide component. GHG emissions of each industry differ markedly between GWP_{100} and GWP_{20} especially where animal agriculture is the predominant land use. **Dalmorton** (***NNC03***), **Inland Slopes** (***NSS01***) and particularly the **Strzelecki Ranges** (***SEH04***), where dairying is prominent, show this well.

5.4.2 Sequestration potential

As with emissions, the average landscape sequestration potential in IBRA sub-regions increases with rainfall in both FullCAM modelling of the intensive agricultural zone and RangeASSESS modelling for the extensive zone. Faster plant growth is driven by higher rainfall and associated with faster accrual of carbon in the landscape. Sequestration potential per hectare is generally higher in the intensive zone than in the extensive, though some overlap is seen. Carbon sequestered out to a century after restoration

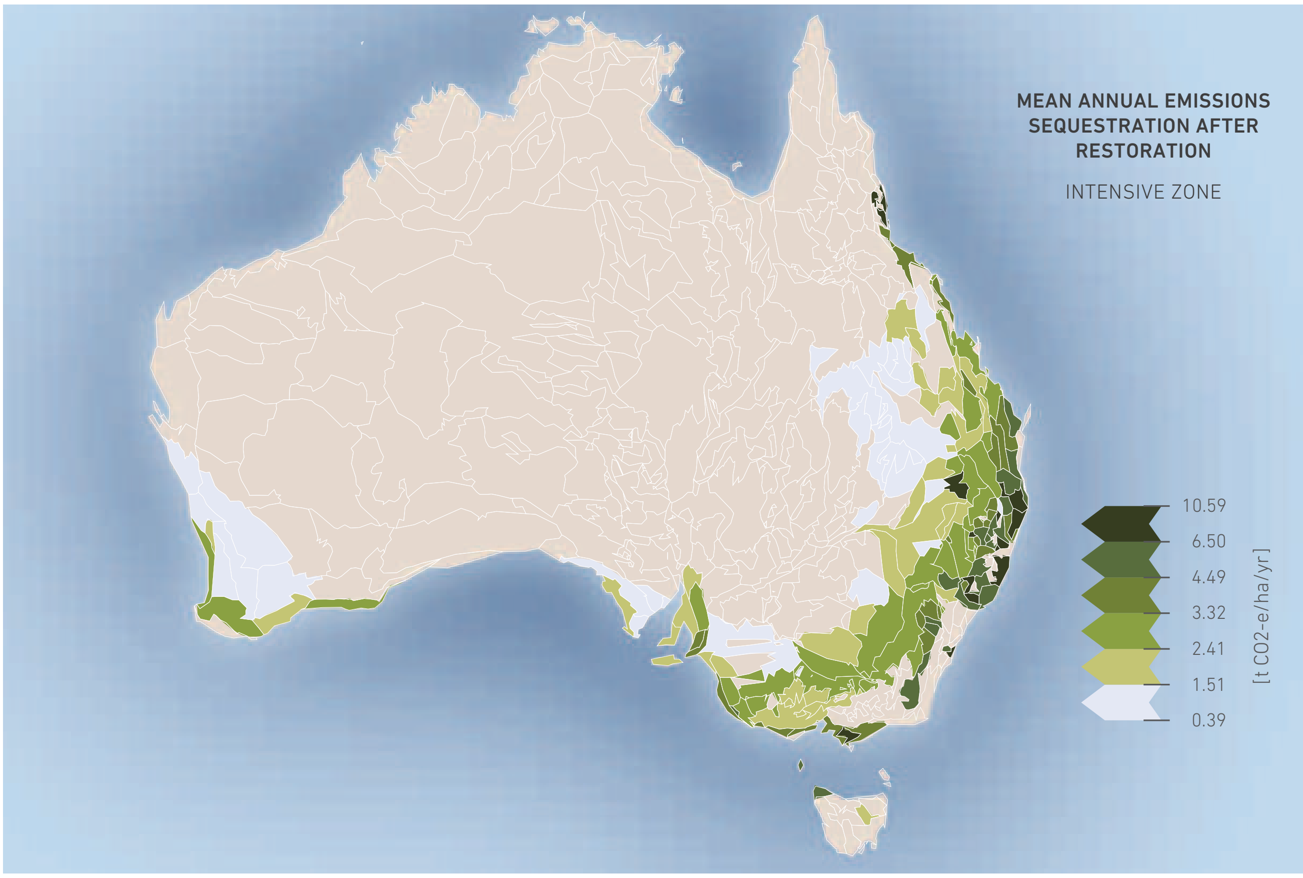


Figure 5.9 Intensive zone: sequestration potential after restoration, as modelled with FullCAM.

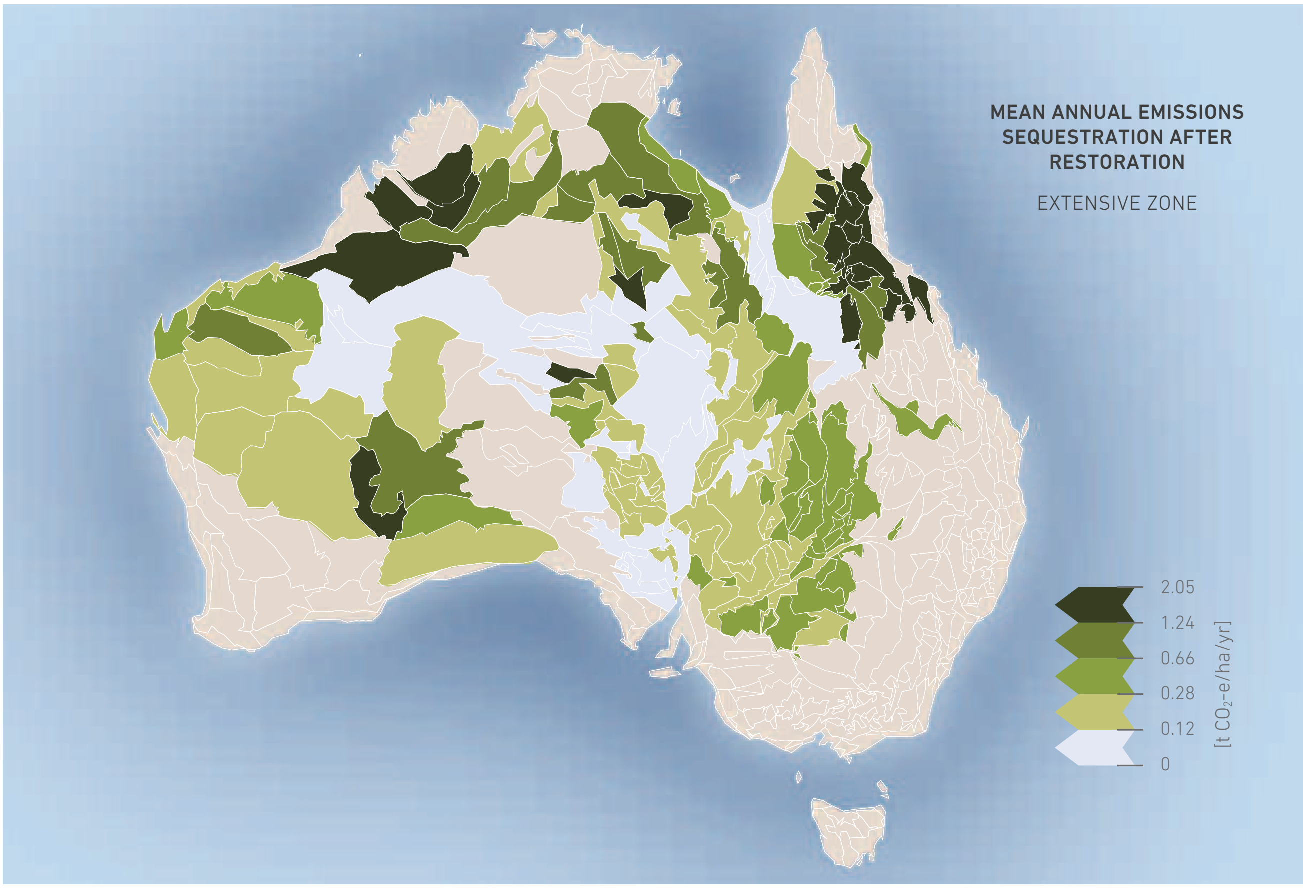


Figure 5.10 Extensive zone: sequestration potential after restoration, as modelled with RangeAssess.

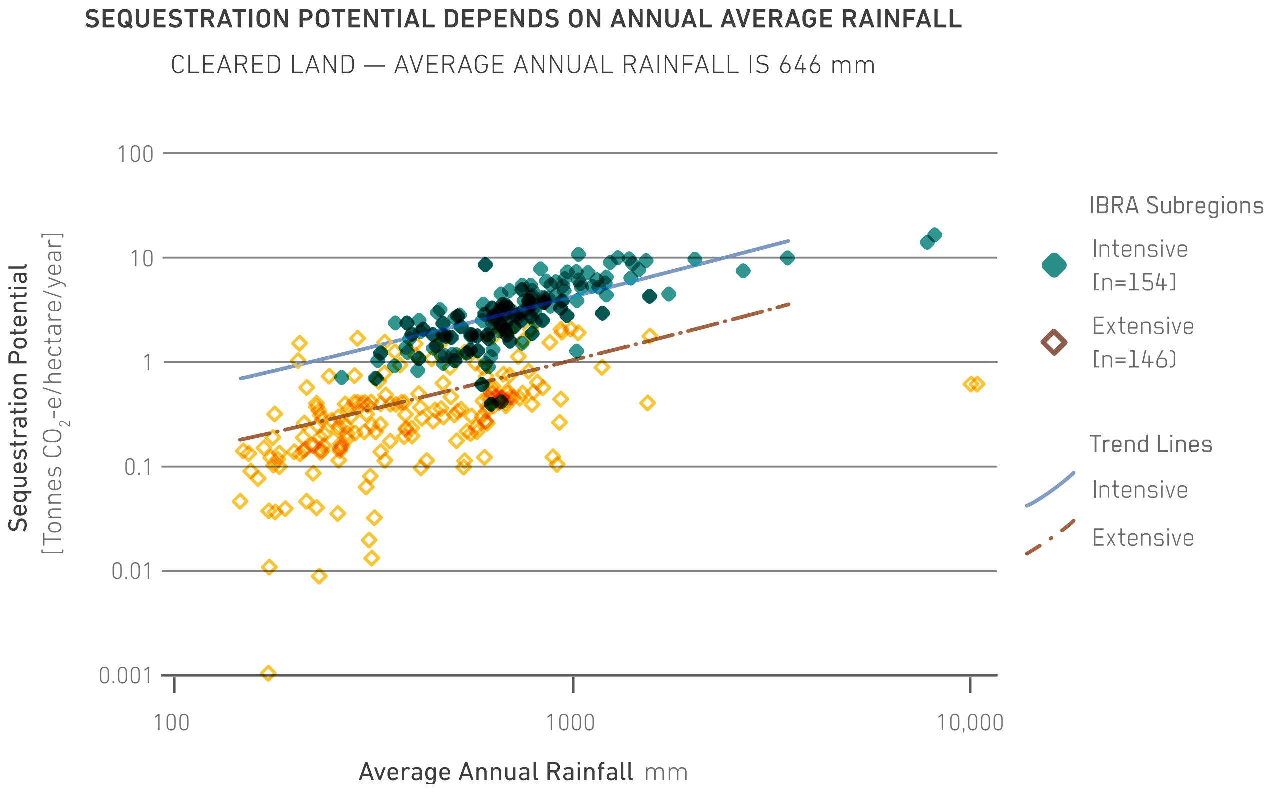


Figure 5.11 Sequestration potential of cleared land vs. rainfall in intensive and extensive zones.

totals less than that emitted at time of clearance in every sub-region of the intensive zone.

Areas with high sequestration potential correspond with those of high agricultural productivity and emissions (*Fig. 5.6*) and are mapped in ***Figures 5.9 & 5.10***.

A summary of sequestration potentials, which fall in the range 0.40 — 10.59 t CO_2-e/ha/yr in the intensive zone and up to 2.05 t CO_2-e/ha/yr in the extensive zone, are presented in ***Table 5.7***.

Table 5.7 Quartile and median measures of sequestration potential for intensive and extensive zones.

Quartile	Sequestration potential after restoration [t CO_2/ha/yr]	
	Intensive	Extensive
Q1	1.815	0.137
Median	2.876	0.253
Q3	4.344	0.619

Modelled carbon sequestration through revegetation is an average of three randomly sampled hectares of cleared land in each intensive sub-bioregion over an 87-year model run, expressed as tonnes of carbon dioxide per hectare per year (t CO_2/ha/yr). Mean annual carbon sequestration potential (SP) shows significant and moderately strong positive association with AAR in the intensive zone and significant but weak correlation in the extensive zone (*Table 5.5*, *Fig. 5.11*). Our results suggest that rainfall explains around 58% of variability in SP in the intensive zone but only 30% of SP in the extensive zone. This may reflect greater rainfall seasonality over large areas of Australia's rangelands, especially in the northern tropics.

5.4.2.1 FullCAM outputs

FullCAM output representing carbon sequestration over our model run is given for the same sample of intensive zone sub-regions as presented in ***Table 5.6***, ***Part 5.4.1***. ***Figures 5.12 a – f*** summarise this information. The highest totals and fastest rates of atmospheric CO_2 sequestration per hectare are generally associated with

MODELLED TIME SERIES OF LANDSCAPE CARBON

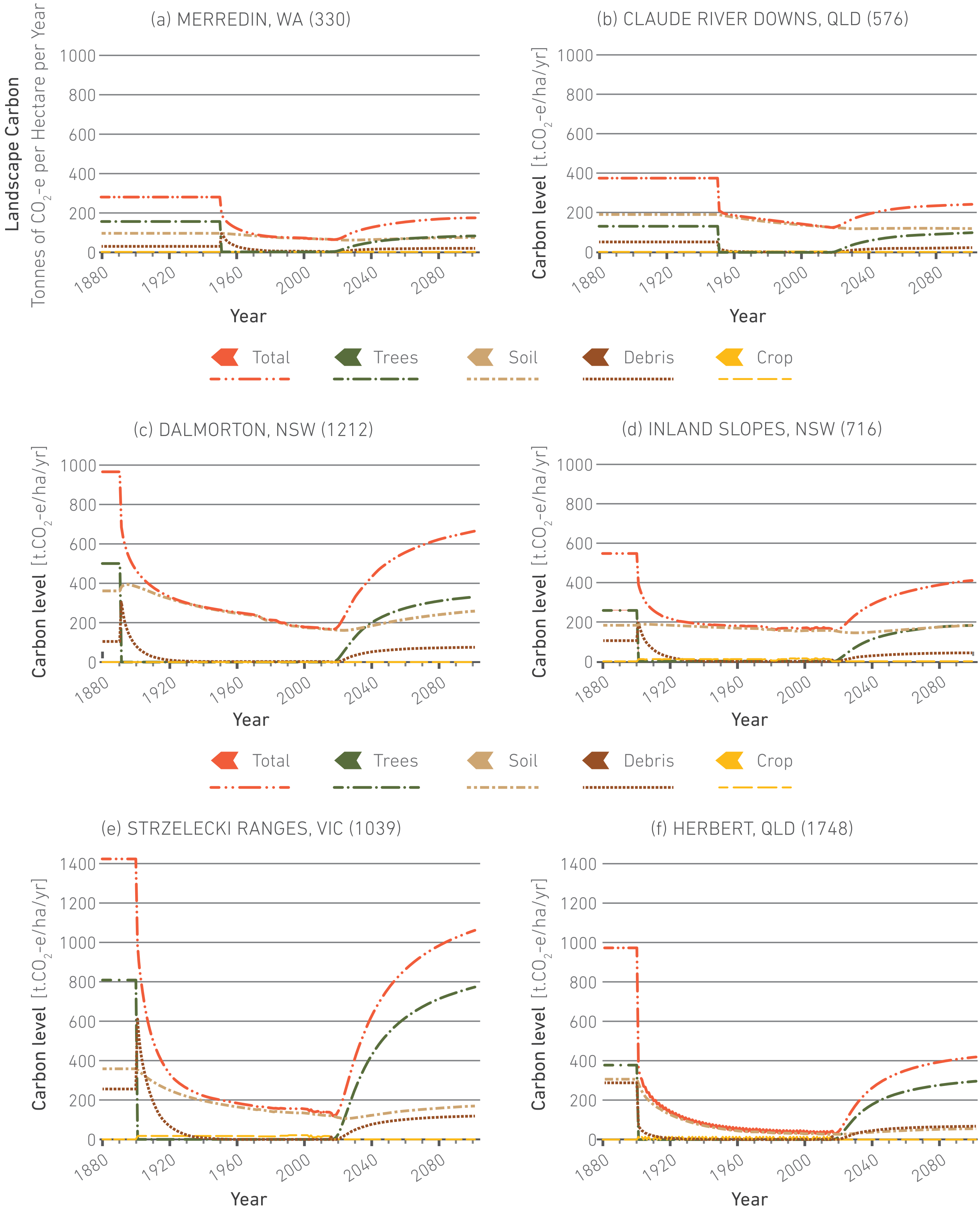


Figure 5.12 Modelled time-series of landscape carbon (t CO_2 e/ha) for a sample of six IBRA sub-regions in the intensive agricultural zone, from pre-disturbance times through forest or woodland clearance, period of agricultural or other use then accumulation in vegetation, soil and debris after restoration from 2015.

high AAR and large pre-European landscape carbon totals (***Figures* 5.9, 5.11, 5.12 *c, e***).

Carbon levels in pre-disturbance landscapes declined markedly and suddenly with the removal or modification of pre-European vegetation, as described in ***Part* 2.1.3** and ***Figure* 5.12**. Soil carbon declined more gradually than carbon stored in woody vegetation or debris, but continued on a downward trajectory for decades in most cases. The contribution of crop or pasture carbon to the landscape total is invariably low although seasonal variations can be discerned in some sub-regions, especially where high-biomass pasture (e.g. SEH04, ***Fig.* 5.12 *d***) or crops (sugar cane in WET01; ***Fig.* 5.12 *f***) are grown.

Carbon accumulated after restoration of pre-clearance vegetation shows asymptotic growth as is often seen in biological systems. Carbon stocks initially increase quickly, but this high growth rate flattens off as vegetation matures. Standing carbon in trees contributes the majority of this response, especially in the period immediately following revegetation. Additions to soil carbon are more gradual or marginal, and may represent only slowed rate of loss rather than material increase (***Fig.* 5.12 *a & b***; see also ***Part* 4.1**). More arid areas (e.g. AVW01 and BBS12) exhibit decades of continued loss of soil carbon despite rehabilitation of woody cover while NSS01 and WET01 show very low levels of CO_2 sequestration to soils over the model run. This results from the failure of forests and woodland ecosystems to reach maturity within the period modelled, and the long lag in debris and soil carbon accumulation.

5.4.2.2 RangeASSESS outputs

The outputs for RangeASSESS were carbon densities (t/ha) for soil, biomass (vegetation) and the total, for each of the modeled rangeland zones, as discussed in Part 4. The

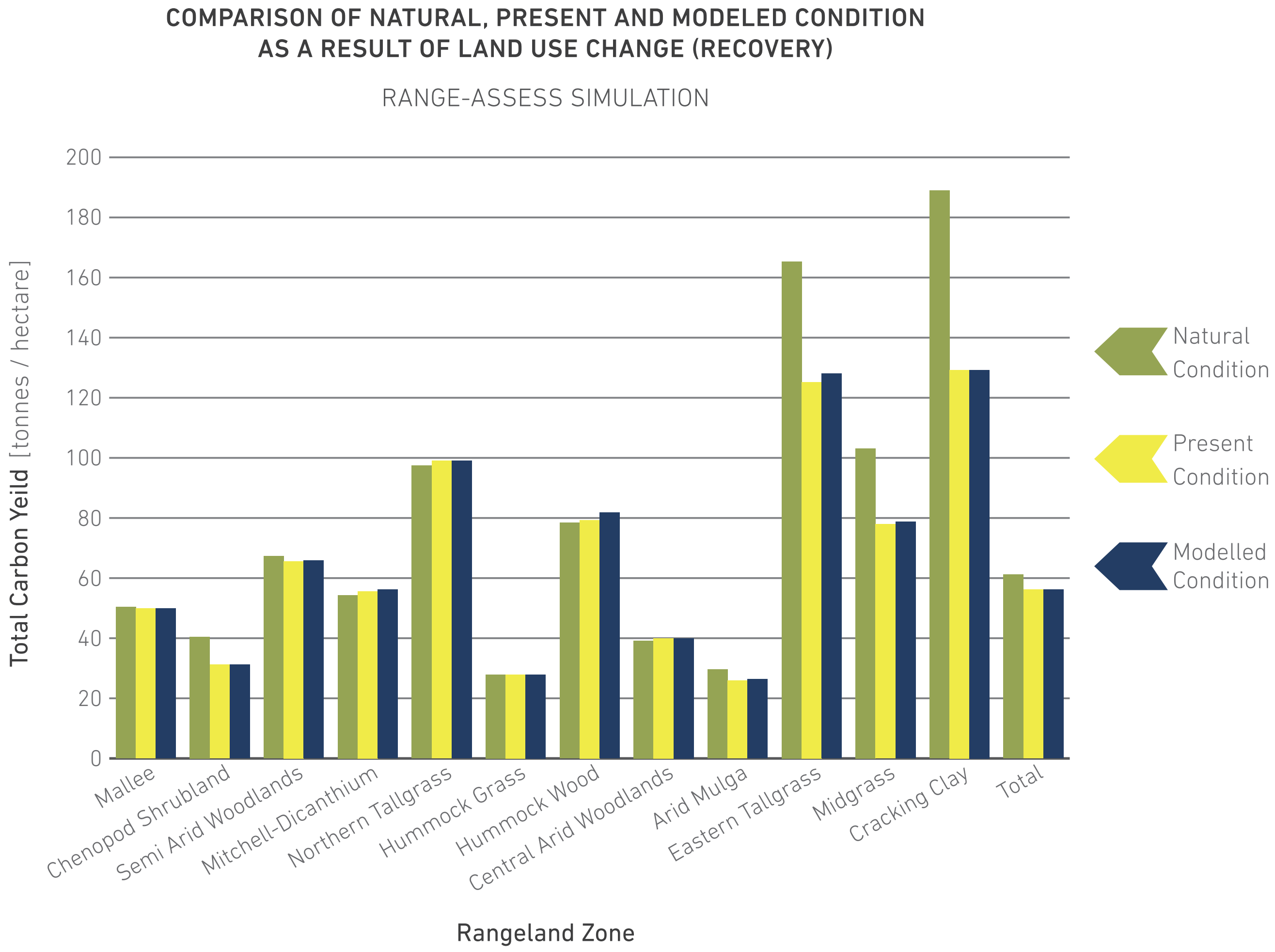


Figure 5.13 Results of the RangeASSESS simulation comparing natural condition with present condition and modeled condition, as a result of land use change (recovery).

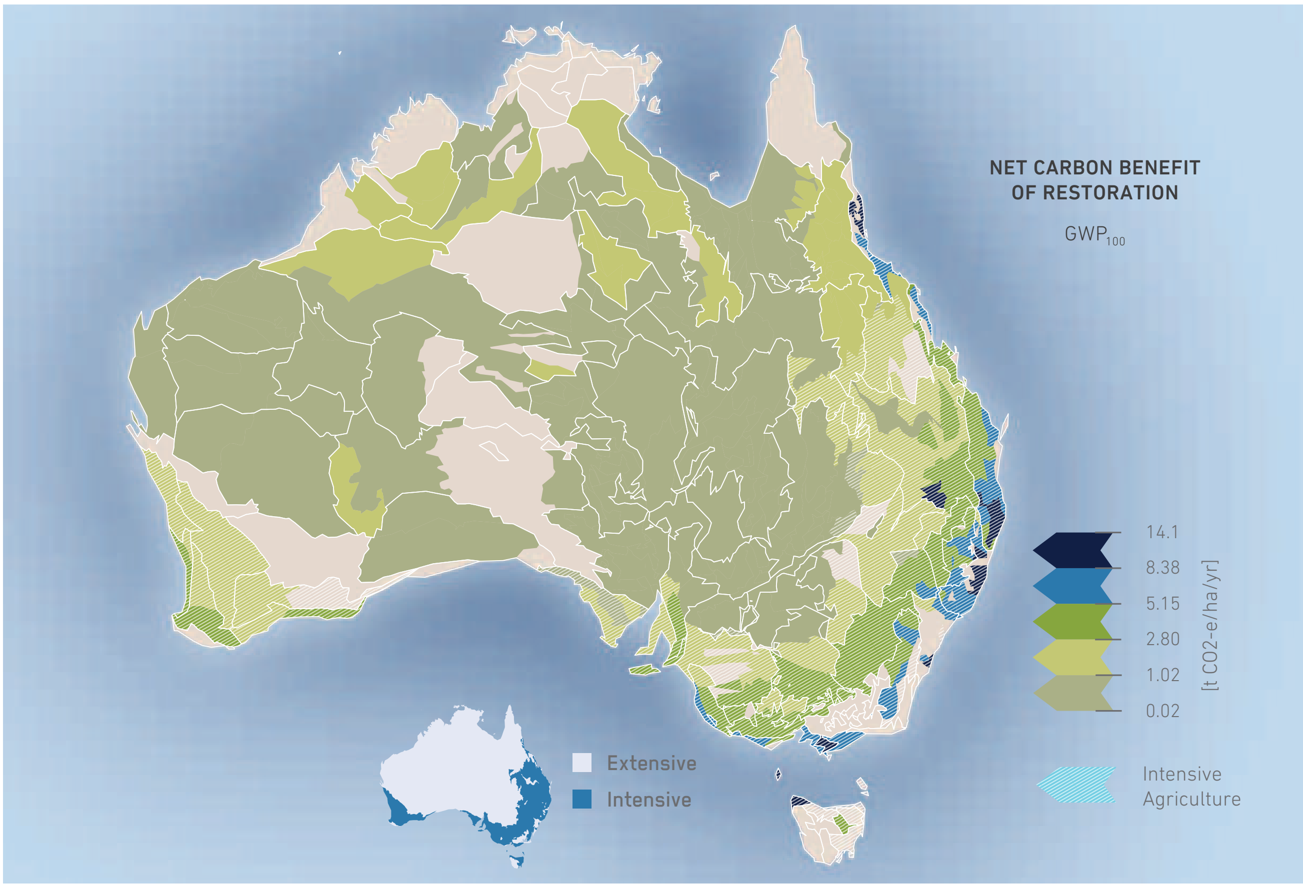


Figure 5.14 Net carbon benefit of restoration (t CO_2-e/ha/yr) in 300 IBRA sub-bioregions when agricultural emissions are measured at GWP_{100}.

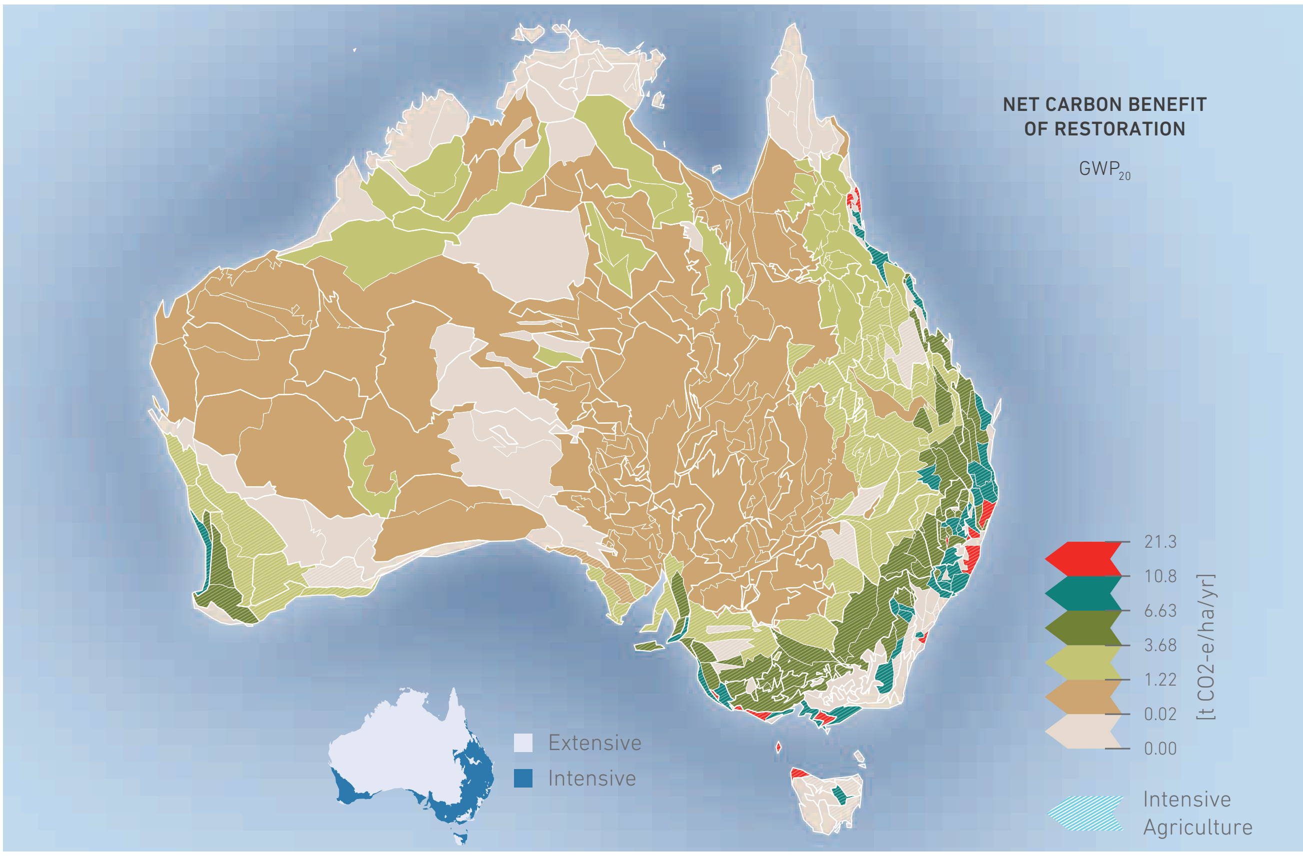


Figure 5.15 Net carbon benefit of restoration (t CO_2-e/ha/yr) in 300 IBRA sub-bioregions when agricultural emissions are measured at GWP_{20}.

components were summed to achieve the total. The multiple runs of RangeASSESS were averaged and compiled into a dataset. These are presented in ***Figure* 5.13**. The eastern tall grass and cracking clay rangeland zones show relatively large declines between their respective natural states and present conditions. Although the difference between present condition and modeled condition are relatively small, the comparatively large area of these rangeland zones result in significant carbon stock changes at a continental scale.

5.4.3 Area to be restored for net zero-emissions

Average per-hectare emissions and sequestration potentials (SP) across all 300 IBRA sub-regions considered here show statistically significant positive correlations with rainfall (α=0.05; ***Figs.* 5.6, 5.9, 5.10**). This reflects rainfall as a primary driver of both of the type of agricultural industries supported and hence their greenhouse intensity, and of the relative potential for woodland or forest growth in each geographical area. The sum of emissions (t CO_2-e/ha/yr) and sequestration (t CO_2/ha/yr) gives the net carbon benefit (NCB) of conversion for an average cleared hectare in each IBRA sub-region (***Eqn* 2, *Part* 5.3.4**).

The net carbon benefit of a change in land use from current use to carbon sequestration is useful only as a step towards defining the area of land that would need to be restored to produce a net-zero land use emissions outcome. As NCB represents the sum of average business-as-usual emissions and sequestration potential per hectare for each sub-region, the distribution of areas with high NCB follows closely that of its component parts (***Fig.* 5.14, 5.15**).

A summary of average NCB of conversion from current agricultural use to carbon sequestration, which at GWP_{100} fall in the range 0.779 – 14.155 t CO_2-e/ha/yr in the intensive zone and up to 2.281 t CO_2-e/ha/yr in the extensive zone, is presented in ***Table* 5.8**.

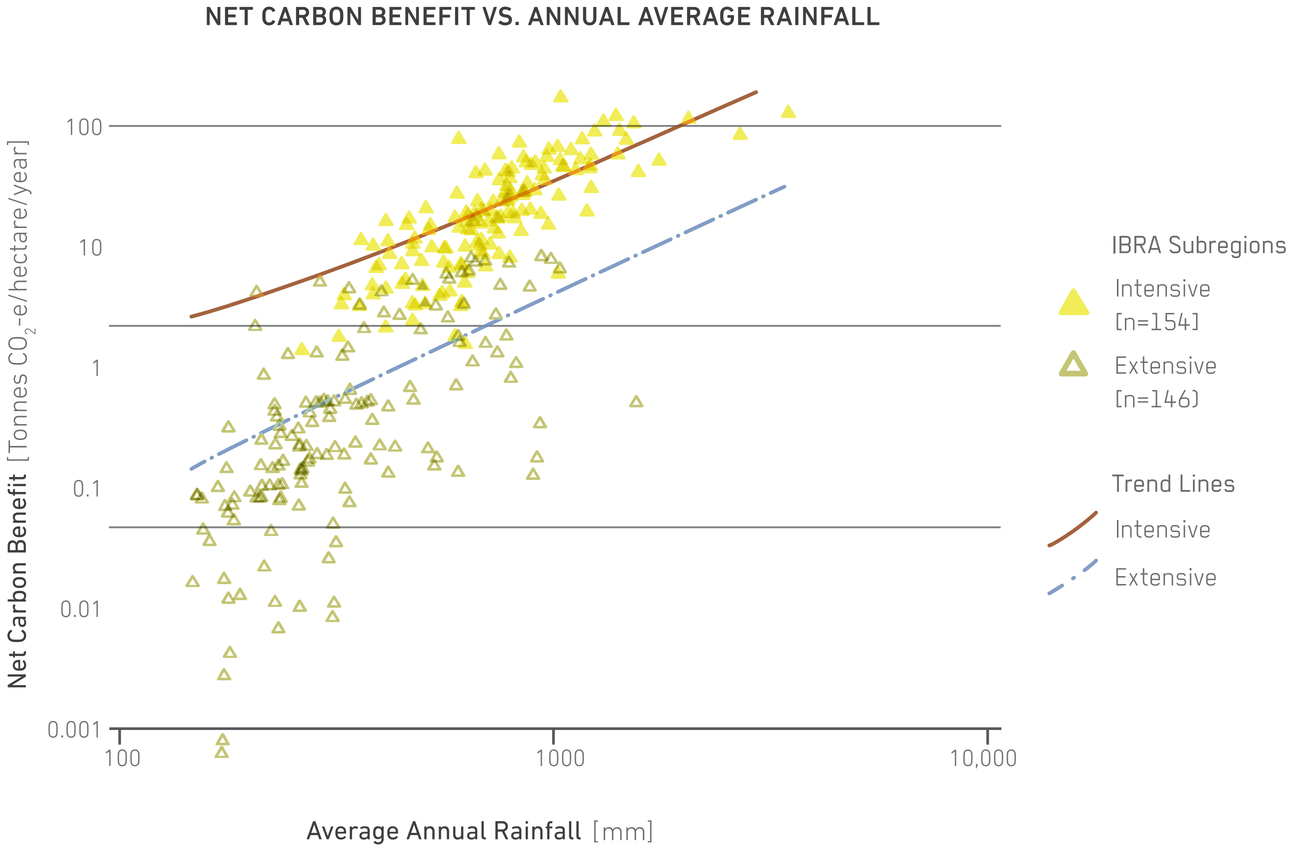
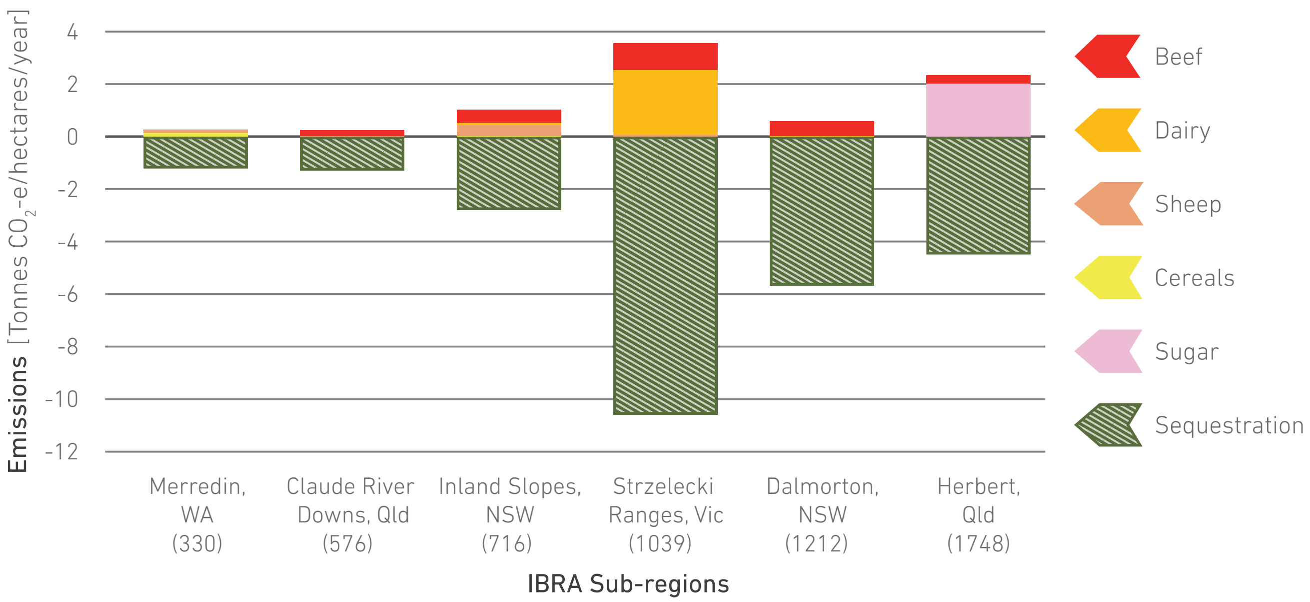


Figure 5.16 Mean annual net carbon benefit (t CO_2-e/ha/yr) associated with a change from current land use to carbon forestry on cleared land, against average annual rainfall (AAR; mm), in intensive (n=154) and extensive zones (n=146).

ANNUAL EMISSIONS BY SOURCE AND SEQUESTRATION POTENTIAL

(a) AT GWP$_{100}$



(b) AT GWP$_{20}$

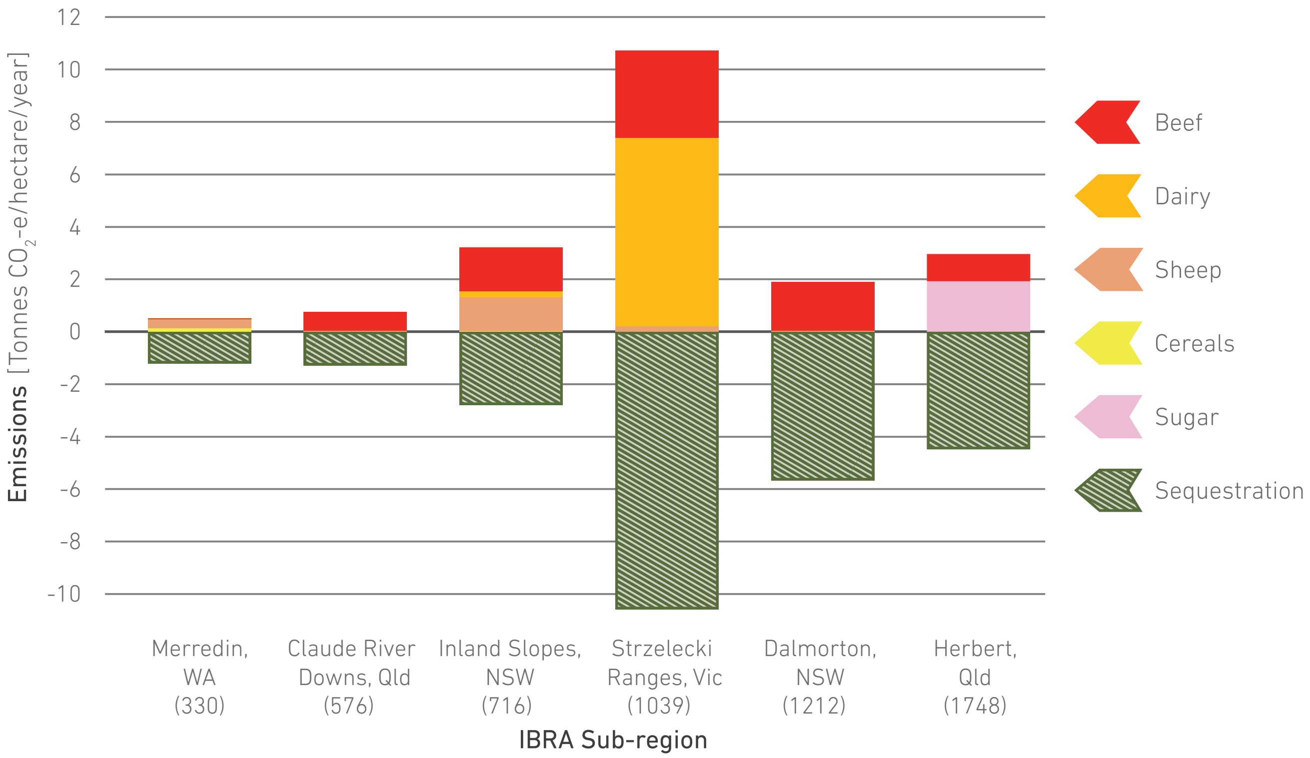


Figure 5.17 Annual emissions by source at GWP$_{100}$ (a) and GWP$_{20}$ (b) and sequestration potential (t CO$_2$-e/ha/yr) of a representative cleared hectare in each of a sample of IBRA sub-regions. Numbers in parentheses are average annual rainfall (mm).

Table 5.8 Quartile and median measures of net carbon benefit for intensive and extensive zones.

Quartile	Emissions [t CO_2-e/ha/yr]			
	Intensive		Extensive	
	GWP_{100}	GWP_{20}	GWP_{100}	GWP_{20}
Q1	2.345	3.189	0.159	0.187
Median	3.571	4.936	0.273	0.411
Q3	5.875	7.421	0.714	0.795

In the intensive zone factors other than rainfall influence strongly the distribution of emissions. This is likely driven by a combination of physical, social and economic factors: very high emissions activities such as dairying are more reliant on high rainfall spread throughout the year, especially for consistent pasture growth, as well as on proximity to markets, access to irrigation water and other social factors to maintain high productivity. Such activities may also depend on high nutrient levels, often from fertilisers, and other inputs. Their distribution is therefore highly variable, as are the heavy greenhouse emissions from these activities. The relationship of rainfall with sequestration potential is purely biophysical, so shows a stronger correlation. These differences are reflected in lower r^2 value for AAR vs. emissions than for AAR vs. sequestration in the intensive zone (***Table 5.5***).

Conversely, rainfall is a better predictor of emissions than of SP in the extensive zone. The extensive agricultural zone extends from the south coast to the far north, including both the very dry interior and the monsoonal tropics. Industries with a very strong emissions signature are largely absent from these areas and animal numbers are predominantly driven by rain-fed pasture growth. Average annual rainfall represents a total, and does not reflect the extreme seasonality of rainfall affecting especially the north, and is therefore a relatively poor predictor of extensive zone SP. This contrast is picked up in regression analysis, which shows a moderately high r^2 value for AAR vs. emissions but low correlation between AAR and sequestration (***Table 5.5***).

These effects are reflected in the response of mean annual NCB to variability in AAR. The mean annual NCB associated with the conversion of a hectare of cleared land from current use to carbon sequestration shows a significant, strong positive correlation with AAR in the intensive zone but weak to moderate association in the extensive zone. Rainfall explains approximately 62% of NCB in areas supporting intensive agriculture, but only around 42% of NCB variability in the extensive zone (***Table 4.2, Fig. 5.16***).

At GWP_{100}, annual sequestration potential exceeds total annual emissions in each of the six sample sub-regions, and this pattern is largely reflected throughout the intensive zone (***Fig. 5.16 a***). This result reflects the potential in the vast majority of sub-regions for landscape carbon capture to balance business-as-usual emissions from our suite of agricultural activities, albeit with significant change to land use patterns. Among these sample sub-regions, emissions exceed sequestration potential per hectare only in the Strzelecki Ranges (SEH04), where dairying is prominent. This is the case only under GWP_{20}, and is due to the strong warming signature of methane and the strong emissions per hectare of the dairy industry (***Fig. 5.17b***). Carbon dioxide sequestered is represented as a negative emission in ***Fig. 5.17a – b***.

The objective of this report is to present a net zero emissions outcome for land use. The scenarios described below illustrate a pathway to net zero agricultural emissions by balancing current emissions with sequestration in living vegetation. Following the logic of ***Eqn. (2)***, the ratio of emissions to net carbon benefit (emissions + sequestration) is our measure of the proportion of land to be revegetated in each sub-region to arrive at a new scenario whereby sequestration somewhat exceeds emissions on an annual basis over an 87-year period. This proportion is shown for our six example sub-regions in ***Figure 5.18***.

5.4.4 Local Value of Agricultural Production

High-value sub-regions of the intensive agricultural zone show similar spatial distribution to areas producing high levels of greenhouse emissions (***Fig. 5.19***). The maximum average LVAP was $1580 per hectare of cleared land in western Victoria's southern coastal plain, but more than 66% of intensively-farmed sub-regions produce on average less than $300/ha/yr. This includes much of Australia's dryland cropping. In the extensive zone, where agriculture is largely limited to livestock grazing on native or mixed

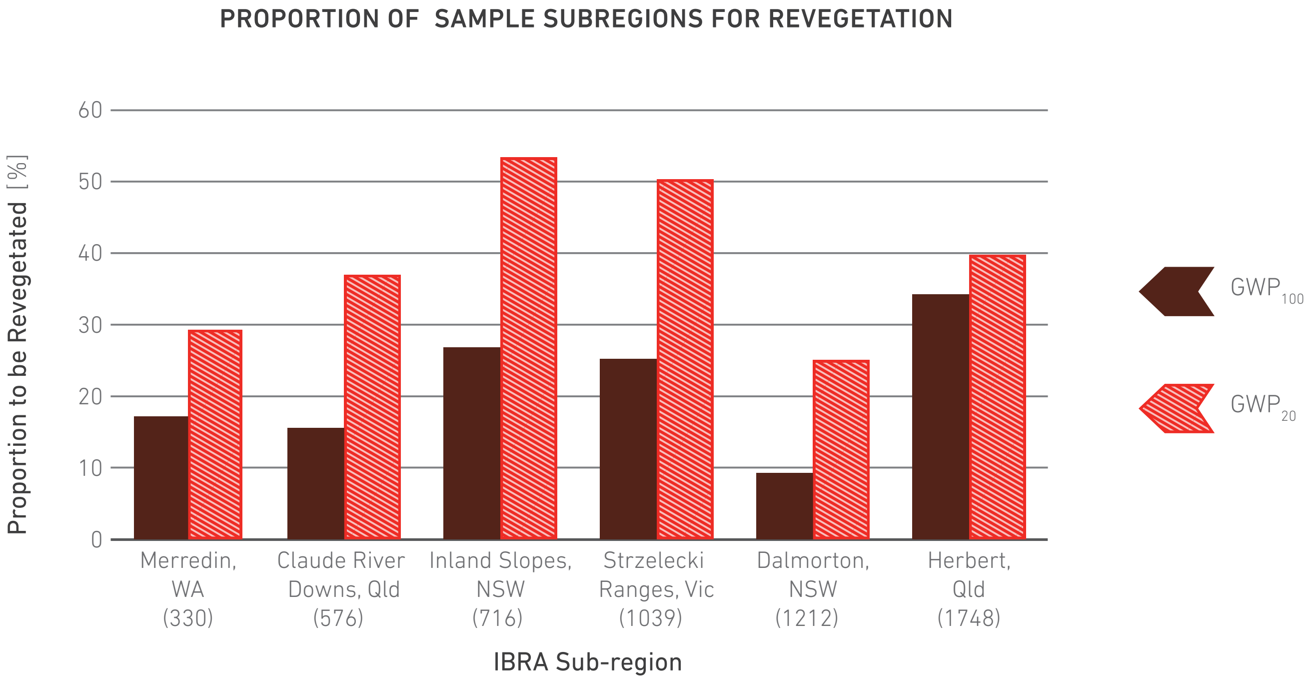


Figure 5.18 Proportion (%) of six sample IBRA sub-regions to be revegetated to reduce and offset emissions under GWP_{100} and GWP_{20}. Numbers in parentheses are average annual rainfall (mm).

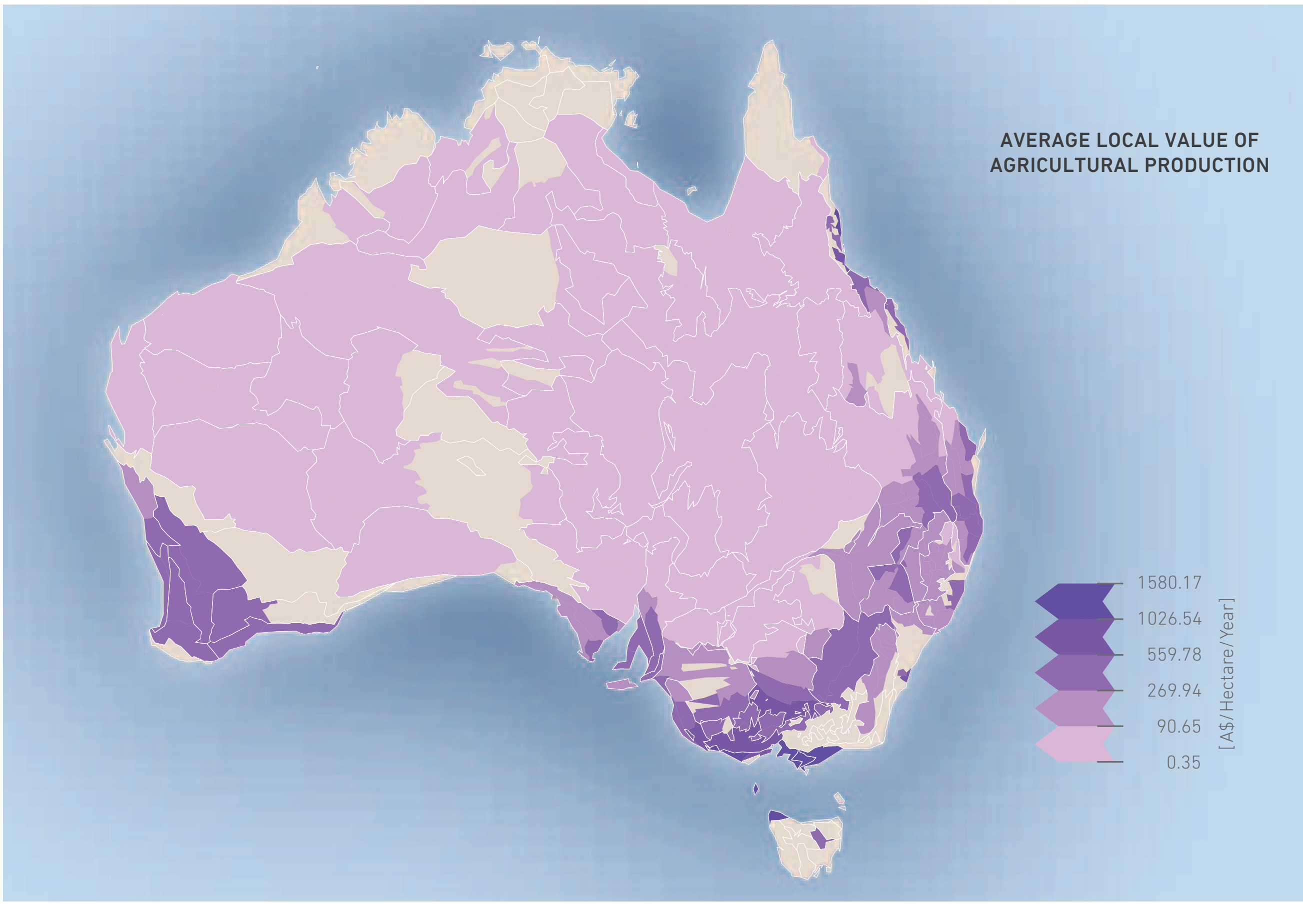


Figure 5.19 Mean local value of agricultural production on cleared or heavily modified land in 300 agriculturally productive IBRA sub-regions.

LOCAL VALUE OF AGRICULTURAL PRODUCTION VS. ANNUAL AVERAGE RAINFALL

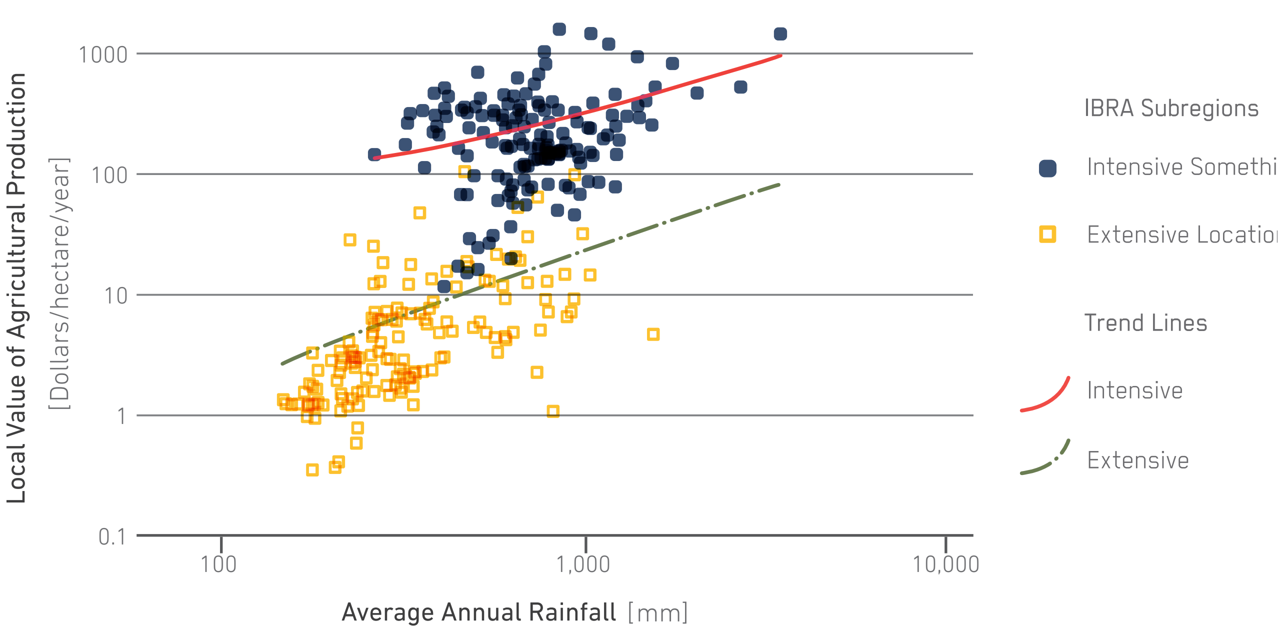


Figure 5.20 Local Value of Agricultural Production (LVAP; $/ha/yr) on cleared land against Average Annual Rainfall (AAR) [mm] in intensive (n=154) and extensive zones (n=146).

LOCAL VALUE OF AGRICULTURAL PRODUCTION AND EMISSIONS

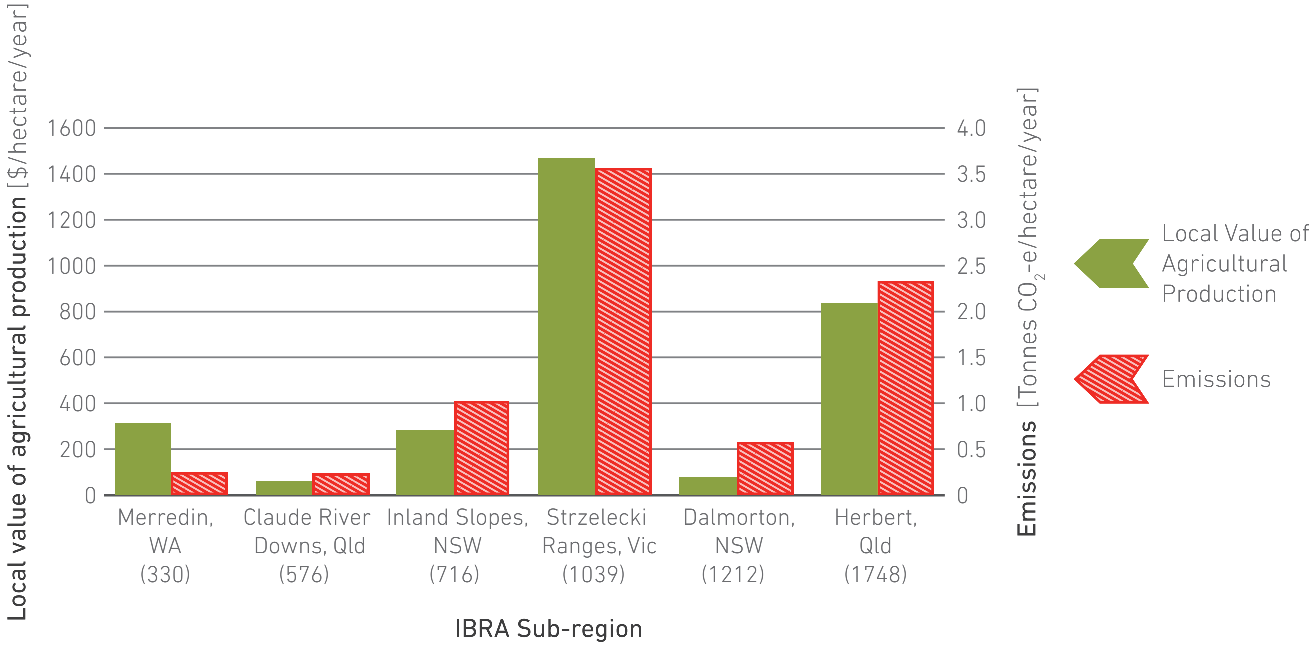


Figure 5.21 Local Value of Agricultural production (LVAP) [$/ha/yr] and emissions (t CO_2-e/ha/yr at GWP_{100}) for six sample IBRA sub-regions. Numbers in parentheses are average annual rainfall (mm).

pastures, lower animal densities as well as social and economic factors result in far lower LVAP per hectare. Economic productivity in the extensive zone ranges from \$0.35—\$104/ha/yr but 92% of sub-regions return less than \$20/ha/yr.

Drivers other than rainfall clearly influence the annual farm-gate production value of a hectare of land in IBRA sub-regions, and rainfall is relatively less influential than many other factors in driving the productive value of land. Among these factors are topography, land use history, soil type, distance from markets and transport hubs, and competing land uses. Local Value of Agricultural Production is weakly associated with AAR in the intensive zone and somewhat more closely correlated in the extensive zone (***Table* 5.5**, ***Fig.* 5.20**). The r^2 values from analysis suggest that rainfall explains only around 7% of variability in LVAP per hectare in the intensive zone but 40% in the extensive zone. Much of the variability in farm-gate value of production is hidden from this analysis because it occurs at spatial scales far finer than IBRA sub-regions. Nevertheless at the scale of this study, LVAP is a useful measure of per-hectare opportunity cost of land use change to carbon sequestration. A summary of LVAP is presented in ***Table* 5.9**.

Table 5.9 Quartile and median measures of Local Value of Agricultural Production for intensive and extensive zones.

Local Value of Agricultural Production [\$/ha/yr]		
Quartile	**Intensive**	**Extensive**
Q1	125.00	1.75
Median	193.25	3.35
Q3	336.69	7.55

An estimate of the local value of agricultural production per hectare per year is given for our six example sub-regions in ***Figure* 5.21**, where emissions at GWP_{100} are repeated for comparison.

5.5 Land use scenarios

Land use is the only sector of the economy that can act as a carbon sink. The following scenarios are designed such that carbon dioxide is withdrawn from the atmosphere quickly enough to balance anthropogenic additions of greenhouse gases from agricultural sources to the atmosphere, and these emissions are also reduced. Scenarios 1 and 2 present pathways to and beyond zero net annual emissions from land use activities in each of the 300 IBRA sub-bioregions where vegetation has been cleared or modified by grazing and where agriculture, defined here as dairy, beef and sheep grazing, and cereal and sugar cropping, was present in 2006 according to the ABS agricultural census taken in that year. Fundamental to each scenario is the active or passive revegetation of a proportion of the cleared land in each IBRA sub-region, and hence the biosequestration of atmospheric CO_2 in growing vegetation, plant debris and soils.

For this exercise we revert to standard UNFCCC accounting as used by the IPCC and Australia's National Inventory Report. Though not comprehensive with regard to agricultural sources of greenhouse emissions, these standards are widely accepted and easily recognisable. Scenario 1 uses 100-year global warming potential (GWP_{100}), while scenario 2 is based on twenty-year accounting (GWP_{20}). The basis for most greenhouse reporting is GWP_{100}, but GWP_{20} better captures both the greenhouse potency of methane in its relatively short atmospheric lifetime, and the timeframe available to humankind in which to make serious cuts to emissions.

These scenarios do not include emissions from Land Use, Land Use Change and Forestry (LULUCF) aspects of agriculture, including those from deforestation for pasture or cropping and from grassland following deforestation (***Part* 3.1**). This means that the zero emissions scenarios presented below assume a cessation of clearing for agriculture. Nor are the large emissions from native forest logging (***Part* 3.3**) considered here.

We have made assumptions related to emissions per hectare of some activities which are likely to understate the reality. For example, we have assumed a low level of nitrogen fertiliser application to dairy pasture, and none to that for beef, when in fact large quantities are often applied especially to dairy pasture. We have also assumed low percentages of fertiliser nitrogen emitted as nitrous oxide for sugar crops (***Table*** *5.3*).

Our modelling assumes that the proportion of cleared land in each IBRA sub-region designated for revegetation will be completely removed from productive use other than carbon sequestration. Where the area of land available for grazing is reduced, the number of grazing animals is reduced in the same proportion. Emissions reductions resulting from the reduced total number of beasts are additional to carbon sequestered in growing vegetation, as per Eqn. 1. This allows our scenarios to go beyond simply offsetting BAU sub-regional emissions and theoretically reach a negative emissions state for our suite of activities in each geographical area and subject to the conditions in the previous paragraph. This is crucial for a number of reasons:

- Revegetation can at best replace carbon previously emitted from the landscape when vegetation was cleared
- Merely balancing BAU emissions without reducing them does not achieve a net negative land use emissions outcome
- Ongoing reduction in atmospheric greenhouse gas concentrations are necessary to increase humanity's chance of avoiding climate tipping points and reduce the current incidence and risk of extreme weather events
- Other sectors of the economy continue to emit large amounts of greenhouse gases, and though these scenarios are not designed to offset emissions from other sectors, the land use sector is the only one that theoretically has the potential to do so

We recognise that the proportion proposed for revegetation is in some cases unfeasibly large if it means taking currently productive land out of production. But in practice this will not always be true. In some sub-regions, there will be a large amount of cleared land that is not agriculturally productive, and as such revegetation will not impose any financial opportunity cost, .

In addition, enhanced carbon management in farm forestry may sequester far more carbon than is reflected in our modelling, which relied on mixed environmental plantings with minimal subsequent management. This would reduce the area of land required, and hence also the opportunity cost. Independent of payment for sequestered carbon, farm forestry could in some cases add an income line to rural businesses. Indeed such opportunities for landholders would be further enhanced if native forests were properly valued and government subsidies were removed from current logging operations (***Part*** *6.3*).

In most cases, less productive land will be a more attractive proposition for revegetation, and often this will be land currently grazed and not cropped. Cropped land is generally less likely to be revegetated because opportunity costs will be higher. As other authors have pointed out, large areas of Australia's rangelands could potentially be rehabilitated at very low opportunity cost per hectare.

Steeper, heavily-cleared but sparsely – or seldom – grazed hillsides are an example of areas that may be amenable to revegetation at low opportunity cost to landholders. Land at risk of salt may also be able to be revegetated in sympathy with current uses. Such areas mostly occur in the intensive zone and are quantified in ***Part 5.6.***

Australia's cultivated and rangeland soils have lost much of their carbon since they were cleared of vegetation. Given that it is neither possible nor desirable to revegetate more than a minor proportion of cleared agricultural land, at least in the intensive zone where sequestration potentials are highest, total carbon re-sequestered in landscapes would always be small in comparison to total historical emissions. Nevertheless, FullCAM modelling shows an increase in soil carbon over long periods while forest or woodland vegetation cover is maintained, and soil carbon may approach pre-clearance levels over a timescale of centuries. Other studies have concluded that revegetation is the best way to halt soil carbon decline and increase landscape carbon stocks on degraded land (e.g.[41, 42, 43]).

In these scenarios, the capacity of agricultural soils to sequester atmospheric carbon dioxide and hence offset emissions from other sectors is not considered; see ***Part 4.1*** for analysis of this. Nor are other methods of reducing agricultural emissions included in our scenarios, though these offer some potential (***Part 6.2***). The total emissions reduction considered feasible after a review of the abundant literature available falls well short of that required to make the sector a net GHG sink.

The agriculture sector itself, while it remains a large greenhouse gas emitter, can by definition not function as a sink for other sectors. This is because relatively minor

Table 5.10 Outcomes of restoration in Scenario 1, based on emissions profiling at GWP_{100}.

Zone	Restored [%]	Restored [Mha]	Total sequestration [Mt CO_2/yr]	Avoided emissions [Mt CO_2-e/yr]	New total emissions [Mt CO_2-e/yr]	Net carbon benefit [Mt CO_2-e/yr]	Total cost [$M/yr]
Intensive	19	16.2	36.3	11.2	36.3	47.6	5,058
Extensive	12	39.3	9.3	2.0	9.3	11.4	335
Total	13	55.5	45.6	13.2	45.6	59.0	5,393

reductions in the rate of some emissions, such as from land clearing, soil or enteric fermentation, do not remove from the ledger other emissions, for example from the burning of coal. To perform such a function, emissions from land use would have to be in equilibrium with landscape sequestration, then further sequestration possibilities would need to be found. The following scenarios look toward such an equilibrium.

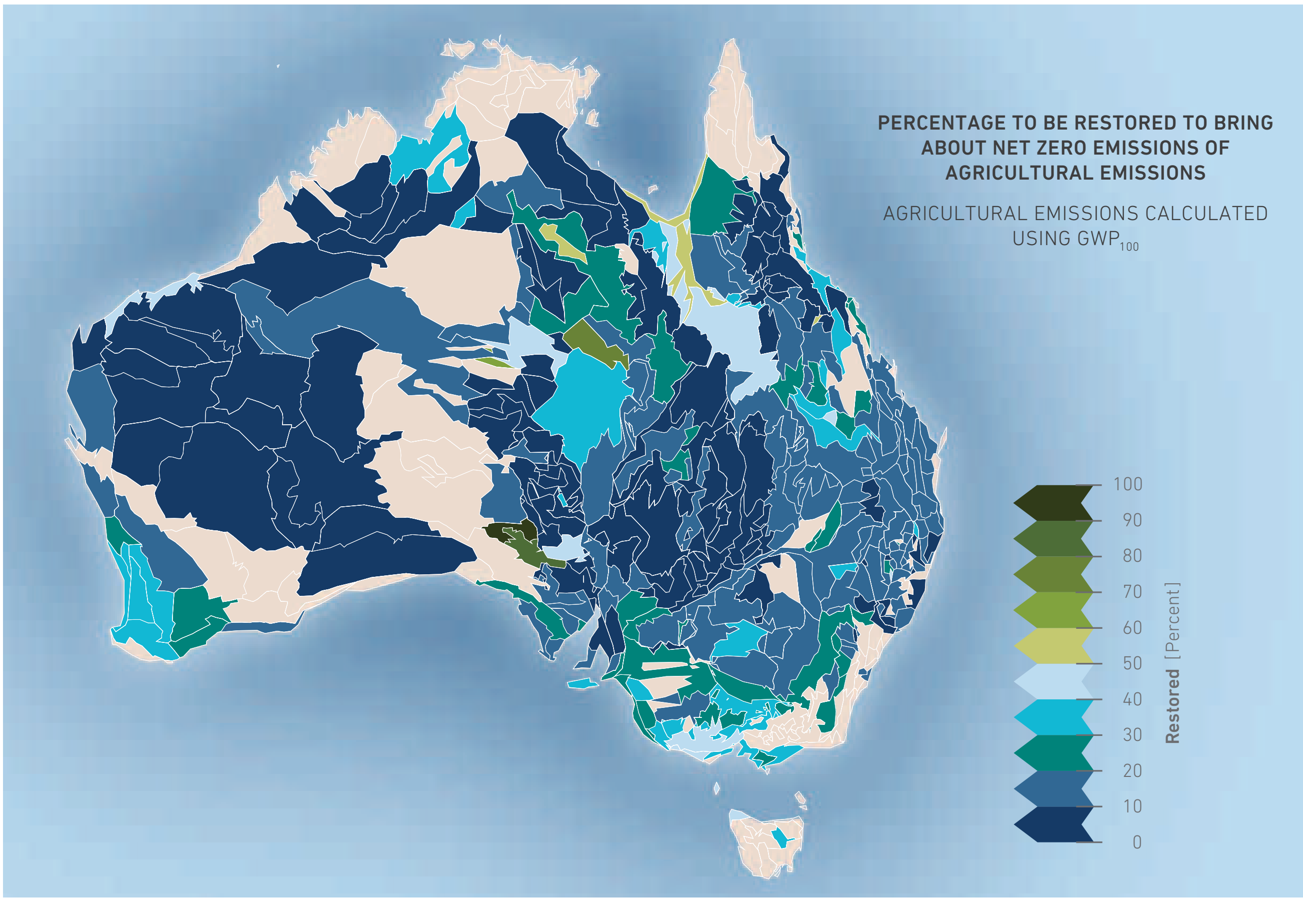


Figure 5.22 Percentage of 300 agriculturally-active IBRA sub-bioregions to be restored to bring about net zero emissions from agriculture, based on emissions profiling at GWP_{100}.

Table 5.11 Outcomes of restoration in Scenario 2, based on emissions profiling at GWP_{20}.

Zone	Restored (%)	Restored (Mha)	Total sequestration (Mt CO_2/yr)	Avoided emissions (Mt CO_2-e/yr)	New total emissions (Mt CO_2-e/yr)	Net carbon benefit (Mt CO_2-e/yr)	Total cost ($M/yr)
Intensive	39	32.8	75.3	63.1	75.3	138.4	9,564
Extensive	25	82.1	23.6	13.1	23.6	36.8	669
Total	28	114.9	98.9	76.2	98.9	175.2	10,233

5.5.1 Net zero agricultural emissions at GWP_{100}

Annual business-as-usual emissions (GWP_{100}) and sequestration potential per hectare of cleared land are mapped for all sub-bioregions in ***Figures 5.6, 5.9 & 5.10*** and are shown for a sample of six IBRA sub-bioregions in ***Figures 5.8*** and ***5.16***. Net carbon benefit (NCB) of restoration is mapped in ***Fig. 5.14***. The restoration effort required to balance emissions from land use activities under 100-year accounting is given in ***Fig. 5.22***. The benefits in terms of avoided carbon emissions and sequestration, and costs in LVAP assume that land in each sub-bioregion is retired from its current use in the same proportion as recommended for the sub-region as a whole, such that high-emitting and low-emitting activities are treated equally.

Overall, 13% of Australia's cleared and heavily modified agricultural landscapes would need to be restored to woodland, shrubland or forest to offset emissions from our suite of agricultural industries (***Table 5.10***). Nationwide this intervention would result in the restoration of approximately 55.6 million hectares (Mha), the equivalent of a square somewhat less than 750 km on each side. A national NCB of almost 60 Mt CO_2-e/yr would accrue, around 78% of this from sequestration of atmospheric carbon dioxide and the rest resulting from emissions avoided by removing current activities from land restored. This amount compares to the 2006-2010 total as recorded in the national inventory for agriculture of 85.3 Mt CO_2-e/yr and 545 Mt CO_2-e/yr for the whole economy. These outcomes are explored in more detail below for the intensive and extensive zones.

5.5.1.1 Intensive cropping and grazing

Restoration sufficient to reduce and offset ongoing agricultural emissions from our suite of agricultural industries requires the revegetation of a grand mean of 19% of cleared land per bioregion across all 156 intensive zone sub-bioregions (***Table 5.10***). Less than 20% of cleared land is restored in 100 intensive zone sub-regions (***Fig. 5.21***). Emissions avoided as a result of this choice are around 24% of total business-as-usual emissions from our suite of intensive agricultural activities. The remaining emissions are offset by landscape carbon accumulation in areas restored to woodland or forest. The opportunity cost of this choice in terms of local value of agricultural production (LVAP) foregone is more than $5b per year.

5.5.1.2 Extensive grazing

Restoration sufficient to reduce and offset ongoing agricultural emissions from rangeland grazing requires the revegetation of a grand mean of 12% of cleared or heavily modified grazing land across the extensive zone. Less than 25% of such land is restored in 112 of the 144 extensive zone sub-regions (***Fig. 5.22***). Emissions avoided by withdrawing animal agriculture to the same extent are around 18% of the total from BAU in the extensive zone, and the remainder of the NCB results from increased levels of landscape carbon. The financial opportunity cost of this choice is $335m/yr.

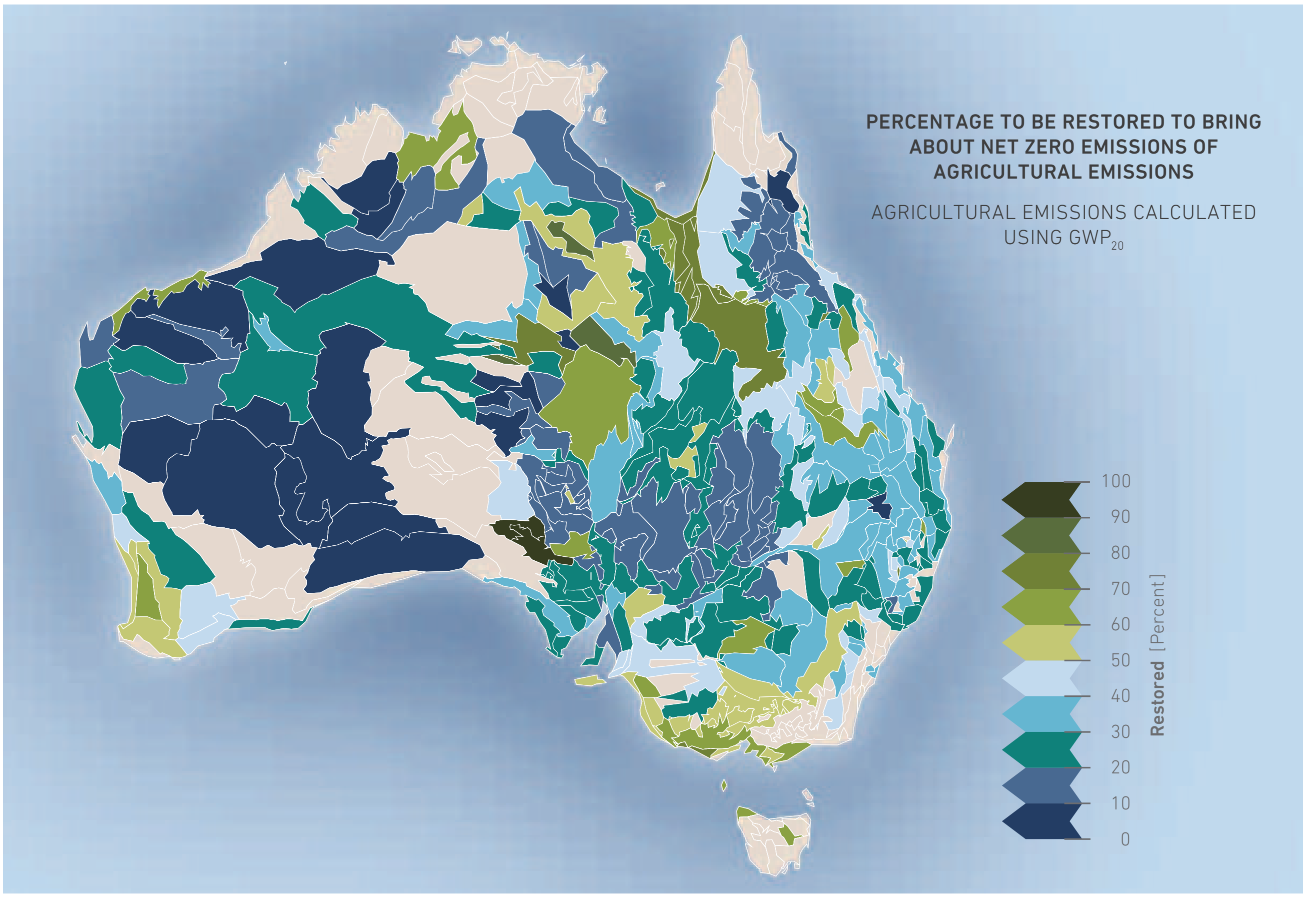


Fig. 5.23 Percentage of 300 agriculturally-active IBRA sub-bioregions to be restored to bring about net zero emissions from agriculture, based on emissions profiling at GWP_{20}.

5.5.2 Net zero agricultural emissions at GWP_{20}

Average annual SP per hectare of cleared land is mapped for all sub-bioregions in ***Figures 5.9 & 5.10*** and emissions and SP are shown for a sample of six IBRA sub-bioregions in ***Figures 5.8 & 5.16***. Net carbon benefit (NCB) of restoration at GWP_{20} is mapped in ***Figure 5.23***. The benefits in terms of avoided carbon emissions and sequestration and costs in LVAP assume that land in each sub-bioregion is retired from its current use in the same proportion as recommended for the sub-region as a whole, such that high-emitting and low-emitting activities are treated equally.

Overall, 28% of Australia's cleared and heavily modified agricultural landscapes would need to be restored to woodland, shrubland or forest to offset emissions from our suite of agricultural industries calculated at GWP_{20} (***Table 5.11***). This intervention would result in the restoration of approximately 115 million hectares, the equivalent of a square 1072 km on each side. This would bring a nationwide net carbon benefit of 175 Mt CO_2-e/yr, around 56% of this from sequestration of atmospheric carbon dioxide and the rest resulting from emissions avoided by removing current activities from land restored. This amount compares to the 2006-10 average as recorded in the national inventory for agriculture of 247 Mt CO_2-e/yr and 779 Mt CO_2-e/yr for the whole economy at GWP_{20}. These outcomes are explored in more detail below for the intensive and extensive zones.

The proportion of cleared land to be revegetated is somewhat greater than under GWP_{100}. This reflects both the great potential of methane (CH_4) to trap heat, and the great volume of methane emissions from agriculture.

5.5.2.1 Intensive cropping and grazing

Restoration sufficient to reduce and offset ongoing agricultural emissions (GWP_{20}) from our suite of agricultural industries requires the revegetation of a grand mean of 39% of cleared land across all intensive zone sub-bioregions (***Table 5.11***). Less than 25% of cleared land is restored in only 19 of the 156 intensive zone sub-regions (***Fig. 5.23***). Emissions avoided as a result of this choice are around 46% of total business-as-usual emissions from our suite of intensive agricultural activities. The remaining emissions are offset by landscape carbon accumulation in areas restored to woodland or forest. The opportunity cost of this choice in terms of local value of agricultural production (LVAP) foregone is about $9.6b per year.

5.5.2.2 Extensive grazing

Restoration sufficient to reduce and offset ongoing agricultural emissions from rangeland grazing requires the revegetation of a grand mean of 25% of cleared or heavily modified grazing land across all extensive zone sub-bioregions. Less than 25% of cleared land is restored in 79 of the 144 extensive zone sub-regions (***Fig. 5.23***). Emissions avoided by withdrawing animal agriculture to the same extent are around 36% of the total from BAU in the extensive zone, and the remainder of the net carbon benefit results from increased levels of landscape carbon. The financial opportunity cost of this choice is $669M/yr.

5.6 Spatial mapping of saline and steep land

Some land that is at high risk of salinisation is likely to be lost from production in the absence of effective intervention. Steep land is also relatively less productive, because it is neither cropped nor frequented by grazing animals. For these reasons such land may be available for revegetation at minimal opportunity cost and with potential for double benefits.

5.6.1 Salinity

At the root of the salinity problem is the changed hydrology of the landscape, itself driven by land use change, usually involving the removal of vegetation. The altered water balance in catchments causes excess water to enter the groundwater hence mobilizing salt that rises to the land surface. Restoration of perennial vegetation in cleared lands can help to reverse rising groundwater levels caused by increased recharge. Australian studies have concluded that as the vegetation intercepts the water, less water percolates to the water table and in due course the water balance is restored (e.g. 46,47).

Revegetation is the most commonly pursued strategy to deal with dryland salinity caused by land use changes. The challenge has always been to identify the regions where it would be most effective to plant trees to address the salinity problem without compromising the agricultural productivity of the land. In this study we focus on determining areas of the IBRA sub-regions that could be prioritised for revegetation with the dual objectives of salinity control and carbon sequestration.

The type of groundwater flow systems (GFS) is important because it provides understanding of both catchment discharge capacity and its response time to change.[46,47,48] Australia's groundwater system has been classified into 3 main types. Local GFS are relatively small (<5km radius) and are quickest to react to increased groundwater recharge. These systems also have rapid response to revegetation. Hence, if we want to view the results of salinity management practices in relatively short time this would be the best scale to target for immediate actions.[47] Local GFS are therefore the only systems considered here.

Intermediate and regional GFS have greater extent and storage capacity and subsequently respond much more slowly to land use changes and management strategies. They require more widespread interventions and major land use changes to have any considerable effect. For simplicity we have excluded multiple flow systems, which often contain more than one aquifer in the same area.

We identify the IBRA sub-regions containing relatively high proportions of land identified as at high risk of salinisation and where catchment-level interventions can deliver quick results because of the presence of local GFS.

5.6.2 Steep slopes

Slope gradient is a primary and crucial variable of grazing distribution of cattle. Various studies have confirmed that animals favour slopes between 0-9% and generally avoid slopes over 10% ($\approx 6^{0}$; e.g.[49, 50, 51, 52]). Such areas are also unsuitable for most crops. Hence we have identified all cleared land of slope ≥10% as having potential for revegetation with minimal opportunity cost.

Steeper slopes also generally indicate groundwater recharge zones, which is a typically favored area for plantation in terms of salinity control as they help to reduce the water table more effectively than when planting in discharge areas (generally slope <3%). The planting of deep rooted, perennial native species in recharge zones associated with pasture or grassland could make a significant difference to long-term salinity risk in these areas.[44, 53]

5.6.3 Data sources and methods

For the purpose of identifying priority revegetation areas the following GIS primary datasets were used. With the exception of IBRA 7 sub regions, all primary datasets were sourced from the Federal government Department of Finance and Deregulation (Australian Government Information Management Office; ***Table* 5.12**).

5.6.4 Area of salt and steep land identified for priority revegetation

Local flow systems were first isolated from the Australian GFS, then the rural cleared land and the high salinity risk areas were clipped to the extent of local GFS and overlaid on each other. This quantified the total area categorised as high salinity risk cleared land on local GFS. These were then allocated to IBRA sub-regions and the proportion of each sub-region for priority attention quantified (***Fig.* 5.24**). Areas of slope ≥10% per IBRA sub-region were quantified directly.

The total area within the intensive agricultural zone and prioritised for revegetation is 7,897,194 ha, or somewhat less than half the area proposed for revegetation in our scenario for net zero agricultural emissions presented in ***Part* 5.5.1**. This area results from the addition of local

Table 5.12 Summary of datasets and their application for spatial mapping of saline and steep land.

Dataset	Application	Reference
Australian Land Use 2010	Identify cleared rural land	
Australian Groundwater Flow Systems	Identify the areas with local flow system	National Land and Water Resources Audit, 2000
Australian Dryland Salinity Assessment Spatial Data	Identify areas at high risk of salinity	
Interim Biogeographic Regionalisation for Australia (IBRA), Version 7.	Report framework	1
	Identify areas of slope ≥10%	

groundwater flow systems declared as at high risk of salinity to those with slope of 10% or more.

We have assumed that these proposed areas will entirely cease any agricultural production and be dedicated to carbon sequestration. In some cases like the Esperance coast in WA, the North coast NSW, the percentage of cleared land proposed for revegetation is large: in these cases more than 50% of the catchment would need to be replanted. While this proportion might seem unfeasibly large, we have aimed to target regions that are likely to undergo large reductions in agricultural production within the coming decades as a result of encroaching salt. This means that revegetation will not impose any long term financial opportunity cost. The six sample sub-regions detailed in ***Part 5.4*** are again presented for comparison of proportion recommended for revegetation on carbon emissions with that recommended on the basis of salt and slope (***Table 5.13***).

In a number of these sample regions, the proportion to be rehabilitated for zero carbon agriculture is less than that which is likely to need rehabilitation to prevent salt encroachment or would cause lower opportunity cost because its slope indicates relatively low productivity. In some cases therefore the implementation of revegetation for carbon sequestration could be a subset of revegetation work.

This study aims only to point out the regions that would be a good starting point for revegetation for the dual purposes of salinity control and carbon sequestration, and that this approach - and indeed others – may permit opportunity costs to be minimised. As catchments differ widely in terms of hydrogeology, rainfall, soil characteristics and other factors, revegetation may not be the best or only approach to deal with the salinity. Further, revegetation lowers water levels locally but would need to be widespread for regional effects.[54] There is a further need to identify the strategic sites within the prioritized areas of the IBRA sub-regions in order to maximize the benefits of revegetation especially in those catchments which have less area to be replanted.[53].

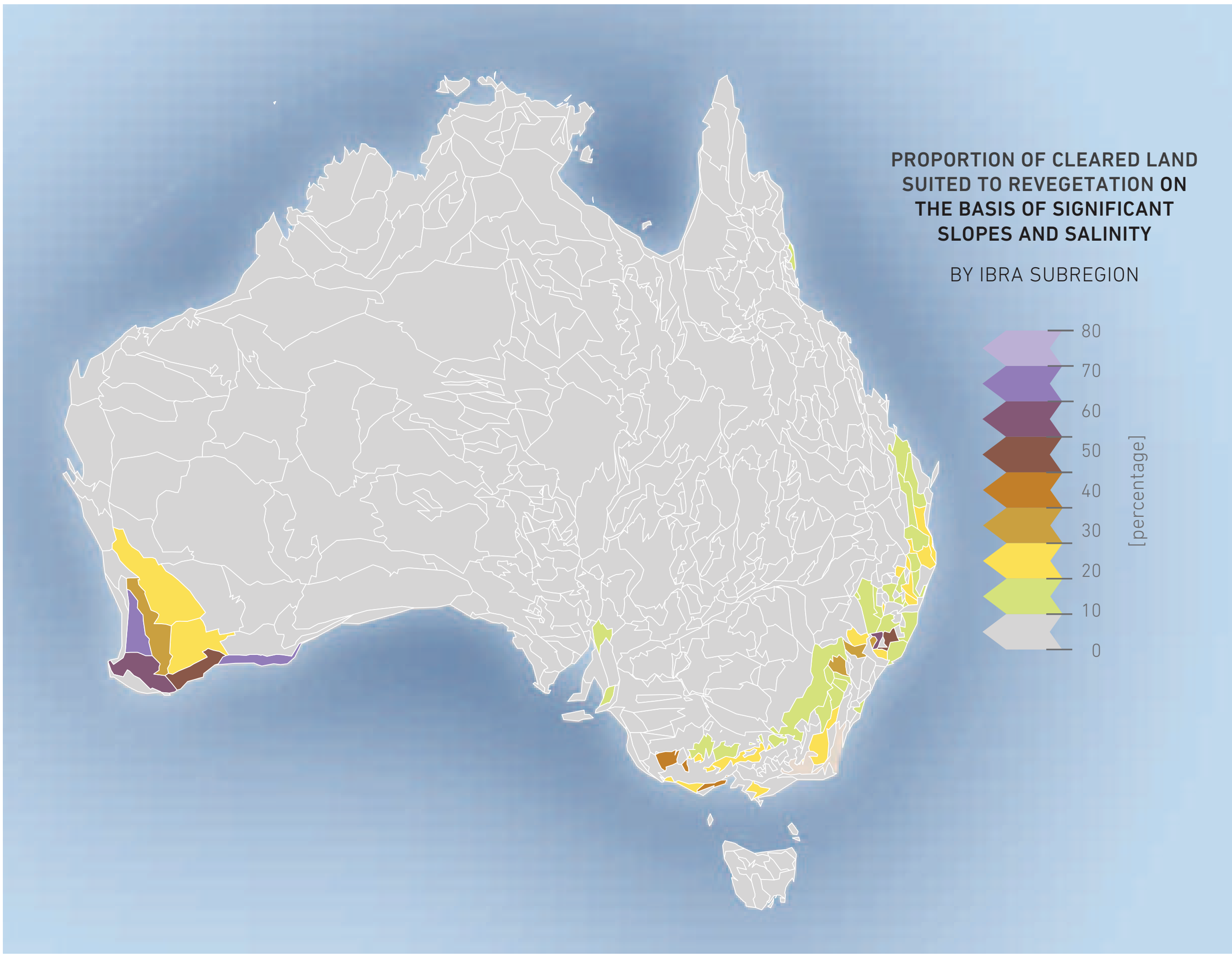


Figure 5.24 Proportion of IBRA sub-regions suitable for revegetation on the basis of high salinity risk and steep slopes.

Table 5.13 Area and proportion of sample IBRA sub-regions recommended for revegetation for carbon, salinity and steep slope.

Sub-region code	AAR [mm]	Sub-region name	Cleared steep slopes		Cleared and at risk of salinity		Total Area for Revegetation (salinity + slope)		Restored for zero carbon outcome
			(ha)	(%)	(ha)	(%)	(ha)	(%)	[%]
AVW01	330	Merredin	419	0	1050919	24	1051338	24	17
BBS12	576	Claude River Downs	4438	0	281	0	4719	0	16
NSS01	716	Inland Slopes	348963	13	82238	3	431200	16	27
SEH04	1039	Strzelecki Ranges	61225	29	306	0	61531	29	25
NNC03	1212	Dalmorton	16888	22	31	0	16919	22	9
WET01	1748	Herbert	6144	6	388	0	6531	7	34

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Part 6:

Climate Change Mitigation

Contents

6 Introduction

This chapter explores climate change mitigation in more detail. We first apply the emissions profiling and sequestration modelling described in ***Parts 5.5 & 5.6*** to a number of actual farms. We use real data on animal numbers, crop types and extents and fertiliser application to model the farms' emissions and hence to calculate the proportion of their cleared land revegetated to give a zero net emissions outcome. We include the farmers' comments on our results.

We integrate current knowledge of available emissions mitigation, for agriculture (***Part 4.2***) and forestry (***Part 4.3***) with the findings from our scenario modelling (***Part 5.6***), to form a roadmap toward zero carbon land use for the Australian continent.

Because active sequestration will be a necessary part of a suite of measures and can provide tangible benefits to rural Australia, we give an assessment of the potential role of short rotation woody crops for biochar production.

Chapter highlights:

- A comprehensive suite of interventions can reduce agricultural emissions from approximately 190 Mt CO_2-e/yr to around 6.2 Mt CO_2-e/yr. This would constitute transformational change.
- Zero carbon forestry is already a reality in some instances, and mainstream operations can be made complementary to reserves set out for carbon sequestration and to protect other values.
- A major expansion of incipient efforts to sequester carbon in farming landscapes, and the development of a carbon plantation / biochar industry offer potential to absorb remaining emissions.

6.1 Farm case studies

We undertook six farm case studies to gauge what proportion of cleared land would need to be revegetated to offset emissions from normal activities on real farms. We also wanted know how our ideas would be received: What stands in the way of implementing a partial revegetation on previously cleared land? Would farmers be interested at all? Had farmers already dedicated land to trees, and if so, why? We learned a lot from the farmers we met, not only those whose properties we profiled, and thank them for their participation.

The farms profiled are representative of a wide range of both locations and rainfall regimes across the intensive zone, and stretch from the Darling Downs to the Victorian Mallee. The farms cover a range of important industries: Dairying, beef and sheep grazing in both irrigated and dry land cropping areas. They also cover a range of farming approaches, including biodynamic, organic, intensive and conventional, and range in size from 45 – 2800ha.

In all cases except one, where data were collected and an interview conducted by telephone, our collaboration with farmers included at least one visit to the farm. Visits included first-hand inspection of farm operations, interviews and data collection. This process was crucial to our understanding of farming generally and of farmers' views on climate. Farmers' comments on our findings — the proportion of cleared land on their holding to be revegetated for a zero-emissions outcome — were obtained during follow-up interviews and/or email exchanges.

The greenhouse profiles below, summarised in ***Table 6.1***, use actual farm data with respect to animal numbers, crop extents and fertiliser use, and other aspects for which information was available, for a one-year snapshot of activities. Farmers were asked to provide data for a typical recent year; most provided information from 2012.

Again the Full Carbon Accounting Model (FullCAM) was used to estimate sequestration potential for each farm. Points for FullCAM modelling were sampled at random within a 1500m radius of the centre of the farm, as identified on Google Earth. Our methods are otherwise identical to those applied in the continental-scale study described in ***Part 5***, with one further exception. Some of the farmers whose properties we profiled had already chosen to revegetate some of their holding. We therefore included all reported tree growth in our inputs to the Greenhouse Accounting Framework calculators, and applied the offset generated to farm emissions. Negative emissions entries represent net emissions from cropping minus sequestration from tree growth. These corrected emissions were used to calculate the proportion of cleared land for revegetation (*Table 6.1*).

Though this analysis proposes revegetation of a part of each of the farms, it is not meant as a set of recommendations or advice to the landholders concerned or any other party. The areas proposed for revegetation may or may not be available or appropriate for carbon sequestration, nor may this be the best use for them even if carbon farming were prioritised and incentivised. This is particularly true where we propose revegetation of a large proportion of the property, such as at Murray Eden. Furthermore, other management options may be available and amenable to the farms in question. These are detailed elsewhere in this report.

Energy use (diesel and electricity) is not considered. Nor could we take account of soil carbon improvements on Winona despite their being scientifically verified.

6.1.1 Belmont

An 1800 ha property near Barham in the NSW Riverina, Belmont produces biodynamic rice, cereals, lamb and wool from 720 ha of irrigated layouts and 400 ha of dry land. In the sample year, Belmont grew 140 ha of rice and 80 ha of wheat, as well as carrying 2500 head of sheep. 140 ha of vetch were grown as a nitrogen supplement and grazed off. Average annual rainfall (AAR) for Barham is approximately 366mm.

Greenhouse emissions from cropping are largely methane and nitrous oxide from crop residue burning , conducted to keep weeds down on this biodynamic farm where

Table 6.1 Summary of findings from studies of six farms representing a range of agricultural activities, farming methods and regions of the intensive agricultural zone.

Farm	IBRA Sub-region	Emissions [t CO_2-e/yr]			Area [ha]	Emissions [CO_2-e/ha/yr]	Sequestration Potential [CO_2-e/ha/yr]	Revegetated [%]
		Animals	Cropping/ trees	Total				
GWP$_{100}$								
Belmont	RIV03	389	-271	118	1760	0.067	7.63	0.9
Dorrigo	NNC04	75	-300	-225	94	-2.394	23.50	-
Murray Eden	RIV03	3612	-39	3573	566	6.313	8.45	42.8
Prestbury	BBS17	642	134	776	1033	0.751	12.98	5.5
Winiam	MDD05	1202	613	1815	2782	0.652	5.85	10.0
Winona	NSS01	591	-109	482	840	0.574	9.48	5.7
GWP$_{20}$								
Belmont	RIV03	1182	-248	934	1760	0.531	7.63	6.5
Dorrigo	NNC04	235	-300	-65	94	-0.693	23.50	-
Murray Eden	RIV03	11400	-63	11337	566	20.030	8.45	70.3
Prestbury	BBS17	2052	129	2181	1033	2.111	12.98	14.0
Winiam	MDD05	1780	631	2411	2782	0.867	5.85	12.9
Winona	NSS01	1767	-111	1656	840	1.971	9.48	17.2

herbicides are off-limits. Nitrous oxide from nitrogen-fixing crops also contributes. Cropping emissions make up about 79 t CO_2-e/yr, or 17% of total emissions net of tree growth when measured at GWP_{100}, with the remainder dominated by enteric fermentation. At GWP_{20}, crop emissions of 102 t CO_2-e/yr make up 8% of total emissions.

Sixty hectares of *Eucalyptus camaldulensis* (river redgum) regrowth on Belmont already sequesters about 350 t CO_2-e/yr. This is sufficient to more than offset the farm's cropping operation, and is comparable to total farm emissions, net of tree planting, when measured at GWP_{100} (468 t CO_2-e/yr). Because environmental plantings and natural regrowth have already vastly improved Belmont's greenhouse position, remaining emissions could be offset with minimal further revegetation of the property (***Table 6.1***).

According to Belmont owner David McConnell, it is a long term aim to maintain the existing level of tree cover while encouraging more areas of regrowth through strategic environmental watering into the future. Mr. McConnell added, "Our commitment to further tree planting has lessened somewhat as a result of some hard economic times associated with drought. The old saying 'you can't be green if you are in the red' comes to mind as the practice of tree planting, fencing etc is quite costly."

6.1.2 Dorrigo Grass-fed Beef

The Dorrigo Grass-fed Beef property runs around 55 head of Angus beef cattle on a holding of 94 ha on the very edge of the Dorrigo plateau and adjoining the Dorrigo National Park (AAR = 2015mm). The farm sells its produce direct into the Coffs Harbour region and some areas of Sydney. No crops are grown at this farm.

Animal emissions amount to about 75 t CO_2-e/yr at GWP_{100} and 235 t CO_2-e/yr at GWP_{20}. Because the landscape sequestration potential at Dorrigo is high (23.5 t CO_2-e/ha/yr; ***Table 6.1***), these emissions are probably already offset by carbon sequestration in woody vegetation regrowth. Around twenty hectares of forest and understory regrowth already sequesters 200 – 400 t CO_2-e/yr, enough to offset animal emissions at both GWP_{100} and GWP_{20}.

Owner Robyn Tuck notes that rotational grazing may make somewhat more efficient use of the property, and make space for further revegetation, but that barriers to implementation include fencing at $7,000/km plus well over $20,000 for water to the whole farm. Despite these costs, Dorrigo Grass Fed Beef has invested in fencing to keep animals out of springs and creeks.

Ms. Tuck is passionate about producing quality food with fresh, natural ingredients. "Grass fed beef is healthier than grain fed beef. My sausages are made with fresh herbs grown on my farm, not manufactured flavours and preservatives." Operating outside the supermarket paradigm also provides satisfaction. "Last year we paid our local butcher around $12,000 to cut and pack our beef. He employs two young people in our town... so it may not be very profitable to us but has community spin offs and adds some strength to our community."

6.1.3 Murray Eden

Murray Eden carries one of Australia's largest dairy herds on 566 ha of irrigated Murray River floodplain near Barham, NSW. A total of around 1100 cattle graze improved pasture for about eight months of the year and are also offered concentrate feeds. Annual milk production is about 5.5 million litres, and Murray Eden also grows wheat, maize and lucerne for use as feed.

The heavy emissions inherent in intensive dairying are evident in the data from Murray Eden; high-performance animals, husbanded to produce at their maximum, produce large greenhouse emissions. At GWP_{100}, the cattle produce 3,612 t CO_2-e/yr, 87% of the farm total. At GWP_{20}, this becomes 11,400 t CO_2-e/yr (96%). Net emissions from cropping are negative because of significant revegetation (***Table 6.1***).

About 71% of the methane emitted at Murray Eden is from enteric fermentation, while most of the rest is from manure management. 15% of manure flows into lagoons, and methane from these (approximately 22 t CH_4/yr) could feasibly and economically be captured for conversion to electricity. The dairy is a big user of electricity, used to power milk refrigeration and pumps, and the investment in methane capture and conversion would be repaid in ten years even at low electricity prices.

Figure 6.1 Milking at dairy.

In recent times cattle have been excluded from 64 ha of river frontage to prevent degradation of river and creek banks, and fencelines planted for shade. In addition, the O'Neill's have fenced cattle out of 20ha of old growth *E. camaldulensis* forest to protect sites of Aboriginal significance, and have also contributed to local LandCare revegetation initiatives, though sequestration in these projects was not included in this study.

The extent of revegetation needed to bring Murray Eden to carbon neutrality would place an untenable burden on the farm (***Table 6.1***), especially given that reductions in area as per our calculations assume an equal reduction in animal numbers.

Murray Eden owner, Phil O'Neill, says farm forestry could be an opportunity, and though this faces opposition on environmental grounds, well-managed logging in river flat country could be a genuinely carbon-positive income stream. The selective removal of some trees would encourage diverse age structures in redgum forests that have undergone severe and repeated disturbance for more than 150 years. Such forests would be protected from fire.

Mr. O'Neill also says that carbon offsets, large-scale solar and methane capture are among the real options for dairies facing carbon constraints. "We need to see what is necessary to position ourselves for climate change, to understand at farm level what is necessary."

6.1.4 Prestbury

Prestbury is on 1033 ha of deep, alluvial black soils with some rocky hills, south-west of Toowoomba in the Darling Downs (AAR = 670 mm). Crops include mung beans, chick peas, sunflowers, wheat and sorghum. Cattle graze both forage crops and improved pasture. In the sample year, 440 ha were cropped with barley, wheat, sorghum and pulses, and around 300 head of beef cattle carried. Most of the property is cropped, but Prestbury also includes 125 ha of improved pasture.

Crops produce 134 t CO_2-e/yr, 17% of total GWP_{100} emissions at Prestbury, or 129 t CO_2-e/yr (6%) at GWP_{20}, with enteric methane causing most of the remainder.

There is some unmanaged native vegetation regrowth on the property. Of Prestbury's cleared land, 5.5% would need to be dedicated to revegetation to offset remaining emissions at GWP_{100}, or 14% at GWP_{20}.

Owners Rob and Sally McCreath recognise the importance of acting against climate change, but also that partial revegetation would take significant effort. "Tree planting in the south may succeed without watering, but [watering] would be essential here for at least the first year," as neighbours and the local LandCare group have found. Mr. McCreath added that there would be a large labor cost to this.

6.1.5 Winiam

Winiam is a 2800ha dryland cereal cropping property in western Victoria's Wimmera region (AAR = 403mm), where >2400 ha are used for cropping and 400 ha is improved pasture. In the sample year, Winiam ran about 1000 breeding ewes and turned off 1400 lambs in addition to sowing 600 ha to wheat, 1340 ha to barley and 500 ha to canola. Vetches are planted as a nitrogen supplement and feed for sheep. Cultivation is by minimum till, with stubble retained.

Emissions at Winiam are more heavily weighted toward crops, with these producing 699 t CO_2-e/yr or 58% of GWP_{100} emissions net of sequestration in trees and 719 t CO_2-e/yr (40%) of total emissions at GWP_{20}. Again the remainder is largely enteric fermentation.

In preparation for a foray into farm forestry, whether for carbon or timber, a 30 ha timber paddock has been surveyed at Winiam.

Winiam's Andrew Colbert feels farmers in the Wimmera are "at the coal face" in facing the effects of regional climate change. "We've lost two inches of growing season rain since the mid-90's," Mr. Colbert said. "That's 20% of our income."

Mr. Colbert reacted to the prospect of revegetating 10 – 12% of his holding with "It can be done — we can deal with that. We don't want to lose another two inches of rain in the next twenty years." Mr. Colbert feels the cost and burden of responding to climate change would ideally be shared across the whole Australian community, instead of rural communities bearing the brunt and being expected to do the work.

6.1.6 Winona

Near the NSW central west town of Gulgong (AAR = 653mm), Winona is a rain fed sheep grazing / cereal cropping farm. In the sample year, 1500 lambs were sold from a flock of 2300 breeding ewes, while 100 ha were sown to oats under a pasture cropping regime.

Crops produced 25 t CO_2-e/yr, 4% of total GWP_{100} emissions at Winona, or 24 t CO_2-e/yr (1%) at GWP_{20}. Enteric methane caused most of the remainder. About 20ha of trees have been planted or allowed to regrow on Winona, and these sequester about 117 t CO_2-e/yr, easily offsetting the cropping emissions. Revegetation sufficient to offset emissions as modelled amounted to 5.7% at GWP_{100} and 17.2%

Colin Seis, owner of Winona, is an innovative farmer who shares the credit for the concept of direct seeding winter cereal crops into perennial pasture. This technique, known as pasture cropping, is associated with increased soil carbon levels, and better nutrient cycling and soil structure as compared to otherwise equivalent soils. Mr. Seis reports soil carbon improvements of up to 9 t CO_2-e/ha over ten years of pasture cropping, and relatively greater improvements at depth. Though we were unable to include the effect of improved soil carbon on overall farm emissions in this study, soil carbon gains (or reversed losses) of this magnitude could make Winona carbon negative as long as the annual gains were maintained, and accrued carbon was not re-emitted from the soil. Pasture cropping is described in more detail in ***Part 4.1.3.1***.

Pasture cropping may also have reduced nitrous oxide emissions by encouraging improved nutrient cycling, though this is not reflected in our emissions modelling. Mr. Seis uses about 70% less nitrogen fertiliser on both crops and pasture, which is reflected in our emissions modelling, as well as lower quantities of phosphorous and herbicide.

"Most ag soils are dysfunctional, and most agricultural problems are ecological problems," resulting from human interference with insects, fungi, water, and nutrient cycling, says Mr. Seis. "They won't be solved with ag. science in its current approach. We need more ecologists, and more women — nurturers — in agriculture."

Figure 6.2 Sunflower crop.

6.2 Toward zero-carbon agriculture

Our modelling in *Part 5* draws on the capacity of the landscape to sequester and store carbon from the atmosphere in sufficient quantities to bring net regional emissions to zero. This modelling relies on conservative estimates of agricultural emissions that do not include the sources detailed in *Parts 3.2.1 & 3.2.4*, namely land clearing for agriculture and savanna burning, but these emissions themselves are among the most amenable to abatement. To the net carbon benefit of land use change presented for 300 IBRA sub-bioregions in *Part 5.6* can be added potential avoided emissions from a range of activities, and abatement of other agricultural emissions through interventions discussed in *Part 4.2* and summarised in *Table 6.2*.

These interventions add up to a large suite of changes in rural Australia, a transformational adaptation of agriculture to the challenges of climate change. Yet even this effort would leave a small deficit — ongoing emissions that would need to be offset before the sector as a whole was carbon-neutral and therefore potentially able to begin offsetting emissions in other parts of the economy. Measured long-term increases in soil carbon stocks (*Part 4.1*) and/or removal of atmospheric carbon in fit-for-purpose plantations with conversion to long-term inert solid carbon (*Part 6.4*) would be a necessary component of a net zero or even negative emissions scenario in agriculture.

Australia's largest agricultural emissions sources are deforestation for agriculture, enteric fermentation, cropland/agricultural soil emissions, prescribed burning of savannas and manure management, in that order. Though not a perfect fit for our categorisation of agriculture into intensive and extensive zones, most of these activities do however fall largely in one or the other. We therefore treat all clearing and savanna burning as occurring in the extensive zone and all cropland / agricultural soil emissions as occurring in the intensive zone. Enteric fermentation emissions are split between zones as indicated by our spatial modelling, which considered animal densities. Emissions from manure management are amenable to abatement only in the intensive zone, and then only partially. In a continental-scale study such as this, these generalisations are appropriate. Our estimate of the emissions abatement available from the measures described previously are presented in ***Figure 6.3***, grouped by intervention across intensive and extensive zones.

Figure 6.3 and the following sections summarise available abatement measures and their effects on the basis of emissions at GWP_{100}, as per the National Inventory Report. They therefore understate both the total size of some emissions, and their abatement potential. Nor do the estimates of abatement potential presented below include any improvements in the status of soil carbon stocks, with the exception of those contained in our FullCAM modelling of land retired from agricultural production and dedicated to growing landscape carbon. This is because of the difficulty inherent in estimating and measuring soil carbon, as described in ***Part 4.1***.

Our recommendations are presented first for the extensive zone then for the intensive zone, and within these also in order of size as they are in ***Table 6.2***.

Table 6.2 Agricultural activities, current emissions, applicable abatement interventions and estimated maximum available abatement by agricultural zone at GWP_{100}.

Agricultural Zone / Emissions Source	Current Emissions [Mt CO_2-e/yr]	Intervention	Estimated Potential Abatement [Mt CO_2-e/yr]
Extensive zone			
Land clearing for pasture	58.5	Cease land clearing	-58.5
Re-clearing	23.8	Cease re-clearing	-23.8
Clearing for crops	15.4	Cease clearing for crops	-15.4
Savanna burning	10.9	Reduce burning	-9.8
Landscape sequestration	0	Limited revegetation	-9.3
Enteric fermentation	11.4	Reduce through herd reduction	-2
		Reduce through technology / management	-1.9
Extensive zone total	120.0	New extensive zone total	-120.7
Intensive zone			
Landscape sequestration	0	Limited revegetation	-36.3
Enteric fermentation	47.6	Reduce through herd reduction	-11.2
		Reduce through technology / management	-7.2
Soils	16.4	Various	-4
Manure management	3.3	Various	-1.7
Intensive zone total	67.3	New intensive zone total	-60.4
Grand total	187.3	New grand total	-181.1
		Deficit	6.2

*Totals differ slightly from those in *Part 3* because these calculations use our own estimation of emissions from enteric fermentation, as used in the modelling (*Part 5*). These nevertheless sum to within 5% of the 2006 – 2010 average recorded in the National Inventory Report (NIR). Totals reported here also sum to within 1.5% of those in the NIR.

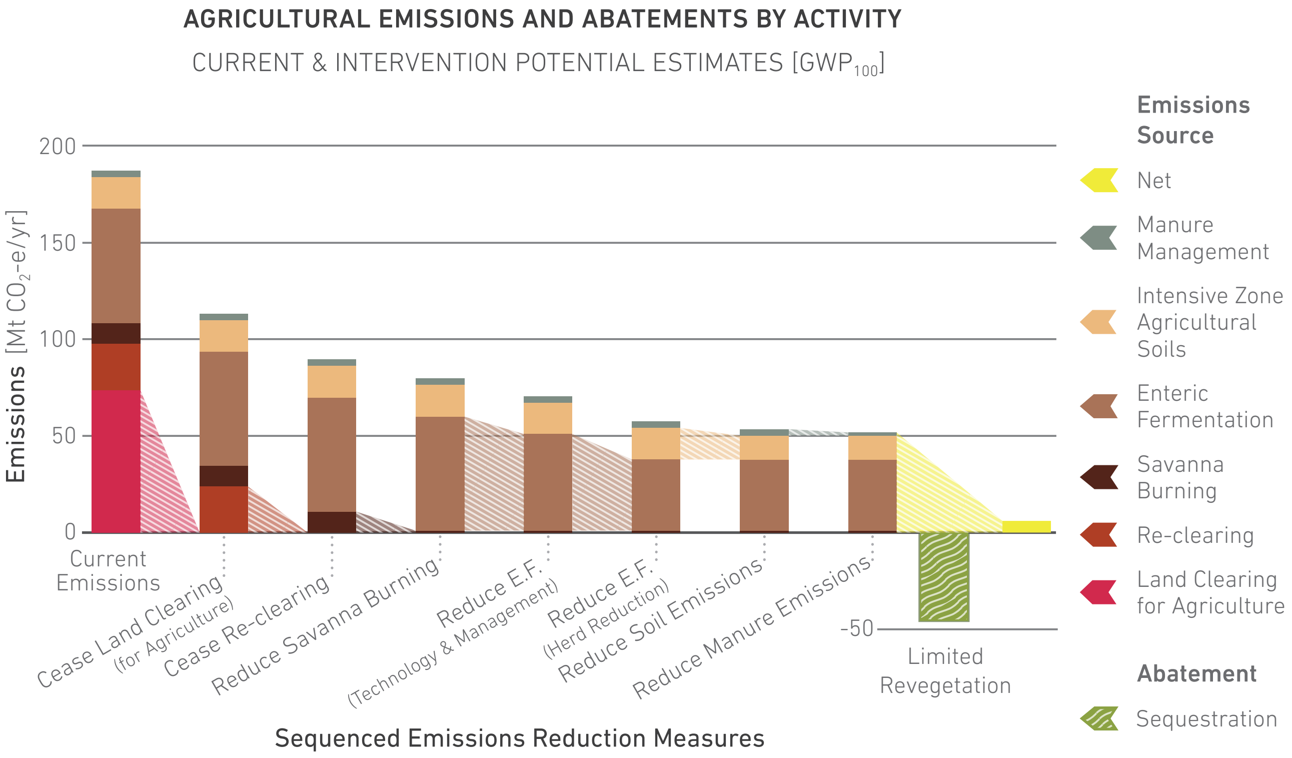

Figure 6.3 Sequenced reduction in greenhouse gas emissions from changes to agricultural activities.

6.2.1 Extensive zone agriculture

Though many areas of the extensive zone promise low carbon sequestration potential per hectare, their vast extent compensates for this in terms of the total carbon benefit available from land use changes. The economic opportunity cost of changes to land use patterns is also generally low in the extensive zone.

Our analysis of agricultural activities in the extensive zone shows a median local value of agricultural production (LVAP) of just $3.35/ha/yr, with an interquartile range of $1.75 – $7.55 (***Part 5.5.4***). This means that the middle 50% of hectares used for production in the extensive zone generate annual earnings in this range, and that the opportunity cost of withdrawing grazing animals from an average hectare of the extensive zone would be low. It also suggests that new agricultural ventures on cleared land will require large areas to make a profit, and that even this is likely to be conditional on other factors being favourable. With even a minimal charge on carbon emissions or economic reward for custodianship and maintenance of existing landscape carbon and other natural values, such clearing for economically marginal activities would be priced out.

More broadly, the value of ecosystem services and costs of pollution have been modelled by The Economics of Ecosystems and Biodiversity (TEEB), a global coalition of environmental and business interests. The TEEB analysis showed that beef and dairy cattle production in Australia and New Zealand cost US$17.3 billion in natural capital while earning US$3.4 billion in revenue, a loss of US$13.9 billion annually in unpaid external costs.[1] A substantial proportion of Australia's rangeland grazing herd and land extent is also controlled offshore.

6.2.1.1 Stop extensive zone land clearing and re-clearing

Let us be clear: clearing for agriculture, especially for pasture, replaces relatively intact native landscapes and the relatively stable carbon stocks they contain, with an ongoing source of CO_2 emissions from soils and often methane emissions from enteric fermentation. Biodiversity, resilience to disturbance, regulation of regional climate and other ecosystem services are replaced by ongoing land degradation and more fragile landscapes. Cessation of clearing should be the new baseline, and could reduce emissions from agriculture by 82.7 Mt CO_2-e /yr even if clearing for crops continued.

Land clearing in the extensive zone is a recent and ongoing phenomenon, largely only since the 1960s, and in modern times 75% has taken place in Queensland. Clearing for pasture represents a large emission — 58.5 Mt CO_2-e/yr — for very little return to either the majority of landholders or the broader community, and has onerous costs.

Re-clearing of cleared land incurs emissions of 24.2 Mt CO_2-e/yr. This activity occurs at great expense to landholders, despite the availability of rebates for diesel burned in the exercise. Re-clearing of recently cleared land perpetuates the loss of carbon from these lands, and prevents landscape carbon stocks from recovering.

Clearing for crops is more minor but still emits 15.4 Mt CO_2-e/yr, and like clearing for pasture can be avoided completely. Much of Australia's current clearing for crops is occurring in the Ord scheme, where 70,000 ha were being cleared at the time of writing. These lands were earmarked for sorghum cropping to supply the Chinese wine industry. Other recent clearing for crops has taken place on Cape York, as well as the rest of Queensland, NSW and SA. It is likely that this is in areas marginal for cropping.

Emissions from conversion of forest land to grassland, forest land to cropland, and re-clearing, including clearing of shrubland and other vegetation types not categorised as forest, can be brought rapidly to zero simply by ceasing these activities. Soil carbon emissions from recently cleared land would diminish if re-clearing also stopped, though this may take years to decades and stocks may not recover to original levels in a human lifetime. In the absence of new clearing and with a focus on revegetation, Australia's uncounted emissions from soil erosion could be vastly reduced (***Part* 3.2.1.4**).

6.2.1.2 Abatement of emissions from prescribed burning of savannas

We assume the 90% reduction in savanna burning for pasture noted as the 'potential' for reduction in all savanna burning by Andersen and Heckbert (2009[2]) to achieve an abatement from this source of 9.8 Mt CO_2-e/yr. However, even the lower estimate of 34% from the same authors would achieve abatement on the order of 3.7 Mt CO_2-e/yr. Emissions considered in the NIR are limited to those burns conducted for agriculture, but far greater areas are burned than are recognised. Reduced extent, frequency and severity of savanna burning are also likely to reduce the unaccounted emissions of short-term climate forcers, such as carbon monoxide and methane, precursors to tropospheric ozone, and of black carbon (***Part* 3.4 *&* 4.4**).

Emissions avoided by the complete cessation of savanna burning for pasture would not necessarily be replaced by emissions from wildfire. As demonstrated by research, wildfire can be minimised and would not necessarily come to replace prescribed burns (***Part* 4.2.4.1**). The success of the West Arnhem Land Fire Abatement project indicates that there is scope for great reductions in savanna burning emissions, and that this can bring corollary benefits.

By imputing the value of tropical savannas and other native woodlands, shrublands and grasslands, such as the brigalow, mulga and Mitchell and tallgrasses as carbon stores, and managing these landscapes to maximise carbon sequestration and retention, both climate and employment benefits could be realised. Indigenous, landholder and scientific land management expertise could be applied across the rangelands to ensure that sequestered carbon is held long-term and risk of re-emission due to wildfire, disturbance or drought is minimised.

6.2.1.3 Sequestration of carbon in extensive zone landscapes

In addition to avoided emissions from land clearing and enteric fermentation, reduced grazing pressure can lead to a gradual recovery of landscape carbon stocks. Our RangeAssess modelling, presented in ***Part* 5**, suggests that a reduction in animal numbers and the space they occupy can make large improvements to landscape carbon levels. We modelled complete exclusion of grazing animals from rehabilitated rangeland areas, and assumed a 50% reduction in feral animal densities and implementation of prescribed burning for hazard reduction. Under these conditions, restoration of 39 Mha (of a total of >400 Mha cleared or heavily modified by grazing) could sequester more than 9.3

Mt CO_2/yr, including slowing or reversal of soil carbon loss on areas revegetated.

Other studies have concluded that the sequestration accessible by restoration of tropical rangelands cleared for or modified by grazing may be up to 100 Mt CO_2-e/yr, with another 20 Mt CO_2-e/yr of potential in the arid mulga.[3] This assumes that 40% of Australia's tropical, semi-arid and arid rangelands are degraded and amenable to restoration, and that carbon sequestered in the landscape can be kept there. Witt *et al.* (2011[4]) modelled sequestration from exclusion of grazing animals from 50% of the semi-arid Mulga Lands bioregion at up to 14 Mt CO_2-e/yr. These examples represent a far more drastic restriction of the area available for grazing than we have proposed, and despite large uncertainties support the conclusion that degraded rangelands offer a large and untapped opportunity for landscape carbon sequestration.

Our objective of zero net emissions from each of 146 extensive zone sub-bioregions therefore represents a feasible and conservative effort. If landscape carbon gains can be maintained, more extensive cuts to rangeland animal numbers could produce, for some period at least, sub-bioregions that are materially carbon emissions-negative. This would require that landscape carbon gains were permanent, once again implying maintenance works and fuel reduction burning in an effort to prevent re-emission.

6.2.1.4 Reduce emissions from extensive zone enteric fermentation

Enteric fermentation (EF) on the rangelands is the next largest contributor to extensive zone emissions, but interventions to reduce EF are difficult to apply to rangeland animals (see ***Part 4.2.2***). Our modelling (***Part 5***) suggests that excluding cattle and sheep from 12% of the extensive zone rangeland grazed area, and reducing animal numbers in the same proportion, could reduce emissions by >2 Mt CO_2-e/yr, or about 18% of all rangeland EF emissions as represented in our modelling (11.4 Mt CO_2-e/yr). However this is a relatively modest proportion of total EF emissions from grazed beef and sheep (58.9 Mt CO_2-e/yr), because extensive zone animal densities are low compared to those in the intensive zone. Landscape carbon gains can be won when grazing animal pressure is reduced (see ***Part 6.2.3***).

A 2009 analysis of the Queensland beef industry concluded that even if best management practices were encouraged by policy settings and a price on emissions, a reduction in EF emissions of 20 – 40% may be possible by 2020 but would require 'significant technological development and societal change', as well as 'policy incentives' (Charmley 2009 p. 39[5]). These interventions would likely include reduced herd sizes and exclusion zones, though this is not specified. We adopt the lower bound of Charmley's estimate as representative of the potential to reduce EF by means other than reduction of animal numbers, to arrive at a further abatement of 1.9 Mt CO_2-e/yr.

Though emissions abatement of this magnitude is worth pursuing by all available means, a reduction in Australia's total herd is a practical option that promises a guaranteed and potentially immediate dividend in terms of reduced EF emissions. For large reductions in Australia's rangeland EF emissions, the size of the herd will need to be reduced significantly, and reductions beyond those suggested by our modelling offer proportionately greater benefits. Reduction of herd and flock sizes is also one of the cheapest methods of climate mitigation. Abatement of methane emissions is especially important, both because this gas has caused 30% of warming since the time of the industrialisation of agriculture, and because reduced atmospheric methane concentrations can buy time for action on other gases (e.g. [6, 7]).

Other factors support a reduction in animal numbers. Livestock grazing is the major driver of rangeland degradation[8, 9] and sediment loss, for example to the Great Barrier Reef lagoon.[10, 11] Lower stocking rates, judicious management of animal numbers with respect to pasture condition, and limited revegetation, especially along drainage lines and on hill slopes, are all known to reduce these losses.[12]

6.2.2 Intensive zone agriculture

Emissions from enteric fermentation, agricultural soils and manure management offer significant abatement opportunities in the intensive zone. Average sequestration potentials (SP) in the intensive zone are also higher than those in the extensive zone, reflecting higher rainfall and generally more favourable conditions for plant growth.

Our analysis of agricultural activities in the intensive zone shows a median local value of agricultural production (LVAP) of $193/ha/yr, with an interquartile range of $125 – $335 (***Table 5.9***, ***Part 5.4.4***). This means that the annual opportunity cost of changing the use of an average hectare of intensive zone land is relatively high, but because of higher biological productivity this zone also offers greater flexibility in land use choices.

6.2.2.1 Sequestration of carbon in intensive zone landscapes

Our scenarios indicate that 36.3 Mt CO_2-e/yr can be sequestered in cleared intensive zone landscapes with a reallocation of an overall average of 19% of these to natural vegetation. The actual proportion of cleared land revegetated in our scenarios varies widely between IBRA subregions, and the extent quoted here is sufficient to offset ongoing emissions from beef, sheep, dairy, cereal and sugar production. More intensive carbon forestry may sequester more carbon than the totals from our modelling, which relied on mixed environmental plantings with minimal subsequent management, and would reduce the land required.

A number of interventions offer potential to further increase the size of the carbon sink available in intensive agricultural landscapes. These include recovery of soil carbon stocks (***Part 4.1***) and agroforestry for carbon and / or wood and fibre products. We explore the potential of short rotation woody crops, planted in mixed agricultural landscapes, to permanently sequester atmospheric carbon as part of a biochar production industry in ***Part 6.4.3***. Any verifiable gains from these would be additional to those from retirement and revegetation of agricultural land.

There is ample evidence that increasing woody vegetation coverage on pasture land can actually improve conditions for stock, as well as providing defence against secondary salinisation and reducing erosion. Land use efficiencies may be gained through such methods as rotational grazing, intensification, and such methods may also contribute to increases in soil carbon (***Part 4.1***). Caution must be taken however that the net effect on emissions of such change is positive.

At least 12.7% (3.14 Mha) of Australia's cultivated land was dedicated to fodder crops in 2006.[13] Moreover, an average of about 9 million tonnes of grain was fed to domestic production animals of all species between 2006 – 2012, indicating that a further ≈4.5 Mha of cropland were dedicated to this use. The sheer extent of land used to grow feed for animals suggests that there is significant capacity to reduce the footprint of our agriculture without effects on food produced for humans. Some cleared land in the south and east of Australia is also rarely or lightly stocked and may represent largely unused legacy clearing. As such it may offer scope for zero-opportunity cost revegetation.

A reduction in ruminant animal numbers of 24% as proposed for the intensive zone (***Part 5.6***) would reduce somewhat the requirement for fodder and feed grains, but the feed grain sector supplies industries based on non-ruminant species as well. It is also clear that some land must be used to grow fodder for ruminants, to allow for periods where because of seasonality or drought, feed growth is reduced.

Measurement of carbon sequestered in intensive agricultural landscapes and soils is subject to many of the constraints and difficulties described above (***Parts 4.1 & 6.2.3***), especially the requirement to protect landscape carbon stocks against re-emission. Nevertheless, retirement and revegetation of agricultural land offers relatively stable carbon storage, and is the only intervention considered with high confidence to offer moderate to high sequestration potential (Sanderman *et al.* 2009, p. 49[14]).

Grazing management can be aimed specifically at maintaining ground cover and pasture growth, with the dual objectives of reducing the spatial footprint occupied by grazing, and either increasing soil carbon stocks or slowing their decline where this can be verified. Though such verification would require a concerted scientific effort to establish soil carbon baselines and monitor changes at fine spatial scales, it would permit improvements or slowed declines to be lauded and rewarded. Appropriate techniques may include rotational grazing and pasture cropping, though these would require careful assessment (***Part 4.1***). Activities known to reduce ground cover and soil carbon or cause soil loss and damage, such as consistent overstocking of grazing land long into droughts, could be strongly reduced.

6.2.2.2 Reduce intensive zone enteric fermentation

The land use changes proposed in our scenarios would result in around 11.2 Mt CO_2-e/yr in emissions avoided, with the remaining 36.3 Mt CO_2-e/yr offset by sequestration in the landscape. These avoided emissions come from a 24% reduction in the national herd and flock sizes, which could be spread across the dairy, beef and sheep sectors.

Enteric fermentation from cattle and sheep in the intensive zone is somewhat more amenable to abatement by means other than herd/flock reductions than extensive zone EF. However as described in ***Part 4.2.2***, the capacity to further reduce methane emissions is limited because the low-hanging fruit has by and large been taken. We estimate that the remaining EF emissions from intensive agriculture can be reduced by 10 – 20% (3.6 – 7.2 Mt CO_2-e/yr) if sufficient resources are allocated.

To maximise the achievable benefits, industries which are overall small sources of greenhouse gases, or where animals are integral to mixed farming operations, (as such efficient), could be supported with a well-resourced scientific effort and incentives for success in reducing emissions. Priorities may include:

- Herd management specifically designed to improve methane efficiency of dairy and beef herds
- Increased penetration of secondary plant compounds and other dietary amendments, especially where these can be sourced from the agricultural produce, food or beverage processing industries, or from purpose-grown crops.

6.2.2.3 Reduce emissions from intensive zone agricultural soils

A majority of these emissions arise in the intensive zone. Reductions in animal numbers would reduce soil emissions due to animal production by about 24%, or 1 Mt CO_2-e/yr. These are therefore covered in our analysis of emissions avoided by reallocation of a proportion of Australia's agricultural land to carbon sequestration purposes.

Only about 31% of applied nitrogen is recovered in harvested crops,[15] so there is scope to reduce some of the 4 Mt of fertiliser-related emissions by improving the efficiency of use of applied nitrogen. However a complex range of interactions between soil characteristics, specific crop or other land use, fertiliser type, timing of application, soil moisture levels and other factors influence the rate of nitrogen lost as N_2O. This makes it difficult to estimate the scale of further emissions reductions accessible through management improvements. It has been estimated that, worldwide, there is potential for reducing emissions from fertiliser by 20%,[16] but many Australian farmers already apply best management practices.

Nevertheless, it seems there is some potential to reduce N_2O emissions from both pastures and crops through the increased use of controlled release fertilisers, nitrification inhibitors and management improvements. Increased research effort, improved affordability of and access to precision agricultural technology and controlled release fertilisers can make a contribution. Implementation of alternative pasture / crop management techniques where these are demonstrated to have a positive effect on soil carbon and /or offer emissions reductions via nutrient cycling can also be prioritised.

Consideration may also be given to reducing the area planted to some crops, such as those sugar crops located on acid sulphate soils, as these emit particularly strongly.[17] If such crops were replaced by revegetation for carbon sequestration, especially in areas of high sequestration potential, the emissions abatement return would be significant.

6.2.2.4 Reduce emissions from intensive zone manure management

Control of emissions from manure management involves managing two distinct gases, methane and nitrous oxide. Methane from manure arises mainly from piggeries and dairies. We estimate it is feasible to capture and re-use 90% of piggery methane and 25% of that from dairies, or about 1.1 Mt of the total 1.5 Mt CO_2-e/yr from these sources.

Increased use of nitrification inhibitors in dairies and feedlots may directly reduce N_2O emissions and would come at a cost, but minimisation of manure stockpiles is a cheap and accessible method of reducing their emissions. Removal and re-use of feedlot manures can also reduce both pre-farm and on-farm emissions from fertiliser use. It is possible that a reduction of 50% of business-as-usual emissions from feedlot manures could result from improved management, offering abatement of about 0.5 Mt CO_2-e/yr. We estimate that the reduced herd and flock sizes proposed in our scenarios would bring about a further marginal abatement (≈0.1 Mt CO_2-e/yr).

6.3 Toward zero carbon forestry

6.3.1 Protection of standing carbon and forest resilience

The most effective way to reduce emissions from forestry and protect standing carbon in biomass is to change the current management regimes in native forests, particularly logging practices in southern Australia. This would involve the cessation of clearfell logging in all of Australia's native forests. Large stocks of carbon would then remain in the forest, even with the natural disturbance frequencies of fire. In addition, forests already logged possess a carbon sequestration potential that would see these areas sequester atmospheric CO_2 as they recover from prior disturbance. As discussed, Mackey *et al.* (2008[18]) argue that the carbon sequestration potential of these logged forests is 2,000 Mt C, equivalent to 7,500 Mt CO_2.

The cessation of clearfell logging would also render these forests more resilient to the impacts of fires.[19] As indicated in ***Part 4***, older forests sustain fire impacts of lesser severity. However, changed regimes of more frequent fires (i.e. less than 20 years) may present serious problems for the capacity of some areas of these forests to persist into the future. This is already evident in north east Victoria where the eucalyptus tall open forests around Mount Feathertop have been impacted by three fires in the past ten years. Although it is beyond the scope of this report to analyze adaptation measures, some areas of forests will require some degree of management intervention to manage and reduce the risk of more frequent fires.

6.3.2 An expanded reserve system and improved forestry practices

A zero carbon forestry plan requires an expanded reserve network across the Australian continent. Much of the existing reserve system was selected upon a 'useless land hypothesis', where land not considered valuable for agriculture and forestry were placed into national parks and other reserves.[20] An expanded reserve system would take into account areas of importance for carbon stocks and carbon sequestration potential, including all eucalyptus tall open forest.

For areas outside the reserve system, we propose a degree of forest management with the purpose of wood extraction. This would not consist of commodity wood products, but high value specialty products that are currently not available from the plantation estate. This strategy would invert the current structure of the native forest logging industry to one that utilises high value wood products from a relatively small area. Furthermore, this different approach to forestry would utilise areas in relatively close proximity to markets and logging of more remote forest areas would be rendered uneconomic.

Examples of this type of forestry are already in practice. For example a small farm forestry business, Australian Sustainable Timbers, employs low impact forestry practices, such as single tree selection and creating small gaps in the tree canopy to stimulate regeneration. In 2008, Australian Sustainable Timbers won the contract to supply 10,000m^2 of Spotted Gum veneer to the new Melbourne Convention Centre, a major project with a budget in excess of $400m. Australian Sustainable Timbers success was based on its capacity to supply and its higher environmental performance in contrast to its competitors. Only a small area of forest was logged to supply the contract. Such practices provide a template for other parts of Australia to follow.

The key measures for a zero carbon forestry plan are to (informed by Lindenmayer and Franklin 2002[21]):

1. Expand the existing reserve system for native forests;
2. For forests outside the reserve system, management strategies must complement the reserve system;
3. For forests outside the reserve system, management strategies must use natural historic disturbance regimes to inform logging and other management practices in utilising wood for processing. This is inclusive of maintaining connectivity, landscape heterogeneity, stand complexity, aquatic ecosystem integrity;
4. Utilise risk spreading strategies (i.e. do not protect values in isolation, but have multiple values across multiple sites)

6.4 Biochar from tree crops

Short rotation woody crops grown as a feedstock for biochar production may have far greater potential to provide ongoing carbon sequestration than permanent plantations, because on decadal timescales they can be harvested and re-harvested from a relatively small spatial footprint. Consistent with Ajani *et al.* (2013[22]) and Mackey *et al.* (2013[23]) we challenge the view that offsets have any legitimate role in climate change mitigation, and consider that efforts need to not only be focused on reducing emissions, but on actively sequestering CO_2 from the atmosphere. Biochar production systems are one of the few systems with potential to achieve continuous draw-down of carbon dioxide from the atmosphere and ought to be prioritised for research and industry development.

6.4.1 What is biochar?

Biochar is charcoal made from biomass (plant matter) that is used to improve soil fertility and sequester carbon.[24] When the term 'biochar' is used, it generally refers to charcoal that has been made in a controlled environment.[24] Some scientists consider this distinction important, and refer to charcoal produced in an uncontrolled environment, e.g. on farms using home-made kilns, as 'char'.[24]

Conversion of biomass to biochar results in around half of the carbon (C) in biomass being retained as solid biochar[25] which is added to soil and remains stable for at least 500 years.[26] This means biochar provides long-term carbon sequestration, and as biomass feedstocks can be produced continually using the same land, biochar production could enable high levels of CO_2 'draw-down' from the atmosphere.

Farmers around the world have used charcoal made from wood or other on-farm biomass for centuries. The earliest known use of charcoal for soil amendment is in the Amazon Basin, where 'Terra Preta' soils have been measured to have three times the amount of organic carbon, nitrogen and phosphorous than adjacent soils.[27] The nutrient richness of this soil is attributed to indigenous peoples' application of char as part of traditional land use practices over 2500 years ago.[27] In Australia, research into biochar's potential for increasing agricultural productivity has been underway for nearly a decade.[24, 28]

6.4.2 Biochar feedstocks

Plant biomass feedstocks used to make biochar can include crop or forestry waste, or dedicated crops currently grown for energy such as corn and plantation wood harvested at short intervals. We focus on the use of woody crops as the multiple environmental and economic benefits of integrating tree cropping and agriculture are well documented[29] and wood is a common feedstock for biochar production around the world.[25] Woody crops grown for harvesting within a short period of establishment are known as short rotation woody crops (SRWCs). Short rotation woody crops have been identified as suitable biomass feedstocks for electricity generation and production of liquid fuels, eucalyptus oil, firewood and paper[30–32] , however, SRWC biomass would also be useful for biochar production.[33]

In particular, mallee eucalypts that grow multiple stems and can regenerate quickly by coppicing after harvesting have been identified as particularly suitable biomass crop species for integration with Australian dryland agriculture.[29] Mallee eucalypts, of which there are about 180 species,[29,34] are adapted to low rainfall environments where their growth and survival rates are higher than other species.[35] Low rainfall environments — that is, land where average annual rainfall is between 250 and 400mm,[29] have been the focus of much research into the potential for mallee crop establishment, which has identified species suited to particular regions.[29,35] In higher rainfall environments, *Eucalyptus globulus* (bluegum) and other common commercial species could also be managed in short rotation for a biochar market.

6.4.3 Emissions profile of biochar made from mallee wood

The effectiveness of SRWC-based biochar systems for climate change mitigation depends on the greenhouse gas (GHG) emissions profile of these systems. The GHG emissions necessary for biochar's production, from 'cradle to grave' need to be significantly less than the amount of CO_2 captured through photosynthesis and stored in the final product for a net sequestration benefit to be achieved. For example, if wood was trucked 600 kilometres and made into paper, it would not have a net positive carbon profile because the fossil fuels use necessary for transport and the electricity used in paper manufacturing are greater than the carbon sequestered by the trees.[36]

A lifecycle GHG emission analysis of mallee crops grown in south-west Western Australia found a GHG emission profile close to neutral, with over 70% of emissions associated with mallee production attributed to harvesting and transport.[37] An Australian lifecycle assessment (LCA) of the emissions associated with wood heating[38] is also useful, as plantation firewood forestry systems are similar in terms of the short interval between harvesting events. Paul *et al.* (2006[38]) showed that plantation firewood systems result in a net GHG benefit — which means that carbon storage in wood retained in the plantation is greater than all emissions associated with the full life cycle of the product, including harvesting, transport and combustion in a well operated wood heater with 65% or greater efficiency.[38,39] At a more general level, Tucker and colleagues(2009[36]) examined the Australian forestry sector and found that in plantation forests and regrowth native forests, more carbon is sequestered by trees through photosynthesis and retained at the forest site than is emitted through silvicultural management, application of fertilisers, harvesting, transport and other associated GHG emissions.

Biochar production systems using either waste biomass or dedicated feedstock crops, can have a carbon abatement between 2 – 5 times greater than would be possible if the biochar feedstock was burnt as a substitute for fossil fuels.[40] Lifecycle assessments of biochar examine all emissions involved in biochar production and application: emissions from production and transport of the feedstock, from production of biochar, transport and application of biochar. An LCA of biochar production by slow pyrolysis at three different scales and involving ten types of feedstock from North America and the UK is reported by Hammond *et al.* (2011[26]). This study, which included short rotation woody crops as a feedstock, found net carbon abatement in each of the systems examined. Despite economies of scale, the difference between small and large scale biochar production systems was not great (***Table 6.3***). Lifecycle assessments of biochar production systems using Australian wood have not yet been undertaken

Table 6.3 Carbon abatement from three slow pyrolysis biochar systems. Adapted from Hammond *et al.* (2011[26])

Comparison of Three Pyrolysis Biochar Systems

All scenarios assume biochar is applied to wheat cropping land.

"**Small**" : On-farm, rural, or village pyrolysis

- 10km transport
- Feedstock input: 2000 t/yr
- Biochar output: 500 t/yr

Carbon emission abatement [t CO_2-e] per tonne of oven dry feedstock	**0.7 – 1.1**

"**Medium**": Urban environment or serving light industry

- 45km transport
- Feedstock input: 20,000 t/yr
- Biochar output: 5,000 t/yr

Carbon emission abatement [t CO_2-e] per tonne of oven dry feedstock	**0.8 – 1.2**

"**Large**": Industrial area and good supply routes needed

- 65km transport
- Feedstock: 100,000 t/yr
- Biochar output: 25,000 t/yr

Carbon emission abatement [t CO_2-e] per tonne of oven dry feedstock	**0.9 – 1.3**

The lifecycle assessment of GHG emissions from biochar systems reported in Hammond *et al.*[26] modelled three scenarios, summarised in ***Table 6.3*** above, with 65km the greatest distance assumed for transport. If crops are grown mainly in dryland areas where integration of forestry with agricultural systems is more likely to be attractive to landholders[29], transport distance to markets is likely to be far greater than 65km unless processing facilities are established in a decentralised fashion across the landscape. This approach would involve considerable planning, but is more likely to ensure that biochar production has maximum economic benefits to rural communities and that carbon abatement is at a maximum.

In rural Australia, physical proximity to processing facilities is arguably the most important factor that constrains the expansion of farm forestry. Polglase *et al.* (2008) consider that the maximum transport distance for farm forestry systems is one hundred kilometers. This is the distance from the 'farm gate' used to generate hypothetical scenarios for farm forestry development in Australia.[35]

6.4.4 Opportunities for mallee cropping to support biochar production

Several studies analyse the potential for establishment of dedicated crops, including trees, for carbon sequestration purposes, and as feedstocks for bioenergy generation in Australia (e.g.[30,35,41–44]). Some of these studies have modelled growth rates and potential wood volumes that could be produced across high and low rainfall zones.[30,35,43] We consider SRWC for biochar production could most realistically be grown in regions identified by Polglase and colleagues (2008[35]) as being suited to farm forestry development.

Regional opportunities exist for farm forestry at local and regional scales, for example in the West Australian wheat belt where mallee eucalypts and other woody crops have been investigated for their potential for integration with dryland wheat cropping.[29,45] This would have carbon abatement benefits but was also driven by an urgent need to combat dryland salinity.[29,45] Further, a 2008 review of regional opportunities for agroforestry systems in Australia[35] ranks areas of high interest in tree growing around Australia, based on regional forestry practitioners' knowledge of which species grow well in their region, and analysis of regional Natural Resource Management plans. Original modeling of the feasibility of ten scenarios including mallee crops and other species for bioenergy production as well as permanent sequestration is presented.[35] This work was taken further by Polglase *et al.* (2008[43]) who identified areas where it would be most profitable to grow permanent forests or plantations. This report found that only when a carbon price of $40/t is reached will carbon forestry — that is, the establishment and maintenance of permanent forests or plantations — become profitable in Australia.

A recent estimate of the amount of wheat and crop land that could be planted with short rotation eucalypt crops for the purpose of energy generation in Australia is around 2,286,000 ha, which would provide annual production of

Figure 6.4 Oil mallee eucalypt plantation complementing a wheat crop, south west Western Australia. Source: Landcare Australia.

approximately 15 million tonnes of dry wood.[30] To a first approximation, this volume could result in the sequestration of slightly less than 14 Mt CO_2-e/yr if converted to biochar.

This volume however is ambitious given that the fastest expansion of forestry ever seen in Australia resulted in 100,000 hectares being established annually.[43] In their assessment of current status and prospects for carbon forestry in Australia, Mitchell *et al.* (2012[44]) agree that previous estimates of the amount of land that could be used for carbon forestry have far exceeded the area that has in reality been achievable. Tree growing for carbon sequestration purposes in Australia is estimated at around 65,000 hectares in 2011[44] and mainly comprises mallee eucalypt plantations grown by for-profit companies. Not-for-profit organisations have grown nearly 9,000 hectares of biodiversity and mallee plantations for carbon sequestration.[44]

The Carbon Farming Initiative included biochar as an eligible activity,[46] and research supports the conclusion that a biochar industry would have benefits for climate change mitigation as well as agricultural productivity in Australia. Furthermore, there is a strong prospect that adoption of a biochar feedstock industry can provide economic opportunities to rural communities.[47]

To support this vision, industry standards that protect the integrity of the biochar product need to be developed, according to Cox *et al.* (2012[24]), following a review of the implications of biochar for agricultural productivity. In particular, risks to human health and the environment need to be managed.[24] Biochar production involves high temperatures and the production of oil and gases that are harmful to human health. There is a need to test biochar end products for trace metals and other potentially toxic elements, as it is very difficult if not impossible to remove biochar from soils once it has been applied.[24] In the context of rapidly accelerating climate change, where the need for effective mitigation strategies and improved agricultural systems is urgent, it is essential that the emerging biochar industry is designed to effectively manage such risks.[48]

Increasing soil carbon and planting trees on a massive scale is a central plank of the Australian Government's 'Direct Action Plan' climate change mitigation policy.[49] According to Monash University researcher Tim Lubcke, 77 million m3 of wood need to be produced annually for sequestration through tree plantations to meet the Federal Government's 5% emissions reduction target.[50] This is more than three times the 23 million m^3 of logs harvested in Australia in 2011 – 2012.[51] Lubcke also emphasises that afforestation at this scale is unlikely.

While SRWCs for biochar production should not be seen as a panacea, pursuing the development of a regional biochar production industry would assist the agriculture and land use sector to play a role in climate change mitigation, while having tangible benefits for productivity, rural livelihoods and the environment.

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Part 7:

Impacts and Conditions

Contents

7 Introduction

This report describes scenarios upon where the Australian Agriculture and Forestry sectors can act as a sink for anthropogenic greenhouse gas emissions generated within those sectors. It presents an opportunity whereby land use can assist in the overall effort of mitigating the extreme effects of climate change through emissions abatement and landscape carbon sequestration.

Chapter highlights

- Financial opportunity costs are significant but not daunting, and compare well with both the current cost of climate disturbance and the hidden costs of grazing.
- There is ample capacity to replace animal protein foregone with protein sourced from plants. Land released from fodder and feed crops exceeds that needed to grow legumes by a factor of more than 5.
- Maintenance of landscape carbon and ongoing sequestration can add economic activity to rural areas.
- Clearfell native forest logging is uneconomic and should stop.
- Australians have a shared responsibility to protect our productive rural landscapes.

7.1 Maximising benefits, minimising costs

7.1.1 Minimising economic impacts

We have estimated the opportunity cost of restoration (or relaxation of grazing pressure) as equivalent to the Local Value of Agricultural Production (LVAP) in dollars per hectare, multiplied by the number of hectares affected (***Section 5.4.2.2***). We recognise that LVAP is an insufficient proxy for overall costs, because it does not consider implementation costs. These may take many forms, including infrastructure, training, labour and research. Indeed the cost of planting trees in our scenarios will be large and it constitutes a long-term task (see ***Section 6.4.4***). Detailed analysis of the economic costs and benefits of land use change on the continental scale is beyond the scope of this report, however it does represent an opportunity for further investigation.

The values of all grazing animal products, including meat, milk and wool, were included in our total LVAP, as were those of all broadacre crops (***Section 5.3.5***). On a nationwide basis, cereals and sugar, included in our study, account for 72% of the total value of broadacre cropping.[1] Our inclusion of all other broadacre crops in our calculations therefore exaggerates significantly the opportunity cost of regeneration.

Like other economic indicators, LVAP fails to account for very large and mostly ignored environmental costs[2] or externalities. These include the impacts of climate change caused by anthropogenic greenhouse gas emissions, soil degradation, biodiversity loss and other environmental impacts. These would likely push the land use sectors into deficit were they accurately accounted. In fact the externalised costs of Australian grazing are probably double the opportunity cost, to all broadacre cropping and all grazing, of the interventions we suggest. Among costs that are well-quantified, exceptional circumstances drought relief payments are already high and trending upwards. These are likely to increase far more if the more extreme projections of climate change eventuate.[3] The cost of disrupted production during severe weather events, exacerbated by climate change, is also high.

It is clear that where high-value, emissions-intensive activities are prevalent, both sequestration potential and opportunity costs are also high (***Section 5.4.4***). Conversely, low emissions activities occupy areas of low sequestration potential and offer comparatively lower economic returns and hence lower opportunity costs. This observation constitutes a good starting point for debate as to where revegetation efforts should be prioritised, once the need for them is accepted.

To minimise opportunity costs, the least profitable land would be revegetated first. In mixed farming operations and across regions with a mix of activities, this will usually coincide with land used exclusively or predominantly for beef and sheep grazing, rather than cropped or dairying areas. It is the mean LVAP for IBRA sub-regions on which we have based calculations of opportunity cost, without analysing the details of the relationship between predominant industries and per-hectare earnings. The spatial variability inherent in agricultural activities, though not reflected in our IBRA sub-region-scaled analysis, will supply some opportunities for revegetation at an opportunity cost far lower than the mean for any one region.

Other opportunities may exist to revegetate land at low or potentially zero opportunity cost, and in sympathy with food production. These include areas that are currently salinity-impacted or are at high risk of becoming so in the future and those areas whose very steep topography limits their value as pasture (***Section 5.6.4***). There may be opportunities to revegetate land that has been cleared but is not currently productive. In such cases, the opportunity cost in terms of LVAP would be comparatively low, whereas payments for custodianship of carbon plantations from a society prepared to front the costs of climate change mitigation would be high.

Intensification may offer an opportunity for some producers in either the extensive or intensive zones to maintain production levels while reducing their spatial footprint. Land released as a consequence would be available for carbon sequestration, though emissions would not necessarily be reduced and may in fact increase. For example, intensification may rely on higher rates of fertiliser application. Such potential trade-offs will require dedicated research and careful consideration.

Studies indicate that some livestock producers recognise their power to act and are willing to play a role in climate change mitigation (e.g.[4–7]). The National Farmers' Federation has also recognised the need to become active in addressing the impacts of climate change. They have advocated for further engagement.[8] Many individual farmers have already taken steps to protect areas of their land regardless of cost, often motivated by a care for the land, on which they and their families live, and their understanding of their role as custodians across many generations spanning past, present and future. A number of examples of this are presented in ***Section 6.1***. There are also many examples of successful restoration projects undertaken by philanthropic organisations or individuals; for further reading on such efforts we recommend Eckersley (2013[9]).

7.1.2 Avoiding impacts on food production

What we propose includes a reduction in meat production. The total reduction would not necessarily impact on domestic consumption as more than half Australia's beef, veal and sheep meat are exported. One consequence, then, would be a reduction in meat exports. Other options, discussed below, are: dietary changes, alternative sources of meat and substitution of meat protein with increased production of grain legumes.

7.1.2.1 Continuing trend towards reduced ruminant meat consumption

Individuals can choose to reduce their consumption of foods that embody a high greenhouse emissions profile, just as people routinely choose to consume less of foods they consider bad for their health. There is no dietary reason why meat from ruminants cannot be consumed less often or even be considered a specialty. We are not proposing vegetarianism and veganism, although these are relatively common dietary choices in Australia and elsewhere. However, society may wish to recognise food products with lower environmental impact, including those with lower embodied greenhouse emissions.[10, 11]

Instead, we propose reduced consumption of ruminant meat, commensurate with the reduction in animal numbers proposed in ***Section 5.6***. These amount to a 24% reduction in sheep meat production and a 20% reduction in beef. For a person to reduce their intake of these products by 20% is not difficult; even a 50% reduction is easy for most people to achieve. Across Australian society, red meat consumption per capita has reduced by about 46% since the late 1930s.[12] In 1998 – 1999, the last year for which the ABS holds records, Australians were eating around 200g per day of all meats and meat products - about 140g/day of this from ruminants and this was trending down.[12]

There is increasing recognition that excessive consumption of meat and meat products is a contributing factor to poor human health outcomes. A reduced meat consumption would benefit individuals and populations.[13] Friel *et al.* (2009[14]) modelled the population health effects of a 30% reduction in red meat production and consumption for the United Kingdom, in view of a proposed reduction in agricultural greenhouse emissions of 50%. This study found that the burden of ischaemic heart disease could be reduced by 15% in the UK. Meat production, whether pasture or feedlot-finished, produces less food per unit of resource invested than non-meat options.[15]

At the same time, implications for global food security demand serious consideration. For nearly a billion people, the under-consumption of protein is more pressing than the individual and collective risks of over-consumption. While meat consumption is growing rapidly in Asia, on a per capita basis Asian and global consumption remains less than that in North America[16] and Australia. Such discrepancies mean that mitigation of livestock emissions needs to simultaneously tackle severe under-nutrition in some parts of the world.[16, 17]

McMichael and colleagues (2007[18]) propose a working global consumption target of 90g of meat per person per day, down from the current average of 100g for all meats, and necessarily shared more evenly than the current ten-fold variance between populations. They specify that for climate and health advantages to be achieved only 50g per day should come from ruminant livestock. For most consumers in wealthy nations like Australia, a target of 50g of ruminant-sourced meat per day would be a substantial reduction. Although far from all the mitigation effort needed by individuals, if the target was adopted across the population it would represent a 'profound shift in human tastes and sustainable consciousness' (Cribb, 2010, p. 193[19]).

7.1.2.2 Alternative meat sources

Some authors have proposed consumption of alternative, non-ruminant species such as kangaroo, with a simultaneous reduction in the national ruminant herd.[20, 21] Such alternative meat sources face consumer preference barriers and have been challenged on animal welfare grounds. The claims of Wilson and Edwards that macropod meat could replace a significant proportion of current red meat supplies have been disputed.[22] Despite this, macropod meat has gained some acceptance in the Australian market, continues to grow market share and could eventually replace a greater proportion of the traditional red meat supply than it does today.

7.1.2.3 Replacing ruminant protein with plant protein

An element of the scope of this report is that the total food supply for humans should not be reduced. This means that protein from ruminant animals should be substituted by an alternative, plant-based protein source, such as legumes for human consumption. Although an explicit, direct scenario is beyond the scope of this report, the purpose of this section is to show that such a substitution is practical. We recognise that the amino acid content of legumes is not complete and would require supplementation with vegetables, eggs, milk or other carefully chosen foods. The herd and flock reductions proposed in ***Section 5.5*** provide a useful illustration of the potential efficiencies to be gained through such a substitution.

In ***Section 5.5***, we proposed removing an average of 24% of the animals in intensive zone sub-regions and 18% of those in extensive zone sub-regions. These livestock numbers (from both intensive and extensive zones) total 19,982,000 sheep and 4,612,000 cattle. They amount to approximately 26% of the national sheep flock and 16% of cattle.[23] Given that Australia's total production (annual turn-off) is 443,500 t/yr of sheep meat and 2,152,000 t/yr of beef and veal, the removal scenario would reduce, at most, Australia's production of sheep and cattle meat by 115,300 and 344,300 t/yr respectively. In practice, the reduction would be less than this because revegetation would likely involve less productive regions (***Section 5.4***), where turnoff percentages are lower.

These conservative numbers suggest a reduction in meat production of 459,630 t/yr. If an average meat protein content of 22% is assumed,[24] this amounts to 101,119 t/yr of protein. This total protein for human consumption could be substituted by 202,000 ha of grain legumes such as faba beans, chickpeas and soybeans, assuming a yield of only 2 tonne per ha and a grain protein content of 25%.[25]

We recognise that such a translation is an oversimplification and fails to take account of many factors, including the fact that legume crops are particularly sensitive to reduced rainfall and that grazed land is often not amenable to cropping. Furthermore, grazing animals are somewhat more resilient to short reductions in rainfall than seasonal crops. Nevertheless, scientific modeling and analysis indicates that there is ample capacity for such a transformation.

In ***Section 2.2.1.2***, we showed that around 7.5 million ha/yr of cropland is used to supply feed and fodder to animals. Again, it would be a gross generalisation to suggest that all of this land is available for other purposes. Some of the grain fed to animals is deemed not of sufficient quality for human consumption and there are good reasons for feeding some of our grain to animals, including ruminants. We have also assumed reductions only in the number of beef cattle and sheep, not dairy cattle. However, again the numbers suggest spare capacity. Although it is not possible to accurately identify the area of cropland that could be released, if we hypothesise a reduction of 15% in the requirement for feed and fodder crops and apply this to the area under such crops, we still see more than 1.1 Mha of land released from grazing. This number far exceeds the area needed to supply grain protein for human consumption.

We recognise that such proposals as these may meet with considerable cultural and industry resistance. But there are precedents. Zero Carbon Britain 2030[26] recommends a reduction in grazed livestock production of 80—90%, stating:

".. this proposal goes against very strong preferences, powerful vested interests, and an almost universal historical trend towards higher consumption of livestock products. A reduction in grazing livestock is proposed because logic and evidence compel it, not for any other reason."

This acknowledges the high emissions from ruminant livestock in comparison to other agricultural industries. Although Australian agriculture is very different from British Isles, the conclusion that a reduction in animal numbers is necessary for material abatement of the sector's emissions. The ZCB plan concludes that with a sufficiently high carbon price, ruminant products will become a 'niche' market product due to their low carbon efficiency. A price on carbon may be the most easily-applied policy to achieve the reductions necessary while spreading costs across society; though unproven, a regime of direct payments for revegetation may also be able to put downward pressure on animal numbers.

Reducing meat consumption also resonates with other environmental concerns. A recent assessment of the environmental costs of livestock production relative to the planet's environmental boundary conditions suggests that 'the livestock sector alone occupied 52% of humanity's suggested safe operating space for anthropogenic greenhouse gas emissions' and exceeded other boundary conditions (Pelletier and Tyedmers 2010, p.18372[27]).

7.1.3 Maintaining landscape carbon in the long term

Our scenarios assume that landscape sequestration is permanent — 87 years in our calculations — but all carbon sequestered to landscapes as a result of land use changes are at risk of later being emitted as a result of fire, drought or other uncontrolled events. This is true for soil carbon as for carbon in above-ground biomass and poses a barrier to entry to existing carbon farming schemes. Any plan to capture carbon from the atmosphere and store it in the landscape will have to minimise such risks and ensure that they are distributed both spatially and across society, not borne solely by landholders.

Active management to minimise the risk of subsequent re-emission of sequestered carbon will add costs, but would also increase economic opportunities in rural and remote areas. Revegetation and landscape carbon maintenance could go from being minor industries to become significant contributors to rural economies.

7.1.4 Ongoing sequestration in wood and biochar

Australia's forests and woodlands are estimated to be currently storing over 10,000 Mt of carbon. Studies of some regions indicate that this value could be higher. Anthropogenic disturbance, mostly in the form of logging for paper and timber products, is mostly concentrated in the most productive and carbon intensive forests, such as the eucalyptus tall open forests of south eastern Australia. The disturbance of these forests results in a large pulse of carbon being moved from the forest ecosystem to the atmosphere. Much of the wood removed from these forests is assigned to low value commodities, such as woodchips. This is in contrast to much of the agriculture sector, where higher value commodities generate higher incomes for farmers and communities alike. It is proposed in this report that management of these forests take on an adaptive approach.

Where the environmental, social and economic values of the carbon stored in the forest exceeds that of the wood based commodity, these forests must be managed to protect these values. This provides a low cost alternative in land management that would have negligible impact on communities and economies but bring large benefits. In fact, such alternative uses may generate increased income for communities living in and around these forests, where multiple values of the forests benefit a wider range of people in the community, as opposed to these forests being solely managed as a fibre resource for a small number of industry organizations. The added potential of previously degraded land being restored through agroforestry practices can also contribute to a range of positive regional economic and ecosystem outcomes. This is well covered by Nuberg *et al.* (2009[28]).

Harvesting of above-ground biomass from carbon plantations on rotations from years to decades, for example in short rotation woody crop regimes, would allow for repeated sequestration on a given area of land. As long as harvested carbon was permanently sequestered, for example in inert biochar produced for this purpose, this could lead to faster removal of atmospheric carbon than would be achieved in unharvested plantings (***Section 6.4***).

7.1.5 A shared responsibility

While there is a growing body of literature on the need to support producers in their adaptation to climate change (e.g.[29, 30]), there is a pressing need for research on how to support them to make transformational change, abating emissions even as they adapt. Likewise, there is an urgent need for rational debate about where emissions cuts can and should be made, taking into account the relative economic and food values of different products. These are responsibilities our society should accept. Serious effort is needed to establish how primary producers will best be encouraged and assisted to participate in a society-wide climate change mitigation effort.[311]

7.1.5.1 At the market

Consumers can make meaningful impacts through their individual choices but policy will also be important. Market mechanisms are well understood and carbon pricing can be used to increase the price consumers pay for greenhouse-intensive products, permitting market shifts toward products that embody less emissions. Farmers must be able to turn a profit despite carbon constraints and should be supported in their efforts to sequester carbon.

It is possible that this could come about via direct incentives for emissions reductions, sequestration payments or a combination of mechanisms. Although Australia's *Carbon Farming Initiative*[322] does address a limited range of emissions abatement and bio-sequestration options, a more comprehensive approach could envision landscapes as not only a source of emissions but as a tool for remediation of present and historic climate damage.

At present, current management practices of clearfell logging native forests comes at a cost to the Victorian community, whereby state owned logging enterprises are either subsidised by the respective governments or they do not pay dividends to the community for using and extracting a publicly owned asset. Victorian taxpayers extend generous assistance to the clearfell native forest logging industry. Despite this, the industry makes only marginal profit. This contrasts strongly with the situation in South Australia, where plantation forestry returns both consistent financial and employment dividends and long-term sustainable wood and fibre. The removal of subsidised support for clearfell native forest logging would very likely translate into opportunities in other parts of the rural landscape, including farm forestry and manufacturing based on crop residues.

7.1.5.2 On the land

Australian farmers cope with drought, floods, pests, disease, competition from cheap imports, market and buyer price pressure, changing consumer preferences, government regulation, and natural resource conservation demands. Our farmers are among the world's best for productivity and efficiency. Many producers face large capital expenditure and a reliance on corporate priorities, as well as marginal profitability and exposure to large risks.

To our demands for quality food, we must now add a requirement to take on the climate problem 'at the coal face', and a fair day's pay must be offered in exchange. Farmers and graziers know their land, have the right to decide how that land is used and have the equipment, ingenuity and work ethic to get the job done. Rural Australians will be a crucial human resource as we tackle climate change

Climate change itself has exacted a severe cost on farmers and rural communities, imposing acute stress and testing resilience.[333, 344] Although many producers are confident they will adapt to climate change, the resilience of the Australian landscape itself has been severely reduced. Land degradation, soil carbon loss and other impacts of grazing, cropping and severe drought, and have both exacerbated climate change and made the land more vulnerable.

7.1.5.3 At home and abroad

All participants in food supply chains should accept responsibility for minimising the climate and other environmental impacts of the farming methods they promote. Supermarkets trade heavily on the concept of 'natural capital', and are hugely influential in Australian food markets. They could also play a part protecting our common natural capital, both by encouraging climate- and environment-friendly farming practices and by communicating this fact. For example, price fluctuations that ultimately reflect responsible landscape management (e.g. livestock reductions in droughts) should be passed from the landholder to the consumer as inherent to the production of food. This would allow farming for quality food as well as optimal land condition and carbon results, not simply to make ends meet in a market where most farmers are price takers.

The effect of agricultural exports, where land use in one country is appropriated by another has been characterised as a trade in 'virtual land'.[355] The emissions and other externalities of our current suite of land uses can also be seen in this way. Exported beef constitutes about 70% of national production[366] and places a significant emissions burden on Australia. Live exports comprise 8% of our total exported beef and together with sheep and goats earned just $836m in 2010.[377] These industries occupy vast tracts of land, earn low revenues per unit area, and are largely controlled by corporate or offshore interests. In fact, they cost us far more than they earn, as discussed above.

Unlike those from fossil fuel exports, export meat production emissions are realised within the Australian landscape and economy. This means that countries importing Australian meat, like domestic consumers, derive the product benefit without acknowledgement of or liability for its climate effects. Apart from avoiding greenhouse liabilities, importing nations also avoid the heavy costs of soil loss and degradation and biodiversity loss built into products. It is crucial that Australia recognise these costs and factor them into cost/benefit analyses of agricultural industries.

7.2 Conclusions

This report has shown that it is possible to alter current land uses to achieve zero emissions from the Australian land use sector. Numerous management options are available at local and regional level. As well as mitigating climate change, these have the potential to maintain or improve rural productivity and livelihoods. Such a transformation will require some changes to the way land use change is encouraged and rewarded. In some cases, we will have to pay to get carbon into landscapes and keep it there. In others, leaving ecosystem carbon intact will save money.

For the best climate outcomes, decisions regarding land use change should be made on the basis of the best available science and comprehensively assess the climate impacts of current and proposed land uses, as well as the economic and food values of rural production. Decisions should highly value rural landholders' knowledge and be aimed at minimising both climate risks and opportunity costs. Efforts to implement change should be rewarded, and the inherent risks shared across all of society. These are significant policy challenges.

Australia should work to develop a framework for land use decisions with the best possible climate change mitigation outcome prioritised. Such a framework should include the following principles, some of which will entail a serious and dedicated research effort:

- Aim for a legitimately zero-carbon economy, including land uses, with recognition that offsets in the land use sector are valid only if the land use sector itself is already carbon neutral.
- Adopt native forest management regimes that reflect the magnitude and importance of forest carbon stocks.
- Adopt comprehensive accounting protocols that reflect and make visible the true impact of land clearing. Cease land clearing for agriculture.
- Adopt savanna management methods specifically aimed at minimising greenhouse emissions and maximising savanna carbon stocks.
- Implement available technologies and management to reduce methane and nitrous oxide emissions from agricultural sources. Maximise win-win opportunities across climate, energy and rural livelihoods, for example by converting methane to usable energy.
- Assess rural greenhouse emissions region by region and undertake revegetation such that emissions are reduced as far as possible and residual emissions balanced by sequestration on a regional basis throughout Australia.
- Monitor and mitigate against risks entailed in land use change, such that perverse outcomes for climate are avoided.
- Develop a well-designed and workable scheme to monitor soil carbon fluxes, and orient rural land use practices to achieving verifiable soil carbon improvements, without claiming undue offsets for other economic sectors.
- Investigate biochar as a method of effecting ongoing withdrawals of carbon dioxide from the atmosphere, with downstream benefits from the production process. Feedstocks would not be sourced from natural ecosystems, but form part of a broad landscape restoration policy for cleared and heavily modified land.
- Promote in international negotiations the objective of greenhouse emissions accounting which is both comprehensive and conservative with respect to risk.
- Prioritise action to cut shorter-lived climate forcing emissions — methane, black carbon and ozone precursors — and promote this strategy in international negotiations.

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