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

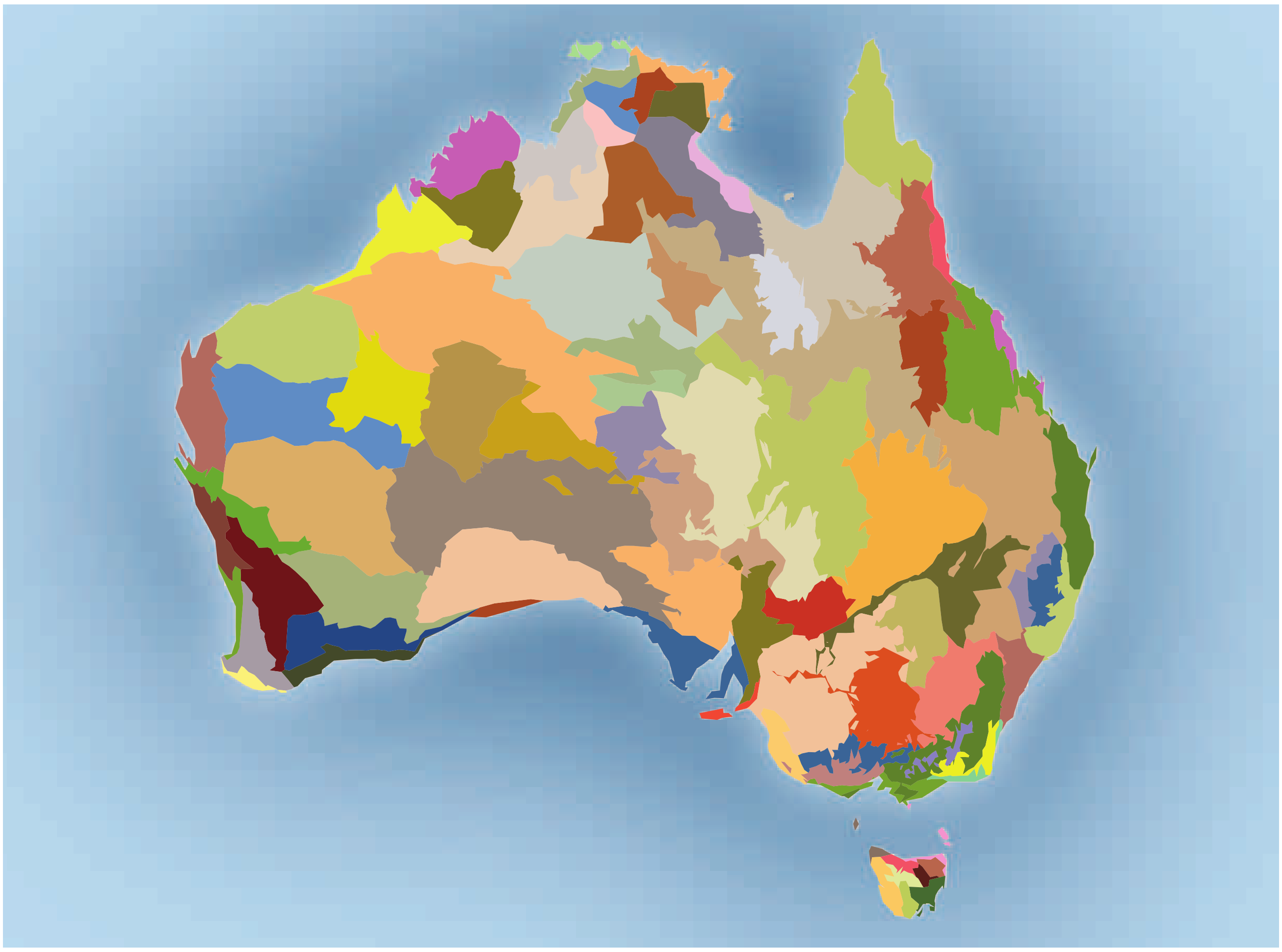

Fig 5.1 IBRA Biogeographical regions.[1] Regions are here differentiated by random colours.

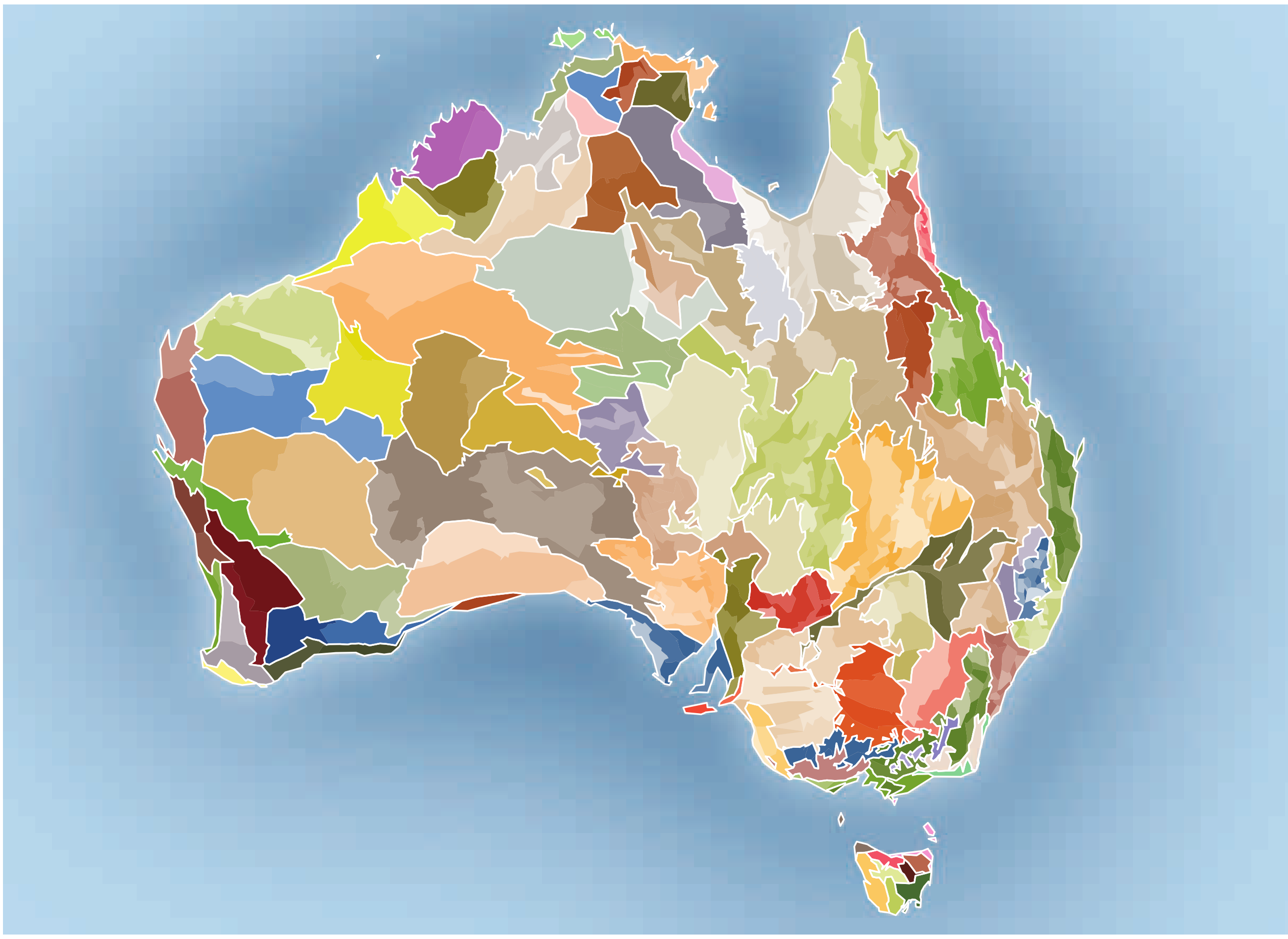

Figure 5.2 IBRA Biogeographical sub-regions.[1] Sub-regions are here differentiated by random colours.

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

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

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.

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.

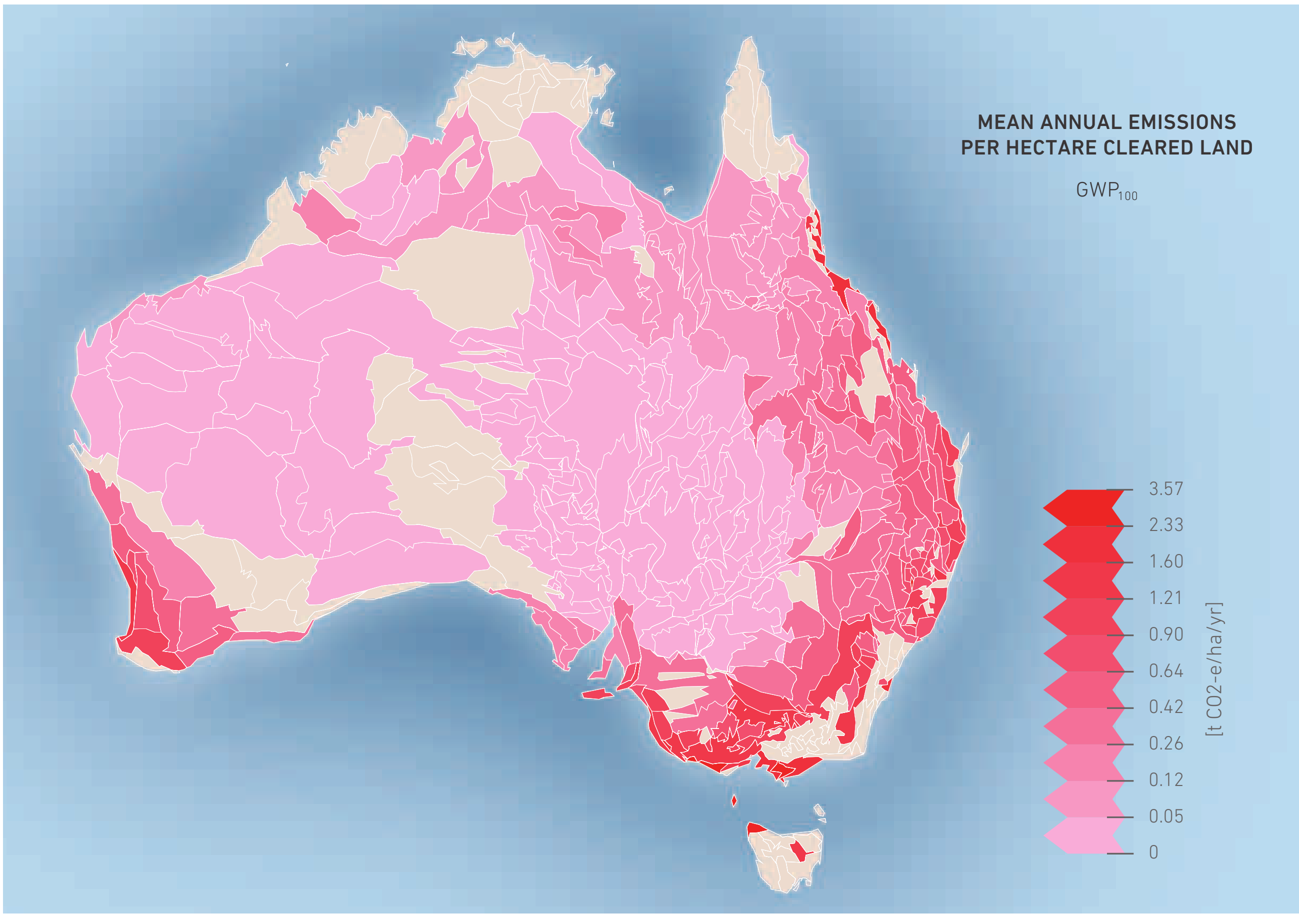

Figure 5.6 Intensive and extensive zones in 300 IBRA sub-bioregions.

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

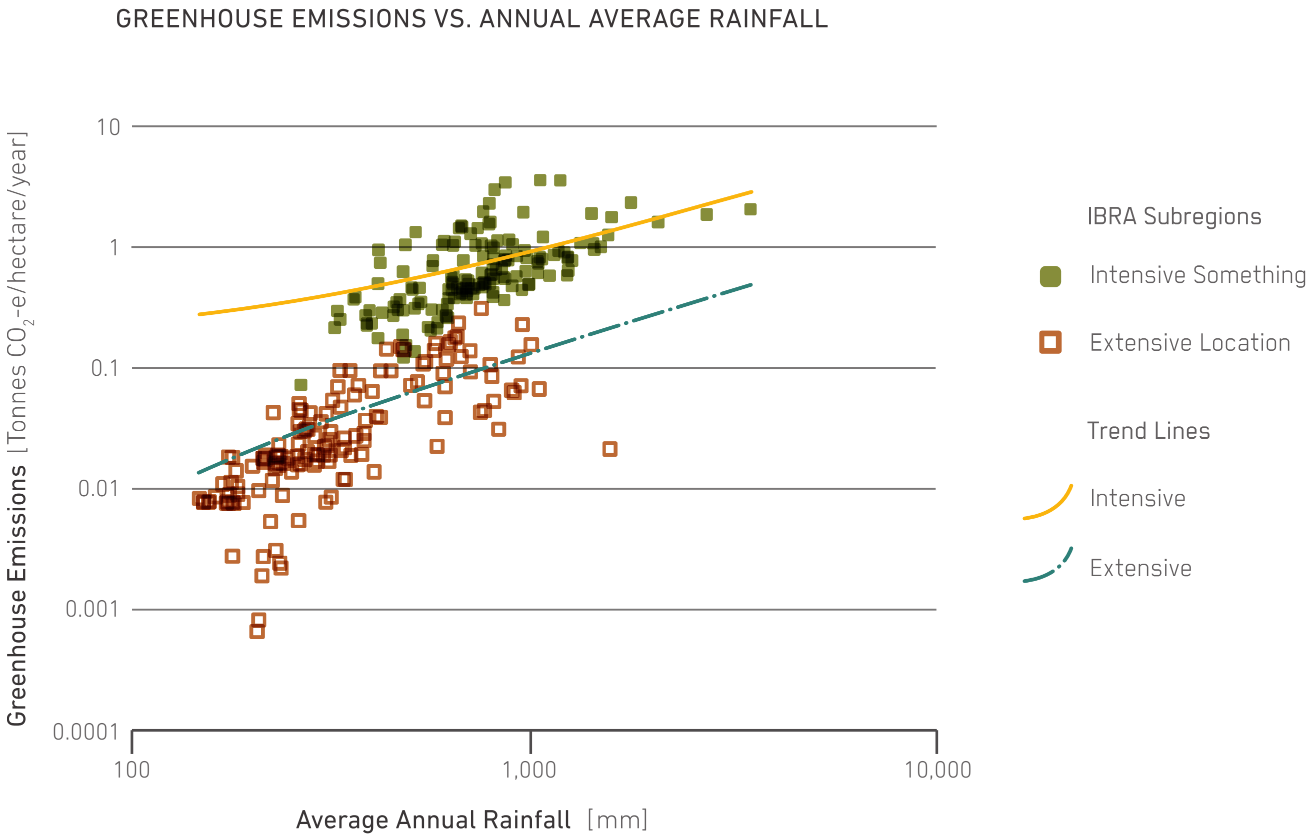

Figure 5.7 Mean annual greenhouse emissions at GWP_{100} (t CO_2-e/ha/yr) from agriculture on cleared land in intensive (n=154, b=1.1147, t_{152}=10.54, p<<0.01, r^2=0.4221) and extensive zones (n=146, b=1.6629, t_{144}=13.18, p<<0.01, r^2=0.5467), against average annual rainfall.

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].

Zone	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

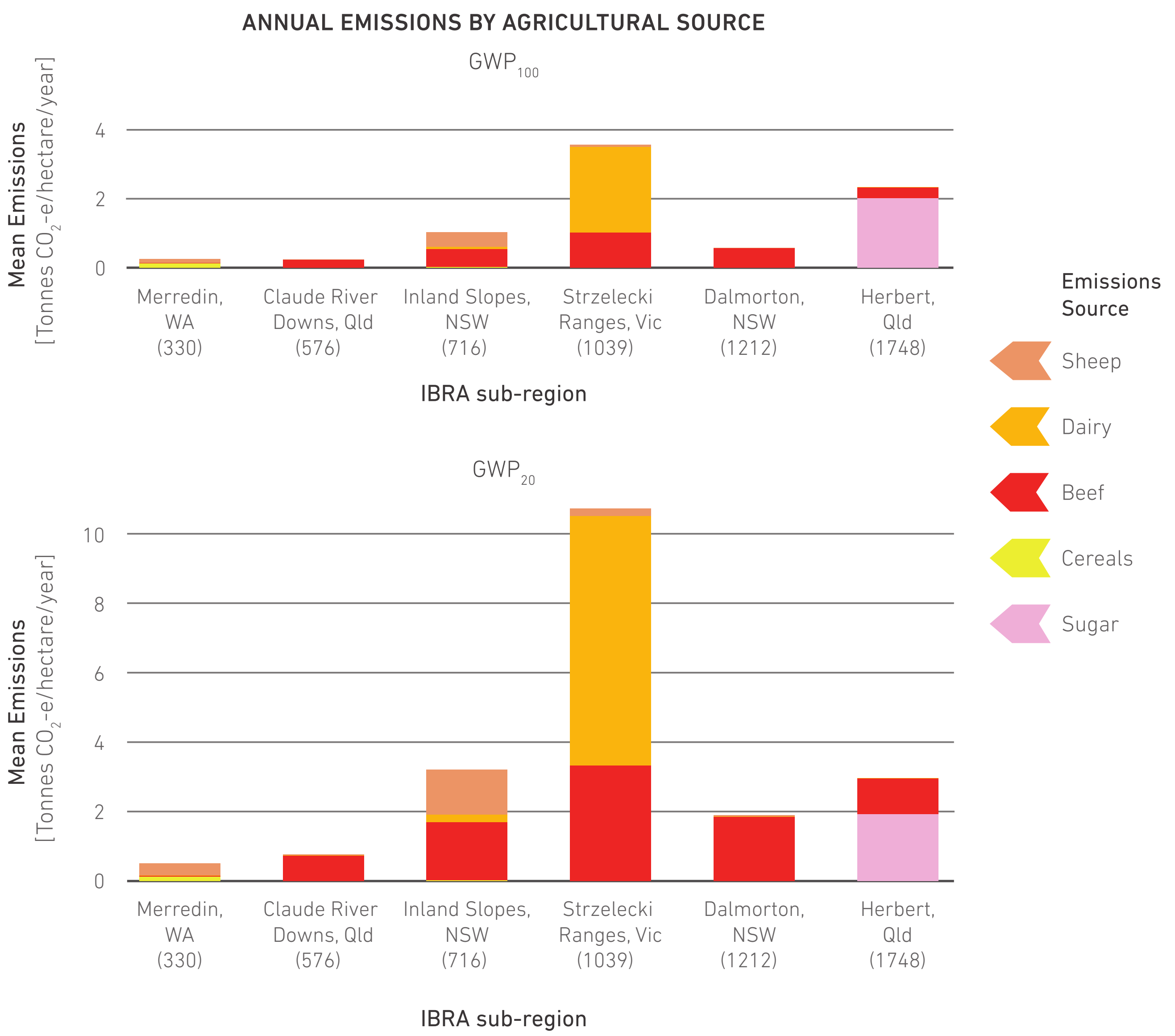

Figure 5.8 Annual emissions from agricultural sources in each of six sample IBRA sub-regions in the intensive agricultural zone. Numbers in parentheses are average annual rainfall (mm).

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

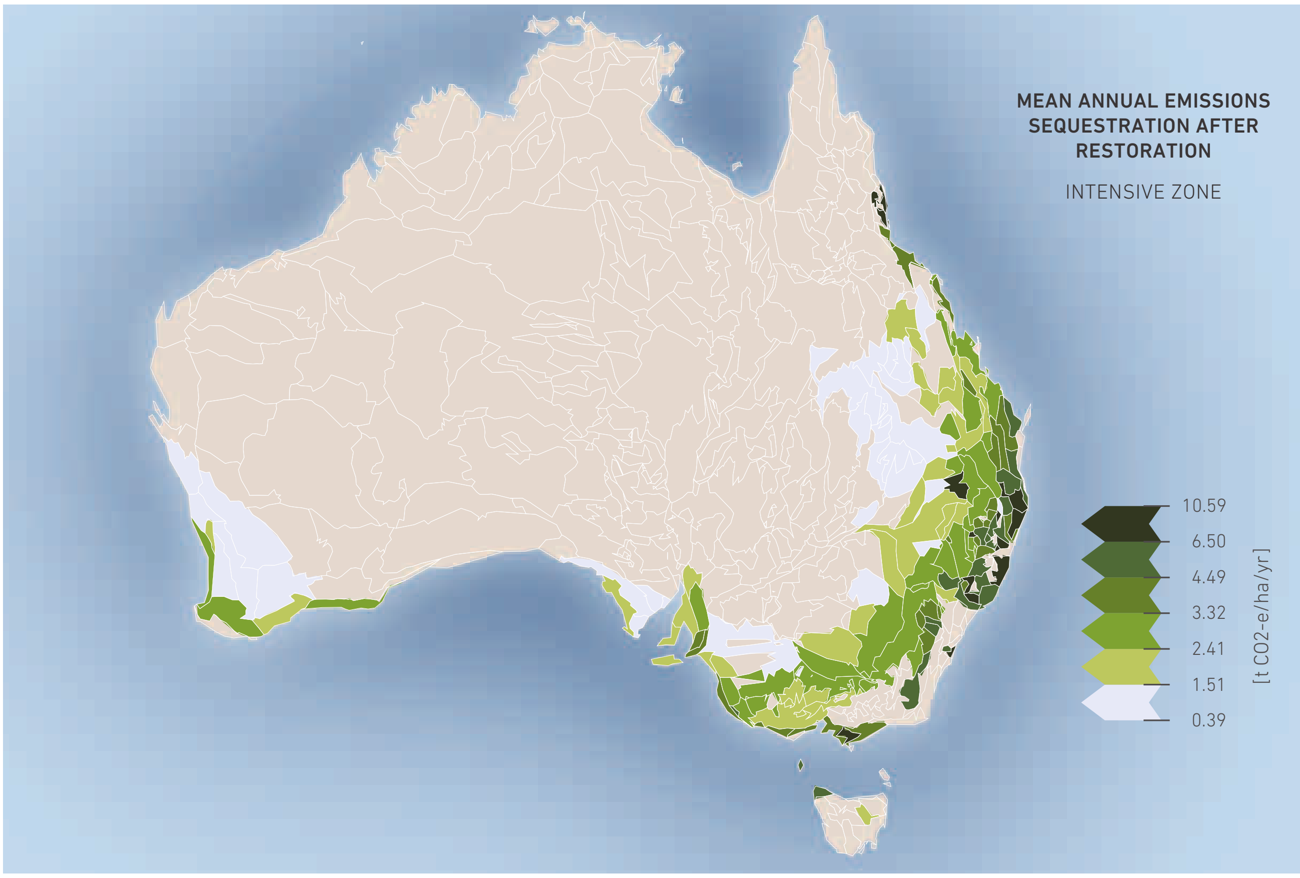

Figure 5.9 Intensive zone: sequestration potential after restoration, as modelled with FullCAM.

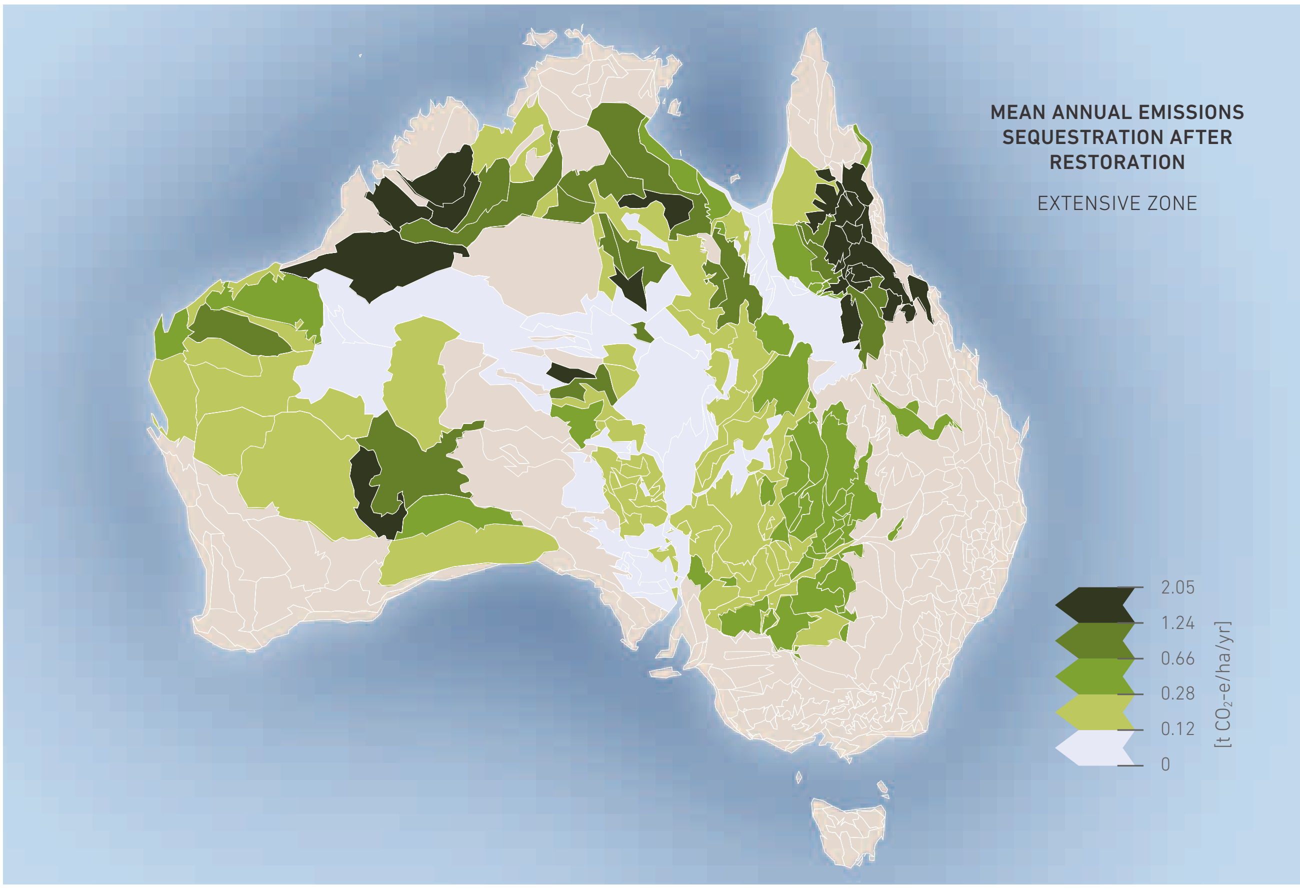

Figure 5.10 Extensive zone: sequestration potential after restoration, as modelled with RangeAssess.

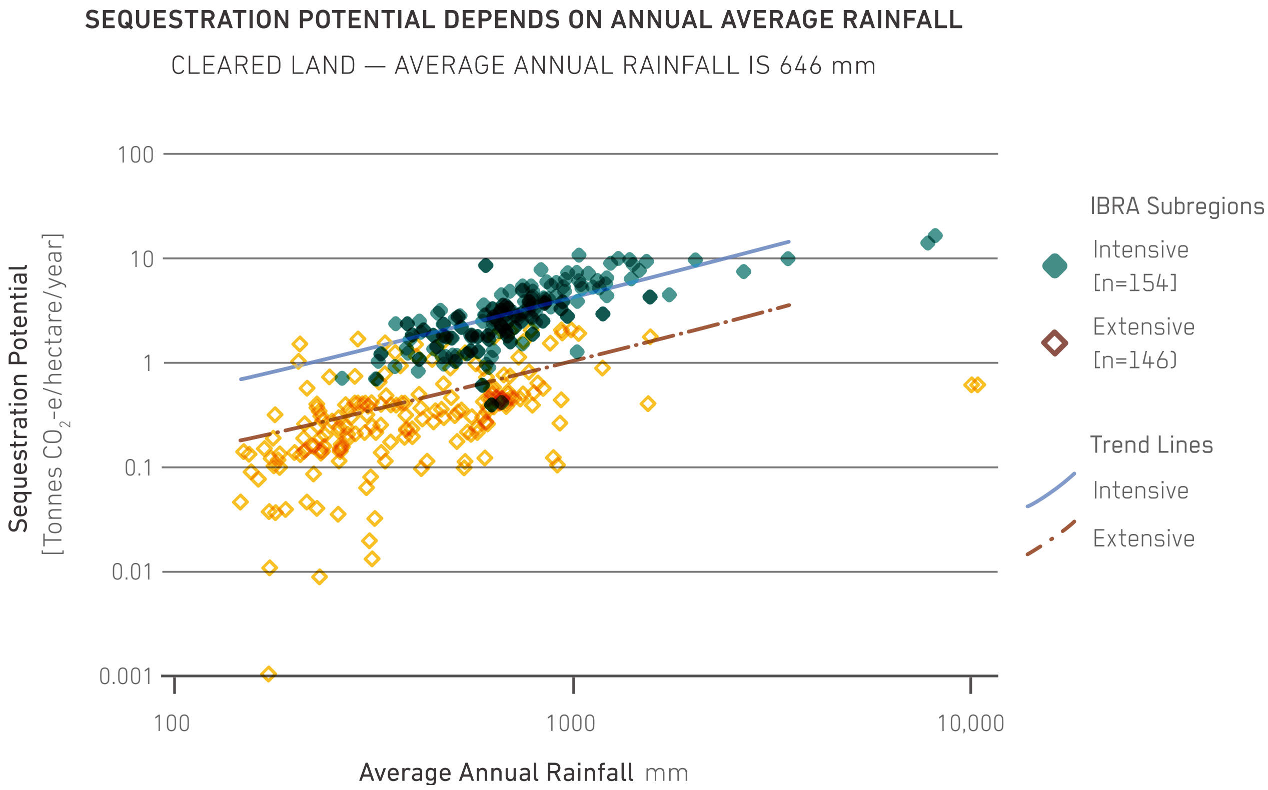

Figure 5.11 Sequestration potential of cleared land vs. rainfall in intensive and extensive zones.

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	Sequestration potential after restoration [t CO_2/ha/yr] 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

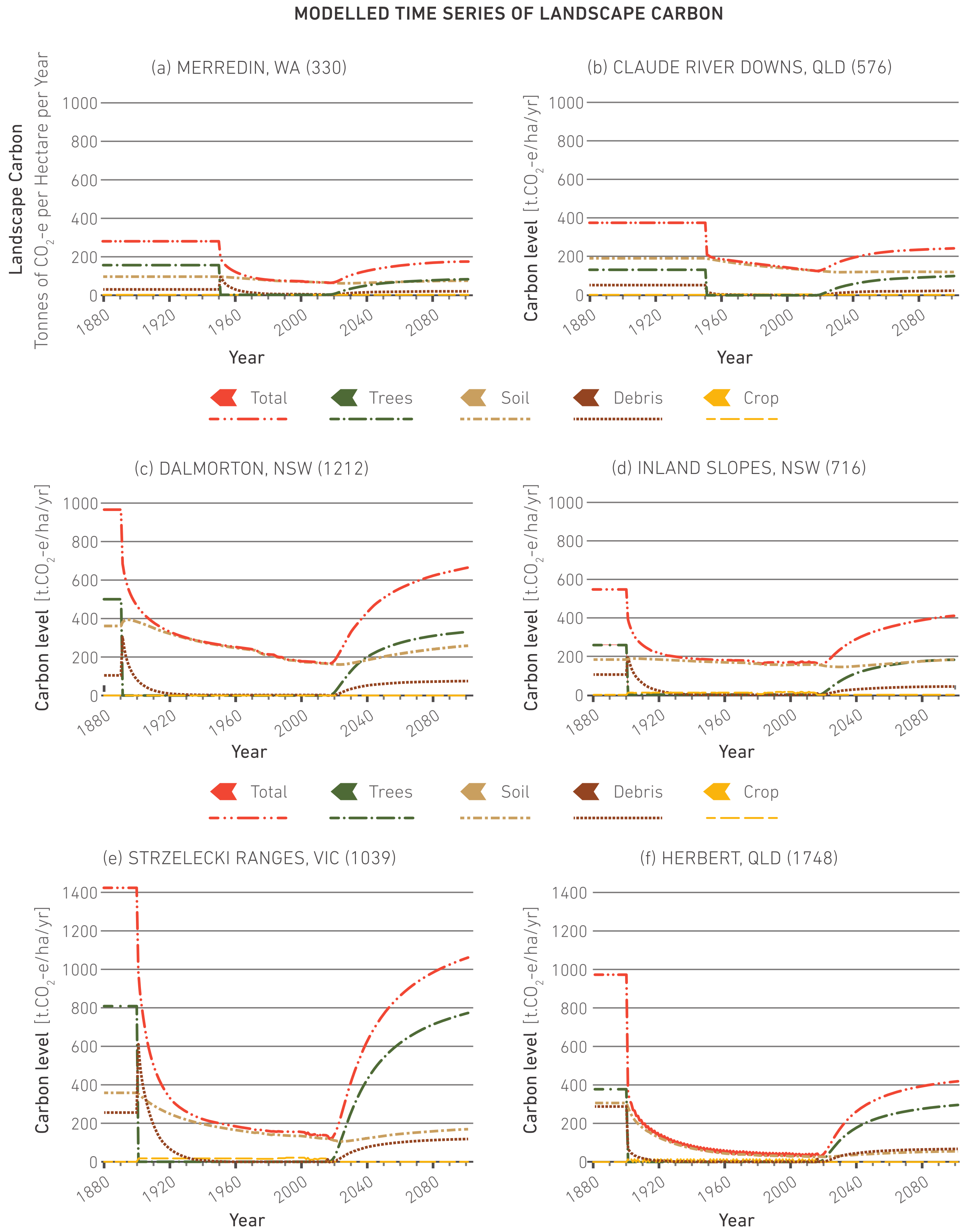

Figure 5.12 Modelled time-series of landscape carbon (t CO_2 e/ha) for a sample of six IBRA sub-regions in the intensive agricultural zone, from pre-disturbance times through forest or woodland clearance, period of agricultural or other use then accumulation in vegetation, soil and debris after restoration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

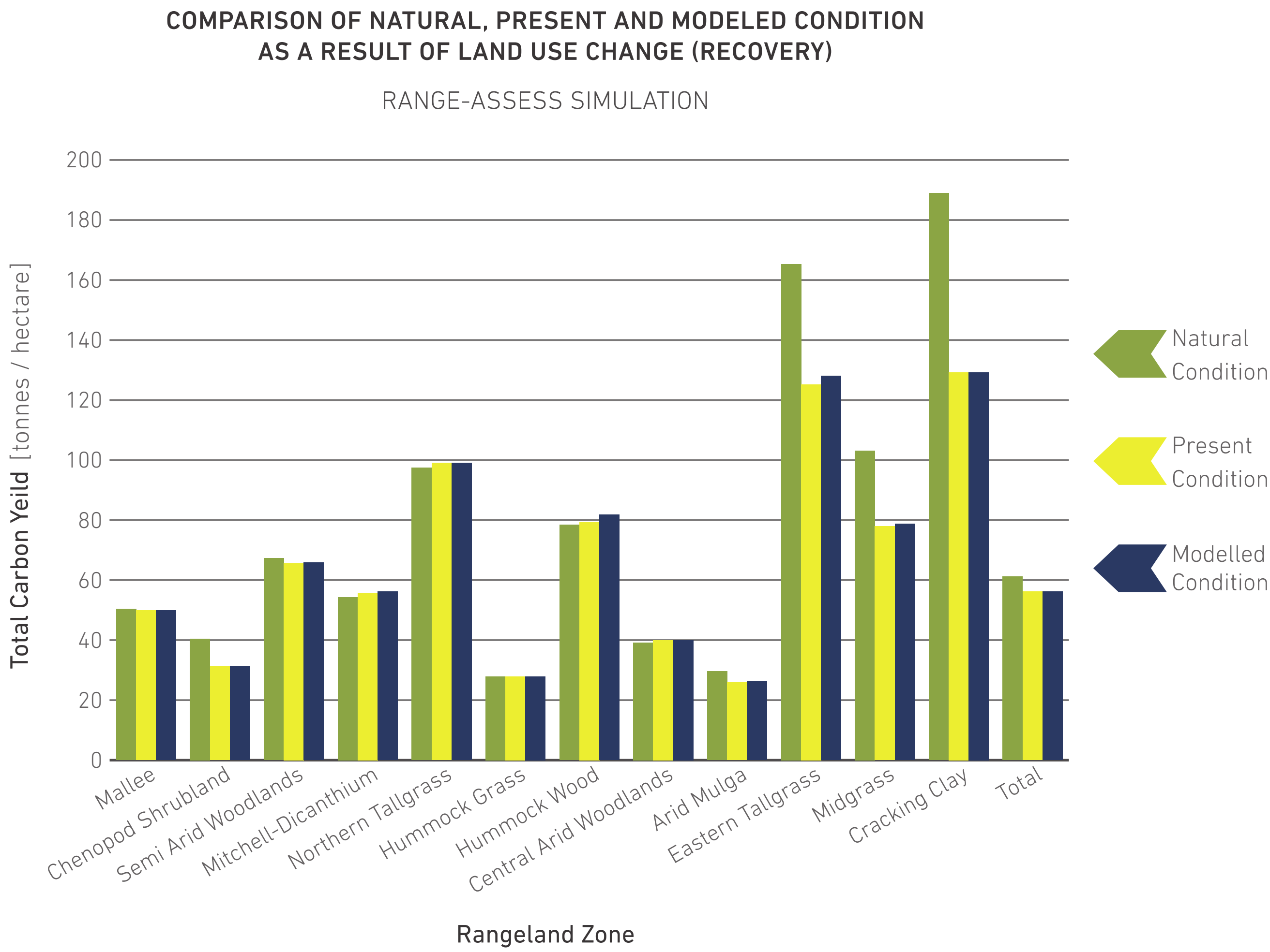

Figure 5.13 Results of the RangeASSESS simulation comparing natural condition with present condition and modeled condition, as a result of land use change (recovery).

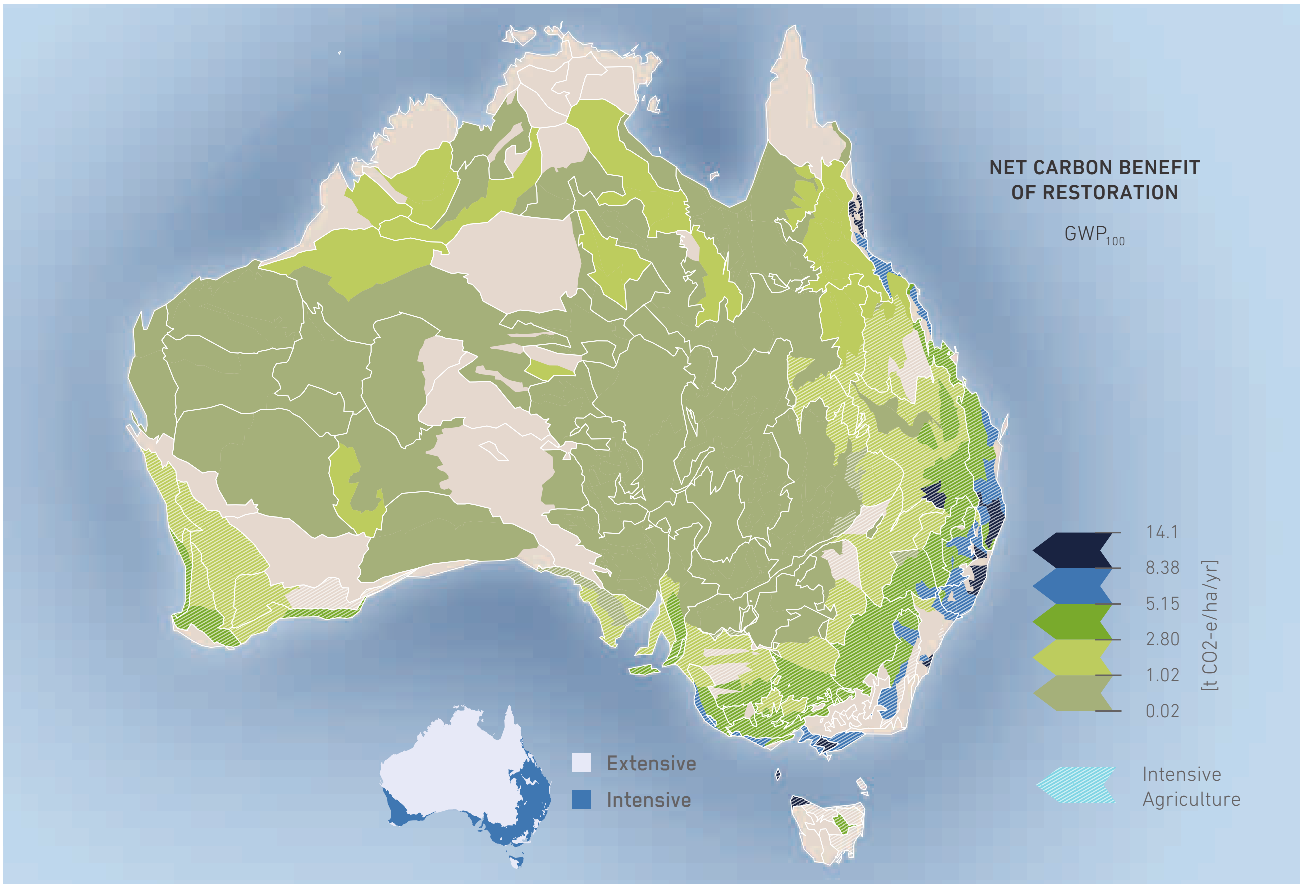

Figure 5.14 Net carbon benefit of restoration (t CO_2-e/ha/yr) in 300 IBRA sub-bioregions when agricultural emissions are measured at GWP_{100}.

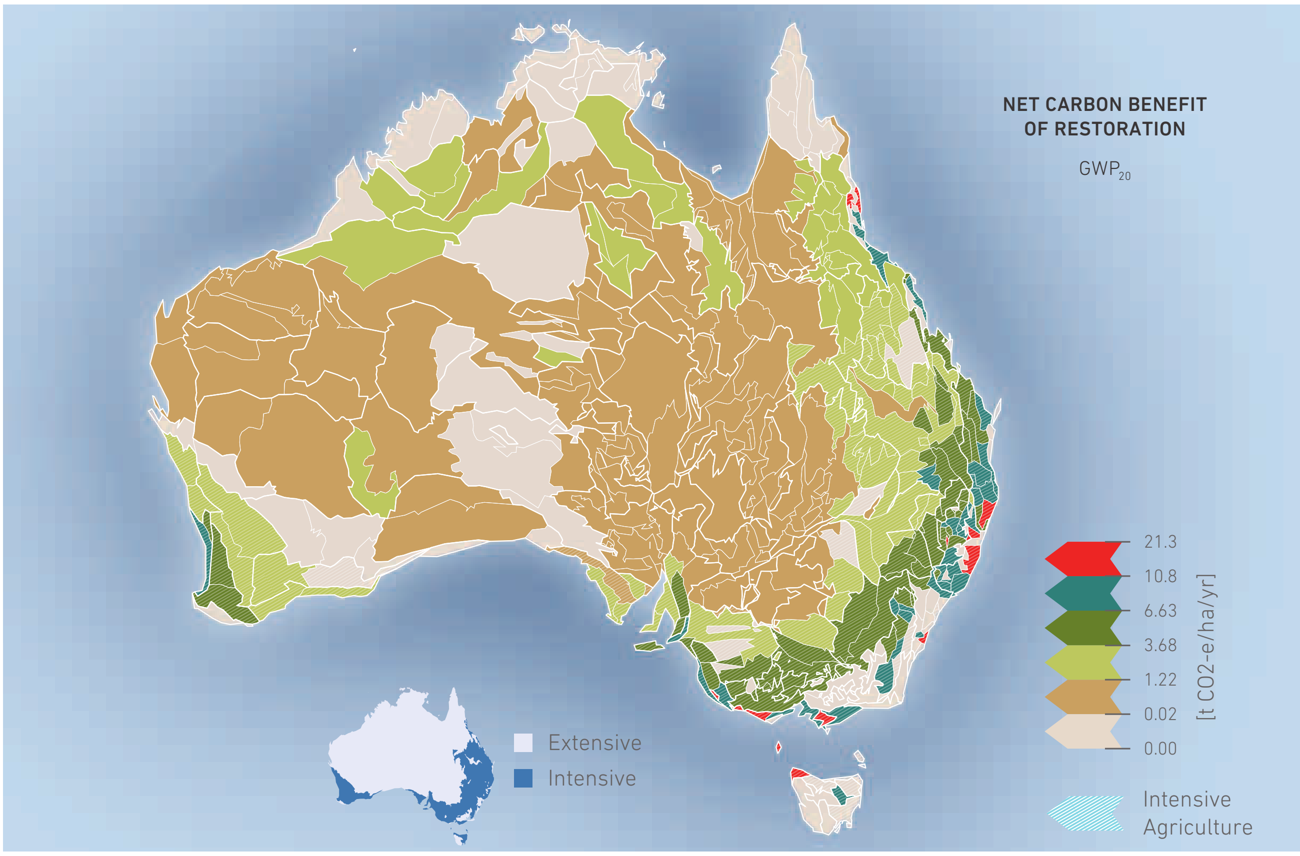

Figure 5.15 Net carbon benefit of restoration (t CO_2-e/ha/yr) in 300 IBRA sub-bioregions when agricultural emissions are measured at GWP_{20}.

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***.

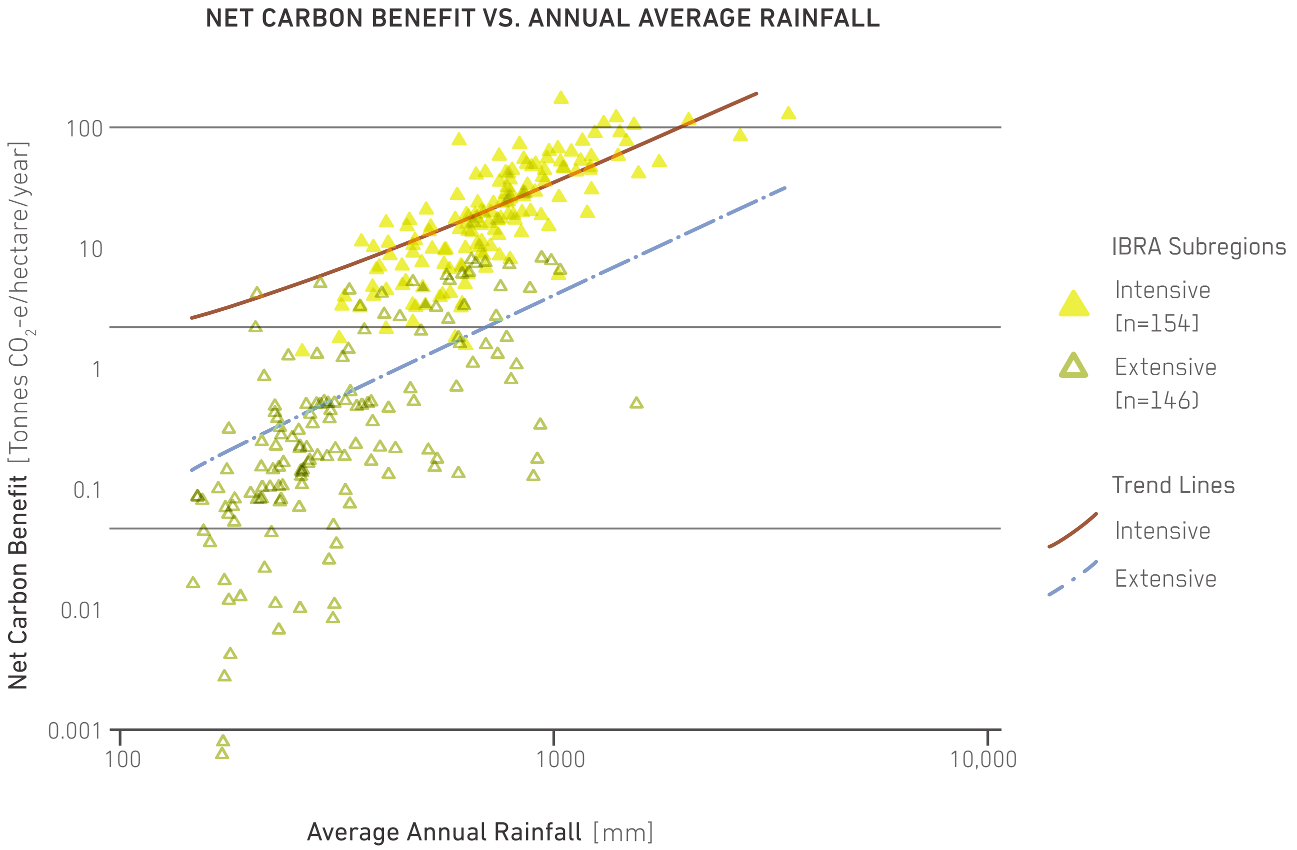

Figure 5.16 **Mean annual net carbon benefit (t CO_2-e/ha/yr) associated with a change from current land use to carbon forestry on cleared land, against average annual rainfall (AAR; mm), in intensive (n=154) and extensive zones (n=146).**

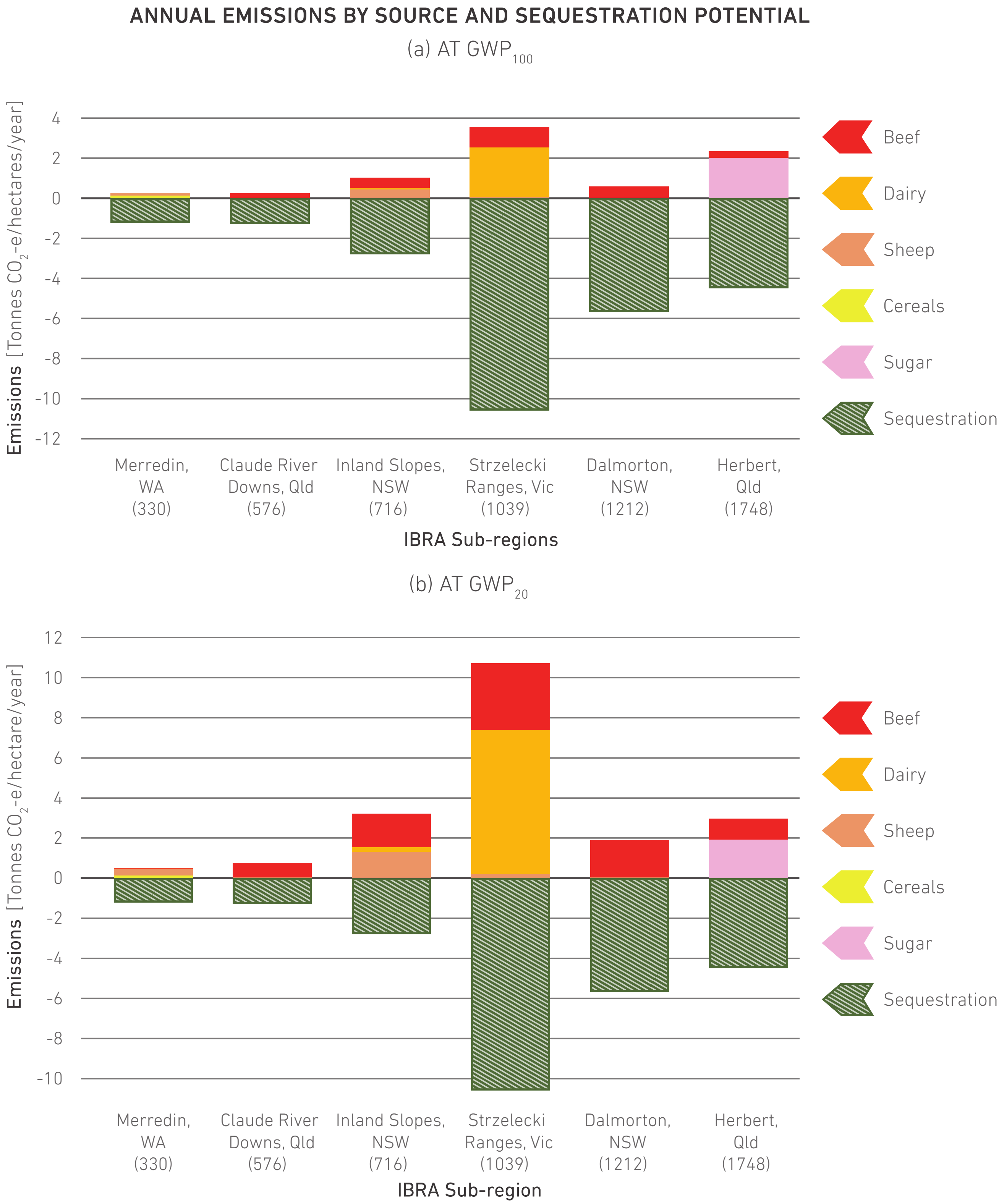

Figure 5.17 **Annual emissions by source at GWP_{100} (a) and GWP_{20} (b) and sequestration potential (t CO_2-e/ha/yr) of a representative cleared hectare in each of a sample of IBRA sub-regions. Numbers in parentheses are average annual rainfall (mm).**

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

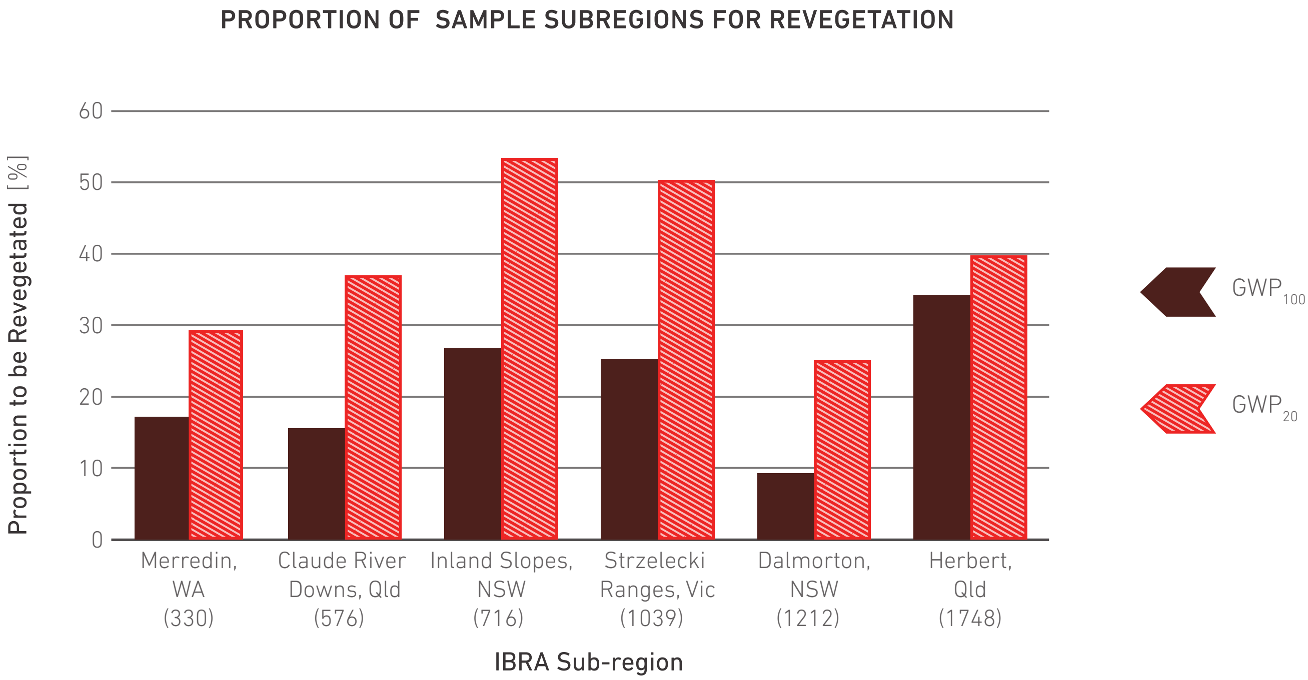

Figure 5.18 Proportion (%) of six sample IBRA sub-regions to be revegetated to reduce and offset emissions under GWP_{100} and GWP_{20}. Numbers in parentheses are average annual rainfall (mm).

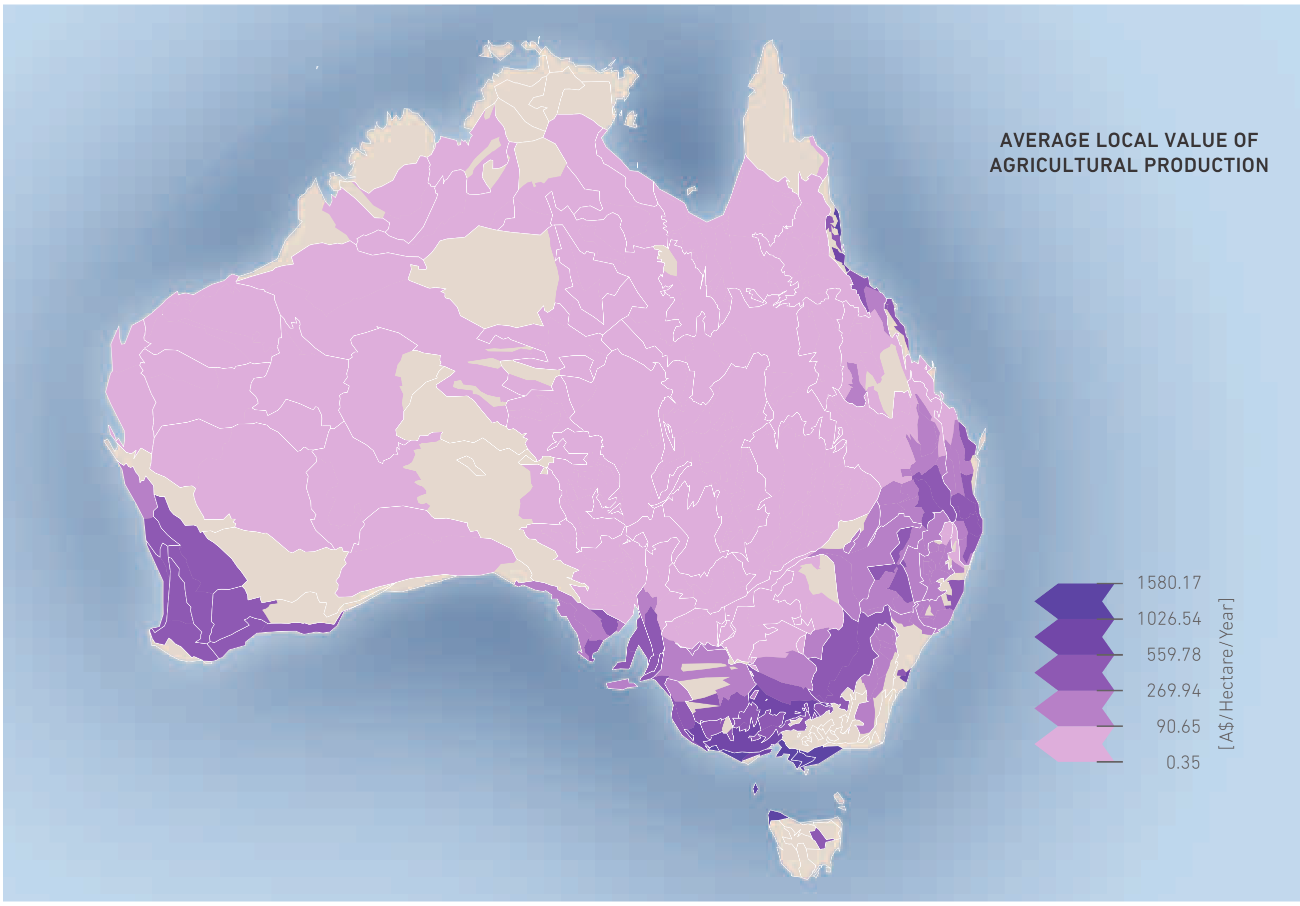

Figure 5.19 Mean local value of agricultural production on cleared or heavily modified land in 300 agriculturally productive IBRA sub-regions.

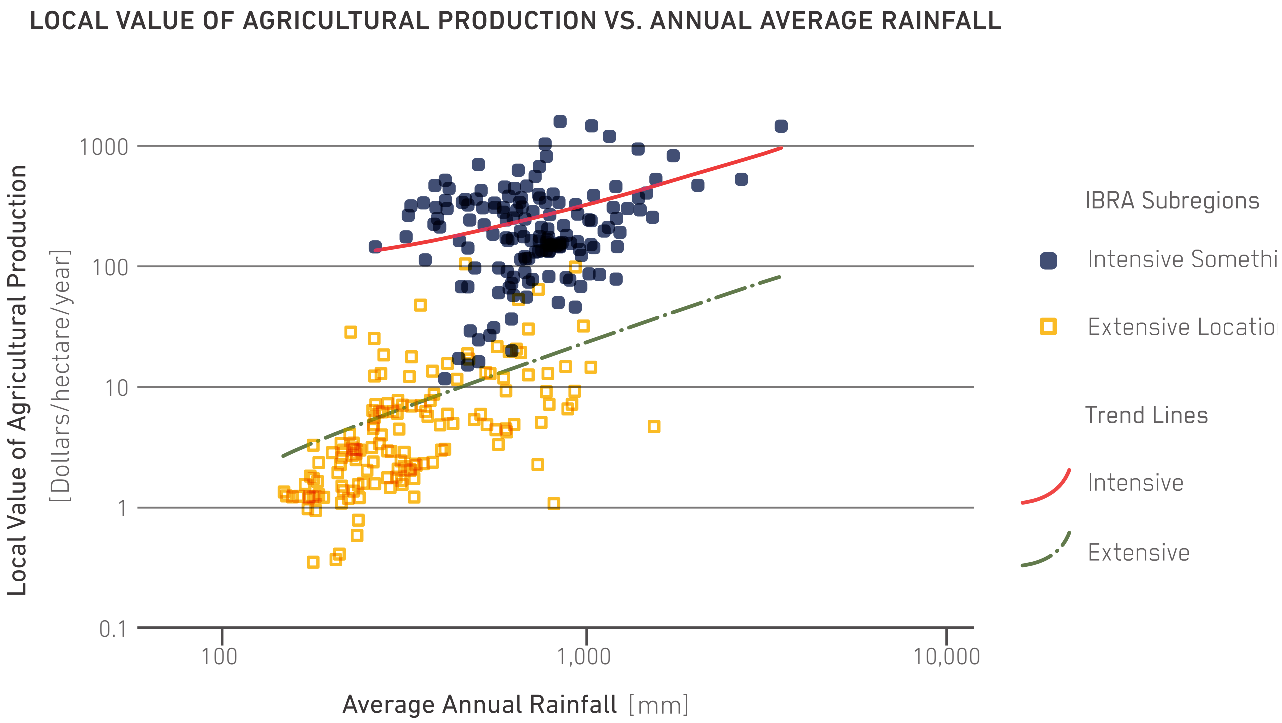

Figure 5.20 **Local Value of Agricultural Production (LVAP; $/ha/yr) on cleared land against Average Annual Rainfall (AAR) [mm] in intensive (n=154) and extensive zones (n=146).**

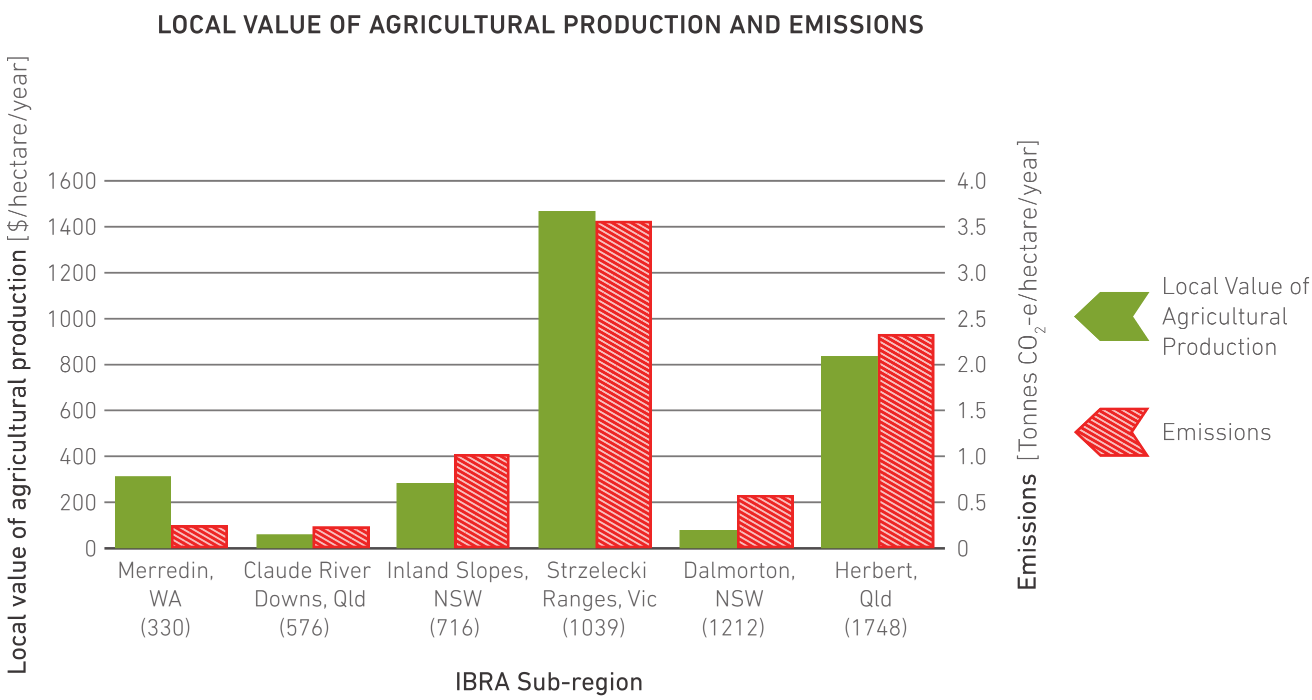

Figure 5.21 **Local Value of Agricultural production (LVAP) [$/ha/yr] and emissions (t CO_2-e/ha/yr at GWP_{100}) for six sample IBRA sub-regions. Numbers in parentheses are average annual rainfall (mm).**

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.

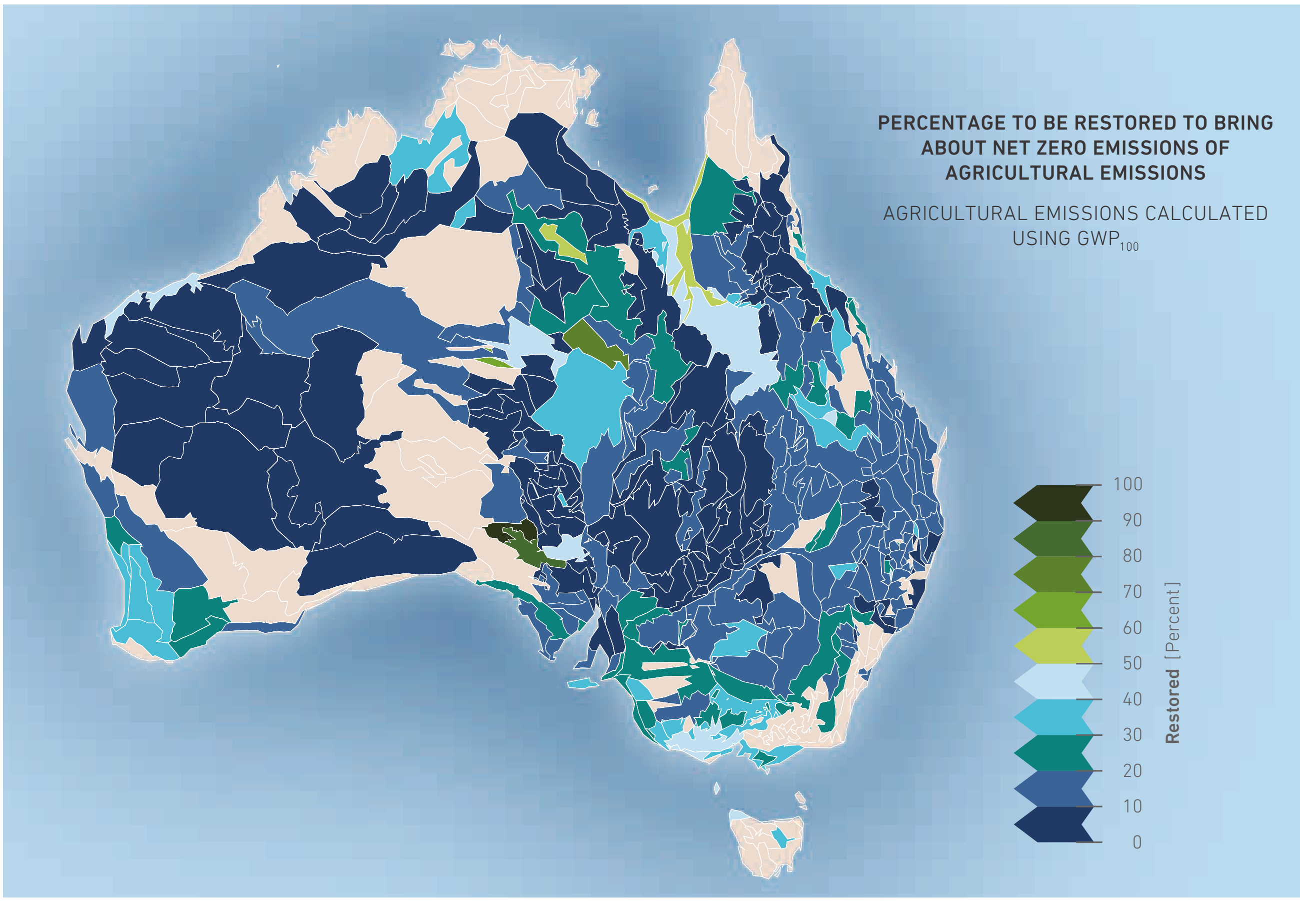

Figure 5.22 Percentage of 300 agriculturally-active IBRA sub-bioregions to be restored to bring about net zero emissions from agriculture, based on emissions profiling at GWP_{100}.

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.

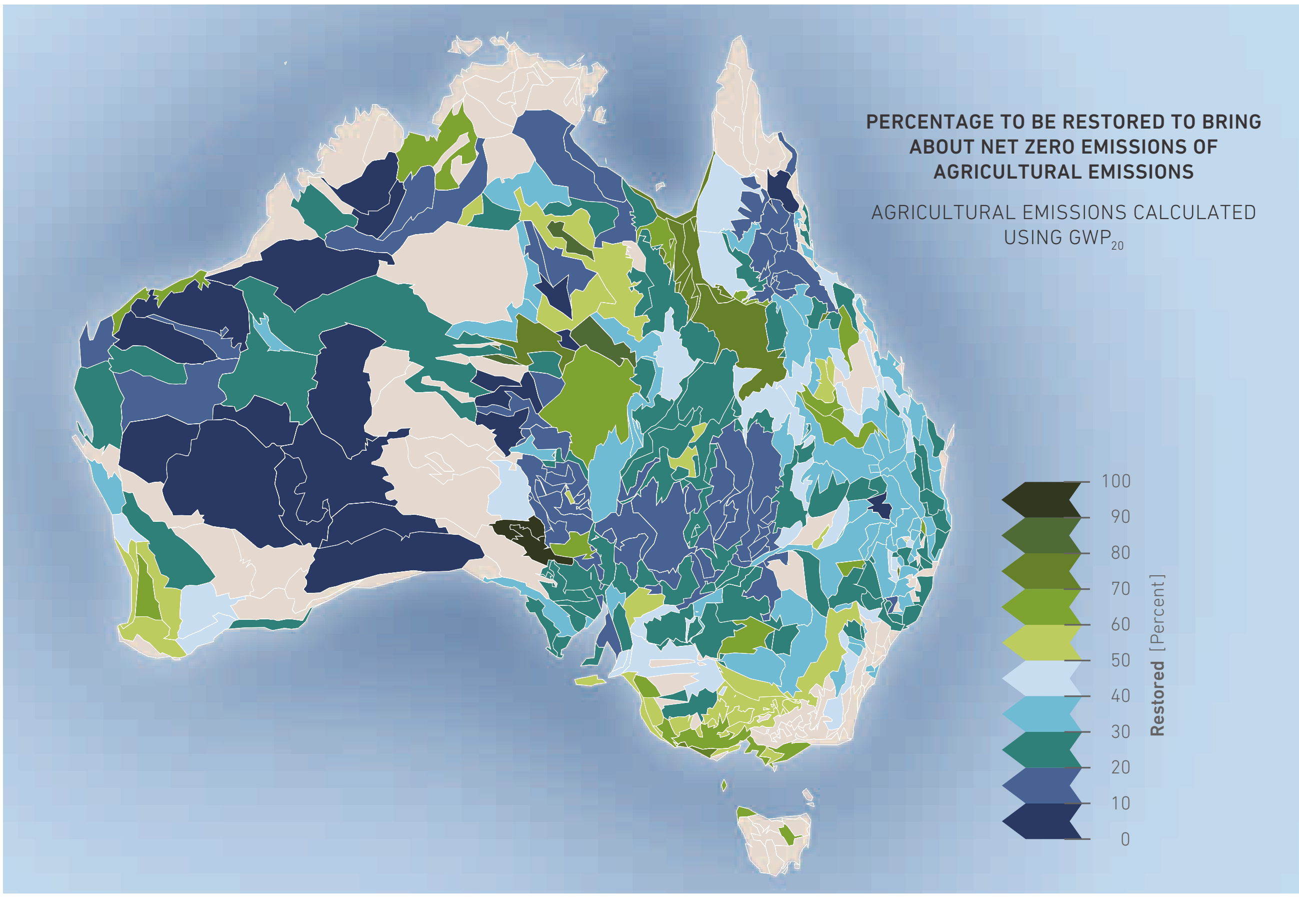

Fig. 5.23 Percentage of 300 agriculturally-active IBRA sub-bioregions to be restored to bring about net zero emissions from agriculture, based on emissions profiling at GWP_{20}.

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% (≈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].

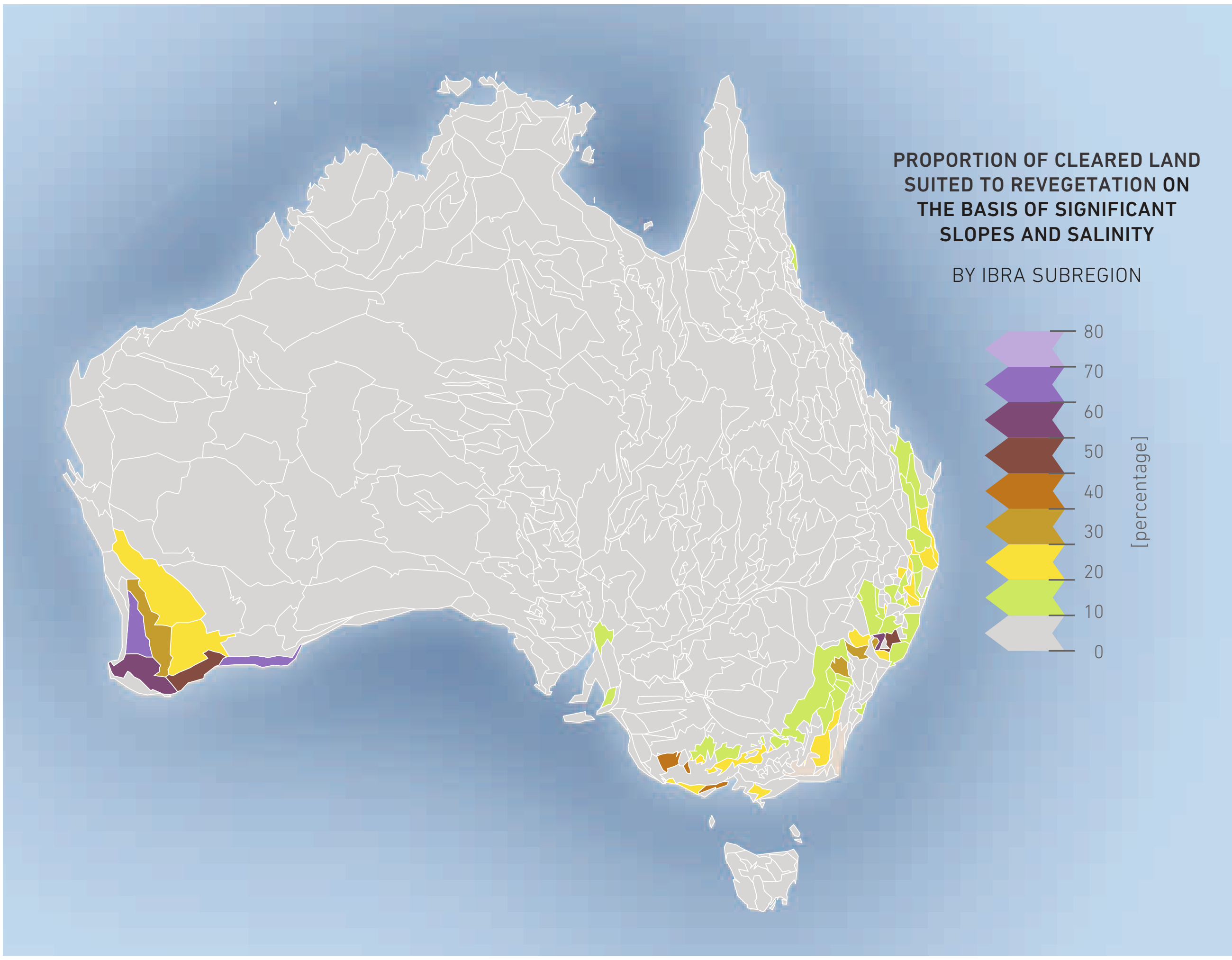

Figure 5.24 Proportion of IBRA sub-regions suitable for revegetation on the basis of high salinity risk and steep slopes.

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 (ha)	Cleared steep slopes (%)	Cleared and at risk of salinity (ha)	Cleared and at risk of salinity (%)	Total Area for Revegetation (salinity + slope) (ha)	Total Area for Revegetation (salinity + slope) (%)	Restored for zero carbon outcome [%]
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.

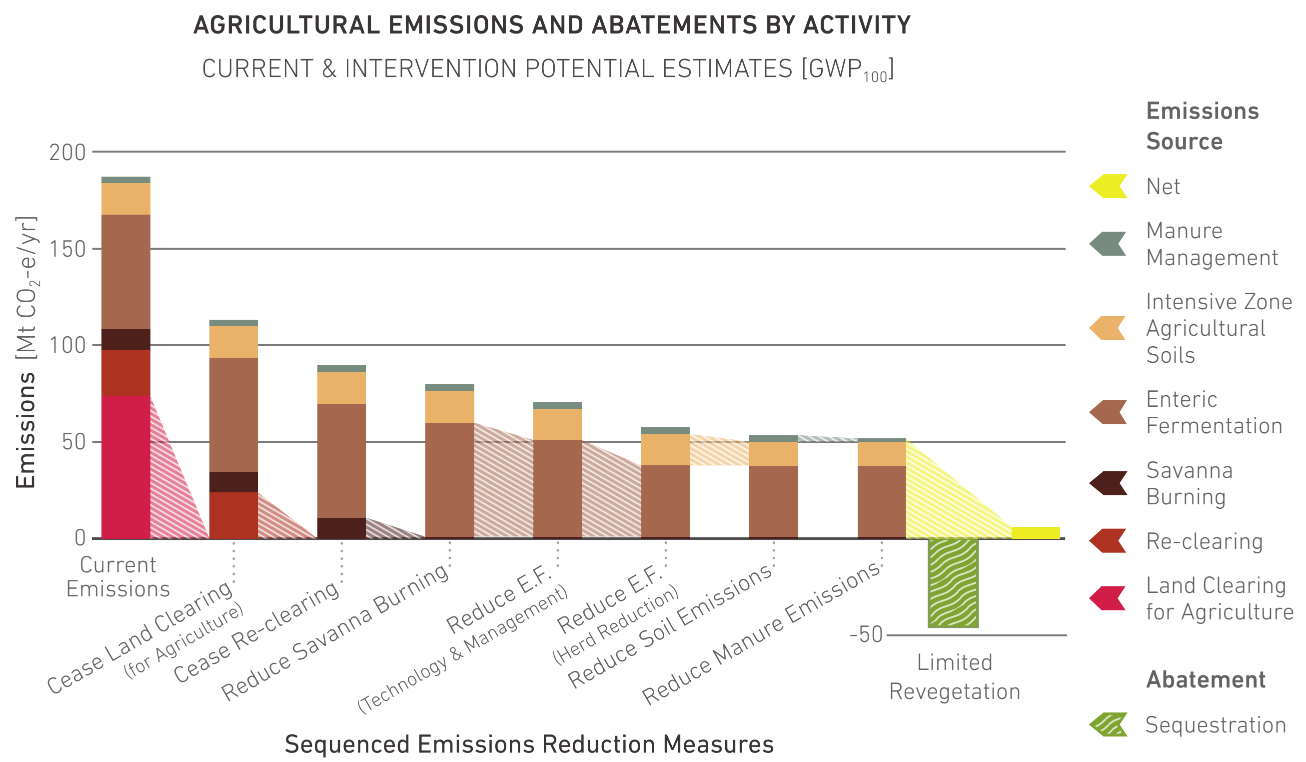

Figure 6.3 Sequenced reduction in greenhouse gas emissions from changes to agricultural activities.

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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