ACIL ALLEN CONSULTING

REPORT TO
THE DEPARTMENT OF JOBS, PRECINCTS AND REGIONS
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SUPPORTING AGRICULTURE TO ADAPT TO CLIMATE CHANGE

STREAM 1: UNDERSTANDING CLIMATE CHANGE AND CURRENT APPROACHES

FINAL REPORT

ACIL ALLEN CONSULTING PTY LTD
ABN 68 102 652 148

LEVEL NINE
60 COLLINS STREET
MELBOURNE VIC 3000
AUSTRALIA
T+61 3 8650 6000
F+61 3 9654 6363

LEVEL ONE
50 PITT STREET
SYDNEY NSW 2000
AUSTRALIA
T+61 2 8272 5100
F+61 2 9247 2455

LEVEL FIFTEEN
127 CREEK STREET
BRISBANE QLD 4000
AUSTRALIA
T+61 7 3009 8700
F+61 7 3009 8799

LEVEL ONE
15 LONDON CIRCUIT
CANBERRA ACT 2600
AUSTRALIA
T+61 2 6103 8200
F+61 2 6103 8233

LEVEL TWELVE, BGC CENTRE
28 THE ESPLANADE
PERTH WA 6000
AUSTRALIA
T+61 8 9449 9600
F+61 8 9322 3955

167 FLINDERS STREET
ADELAIDE SA 5000
AUSTRALIA
T +61 8 8122 4965

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EXECUTIVE SUMMARY

In April 2018, the Agriculture Ministers' Forum (AGMIN) agreed on the importance of ongoing cooperation between governments to support adaptation to climate change and in managing emissions in agriculture. Ministers agreed to develop proposed actions and a work program to inform the development of a coordinated national approach to adaptation to climate change and managing emissions in the agricultural sector.

Ministers requested the preparation of advice providing an overview of climate scenarios and potential impacts; a stocktake of the current work being undertaken by jurisdictions on adaptation and managing emissions; and the identification of opportunities and risks of climate change in agriculture. This work will provide input to officials in their preparation of advice to Ministers, proposing actions and a work program to support a coordinated national approach.

This paper is the first step in the process and provides:

— an overview of climate scenarios and potential impacts
— a stocktake of the current work being undertaken by jurisdictions on adaptation and managing emissions in agriculture
— the identification of risks and opportunities of climate change in agriculture.

Subsequent work will analyse the opportunities and risks of climate change for agricultural industries and propose options for actions which could be considered as part of a work program for a coordinated national approach to supporting the agricultural sector adapt to climate change.

The importance of agriculture

Agriculture continues to be a vital component of the social and economic structure of jurisdictions across Australia and is the major economic driver of regional and rural communities. Australia is a world-leading producer and exporter of agricultural commodities, with exports showing a continuing growth trend over the past five years. In 2016-17:[1]

— total production of agricultural products was valued at over $60 billion
— agricultural exports were valued at an estimated $50 billion
  – Australia was the second and fourth largest global exporter of beef and wheat, respectively, with these commodities also representing the eighth and ninth largest sources of export income across all of Australia's exports
— the agricultural sector employed approximately 251,000 people.

[1] 2016-17 is used as the time period for economic data as it was the most recent year with full national data across all jurisdictions at the time of preparation.

The agricultural sector's strong performance over the past decade has been driven by significant productivity gains and major increases in the value of agricultural products, especially in export markets. Strong export performance has had flow-on impacts in the domestic market. The outlook for the sector is positive and, based on the current growth trajectory, is forecast to be valued at $84 billion by 2030.[2] However, the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) considers the export market going forward will be characterised by increased competition and lower prices.[3] Furthermore, climate change has already impacted Australian agriculture productivity. In the short-term it is expected that increased export volumes will compensate, and that the total value of agricultural exports will remain largely unchanged.

Future climate changes are expected to significantly impact the sector, especially as productivity growth is also beginning to taper off. This is leading to a change in focus, away from continuing productivity and yield gains, to product value and opportunities for value-adding.

Climate change adaptation and managing greenhouse gas (GHG) emissions are key issues for agriculture to address. Adaptation will be critical to maintaining productivity and offsetting the impact of climate change. While the sector only contributes 13.2 per cent to total national emissions, this proportion will increase if other sectors decrease their emissions. Action will be required, especially given that some importers, such as the European Union, are increasingly focused on the emissions intensity of their imports.

The emissions associated with land use change for agricultural purposes, or on land owned by agricultural producers, are counted under the 'Land use, land use change and forestry' (LULUCF) category, not under 'agriculture' emissions. The LULUCF sector includes both sources of emissions and sinks that remove carbon dioxide (CO_2) from the atmosphere and sequester it as carbon in living biomass, debris and soils.

Climate change modelling and scenarios

Australia's future climate will be primarily determined by three factors: the emissions scenario that is being most closely tracked (the scenarios are described by Representative Concentration Pathways (RCPs)), the response of the climate system to that scenario, and natural variability. The Intergovernmental Panel on Climate Change (IPCC):

— has concluded that human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels

— is highly confident that global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate

— considers that for RCP8.5 (the scenario with the highest emissions trajectory), the likely range of temperature change is 2.6˚C - 4.8˚C, by the end of the 21st century.[4]

In 2015, drawing on the IPCC Reports, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology (BoM) developed detailed climate projections for Australia, as a whole and regionally, under three RCPs scenarios. Projections are provided for modelled climate variables, such as temperature, rainfall, wind, and derived variables, such as indices of climatic extremes, fire weather, soil moisture.

CSIRO and BoM's projections were developed for the whole of Australia and for Natural Resource Management (NRM) regions. Jurisdiction level projections were not presented. They are reflective of natural systems, and as such the approach does not readily align with agricultural production regions or reflect local-scale climate conditions that drive on-farm/regional production systems. A number of states have undertaken projections to fill these gaps but there is a lack of commonality in approaches and assumptions, making it difficult to compare like with like. There could be value in improving the ability to better forecast variability/extremes and decadal projections.

The modelling provides insights as to potential climatic conditions out to 2090. Beyond 2030 the scenario pathways diverge quite strongly, dependent on the emissions outcome that is achieved.

2 ACIL Allen Consulting 2019 (in press); *Agriculture – a $100 billion sector by 2030* Phase 2 Report; AgriFutures Australia

3 Based on presentations from the ABARES Outlook 2018 conference.

4 IPCC Climate Change 2014 Synthesis Report Summary for Policymakers https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf

Given that the long-term climate signals, such as gradual rise in temperatures and an overall, but not consistent, drying effect, only manifest themselves slowly, short-term indictors are essential. Indicators relating to extreme weather events, such as time spent in drought and other short-term impacts, are critical. They represent the most obvious impact of climate change from an agricultural perspective. These extremes are particularly important as they provide early indicators as to the need to implement adaptation measures e.g. the impact of heat wave stresses on horticultural crops and dairy production. However, gradual changes such as less autumn-winter rainfall across southern Australia and uncertain rainfall effects in north west Australia are becoming more evident.

A critical gap in relation to the projections is the lack of a coordinated program (across all jurisdictions) to translate the projections into effective local-level adaptation tools, with direct on-farm application, and in the setting of enabling policies and investment strategies. A limited start has been made on this work by CSIRO and some NRM groups.

The majority of detailed research into climate change impacts on Australian agriculture (considered in this analysis) are focused on the period out to 2030, where more certainty exists. Long-term projections go to 2090 or beyond, and some mid-term work has been undertaken with a 2050 focus. Given the greater availability of information, the focus of the report has been on the short/mid-term period, out to 2030. This has been supplemented by 2050 and 2090 considerations as appropriate.

Impact of climate change on agriculture

The assessment of the impacts of climate change projections on Australian agricultural production considered a range of factors:

- the range of agricultural commodities produced, and the main commodities by value
- the mix of agricultural commodities in each jurisdiction, and their relative importance to that economy
- the drivers of production, productivity and profitability, and the range of risks to be managed
- the scale and diversity of the climatic regions in Australia
- the changes in climate already experienced, and the extent to which agriculture has already adapted
- the nature, extent and rate of change projected under the three RCP scenarios.

Nine commodities are assessed: the top commodities by value of production, plus some additions which make a major contributor to one of more jurisdictions. These are cattle, milk (dairy), wheat, sugar cane, cotton, potatoes, wine, mangoes and melons. Some of these have a strong affinity to similar commodities (i.e. wheat to coarse grains). Others have a particular susceptibility to climate change impacts given their specific growing requirements, such as cotton, given high water use; viticulture, given high sensitivity to changes in temperature and heatwave stress, etc.

While this coverage is not comprehensive, a review of the research into the impacts of climate change on the productivity and yields of these commodities provides insights as to how the overall agricultural sector may fare. There is strong research evidence that climate change has already impacted both productivity and yield on a range of commodities and will continue to do so out to 2030. Beyond 2030 there is less certainty but as a general observation the impacts will become more pronounced.

However, there are clear opportunities to stem this drop in productivity through adaptation measures. In the short-term (i.e. out to 2030), the impact from extreme weather events and fluctuations in climatic conditions such as severe/prolonged drought, rather than the underlying climate signal (i.e. increase in temperature and general drying effect), will generate the most impact for the majority of commodities.

There is a considerable amount of analytical work and research examining the impact of climate change on production. However, it tends to be fragmented, with many specific, and regionally focused, in-depth studies. While it may be possible to extrapolate some of these results at a commodity-wide level, given regional differences, and the lack of detailed climate projections at the local/regional level, results need to be treated with caution. There are also challenges in ensuring that research outcomes, in terms of both climate modelling and the impacts of climate change on productivity, are made available in a way that allows them to be applied in decision making at the on-farm level.

Work by ABARES and others indicates that the sector has been able to maintain productivity and yields over the last 25 years. However, 'business as usual' research and innovation (R&I) efforts are just managing to maintain existing levels of productivity, rather than enabling productivity growth.

There are also growing concerns that future productivity gains from R&I will not keep pace with the negative impacts of climate change.

Looking forward to 2030, the impact on most of the sectors examined is significant, even though there is scope to address any reductions in yield through farm management practices and adaptation. However, some sectors, particularly beef will face significant challenges, given the analysis points to a decline in productivity of up to 5 per cent by 2030. More drastic adaptation action will be required to maintain production. Beyond 2030, the impacts across most commodities are likely to be more severe with an acceleration in productivity losses being the norm for most commodities. Concerted adaptation action will be required to maintain both productivity and yield.

Economic impacts

The availability of substantial economic modelling results, such as computed partial and general equilibrium modelling, of climate change impacts across all agricultural commodities and regions is very limited. Economic modelling of climate change from an economy wide perspective is available. However, there is a significant gap in relation to work that is focused on the specifics of the agricultural sector, and that incorporates more sophisticated assumptions and regional changes highly relevant to key agricultural commodities.

Accordingly, a conservative and simplified approach has been adopted to provide some insights as to possible economic impacts and potential consequences of climate change for key commodities. The key assumption underlying the analysis is that the potential changes in productivity and yield indicated by the research, will directly and proportionately flow through to value. The assumption of direct causal relationships oversimplifies the assessment.

The focus on yield and productivity obscures other critical effects, such as impacts on quality, marketability and price; seasonal shifts in production, which potentially affecting market windows, competitive advantages and price; and changed distributions of pests and diseases, which will bring increased costs of management and challenges for export market access. Equally important, it also excludes the effects of drought and storms and other extreme weather events/shocks, which are increasingly important in terms of their economic impact on agriculture.

The analysis does not consider demand side effects, such as changing consumer preferences; nor does it address changes in global markets which may have a significant impact on value (both positive and negative) as future import/export opportunities play out. Furthermore, it does not take into account new and emerging technologies and practices that will support adaptation and emissions management in agriculture and offset the overall economic impacts.

TABLE ES 1 sets out the major value impacts, in real terms, for the three key commodities most impacted by climate change out to 2030. The loss in value is significant. Across all nine commodities the economic outcomes are quite different, even though all show some decline in value. In some cases the declines only become significant after 2030. The combination of potential production and yield declines, coupled with rising production costs, as inputs such as water become scarce and more expensive, results in positive and negative outcomes, in terms of both commodities and jurisdictions. Economic impacts are likely to become more marked beyond 2030.

TABLE ES 1 ECONOMIC IMPACT ON CATTLE, MILK AND WHEAT SECTORS

Agricultural commodity	2016/17 value	2029/30 value (real)
Cattle	$12.14 billion	$8.36 billion
Milk	$3.69 billion	$2.65 billion
Wheat	$7.37 billion	$5.28 billion

Note: Values are in real terms; the real figures are adjusted for inflation of 2.5% per year; based on the Reserve Bank of Australia's target; table only reflects yield declines (rather than changes in production costs or land use)

SOURCE: ACIL ALLEN CONSULTING

There are also possible significant economic implications associated with managing emissions from agriculture. Clearly there will be an interplay between adaptative measures to address productivity losses and the level of emissions, and one may well offset the other to some extent. However, looked at in isolation, the impact on the value of the cattle sector could be nearly as significant as the impact due to declining productivity. The analysis is based on a simple set of assumptions and assumes no abatement actions to offset the declines in value.

As the largest single source of agricultural emissions, the impact from emissions management is likely to be most significant for the cattle sector. While there will be marked differences between commodities and jurisdictions, the analysis illustrates the challenge ahead. The prospect of this significant loss in value emphasises the importance of addressing both emissions mitigation and adaptation methods in tandem.

There are a range of other outcomes with economic implications (to be explored as part of subsequent work), which will flow from the impacts of climate change, including:

— Building resilience - agricultural viability is dependent on individual businesses' ability to manage the increased climatic variability through long-term preparedness planning and risk assessment.
— The value of carbon - abatement actions to manage emissions will, in effect, result in an implicit carbon price, enabling a range of 'carbon farming' initiatives.
— Rural adjustment - the current trend to larger farming enterprises is likely to continue, in part driven by climate change impacts. Coupled with climatic fluctuations and extreme weather events, adjustment will, in turn, link to a range of social impacts. These include regional community development and sustainability; residential mobility; financial wellbeing; employment; mental and physical health, etc.
— Asset valuations - climate change impacts will bring greater attention to the value of farm assets, and other adaptation initiatives. The scarcity of water, in particular, will become a key factor in valuation.

Government actions

Australian governments are implementing policies and programs to facilitate adaptation to the impacts of climate change and manage GHG emissions. There is a growing body of research detailing the impact of climate change on a range of agricultural commodities. Adaptation will be vital to maintaining both the productivity and economic value of the sector into the future.

Jurisdictions have responded to international agreements for action on climate change, such as the Paris Agreement[5], and developed legislative and policy responses through setting emissions reduction targets, and the development of adaptation strategies and plans. There is significant variation in the approach to adaptation planning across jurisdictions, which include commodity-based, state-wide and regionally specific action plans.

A consistent theme across a number of programs is the lack of coordination, particularly in terms of applied R&I to address climate change impacts on agriculture and, importantly, the promulgation of outcomes and lessons at an on-farm level. Policy settings are critical to support this. While there are a wide range of tools and climate projections available, application of these at the local level to assist with day-to-day farm management has been limited.

There are a number of models which could be readily adopted to enhance cross-jurisdictional collaboration and harmonise action. These will be considered through the Stream 2 and 3 work.

Next steps

Climate change presents both opportunities and risks to the agricultural sector. The anticipated productivity and yield losses for many agricultural commodities, in the short to medium-term, will focus attention on adaptation measures, to maintain value and profitability and build resilience. Government policy, consumer preferences and supply chain demands are placing increasing pressure on the agricultural sector to manage its emissions.

Stream 1 has served to identify the underlying issues that agriculture will face. Stream 2 will explore, in detail, the opportunities and risks that climate change presents to the sector. It will consider them within the broader context of the many factors influencing decision making by both government and industry.

[5] The Paris Agreement is an agreement within the UNFCCC, dealing with GHG mitigation, adaptation, and finance, signed in 2016

GLOSSARY OF TERMS

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACCUs	Australian Carbon Credit Units (an ACCU is a unit issued by the Clean Energy Regulator (Regulator) and represents one tonne of carbon dioxide equivalent (tCO_2-e) stored or avoided by a project)
ACORN SAT	Australian Climate Observations Network of Air Surface Temperature
AGMIN	Agriculture Ministers' Forum
AGSOC	The Agriculture Senior Officials' Committee (AGSOC) comprising department heads and CEOs of Australian/State/Territory and New Zealand Government agencies responsible for primary industries policy issues
APSIM	Agricultural Production Systems sIMulator (APSIM) - developed to simulate biophysical processes in agricultural systems
ARENA	Australian Renewable Energy Agency (ARENA)
BoM	Bureau of Meteorology
CGMMV	Cucumber Green Mottle Mosaic Virus
CH_4	methane
CMA(s)	Catchment Management Authority(s)
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent
COAG	Council of Australian Governments
COP21	Conference of the Parties (21st meeting of the parties to the UNFCCC)
CRSPI	Climate Research Strategy for Primary Industries (formerly the Climate Change Research Strategy for Primary Industries (CCRSPI))

CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWR	Commonwealth Department of Agriculture and Water Resources
DCAP	Queensland Government Drought and Climate Adaptation Program (DCAP).
DELWP	Department of Environment, Land, Water and Planning, Victoria
DoEE	Commonwealth Department of the Environment and Energy
EF	emissions factor
ERF	Emissions Reduction Fund
FFDI	MacArthur Forest Fire Danger Index
GCMs	global climate models
Gg N_2O-N/ Gg N	grams of GHG emissions from synthetic fertilizers consist of direct and indirect nitrous oxide (N_2O) emissions from nitrogen (N) added to agricultural soils
GHG	greenhouse gases
GL	gigalitres
ha	hectare
IOD	Indian Ocean Dipole phases - sustained changes in the difference between sea surface temperatures of the tropical western and eastern Indian Ocean
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
km	kilometres
km^2	square kilometres
kt	kilo tonne
kt CO_2-e	kilotonnes of carbon dioxide equivalent
kg CH_4/head/year	kilograms of methane emitted per beast per year
L	litres
LULUCF	Land use, land use change and forestry (LULUCF) sector emissions
ML	megalitres
MLA	Meat & Livestock Australia
MJT	Mean January Temperature °C
m	metres
mm	millimetres (of rainfall)
Mt CO_2-e	metric tons of carbon dioxide equivalent
NANORP	National Agricultural Nitrous Oxide Research Program
NARCliM	New South Wales and Australian Capital Territory Regional Climate Modelling (NARCliM) Project
NESP	National Environmental Science Program

NFF	National Farmers' Federation
NMVOC	non-methane volatile organic compounds (NMVOC) emissions
NO_x	nitrogen oxides
NRM	Natural Resource Management (NRM) regions
NSW DPI	New South Wales Department of Primary Industries
°C	degrees Celsius
Paris Agreement	The Paris Agreement is an agreement within the United Nations Framework Convention on Climate Change, dealing with greenhouse gas emissions mitigation, adaptation, and finance, signed in 2016
PIRSA	Department of Primary Industries and Regions, South Australia
ppm	parts per million
Q-CAS	Queensland Climate Adaptation Strategy
QFF	Queensland Farmers Federation
RCFs	representative climate futures
RCPs	Representative Concentration Pathways (a greenhouse gas concentration trajectory adopted by the IPCC for its fifth Assessment Report)
Rural RDC(s)	Rural Research and Development Corporation(s)
R&D	research and development
R&I	research and innovation
RD&E	research, development and extension
SAGIT	South Australian Grain Industry Trust Fund
SARDI	South Australian Research and Development Institute
SCaRP	Soil Carbon Research Program (SCaRP)
Standardised Precipitation Index	A widely used index to characterise meteorological drought on a range of timescales)
SRDC	Sugar Research and Development Corporation
SRES	The Special Report on Emissions Scenarios (SRES) is an IPCC report (published in 2000). The GHG emissions scenarios described in the Report have been used to make projections of possible future climate change.
tCO_2-e	tonnes of carbon dioxide equivalent
t DM/ha/yr	tons of dry matter produced per hectare per year
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USQ	University of Southern Queensland

1 CONTEXT

This chapter provides a brief introduction to the overall project, outlining its context and broad goals and the three component parts. In addition, it outlines the objectives and structure of the Stream 1 work and its role in the total project.

1.1 Background

On 27 April 2018, the AGMIN meeting agreed on the importance of ongoing cooperation between Commonwealth, state and territory governments to support adaptation to climate change and in managing emissions in agriculture.

Ministers agreed to consider proposed actions and a work program for a coordinated national approach to adaptation to climate change and managing emissions in the agricultural sector. Victoria agreed to coordinate this advice. In subsequent media comments, Ministers Pulford and Littleproud called for the development of a national strategy that supports farmers to adapt as the climate changes and to secure Australia's food and fibre production and regional jobs and communities.

As the first step in this process, Ministers requested that senior officials prepare a paper providing:

- an overview of climate scenarios and potential impacts
- a stocktake of the current work being undertaken by jurisdictions on adaptation and managing emissions in agriculture
- the identification of risks and opportunities of climate change in agriculture.

It is intended that the paper will identify actions and a work program that could inform the preparation of a national strategy for adaptation to climate change and emissions management in agriculture for subsequent consideration by AGMIN in 2019.

1.1.1 Project objectives and scope

The overall objective of the project is to undertake the work necessary to inform the development of advice from the Agriculture Senior Officials' Committee (AGSOC) that proposes actions and a work program to support a coordinated national approach to addressing climate change and managing emissions in agriculture. The work undertaken as part of this project to assemble the supporting evidence will address the points agreed by Ministers:

a) an overview of potential climate change scenarios and impacts over time

b) an analysis of the risks and opportunities of climate change for agricultural industries

c) a description of current work on managing emissions in the agricultural sector

d) a stocktake of approaches to adaptation across jurisdictions

e) proposed actions and work program for a nationally coordinated approach to supporting the agricultural sector adapt to climate change.

1.1.2 Project approach

The project focuses on the work necessary to provide input for consideration by AGSOC as it prepares advice for AGMIN. The work is divided into three work streams:

Stream 1: Understanding climate scenarios and a stocktake of current approaches

Stream 1 focuses on reviewing the existing body of work to provide an overview of climate change scenarios and the implications for agricultural commodities over time.

In reviewing climate scenarios, the focus is on the period up until 2030 where it is possible to draw relatively robust conclusions, based on the work of BoM, CSIRO, ABARES and state research work such as the New South Wales and Australian Capital Territory Regional Climate Modelling (NARCliM) Project. In reviewing the modelling work, it is clear that moving beyond 2030 introduces a much higher degree of uncertainty as to outcomes. Accordingly, possible conclusions are somewhat speculative and indicative.

The work includes a stocktake of current work and approaches across jurisdictions to adaptation and managing emissions in agriculture which considers recently completed, current and planned work in each jurisdiction.

This Stream addresses items a), c) and d) as outlined in the Project scope with the results (Stream 1 Report: Understanding Climate Change and Current Approaches) informing Streams 2 and 3 of the work which focus on analysing opportunities and risks, and how to address them.

Stream 2: Analysis of risks and opportunities of climate change for agricultural industries

Climate change presents both opportunities and risks to the agricultural sector. Government policy, consumer preferences and supply chain demands are placing increasing pressure on the agricultural sector to address its emissions. There are also many other factors that influence decision making by agricultural industries, including global commodity prices, technology and changes in farming practices.

Stream 2 will consider the opportunities and risks that climate change presents for the agricultural sector. It will consider them within the broader context of the many factors influencing decision making. Workshops will be held in each jurisdiction to facilitate engagement with stakeholders to help identify and analyse the opportunities and risks and to provide input into Stream 3.

This Stream addresses point b) in the Project scope above with the results of the work (Stream 2 Report: Risks and Opportunities) informing Stream 3 of the work.

Stream 3: Identification of options for actions and a work program that could inform the development of a national strategy for adaptation to climate change and emissions management in agriculture

Ministers have requested that AGSOC propose actions and a work program for a coordinated national approach to adaptation to climate change and emission management in the agricultural sector. These actions and work program could form the basis of a national strategy. The work will develop options for actions that require national leadership and cooperation across jurisdictions to implement to achieve the desired outcomes.

Stream 3 will inform discussion to identify options for actions and work program for a coordinated national approach to adaptation to climate change and managing emissions in the agricultural sector. The results of this work will address item e) in the Project scope above.

1.2 Drivers and objectives of Stream 1 work

Climate change signals, in the form of mean surface air temperature warming, have been observed in Australia since 1910 and, in particular, since 1950. During this period, the mean surface air temperature has increased 1.0 degrees Celsius (1.0°C). The increase in temperature across Australia has been attributed to the enhanced greenhouse effect. Whilst mean temperatures have increased, maximum heat temperature extremes have increased greater than cool temperature extremes. Mixed changes in rainfall have occurred over this period, with southern Australia experiencing a drying trend in cool season rainfall, while natural variability remains a strong driver. In north Western Australia, rainfall has increased since 1970's and, in south west, declines in cool season rainfall has occurred since the 1990's.[6]

For Australia, increased climate variability and extreme weather conditions often exacerbate an already challenging operating environment for the agricultural sector.

Signatories to the 2015 Paris Climate Accord agreed that addressing climate change requires capping and reducing GHG emissions as soon as possible, if the world is to limit global temperature rise this century to two degrees centigrade (2.0°C) (and ideally to 1.5°C). Australia has set a target to reduce overall emissions by 26-28 per cent below 2005 levels by 2030.

Australian governments are implementing policies and programs to facilitate adaptation to the impacts of climate change and manage GHG emissions. There is a growing body of research detailing the impact of climate change on a range of agricultural commodities. Adaptation will be vital to maintaining both productivity and economic value of the sector into the future. Climate change adaptation is defined as the adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities.[7]

Roles and responsibilities can be clarified. Roles and responsibilities for climate change adaptation in Australia were agreed upon by the Council of Australian Governments (COAG) in 2012. The following risk management framework applied:

- private parties should be responsible for managing risks to private assets and incomes
- governments should be responsible for
  - managing risks to public goods and assets including the natural environment and government service delivery
  - supporting private adaptation by creating an institutional, market and regulatory environment that supports and promotes private adaptation.

The approach of state and territory governments and agricultural industries to climate change adaptation is through the provision of services and research that is guided by jurisdiction specific plans and policies to reflect regional and commodity specifics.

The challenge of managing GHG emissions is highlighted by the Department of the Environment and Energy's (DoEE) annual update of projected emissions under the Paris Conference of the Parties, 21st meeting of the parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) Agreement. To meet its commitments, Australia would have to reduce total emissions by 95 Mt CO_2-e compared to the 2005 baseline.[8] While the Paris Agreement does not set individual sectoral emissions reduction targets, projected emissions are tracked by DoEE for each sector. Managing the emissions from the agricultural sector will need to be part of any national solution if Australia is to meet its commitment. However, trade-offs between sectors may be allowed/required.

Australia's most recent projected emissions update was published by DoEE in late 2018. Agriculture currently contributes around 13.2 per cent of Australia's GHG emissions. Emissions produced by agricultural activity have fallen since 2005, with approximately 69 Mt CO_2-e currently emitted. **Figure 1.1** shows projected agricultural emissions out to 2030.

While Australia has adopted an overall emissions target to meet its Paris Agreement commitments, sector by sector targets have not been set. The emissions target is economy wide to account for the opportunities and difficulties of reducing emissions in different sectors. As emissions in other sectors of the economy decline, emissions from the agricultural sector may increase as a proportion of Australia's emissions.

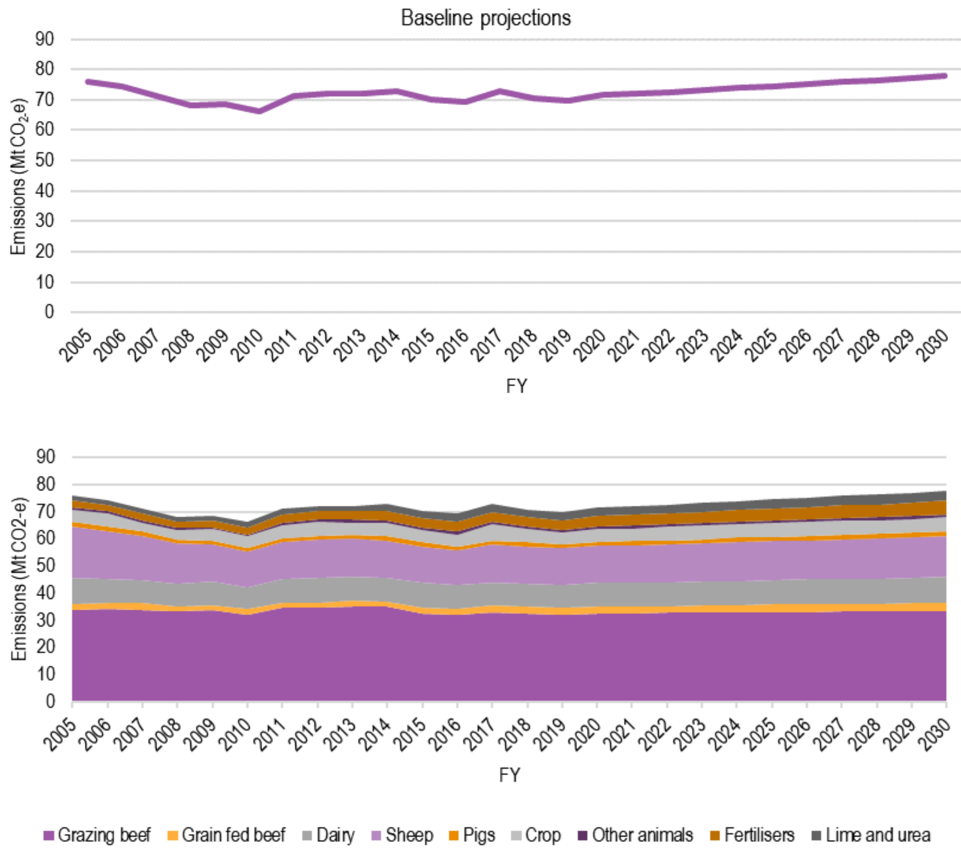
The challenges are considerable, and in an environment of resource constraints, it is important that the efforts to adapt to climate change and manage emissions are done efficiently and effectively.

6 CSIRO (2018) *Climate Change in Australia Projection for Australia's NRM Regions: Causes of Recent Changes (Australia)*. Accessed 25 February 2019, https://www.climatechangeinaustralia.gov.au/en/climate-campus/australian-climate-change/causes-recent-change/.

7 Department of Environment and Heritage (2019) *Adapt NSW: What is Adaptation?* Accessed 25 February 2019, https://climatechange.environment.nsw.gov.au/Adapting-to-climate-change/What-is-Adaptation.

8 Department of the Environment and Energy, December 2018 *Australia's emissions projections 2018;* Australia Government

FIGURE 1.1 PROJECTED AGRICULTURAL EMISSIONS 2005-2030



SOURCE: DEPARTMENT OF ENVIRONMENT AND ENERGY, 2018, AUSTRALIA'S EMISSIONS PROJECTIONS, 2018

The Stream 1 work delivers on two key fronts, namely:

1. a review of what the modelling says about the likely impacts of climate change for agriculture
2. a stocktake of what jurisdictions and researchers have already done, or are currently working on, to help the agricultural sector to manage emissions and adapt to changes in climate.

2

KEY AGRICULTURAL SECTOR ACTIVITIES BY JURISDICTION

2.1 Introduction

Australia is a world leading producer and exporter of agricultural commodities. While the value of agricultural exports has shown a continuing growth trend over the past five years, agricultural commodities are no longer the mainstay of Australia's export income (having been overtaken by resources) as they were in the 1970's. In 2016-17, the agricultural sector was characterised as follows:

— total production of agricultural products was valued at over $60 billion[9]

— exports were valued at an estimated $50 billion[10]

— Australia was the second and fourth largest global exporter of beef and wheat, respectively,[11] with these commodities also representing the eighth and ninth largest sources of export income across all of Australia's exports[12]

— the agricultural sector employed approximately 251,000 people in Australia.[13]

The following section examines some of the aspects of the agricultural industry in greater detail over time including land use, economic overview, historical trends, emissions, employment and future outlook. Only complete, national scale datasets from organisations such as Australian Bureau of Statistics (ABS), ABARES and the DoEE are used in the report. Some of these resources only report at a national level and some provide data at a state and territory level.

A range of specific resources for particular states and territories are available and these can be very useful (even vital) to detail jurisdictional nuances that are important in informing the development of a national agenda. However, for the purposes of the report, using the datasets that break down to a state and territory level (rather than specific state resources) is essential to ensure consistency and enable comparisons across jurisdictions and over time. The 'base' year is 2016-17, as this is the most recent year with the complete datasets as described above. 2016-17 was in the top five warmest years on record, and was characterised by persistent drought in many regions, as well as heavy rainfall causing several floods, notably in the south east parts of the nation.[14] The agricultural industry grew overall, with many sectors reaching new highs in production and value.[15]

[9] Australian Bureau of Statistics, 2016-17, *Value of Agricultural Commodities Produced*

[10] ABARES, 2018, Agricultural Commodities, December 2018

[11] World's Top Exports, viewed January 2019, http://www.worldstopexports.com/wheat-exports-country/, http://www.worldstopexports.com/top-beef-exporting-countries/

[12] Department of Foreign Affairs and Trade, viewed January 2019, https://dfat.gov.au/trade/resources/trade-at-a-glance/Pages/top-goods-services.aspx

[13] ABARES, 2018, Agricultural commodity statistics 2018

[14] Bureau of Meteorology and Reuters, viewed February 2019: http://www.bom.gov.au/climate/current/annual/aus/2016/, https://www.reuters.com/article/us-australia-drought-impact-graphic/farming-impact-of-australias-worst-drought-in-living-memory-idUSKBN1KR060, http://floodlist.com/australia/floods-september-2016-victoria-south-australia

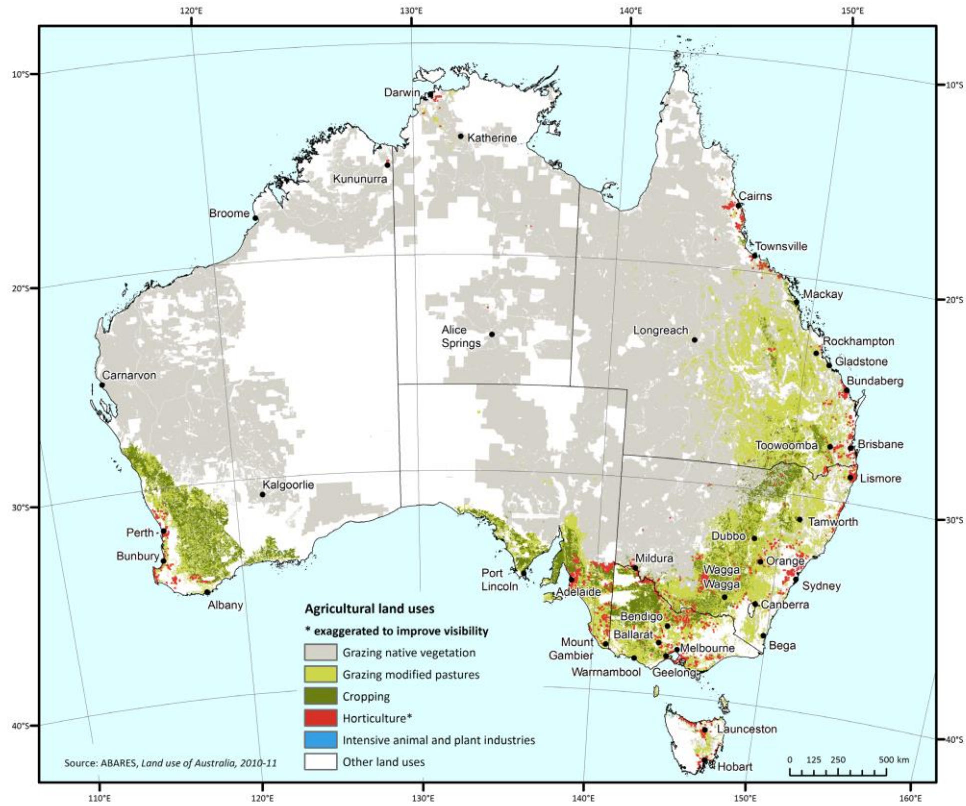
[15] Australian Bureau of Statistics, 2016-17, *Value of Agricultural Commodities Produced,* ABARES, 2018, Agricultural commodity statistics 2018

2.2 National overview

2.2.1 Land use

The areas dedicated to agricultural activity are shown in **Figure 2.1**, representing around 58 per cent of the Australian land mass. **Table 2.1** provides a breakdown of land use by area. The dominant land use. at over 400 million hectares, is livestock grazing. This area includes grazing of both native vegetation and modified/improved pastures and represents 54 per cent of all land uses. Cropping lands comprise approximately 4 per cent of the land mass, which is around 28.5 million hectares.[16]

FIGURE 2.1 OVERVIEW OF AGRICULTURAL ACTIVITY IN AUSTRALIA



SOURCE: AUSTRALIAN GOVERNMENT: DATA.GOV.AU

TABLE 2.1 LAND USE IN AUSTRALIA

Land use	Area (sq. km)	Per cent (%)
Nature conservation	604,671	7.87%
Other protected areas including Indigenous uses	1,163,676	15.14%
Minimal use	1,172,679	15.26%
Grazing natural vegetation	3,448,896	44.87%
Grazing modified pastures	710,265	9.24%
Dryland cropping	275,928	3.59%
Dryland horticulture	743	0.01%
Irrigated pastures	6,048	0.08%

[16] ABARES, 2017 fact sheet, Australia's Agricultural Industries 2017

Land use	Area (sq. km)	Per cent (%)
Irrigated cropping	9,765	0.13%
Irrigated horticulture	4,552	0.06%
Intensive animal and plant production	1,414	0.02%
Production forestry	103,494	1.35%
Plantation forestry	25,752	0.34%
Intensive uses (mainly urban)	13,806	0.18%
Rural residential	17,632	0.23%
Waste and mining	1,860	0.02%
Water	125,542	1.63%
No data	401	0.005%
TOTAL	**7,687,124**	**100.00%**

SOURCE: ABARES - BASED ON LAND USE OF AUSTRALIA 2010-11, VERSION 5, ABARES 2016

2.2.2 Economic overview

An economic overview of key agricultural sectors is provided in **Figure 2.2** and **Figure 2.3**. Cattle and calves and wheat are the primary sources of agricultural value in Australia, worth around $12 billion and $7.3 billion in 2016-17 or 20 per cent and 12 per cent, respectively. Cattle herd numbers fell by around 3,000,000 over the four year period ending in 2016-17, as the rate of slaughter processing was greater than herd replenishment. However, the value of the sector is over 50 per cent higher reflecting strong global/export demand.

Although sheep and lamb herd numbers are over double that of cattle and calves, the value of the sector is only about a quarter. However, sheep and wool production make a significant contribution to the value of production in certain jurisdictions.

Wheat production volumes have increased by almost 40 per cent compared to 2012-13, but the corresponding value has only risen by 3 per cent. Since wheat is major export commodity, this suggests recent global supply is considered abundant by the market, and prices have consequently weakened.[17]

Despite only comprising of around 4 per cent of total national economic value in 2016-17, pulses have exhibited the greatest growth since 2012-13, with increases in value and production of approximately 185 per cent and 110 per cent respectively.[18] This trend is expected to soften as global supply increases and drought conditions constrain output.[19] In contrast, rice and cotton have fallen in both value and production volumes over the same period. In 2016-17 the rice sector is valued at about 13 per cent lower, with a 30 per cent drop in production, compared to 2012-13. The cotton sector has fallen 16 per cent in value and experienced about a 12 per cent reduction in production compared to 2012-13.[20] The key changes in Australia's broad agricultural sectors between 2012-13 and 2016-17 are illustrated in **Figure 2.4**.

[17] Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, *Agricultural commodity statistics 2018*

[18] ABARES, 2018, Agricultural commodity statistics 2018

[19] ABARES, viewed January 2019, http://www.agriculture.gov.au/abares/research-topics/agricultural-commodities/sept-2018/agriculture-overview

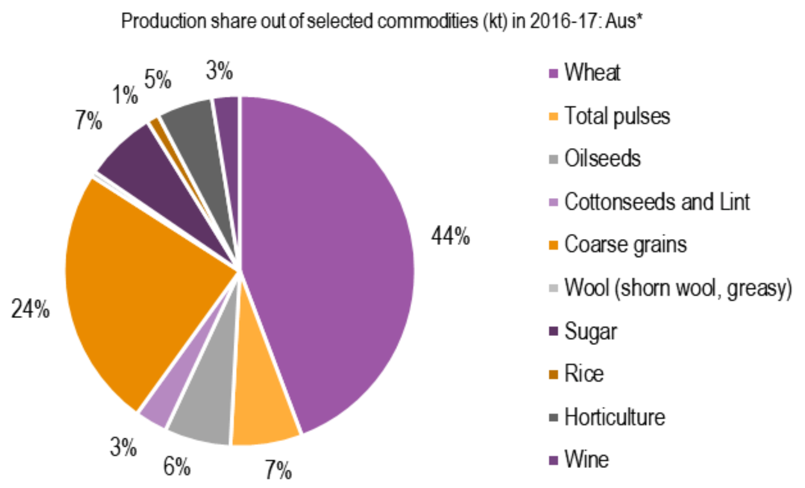
[20] ABARES, 2018, Agricultural commodity statistics 2018

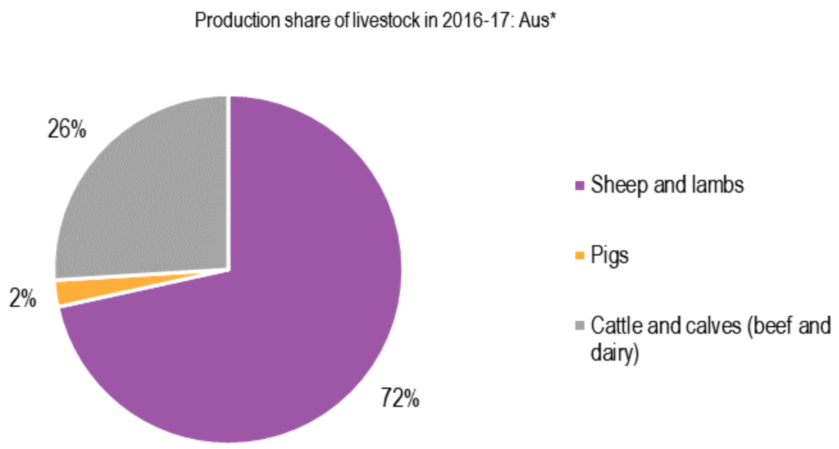
FIGURE 2.2 AGRICULTURAL PRODUCTION AND VALUE: AUSTRALIA, 2012-13 TO 2016-17

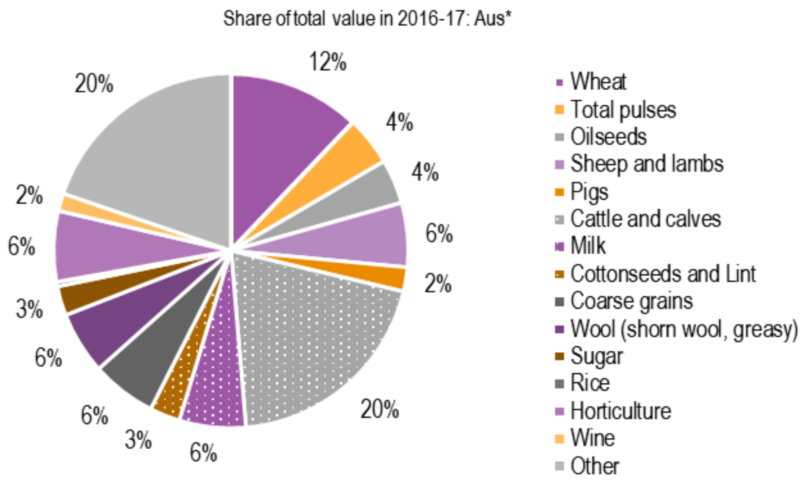
Note: *Production share out of selected commodities listed not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total Agriculture value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000.

SOURCE: PRODUCTION: ABARES, VALUE: ABS

FIGURE 2.3 SHARE OF PRODUCTION AND VALUE: AUSTRALIA, 2012-13 TO 2016-17





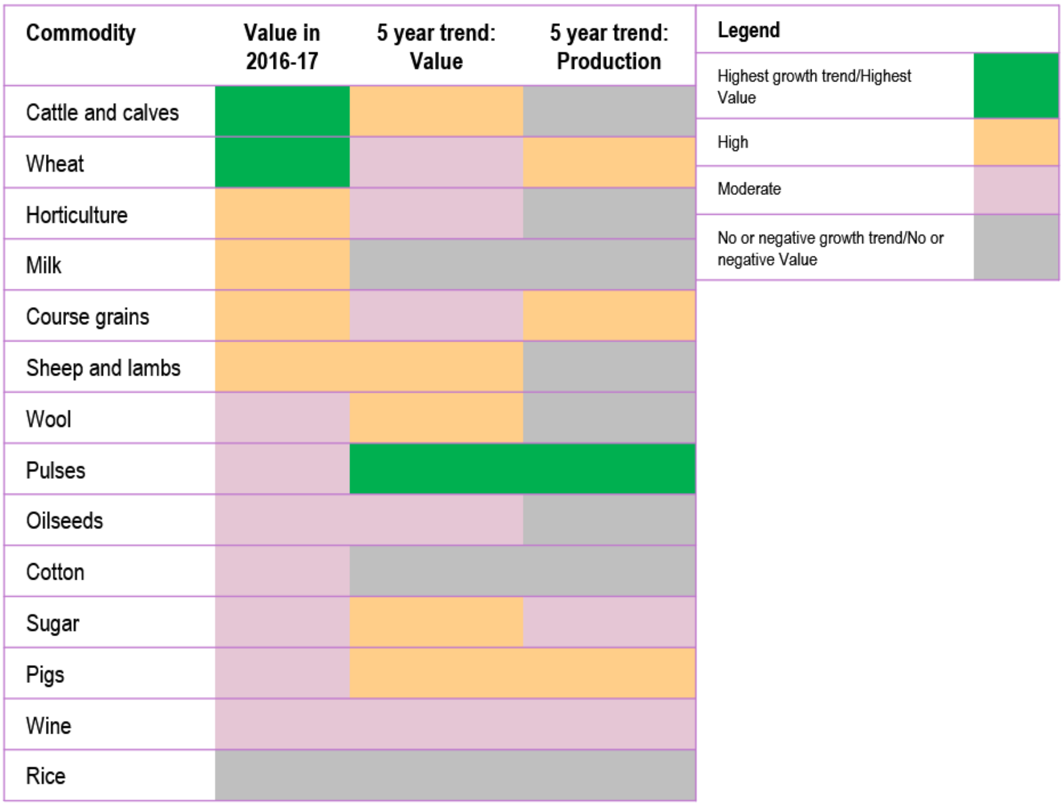


Note: * Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total Agriculture value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000.

SOURCE: PRODUCTION: ABARES, VALUE: ABARES FOR HORTICULTURE, ABS FOR OTHERS

Figure 2.4 illustrates a comparison of ABS's value and production figures for the major commodities at a national level. The graphic highlights the growth of the pulses sector which has been trending up over the past five years in terms of value and production. In contrast, the milk sector has generally been trending downwards but still holds a significant share of value in 2016-17 overall.

FIGURE 2.4 OVERVIEW OF MAJOR AGRICULTURAL COMMODITIES IN AUSTRALIA 2012-13 TO 2016-17



Note: Value refers to Gross value as reported by ABS in nominal terms. Units of production are particular to commodity type. Kilo-tonnes for wheat, horticulture, coarse grains, wool, pulses, oilseeds, cotton, sugar, wine and rice. Numbers for cattle and calves, sheep and lambs and pigs. Mega-litres for milk.

SOURCE: ACIL ALLEN BASED ON ABS AND ABARES DATA

Historical trends

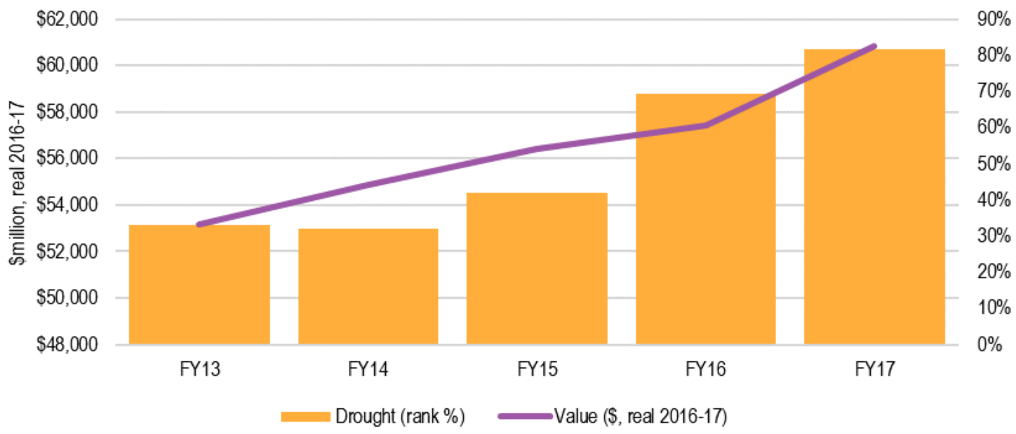
Australia is becoming drier over time. **Figure 2.5** overlays the national value of the agricultural industry and a drought metric. As shown in the chart, the drought index is getting progressively worse but, nevertheless, the value of the industry has continued to increase in real terms.

The drought metric uses the ranking results of 'driest years on record' to calculate the rank as a percentage for each year.[21] The 'dryness' is defined in terms of recorded rainfall, so volumes of water for irrigation extracted from basins are not presented here.

At a state, territory and regional level the impact of a drought is not likely to correspond to an increase in value. At a national level, the imbalance of impact is not as visible. However, this trend also highlights the ability of Australian farmers to produce high value goods whilst facing severe constraints to a key input. Section 2.3 goes into more detail about each state and territory's historical production and value of selected commodities.

21 A percentage is used as for each year, the total number of years available to compare, increases by one - using a percentage accounts for this absolute difference.

FIGURE 2.5 VALUE OF AUSTRALIAN AGRICULTURE AND DROUGHT: 2012-13 TO 2016-17



Note: Rank of the driest years on record. The raw data is originally in calendar years, so an average of calendar year results was taken to present the data in terms of financial years. In 2013, there is 114 years to compare and in 2017 there is 118.

SOURCE: AUSTRALIA BUREAU OF STATISTICS AND BUREAU OF METEOROLGY

Selected historical trends are displayed in **Figure 2.6**. Land-use changes for grazing and cropping between 1993 and 2006 are taken from ABARES 2013 land use report (the latest information available).[22] While a reduction in grazing is evident in significant areas, generally coinciding with an increase in cropping, some pockets display relatively high growth, particularly on the eastern coast. Generally, cropping increased over this period, with all of Victoria, large parts of New South Wales and almost all of the more densely populated area in south-west Western Australia exhibiting an increase in the use of land for cropping.

Sheep production has fallen by about a third since the 1990s, whilst lamb production has increased, reflecting the relative differentials in the values of wool and lamb meat. Australian lamb prices have risen for five consecutive years, whilst wool prices have recovered to relatively steady levels since 2015-16.[23] Meat and Livestock Australia (MLA) forecast production to remain relatively steady to 2020.

The national cattle herd grew throughout the 1990s, averaging around 28 million since the 2000s, with a record number of adult cattle being slaughtered in 2014 and 2015[24]. Australia's second highest commodity in terms of economic value, wheat, has a history of production that is, on average, more variable than livestock on an annual basis. From 2007-08 to 2011-12 there was uninterrupted growth in wheat production, followed by several years of slowdown. However, recent production is almost double that achieved fifteen years ago.[25] The dry conditions in 2018 will no doubt affect these outcomes.

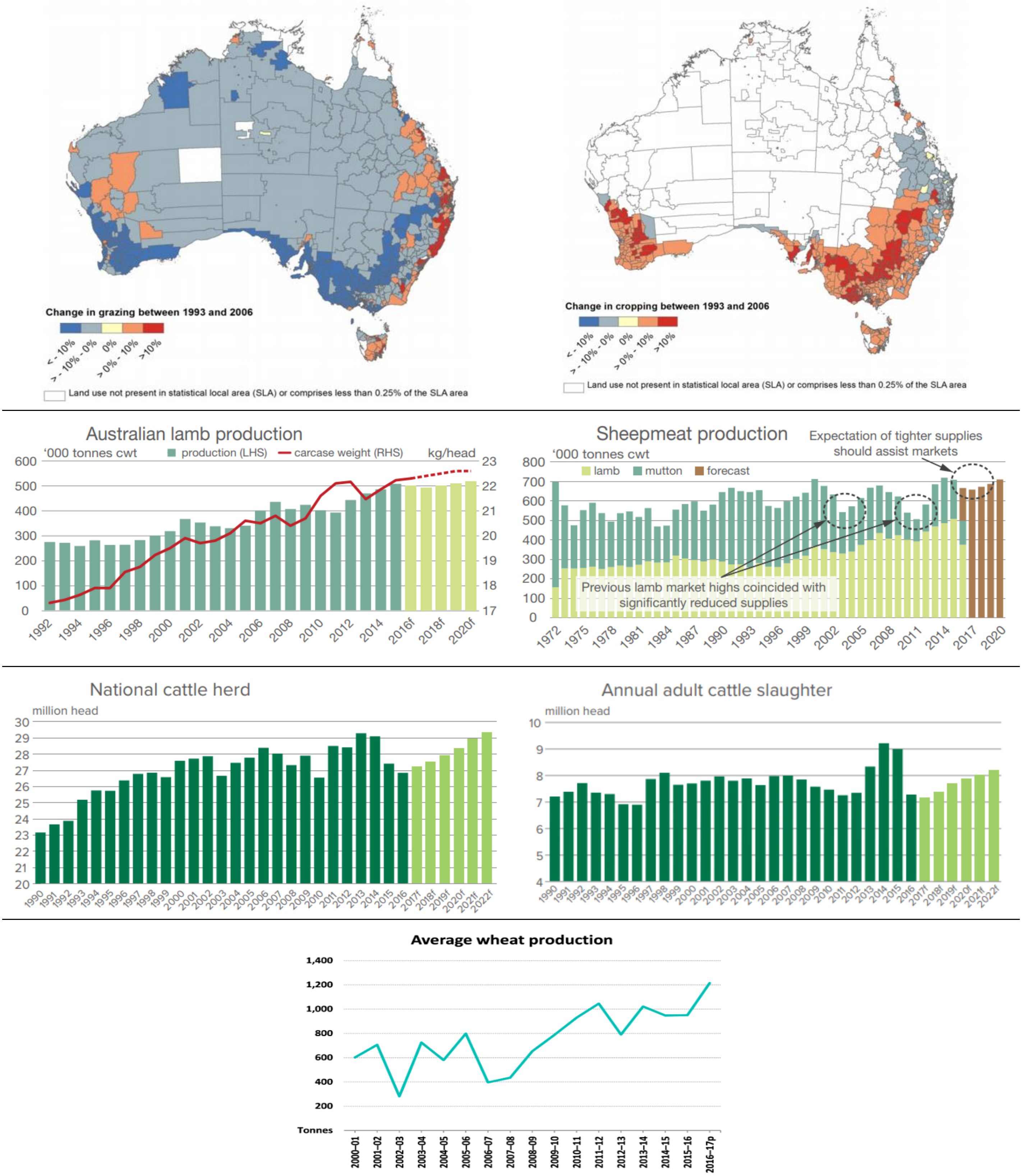
22 Mewett J, Paplinska J, Kelley G, Lesslie R, Pritchard P and Atyeo C 2013, Towards national reporting on agricultural land use change in Australia, ABARES technical report

23 Rural Bank, 2018, Australian Lamb and Sheep Meat Annual Review 2018

24 Meat and Livestock Australia, Industry Projections 2018, Australian Cattle. Meat and Livestock Australia, Industry Projections 2017, Australian Sheep

25 ABARES, viewed January 2019: http://www.agriculture.gov.au/abares/research-topics/surveys/grains

FIGURE 2.6 HISTORICAL LONG-TERM TRENDS: AUSTRALIAN AGRICULTURE



Note: The Land use maps were constructed by ABARES and show a decrease in grazing over the period between 1992-3 and 2005-6 and an increase in cropping and a smaller increase in formal nature conservation. The changes varied significantly between regions. According to MLA, herd production is highly dependent on the wet season and over half the herd in located in Queensland so the wet season in Queensland is a primary driver of supply. Queensland have not had a substantial wet season since 2011-12.

SOURCE: LAND USE: ABARES, 'TOWARDS NATIONAL REPORTING ON AGRICULTURAL LAND USE CHANGE IN AUSTRALIA', OCTOBER 2013. LAMB, SHEEP AND CATTLE: MEAT AND LIVESTOCK AUSTRALIA INDUSTRT PROJECTIONS REPORT. WHEAT: ABARES INDUSTRY OVERVIEW; HTTP://WWW.AGRICULTURE.GOV.AU/ABARES/RESEARCH-TOPICS/SURVEYS/GRAINS

Emissions

As shown in **Figure 2.7**, emissions produced by agricultural activity in Australia have fallen since 2005, with a relatively large decrease since 2014. In 2016 there were approximately 69 Mt CO_2-e of emissions, which is 9 per cent below 2005 levels.[26] However, **Table 2.2** shows the projected emissions published by DoEE in late 2018 (updated annually) categorised by agricultural activity and shows emissions are projected to increase substantially in some categories. DoEE projects emissions to increase to around 78 Mt CO_2-e by 2030.

Land conversion emissions refers to the emissions generated from land being converted to cropland and grassland. The net impact of land-use change that reduces emissions, that is, an increase in carbon stocks or sinks via land conversion to a forested or vegetated state, are not shown because this may not always be directly attributable to agricultural producers. But as this provides an important means to manage emissions from the agricultural sector, LULUCF[27] emission issues are discussed further in section 2.4.1.

Sources of agricultural emissions include enteric fermentation in ruminant livestock, agricultural soils, manure management, liming and urea application and rice cultivation and field burning of agricultural residues. Enteric fermentation accounts for about two thirds of agricultural emissions. The second and third sources contribute a further quarter of the total agricultural emissions, with the remaining sources producing the rest.

The largest sectoral source of emissions within agriculture is grazing beef at over 45 per cent in 2018. Emissions produced are projected to remain stable by 2030, slightly below both current and 2005 levels, at around 33 Mt CO_2-e. The activity that is projected to have the greatest decline is sheep. In 2030, sheep emissions volumes are projected to be 21 per lower than 2005, around 15 Mt CO_2-e. On the other hand, 'lime and urea' are projected to increase emissions by 90 per cent, reaching around 4 Mt CO_2-e in 2030.[28] These projections broadly align with observable practices currently occurring. That is, a decrease in sheep herd, an increase in cropping and associated use of fertiliser, and a continuing strong presence in the cattle market. Section 2.4 below explores emission factors in more detail.

Employment

Employment in the Agriculture, Forestry and Fishing industries has risen in absolute terms but as a percentage of population it has remained unchanged at 2.5 per cent since 2011.[29] [30] Average cash income per farm in Australia was around $205,000 in 2016-17. A breakdown by commodity shows that farms classified as 'wheat and other crops' earnt the highest income at over $420,000, whilst sheep farmers earnt the lowest at around $125,000. This average level of income is the highest farm cash income recorded in the past 20 years.[31] However, income is projected to fall in the short-term as exports soften (see the discussion of the outlook for agriculture below).

26 Department of the Environment and Energy, 2018, State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018

27 LULUCF is defined by the United Nations Climate Change Secretariat as a greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use such as settlements and commercial uses, land-use change, and forestry activities. LULUCF has impacts on the global carbon cycle and as such, these activities can add or remove carbon dioxide (or, more generally, carbon) from the atmosphere, influencing climate.

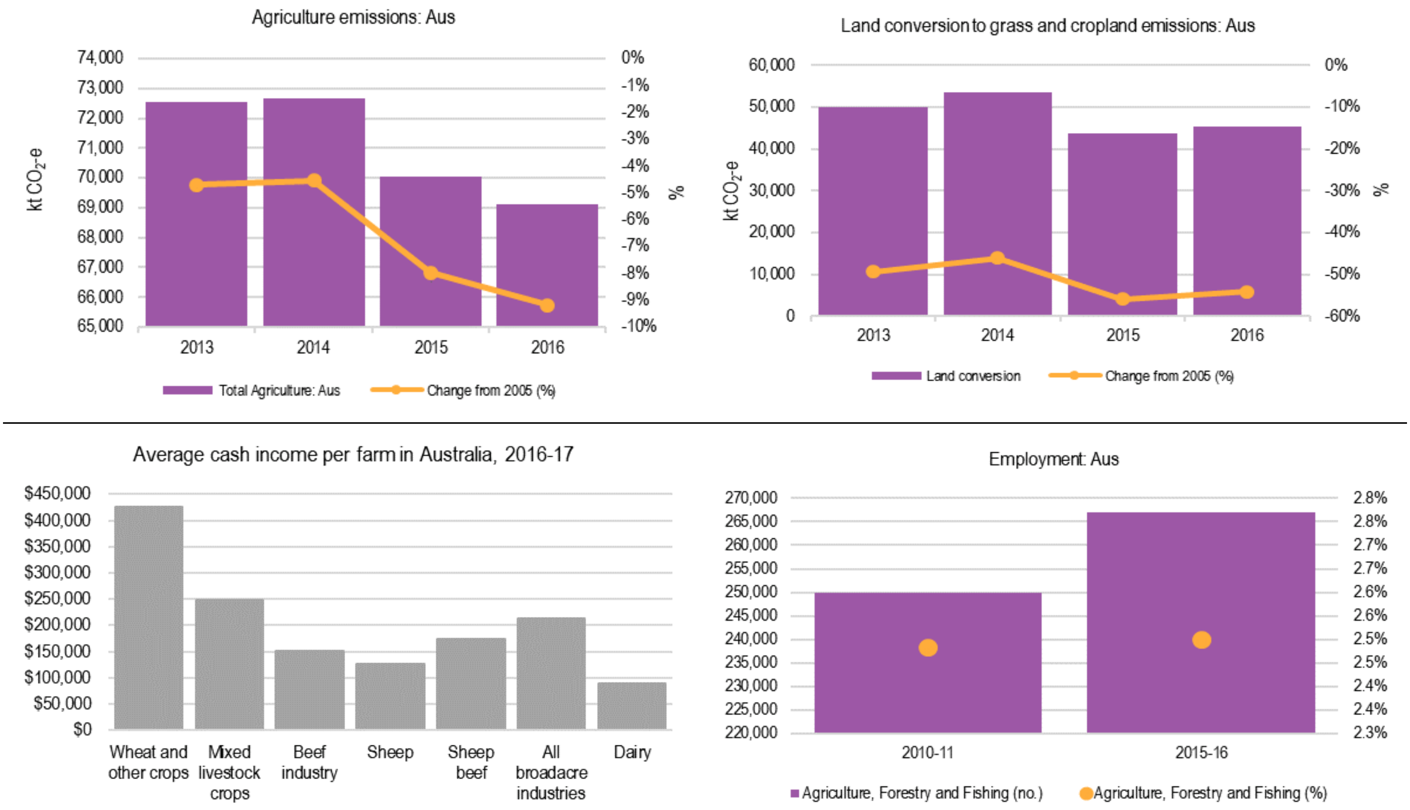
28 Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*

29 Australian Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile

30 ABS figures do not readily provide a breakdown between the agriculture, forestry and fishing sub-sectors

31 ABARES, viewed January 2019, http://www.agriculture.gov.au/abares/research-topics/surveys/farm-performance#performance—by-industry

FIGURE 2.7 EMPLOYMENT AND EMISSIONS: AUSTRALIA, 2012-13 TO 2016-17



Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.2 PROJECTED EMISSIONS

	Emissions (Mt CO_2-e)			Compared to 2005	
	2005	**2018**	**2030**	**2018**	**2030**
Grazing beef	33.8	32.5	33.4	-4%	-1%
Grain fed beef	2.1	2.4	3.1	14%	48%
Dairy	9.8	8.6	9.5	-12%	-3%
Sheep*	18.9	13.8	14.9	-27%	-21%
Pigs	1.7	1.6	1.8	-6%	6%
Crop	4.4	4.6	5.2	5%	18%
Other animals	0.7	0.9	1.1	29%	57%
Fertilisers	2.7	3.5	5.1	30%	89%
Lime and urea	2.0	2.8	3.8	40%	90%

Note: *Sheep refers to sheep and lamb livestock

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, 'AUSTRALIA'S EMISSIONS PROJECTIONS 2018' REPORT RELEASED DECEMBER 2018

Outlook for Australian agriculture

The outlook for Australia's major agricultural commodities is one of increased competition and lower prices, according to several presentations at the ABARES Outlook 2018 conference.[32] However, it is expected the increased export volumes will compensate and the total value of agricultural exports will remain largely unchanged (as illustrated in **Figure 2.8**).

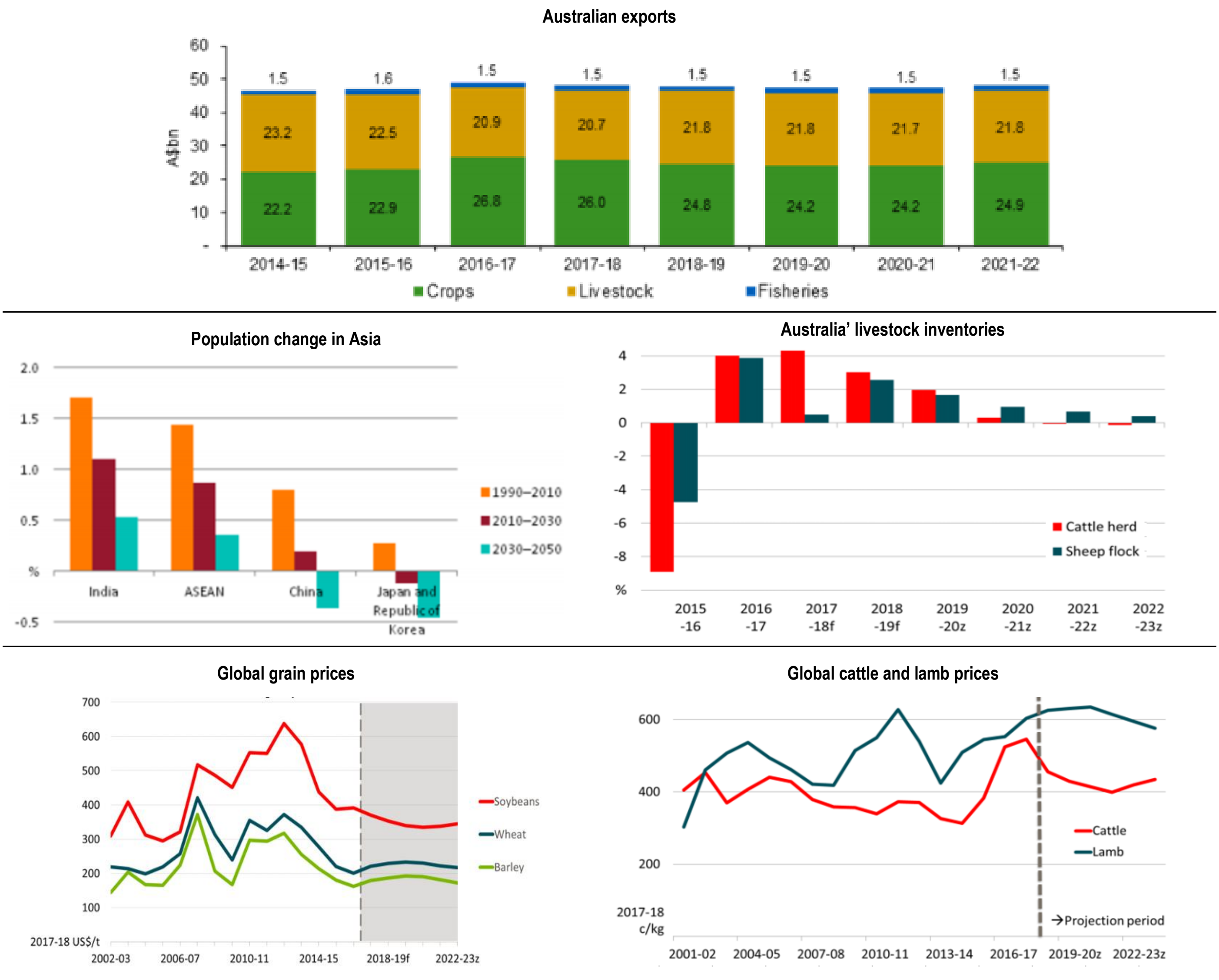
32 http://www.agriculture.gov.au/abares/outlook/archive/2018-program

Australia's exports are forecast to fall up to 2021-22, compared to recent years, with increased competition from Brazil, United States of America (USA), Russia, Ukraine and Argentina into the Asian markets. However, uncertainty and trade tensions between the USA and China remain a significant concern.[33] Population change in Asia is an important demand driver for agricultural exports from Australia. Whilst Asia's total population is expected to increase until at least 2030 (other than in Japan and the Republic of Korea), the rate of growth will be less than that seen between 1999 and 2010.

A period of abundant livestock supply results in slightly lower projected prices up to 2022-23. Demand from the USA is expected to weaken, whilst USA exports are expected to increase, placing competitive pressure on Australian exporters.[34]

Global prices for grains are also expected to remain stable or fall slightly in the short-term (remaining well below the highs of 2012-13). The assumption underlying this projection is an optimistic view that high yields will continue for exporters following the especially good yields producers experienced in both the northern and southern hemisphere in 2016 and 2017.[35]

FIGURE 2.8 AUSTRALIAN AGRICULTURAL: OUTLOOK



Note: 'z' refers to ABARES projection and 'f' to ABARES forecast

SOURCE: ABARES OUTLOOK 2018 CONFERENCE: 'ADVANCING AUSTRALIA AGRICULTURE IN PARTNERSHIP WITH ASIA', DOUG FERGUSON, KPMG; 'PRICES, COMPETITION AND MARKET INNOVATION,' DR ROHAN NELSON, ABARES; 'THE MEAT SCENE,' JACK MULLUMBY, ABARES0.

33 KPMG, 2018, Advancing Australian agriculture in partnership with Asia

34 ABARES, Jack Mullumby, 2018, *The Meat Scene*

35 ABARES, Dr Rohan Nelson, 2018, Prices, competition and market innovation

2.3 Overview at the State and Territory level

The section below examines the following details for each state and territory:

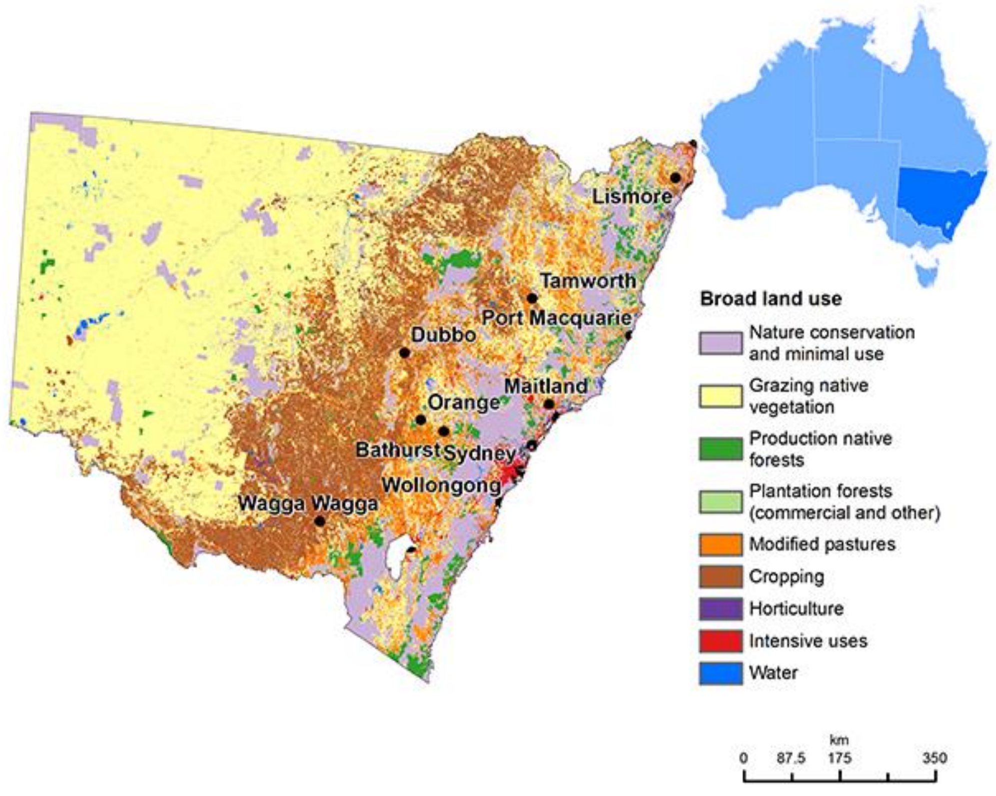
— agricultural land use
— agricultural activity in terms of production and value
— emissions produced by the industry
— employment figures for the industry.

The changes in key agricultural activities are described between 2012-13 and 2016-17, highlighting the largest contributors, the activities showing the highest growth and those lagging.
National production data for sugar, rice, horticulture and wine production are from ABARES and data on value at a state and territory level is from ABS.[36] As indicated above, the most recent, complete, national scale datasets for 2016-17 (i.e. from ABS, ABARES and DoEE) are used to develop the state and territory overview sections. The New South Wales Department of Primary Industries (NSW DPI) has developed a detailed picture of primary industries in the state through its publication *Performance, Data and Insights 2018*.[37]

Land use

New South Wales hosts an extensive agricultural sector with over 80 per cent of the State's land being used for agricultural activities, particularly grazing (see **Figure 2.9**).[38]

FIGURE 2.9 LAND USE: NEW SOUTH WALES



SOURCE: ABARES

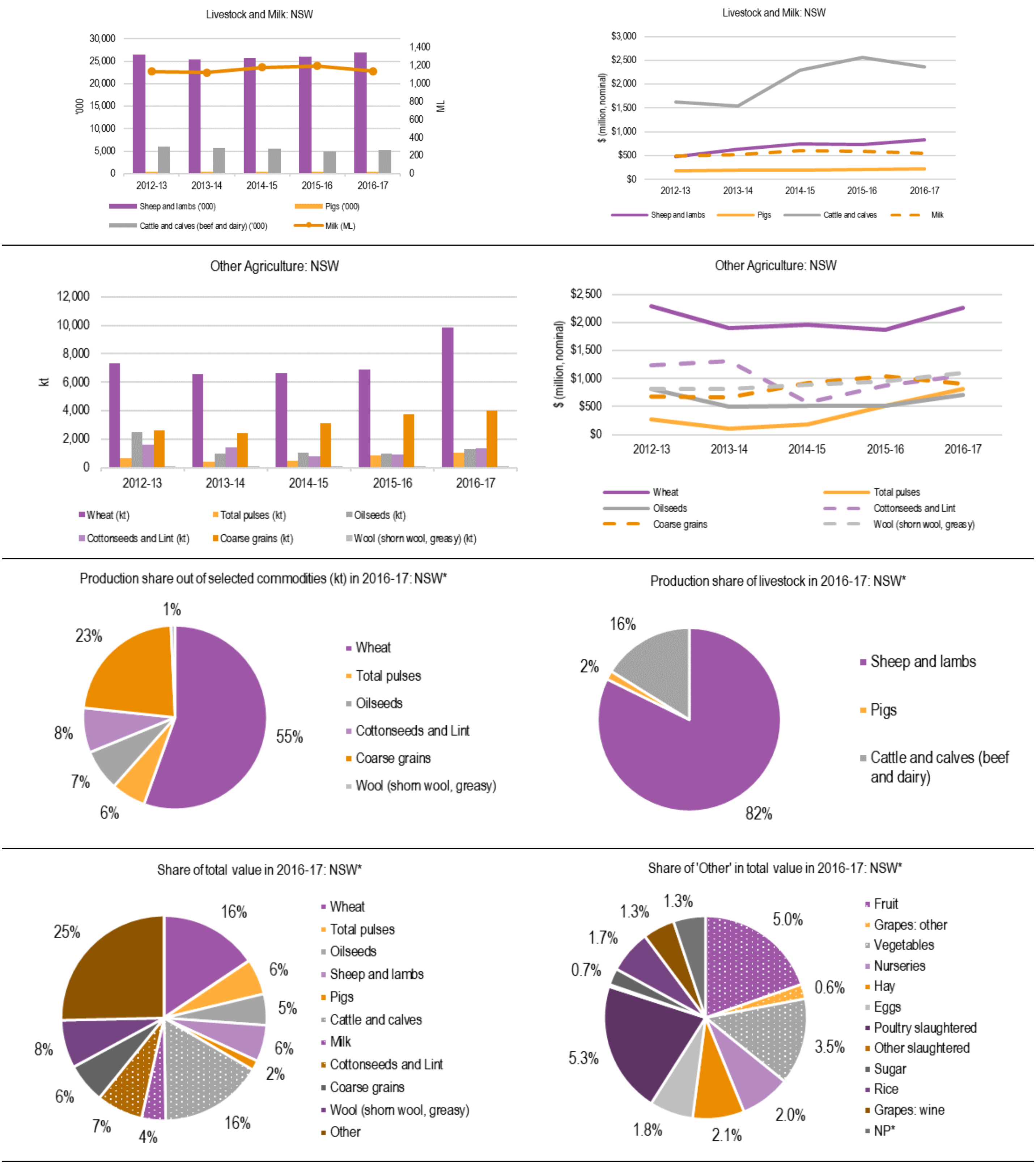
[36] Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018
[37] NSW Department of Primary Industries; Dec 2018: *Performance, Data and Insights 2018* - https://www.dpi.nsw.gov.au/about-us/publications/pdi/2018
[38] ABARES, viewed December 2018, http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/nsw#regional-overview

Economic overview

The economic overview of key agricultural sectors is provided in **Figure 2.10**. Wheat and cattle contribute a significant share of the total value of agriculture in the State, at around 16 per cent each. Overall, production and value of agricultural products trended upwards between 2012-13 and 2016-17. The exception being cotton, which declined in production and value over the period.[39] The commodity displaying the most rapid growth is pulses, where production and value increased in nominal terms by almost 67 per cent and 193 per cent, respectively. Coarse grains is another sector that has exhibited strong growth over this period, with approximately a 52 per cent and 33 per cent increase in production and value, respectively. The share of total value for both pulses and coarse grains is relatively small at around 6 per cent each.

[39] Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018

FIGURE 2.10 PRODUCTION AND VALUE: NEW SOUTH WALES, 2012-13 TO 2016-17



Note: *Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total Agriculture value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000. NP* refers to the amount in which ABS includes in the totals but is not provided for publication for a specific commodity

SOURCE: PRODUCTION: ABARES, VALUE: ABS

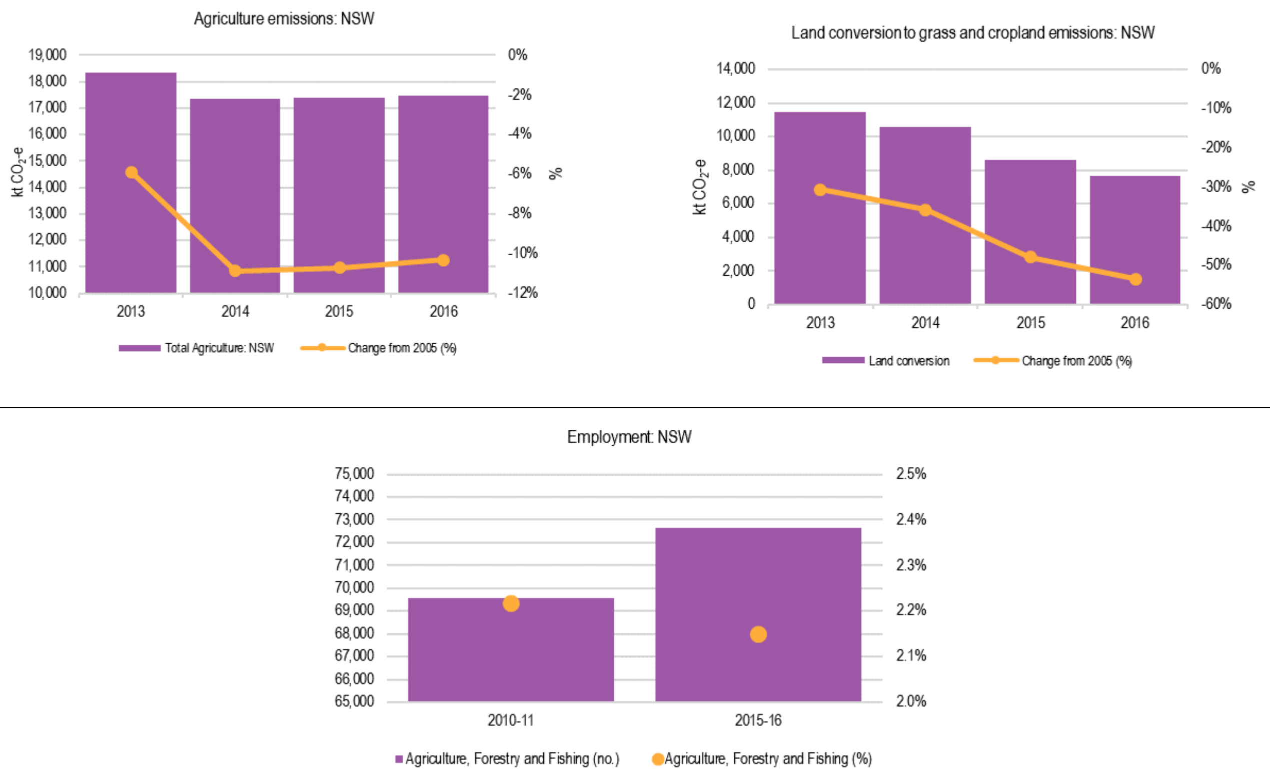
Emissions

As shown in **Figure 2.11**, emissions produced by agricultural activity in New South Wales have fallen since 2005, chiefly due to a reduction in overall livestock numbers. However, they have plateaued since 2014 at around 17,300 kilo tonnes of carbon dioxide equivalent (kt CO_2-e) per year. Emissions produced from clearing land (converted to cropland or grassland) have been steadily falling to below 8,000 kt CO_2-e in 2016, which is over 50 per cent lower than in 2005.[40] Assuming that national trends are translated at a state and territory level, the expected change in New South Wales by agricultural activity is shown in **Table 2.3**. The most significant sector contributions to emissions for New South Wales are highlighted. Emissions from sheep are projected to fall by 2030 and emissions from grazing beef are expected to remain stable, but the emissions are expected to increase for all other agricultural activities in New South Wales.[41]

Employment

Employment in the Agriculture, Forestry and Fishing industries has remained relatively steady since 2011.[42]

FIGURE 2.11 EMPLOYMENT AND EMISSIONS: NEW SOUTH WALES, 2012-13 TO 2016-17



Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.3 EMISSIONS PROJECTIONS: CHANGE BY 2030 IN NEW SOUTH WALES

Agricultural activity	Change by 2030
Grazing beef	●
Grain fed beef	↑
Dairy	↓
Sheep	↓

40 Australia Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile
41 Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*
42 Department of the Environment and Energy, 2018, State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018

Agricultural activity	Change by 2030
Pigs	↑
Crop	↑
Other animals	↑
Fertilisers	↑
Lime and urea	↑

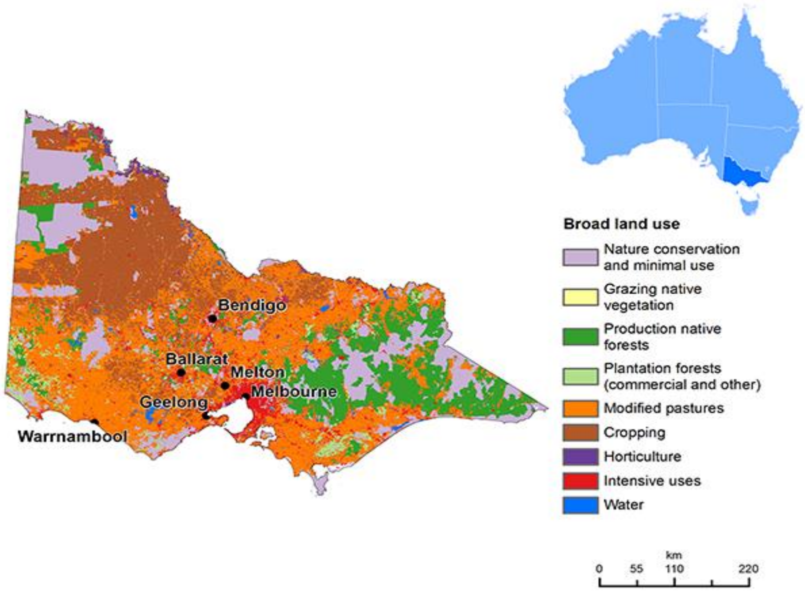
SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

2.3.2 Victoria overview

Land use

Victoria is Australia's most densely populated state with agricultural activity occupying about 56 per cent of land, mostly grazing of modified pasture (see **Figure 2.12**).[43]

FIGURE 2.12 LAND USE: VICTORIA



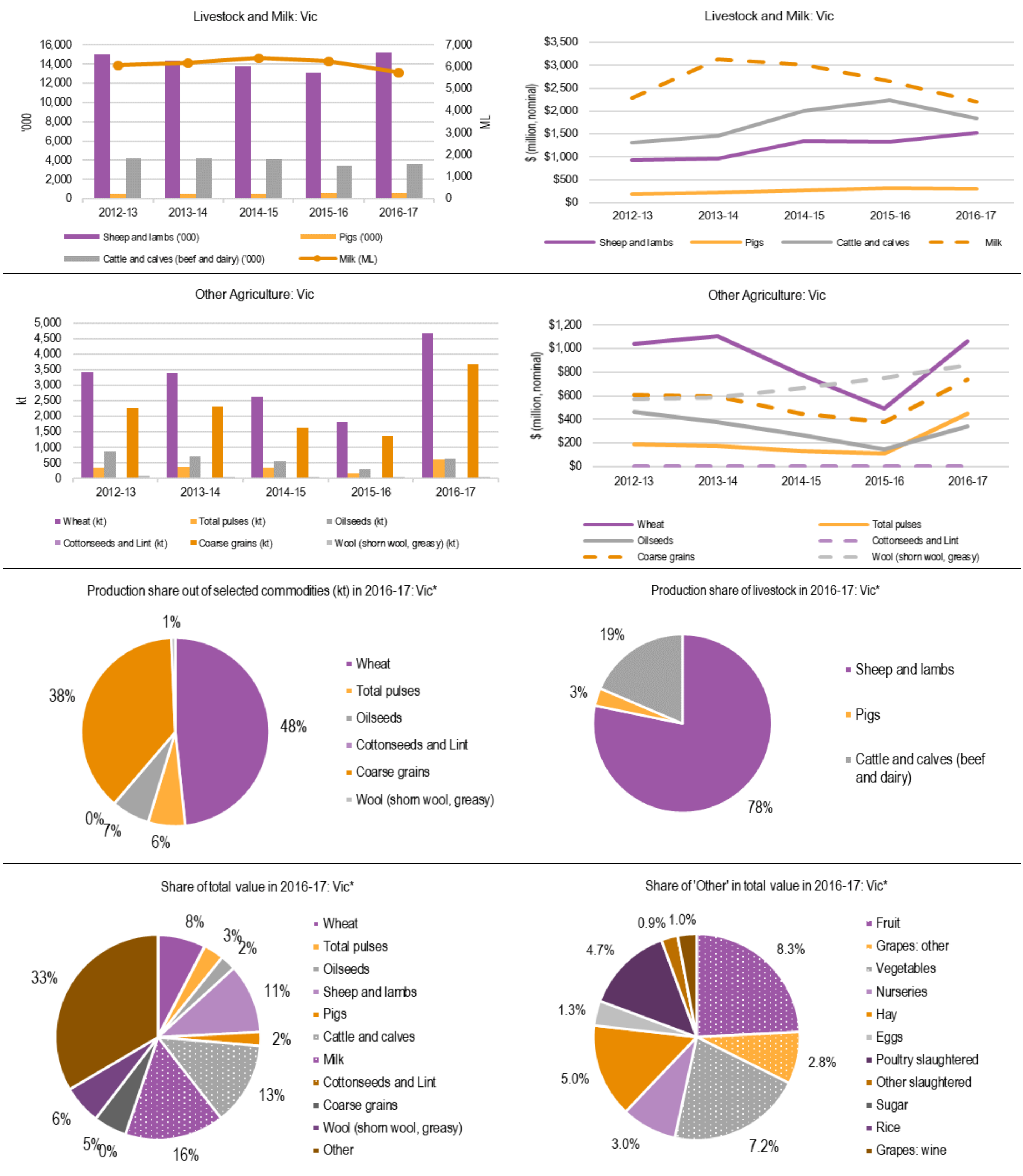
SOURCE: ABARES

Economic overview

The economic overview of key agricultural sectors is provided in **Figure 2.13**. Milk contributes the largest single share of the total value of agriculture in the State, approximately 16 per cent. However, the value of the sector has experienced about a 30 per cent decline in value, in nominal terms, since 2013-14. This is in stark comparison to other selected commodities, including wheat, coarse grains, oilseeds and pulses, which have rebounded from 2015-16 lows. Wheat, pulses, sheep and lambs, pigs and coarse grains all reported record production volumes in 2016-17.[44]

[43] ABARES, viewed December 2018, http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/vic#regional-overview
[44] Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018

FIGURE 2.13 PRODUCTION AND VALUE: VICTORIA, 2012-13 TO 2016-17



Note: *Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total Agriculture value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000.

SOURCE: PRODUCTION: ABARES, VALUE: ABS

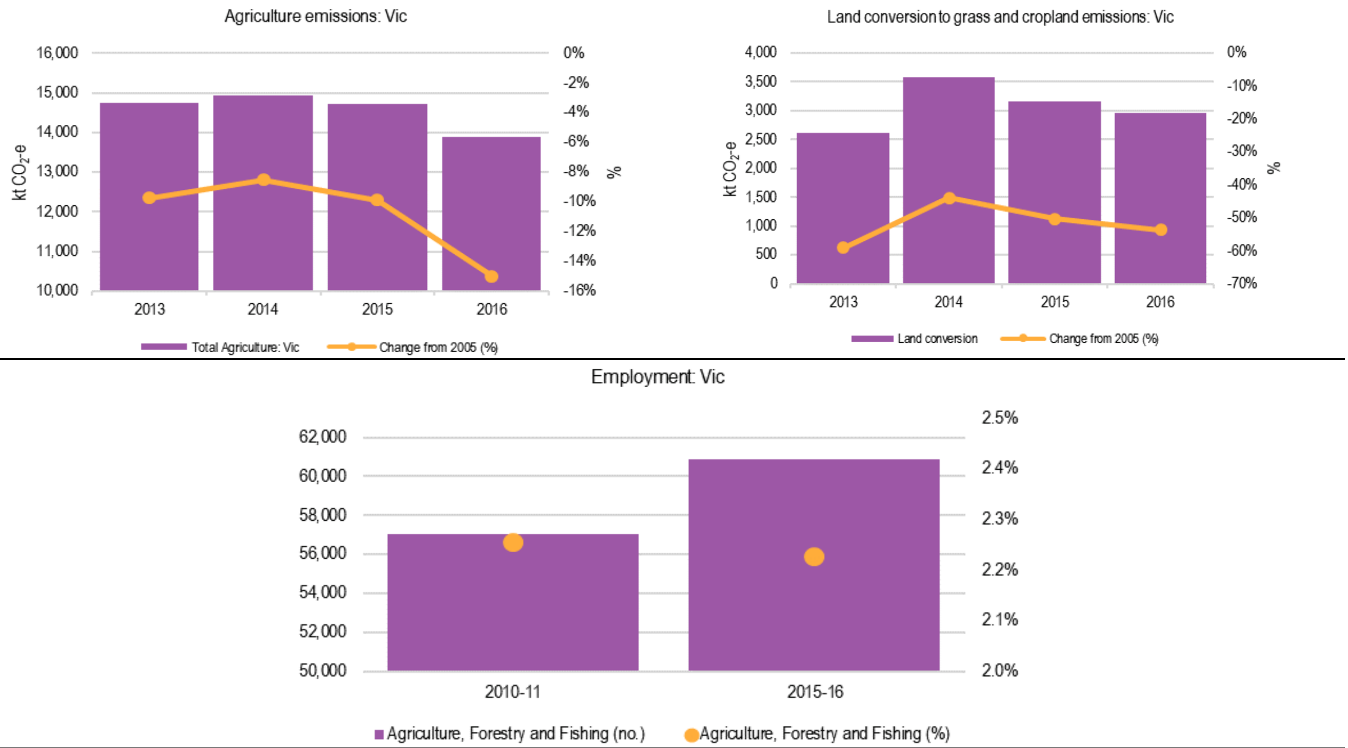
Emissions

As shown in **Figure 2.14**, emissions produced by agricultural activity in Victoria have fallen since 2005, particularly since 2015, with total emissions at about 13,800 kt CO_2-e in 2016. Emissions generated from land clearing (converted to cropland or grassland) peaked in 2014 and is estimated to be about 50 per cent lower than 2005 levels, at about 3,000 kt CO_2-e in 2016.[45] Assuming that national trends are translated at a state and territory level, the expected change in Victoria by agricultural activity is shown in **Table 2.4**. The most significant sources of agricultural emissions for Victoria are highlighted. Emissions from sheep and 'dairy' are projected to fall by 2030 and emissions from grazing beef are expected to remain stable, but the emissions are expected to increase for all other agricultural activities.[46]

Employment

Employment in the Agriculture, Forestry and Fishing industry has remained relatively steady since 2011.[47]

FIGURE 2.14 EMPLOYMENT AND EMISSIONS: VICTORIA, 2012-13 TO 2016-17



Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.4 EMISSIONS PROJECTIONS: CHANGE BY 2030 IN VICTORIA

Agricultural activity	Change by 2030
Grazing beef	●
Grain fed beef	↑
Dairy	↓
Sheep	↓
Pigs	↑

45 Australia Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile

46 Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*

47 Department of the Environment and Energy, 2018, State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018

Agricultural activity	Change by 2030
Crop	↑
Other animals	↑
Fertilisers	↑
Lime and urea	↑

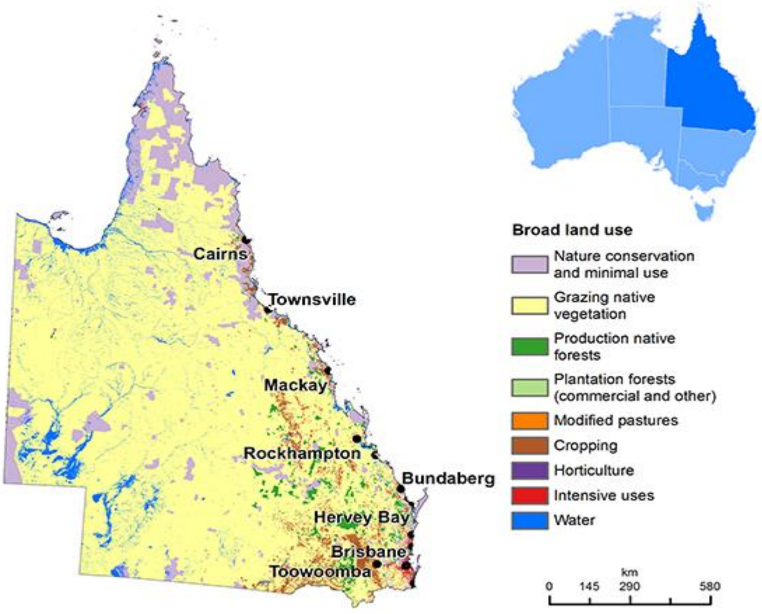
SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

2.3.3 Queensland overview

Land use

Queensland is an important contributor to the nation's agricultural industry with over 84 per cent of the State's land being used for agricultural activities, mostly for grazing of native vegetation (see **Figure 2.15**).[48]

FIGURE 2.15 LAND USE: QUEENSLAND



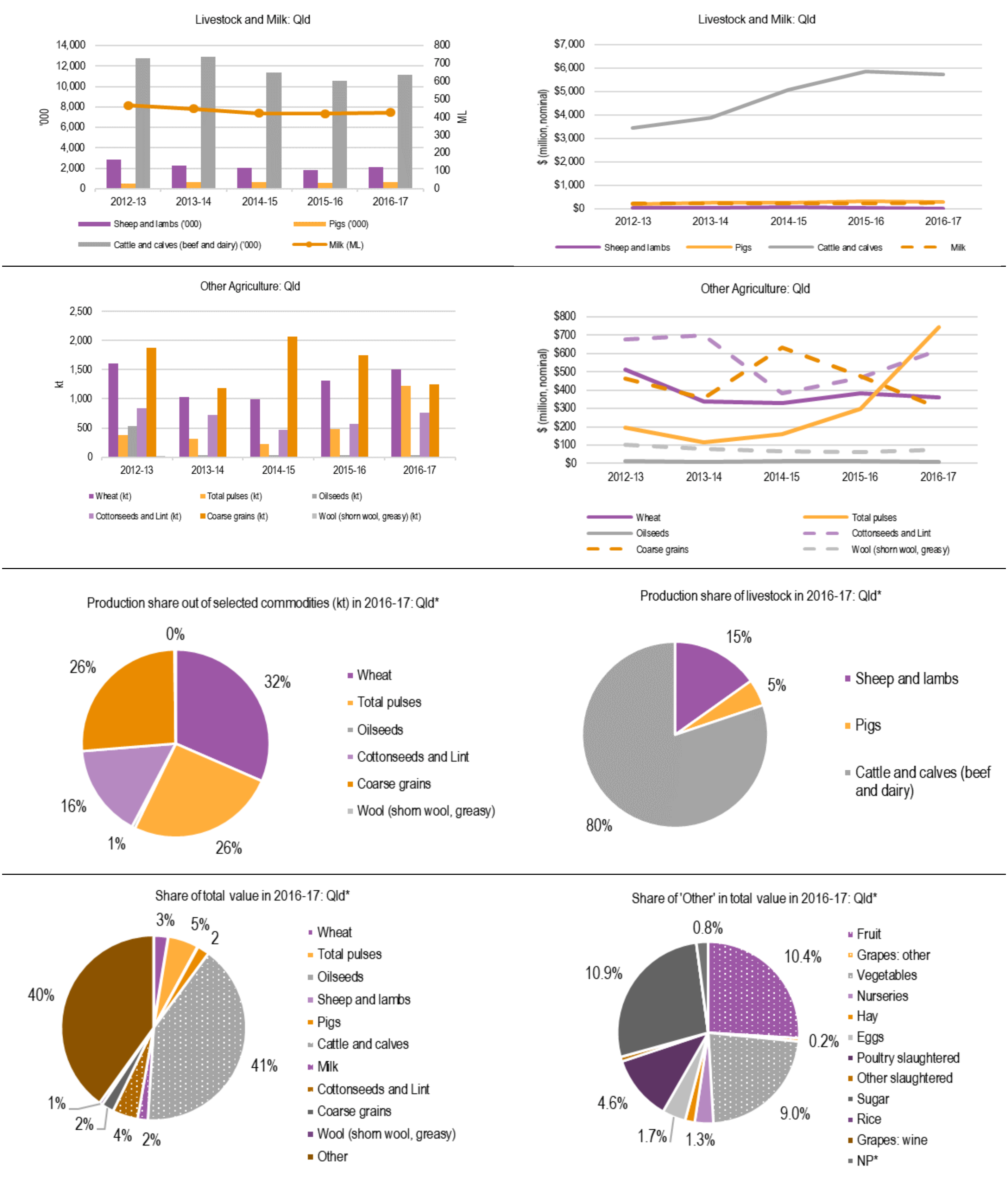
SOURCE: ABARES

Economic overview

An overview of key agricultural activities is provided in **Figure 2.16**. Cattle comprise a significant share of the total value of agriculture in the State; about 41 per cent in value terms and 80 per cent of total livestock numbers (as compared to pigs, sheep and lambs). In 2016-17 there was a split allocation for grains with wheat at 32 per cent and coarse grains and pulses at 26 per cent each. Together they generated about 10 per cent of the State's agricultural value in 2016-17. Pulses, in particular, have shown a significant increase in value and volume since 2014-15, with a 220 per cent increase in production and a 280 per cent increase in nominal value. This gave pulse crops approximately a 5 per cent share of total Queensland agricultural value for 2016-17. Over the same period coarse grains decreased in value and volume by around 34 per cent each and hold a market share of about 2 per cent.[49]

48 ABARES, viewed December 2018, http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/qld#regional-overview
49 Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018

FIGURE 2.16 PRODUCTION AND VALUE: QUEENSLAND, 2012-13 TO 2016-17



Note: *Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total agricultural value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000. NP* refers to the amount in which ABS includes in the totals but is not provided for publication for a specific commodity. Queensland Department of Agriculture and Fisheries AgTrends data may provide updated figures.

SOURCE: PRODUCTION: ABARES, VALUE: ABS

Emissions

As shown **Figure 2.17**, emissions produced by agricultural activity in Queensland are about 6 per cent below 2005 levels, with 18,300 kt CO_2-e emissions in 2016. Land conversion to cropland and grassland is a significant source of emissions in Queensland, with approximately 23,000 kt CO_2-e emitted in 2016. However, compared to 2005 levels this is a reduction of over 60 per cent.[50] Assuming that national trends are translated at a state and territory level, the expected change in Queensland by agricultural activity is shown in **Table 2.5**. The most significant sources of agricultural emissions in Queensland are highlighted. Emissions from grazing beef are expected to remain stable, but the emissions from all other activities are expected to increase.[51]

Employment

Employment in the Agriculture, Forestry and Fishing industry has remained relatively steady since 2011.[52]

FIGURE 2.17 EMPLOYMENT AND EMISSIONS: QUEENSLAND, 2012-13 TO 2016-17

Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.5 EMISSIONS PROJECTIONS: CHANGE BY 2030 IN QUEENSLAND

Agricultural activity	Change by 2030
Grazing beef	●
Grain fed beef	↑
Dairy	↓
Sheep	↓
Pigs	↑
Crop	↑

50 Australia Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile

51 Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*

52 Department of the Environment and Energy, 2018, *State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018*

Agricultural activity	Change by 2030
Other animals	↑
Fertilisers	↑
Lime and urea	↑

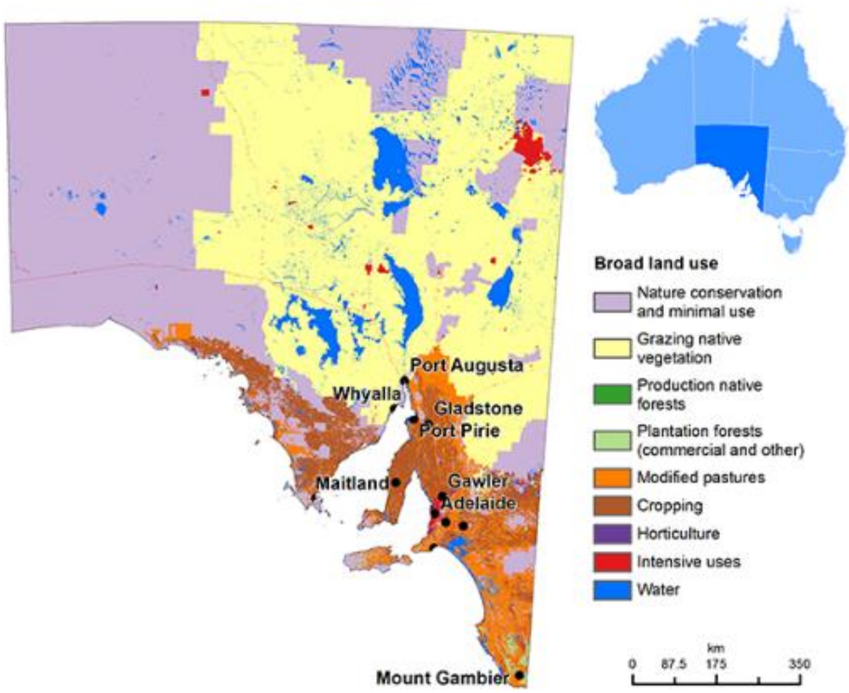
SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

2.3.4 South Australia overview

Land use

Broadly, South Australia consists of two highly disparate landscapes, that is arid desert and fertile vegetation. About 42 per cent of the land is used for agriculture, primarily for grazing on native vegetation (see **Figure 2.18**).[53]

FIGURE 2.18 LAND USE: SOUTH AUSTRALIA



SOURCE: ABARES

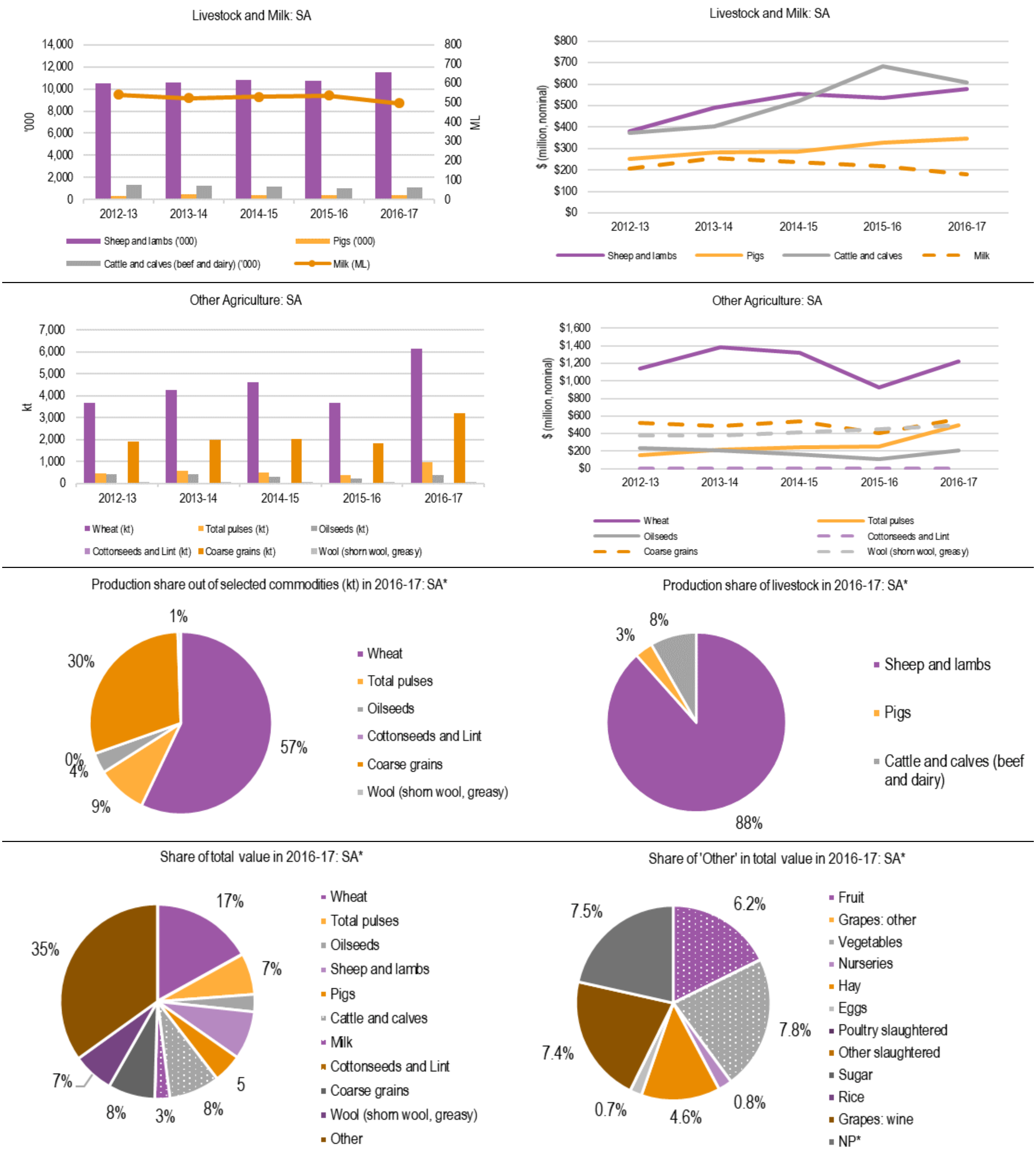
Economic overview

An overview of key agricultural activities in South Australia is provided in **Figure 2.19**. Wheat is the largest generator of agricultural value in the State. The value of pulses production has grown over the time period shown, reaching a 7 per cent share of total value. Cattle represent a commodity of similar size in terms of share of value and has experienced a large increase in value (over 60 per cent), even though herd numbers have recently fallen. The value of sheep and lamb production has steadily increased over the period, to reach similar levels to cattle and calves in 2016-17.[54]

[53] ABARES, viewed December 2018, http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/sa#regional-overview

[54] Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018

FIGURE 2.19 PRODUCTION AND VALUE: SOUTH AUSTRALIA, 2012-13 TO 2016-17



Note: *Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total agricultural value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000. NP* refers to the amount in which ABS includes in the totals but is not provided for publication for a specific commodity

SOURCE: PRODUCTION: ABARES, VALUE: ABS

Emissions

As shown in **Figure 2.20**, emissions produced by agricultural activity in South Australia have fallen since 2005, notwithstanding a spike in emissions in 2014. Approximately 5,500 kt CO_2-e emissions occurred in 2016. Emissions produced from land clearing (conversion to cropland and grassland) fell to new lows in 2016, below 1,000 kt CO_2-e. This is about 50 per cent lower than 2005 levels.[55] Assuming that national trends are translated at a state and territory level, the expected change in South Australian agricultural emissions by activity is shown in **Table 2.6**. The most significant sources of agricultural emissions are highlighted. Emissions from sheep are expected to decline, but the emissions from all other agricultural activities are expected to increase.[56]

Employment

Employment in the Agriculture, Forestry and Fishing industry has remained relatively steady since 2011.[57]

FIGURE 2.20 EMPLOYMENT AND EMISSIONS: SOUTH AUSTRALIA, 2012-13 TO 2016-17

Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.6 EMISSIONS PROJECTIONS: CHANGE BY 2030 IN S OUTH AUSTRALIA

Agricultural activity	Change by 2030
Grazing beef	●
Grain fed beef	↑
Dairy	↓
Sheep	↓
Pigs	↑

55 Australia Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile

56 Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*

57 Department of the Environment and Energy, 2018, State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018

Agricultural activity	Change by 2030
Crop	↑
Other animals	↑
Fertilisers	↑
Lime and urea	↑

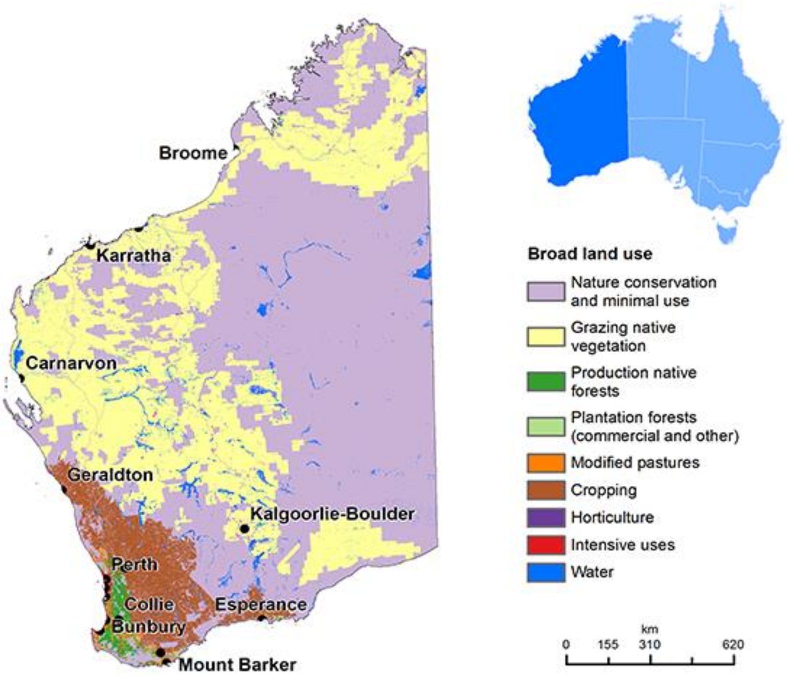
SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

2.3.5 Western Australia overview

Land use

Agriculture in Western Australia covers 42 per cent of the State. Activities are concentrated in the south-western region of the State. However, grazing of native vegetation is undertaken across large parts of the State (see **Figure 2.21**).[58]

FIGURE 2.21 LAND USE: WESTERN AUSTRALIA



SOURCE: ABARES

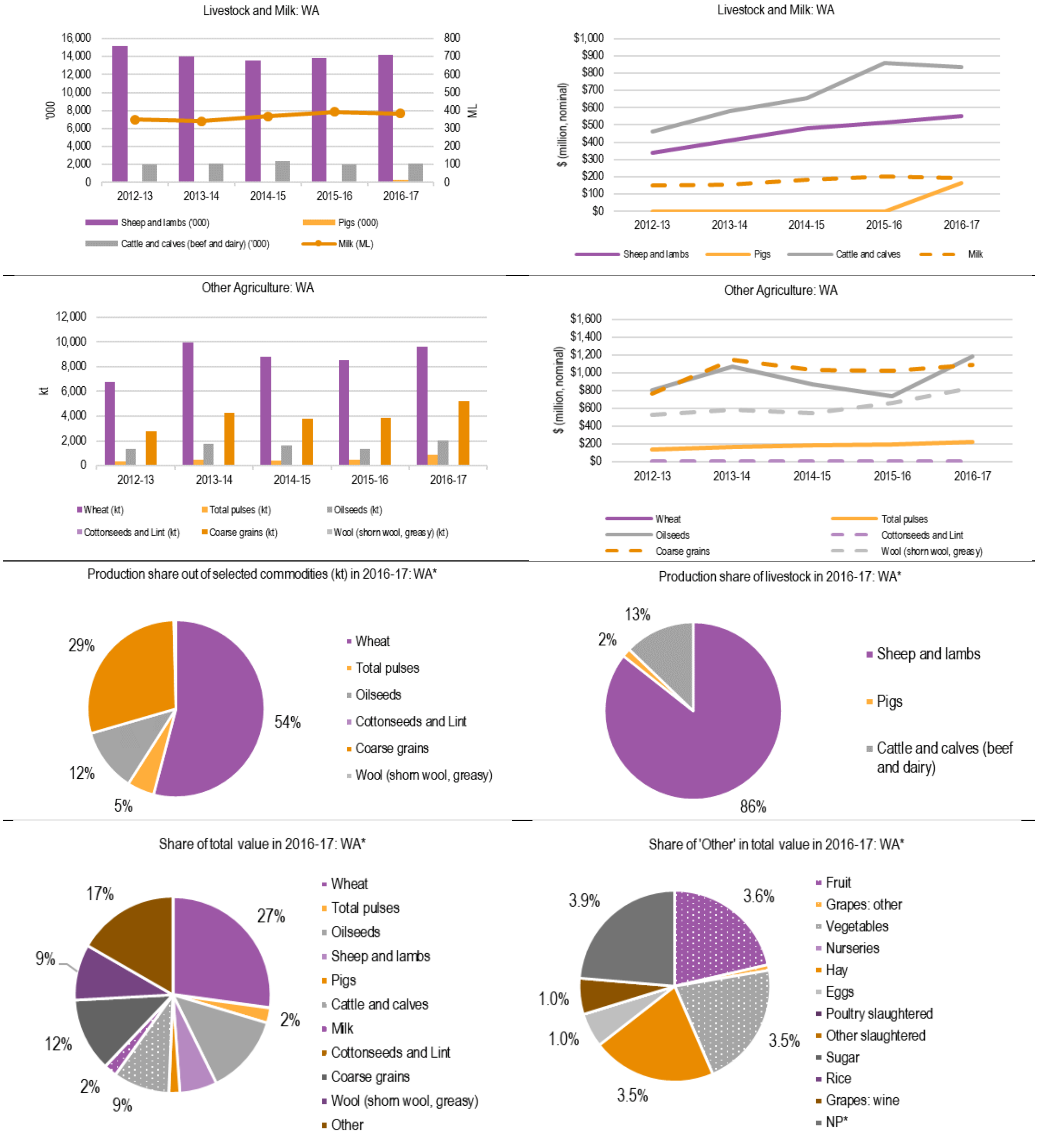
Economic overview

An economic overview of key agricultural activities is provided in **Figure 2.22**. The highest contribution to the total value of agriculture in Western Australia in 2016-17 was from wheat (27 per cent). Wheat production volumes have remained relatively stable since 2013-14. The sector displaying the highest growth is pulses. However, their share of total value in 2016-17 is only 2 per cent. Production of oilseeds and coarse grains have grown by about 50 per cent and 87 per cent, respectively, since 2012-13. They contributed 13 and 12 per cent respectively, of the total value of agricultural production in Western Australia in 2016-17.[59]

58 ABARES, viewed December 2018, http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/wa#regional-overview

59 Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018

FIGURE 2.22 PRODUCTION AND VALUE: WESTERN AUSTRALIA, 2012-13 TO 2016-17



Note: *Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total agricultural value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000. NP* refers to the amount in which ABS includes in the totals but is not provided for publication for a specific commodity

SOURCE: PRODUCTION: ABARES, VALUE: ABS

Emissions

As shown in **Figure 2.23**, emissions from agricultural activity in Western Australia initially fell by almost 25 per cent between 2005 and 2013. But they have subsequently increased to around 8,800 kt CO_2-e (15 per cent below 2005 emissions). Emissions from land conversion reached over 8,000 kt CO_2-e, some 2,000 kt CO_2-e higher than the average over the preceding three years. However, this is still about 10 per cent lower than 2005 emissions.[60] Assuming that national trends are translated at a state and territory level, projected emissions in Western Australia by agricultural activity are shown in **Table 2.7**. The most significant sources of agricultural emissions for Western Australia are highlighted. Emissions from sheep are expected to decline, emissions from grazing beef are expected to remain stable, but the emissions are expected to increase in all other agricultural activities.[61]

Employment

Employment in the Agriculture, Forestry and Fishing industry has remained relatively steady since 2011.[62]

FIGURE 2.23 EMPLOYMENT AND EMISSIONS: WESTERN AUSTRALIA, 2012-13 TO 2016-17

Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.7 EMISSIONS PROJECTIONS: CHANGE BY 2030 IN WESTERN AUSTRALIA

Agricultural activity	Change by 2030
Grazing beef	●
Grain fed beef	↑
Dairy	↓
Sheep	↓
Pigs	↑

60 Australia Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile

61 Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*

62 Department of the Environment and Energy, 2018, State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018

Agricultural activity	Change by 2030
Crop	↑
Other animals	↑
Fertilisers	↑
Lime and urea	↑

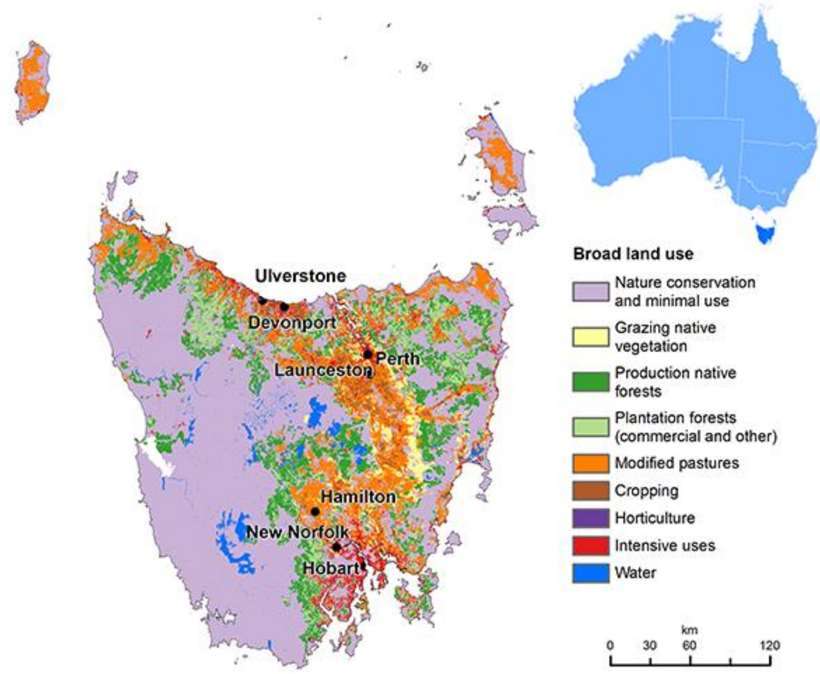
SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

2.3.6 Tasmania overview

Land use

Agricultural activity occupies about 28 per cent of Tasmania, with the grazing of modified pastures predominating (see **Figure 2.24**). [63]

FIGURE 2.24 LAND USE: TASMANIA



SOURCE: ABARES

Economic overview

An overview of key agricultural sectors is provided in **Figure 2.25**. Milk and cattle and calves are the dominant sectors, making up around 22 per cent of production and 20 per cent of Tasmania's total agricultural value in 2016-17, respectively. However, the total value of the milk sector has declined since 2015 in nominal terms. Horticulture is another important sector, contributing around 28.5 per cent of the total value in the state (fruit and nuts at 10.5 per cent and vegetables at 18 per cent). Wheat only contributed 1 per cent of total value in 2016-17 but has exhibited the most growth over this period, with about an 83 per cent increase in volume and a 46 per cent increase in value since 2012-13.[64]

[63] ABARES, viewed December 2018, http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/tas#regional-overview

[64] Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018

FIGURE 2.25 PRODUCTION AND VALUE: TASMANIA, 2012-13 TO 2016-17

Note: *Wool not reported by ABS in 2013-14 so a value extrapolated between 2012-13 and 2014-15. Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total agricultural value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000. NP* refers to the amount in which ABS includes in the totals but is not provided for publication for a specific commodity.

SOURCE: PRODUCTION: ABARES, VALUE: ABS

Emissions

Tasmania's emissions profile is unique among Australian jurisdictions given the significant amount of carbon sequestered through the managed forest estate and the low emissions intensity electricity generation. Tasmania achieved zero net emissions for the first time in 2016. However, Tasmania's agricultural sector contributes a relatively higher percentage (26 per cent in 2016) of the State's overall emissions profile, compared to the rest of the nation, dominated by enteric emissions from dairy and beef cattle, and sheep.

As shown in **Figure 2.26**, carbon emissions produced by agricultural activity in Tasmania have only recently fallen below 2005 levels, with just over 2,000 kt CO_2-e emissions emitted in 2016. Land conversion to cropland and grassland has exhibited annual oscillations. 2016 appears to be a higher emissions intensive year for land clearing with slightly under 2,000 kt CO_2-e emitted, which is about 50 per cent lower than 2005 levels.[65] Assuming that national trends are translated at a state and territory level, the expected change in Tasmania by agricultural activity is shown in **Table 2.8**. The most significant sources of agricultural emissions for Tasmania are highlighted. Emissions from sheep are expected to decline, emissions from grazing beef are expected to remain stable, but the emissions from other agricultural activities are expected to increase.[66]

Employment

Employment in the Agriculture, Forestry and Fishing industry has increased by half a percent (1,000 people) since 2011.[67]

FIGURE 2.26 EMPLOYMENT AND EMISSIONS: TASMANIA, 2012-13 TO 2016-17

Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.8 EMISSIONS PROJECTIONS: CHANGE BY 2030 IN TASMANIA

Agricultural activity	Change by 2030
Grazing beef	●
Grain fed beef	↑
Dairy	↓

[65] Australia Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile

[66] Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*

[67] Department of the Environment and Energy, 2018, State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018

Agricultural activity	Change by 2030
Sheep	↓
Pigs	↑
Crop	↑
Other animals	↑
Fertilisers	↑
Lime and urea	↑

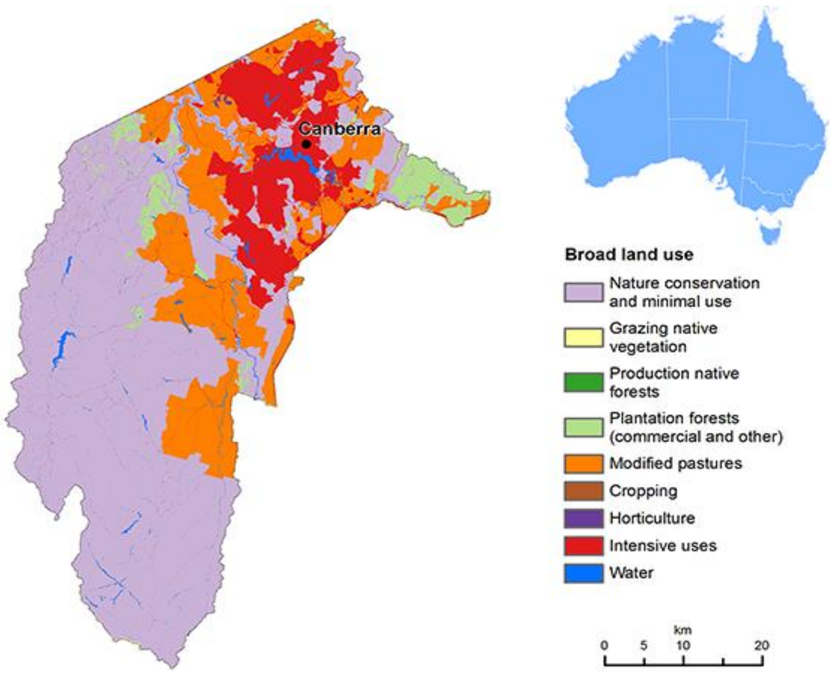
SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

2.3.7 Australian Capital Territory overview

Land use

The Australian Capital Territory is the smallest jurisdiction. Only 15 per cent of the Territory is used for agricultural purposes, mainly grazing of modified pastures (see **Figure 2.27**).[68]

FIGURE 2.27 LAND USE: ACT



SOURCE: ABARES

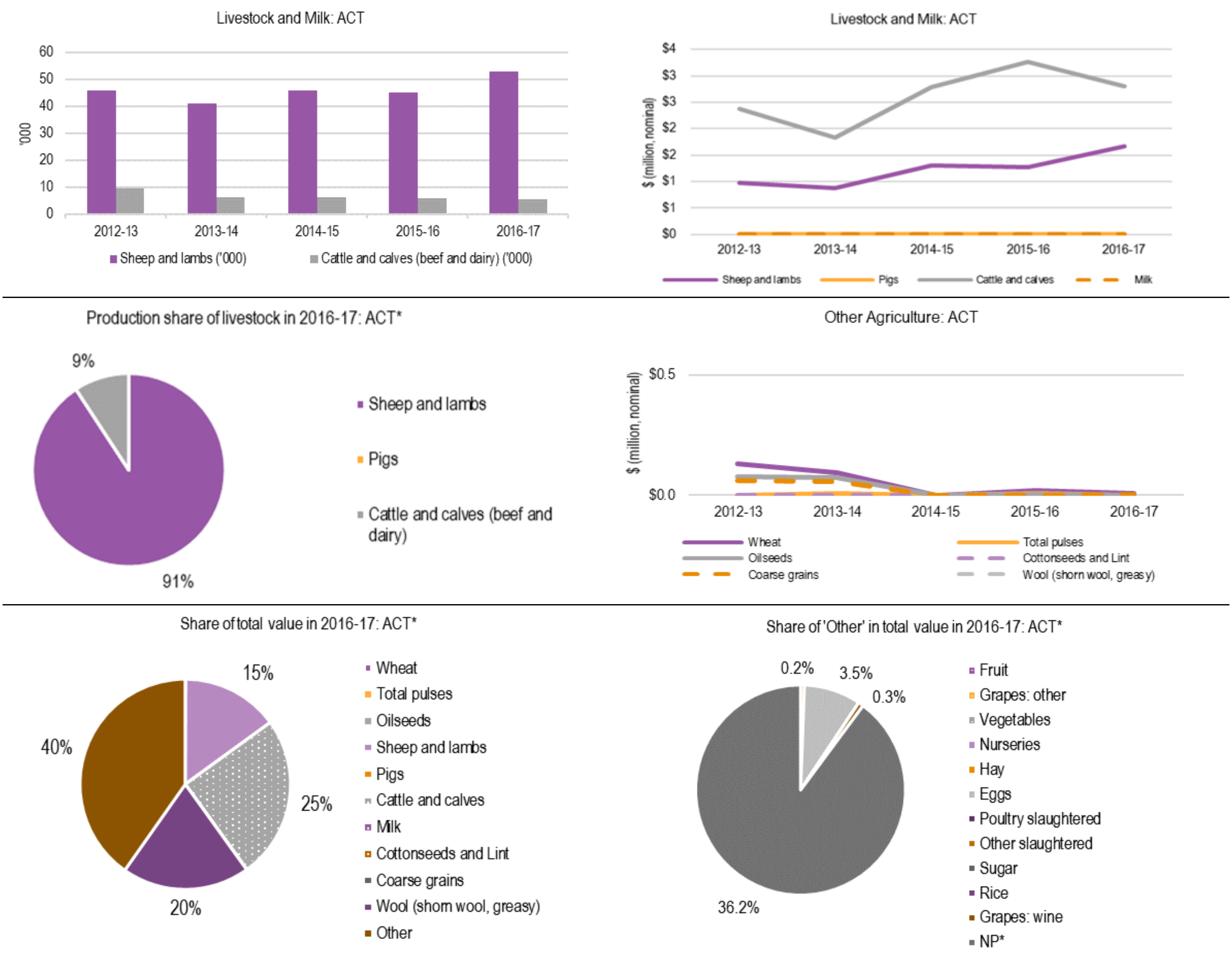
Economic overview

An overview of key agricultural activities is provided in **Figure 2.28**. Cattle, sheep and lambs are the core activities in the Territory. Along with wool, these sectors contributed 60 per cent to the Territory's total agricultural value in 2016-17. The other 40 per cent is mostly egg and vegetable commodities. Since 2014-15, activity in the other commodities such as wheat, oilseeds and coarse grains was negligible.[69]

68 ABARES, viewed December 2018, http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/act#regional-overview

69 Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018

FIGURE 2.28 PRODUCTION AND VALUE: ACT, 2012-13 TO 2016-17



Note: *Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total agricultural value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000. NP* refers to the amount in which ABS includes in the totals but is not provided for publication for a specific commodity

SOURCE: PRODUCTION: ABARES, VALUE: ABS

Emissions

As shown in **Figure 2.29**, emissions produced by agricultural activity in the ACT are well below 2005 levels, with about 24 kt CO_2-e emissions emitted in 2016 or 33 per cent below the emissions in 2005, despite a recent upward trend. Land clearing (converted to cropland or grassland) fell dramatically in 2016, compared to previous years. Emissions produced were around 5 kt CO_2-e which is almost 100 per cent lower than in 2005.[70] Assuming that national trends are translated at a state and territory level, the expected change in the ACT emissions by agricultural activity is shown in **Table 2.9**. The activities that are the most significant sources of agricultural emissions are highlighted. It is expected that emissions from dairy and sheep will decline, those from grazing beef will remain stable, with emissions from all other agricultural activities undertaken in the ACT expected to increase.[71]

[70] Australia Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile

[71] Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*

Employment

Employment in the Agriculture, Forestry and Fishing industry has remained relatively steady since 2011.[72]

FIGURE 2.29 EMPLOYMENT AND EMISSIONS: ACT, 2012-13 TO 2016-17

Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.9 EMISSIONS PROJECTIONS: CHANGE BY 2030 IN AUSTRALIAN CAPITAL TERRITORY

Agricultural activity	Change by 2030
Grazing beef	●
Grain fed beef	↑
Dairy	↓
Sheep	↓
Pigs	↑
Crop	↑
Other animals	↑
Fertilisers	↑
Lime and urea	↑

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

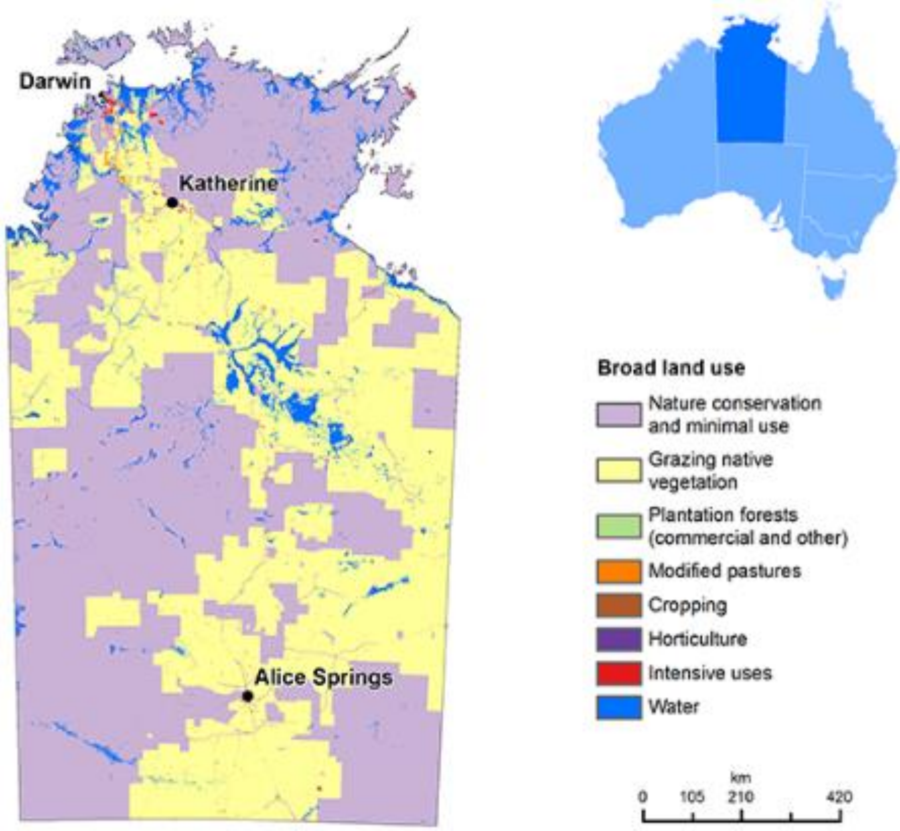
72 Department of the Environment and Energy, 2018, State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018

2.3.8 Northern Territory overview

Land use

The Northern Territory is an important agricultural region in Australia with about 46 per cent of the Territory used for cattle and calves production (see **Figure 2.30**).[73]

FIGURE 2.30 LAND USE: NORTHERN TERRITORY



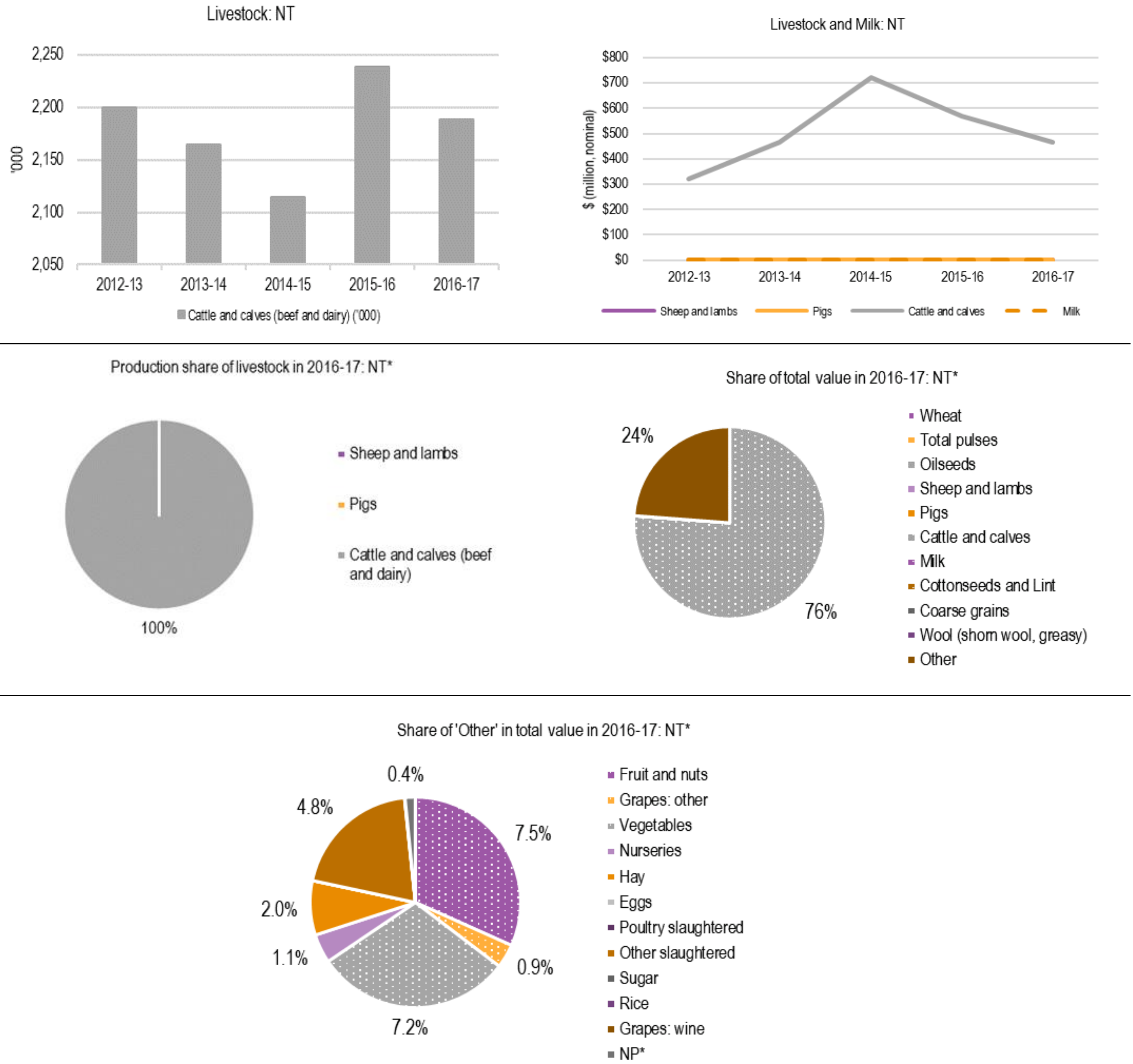
SOURCE: ABARES

Economic overview

An overview of key agricultural activities is provided in **Figure 2.31**. The cattle and calves herd peaked in 2015-16 and has since declined to around 2,200,000 head. The other major agricultural products that are important sources of value are mangoes and melons, valued at around $40 million and $36 million, respectively in 2016-17, according to official ABS statistics.[74] However, other information from the Department of Primary industry and Resources in the Northern Territory suggests that the value of the sectors were closer to $80 million for mangoes and $40 million for melons.[75]

73 ABARES, viewed December 2018, http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/nt#regional-overview
74 Australian Bureau of Statistics, 2012-13 to 2016-17 (inclusive), *Value of Agricultural Commodities Produced*, ABARES 2018, Agricultural commodity statistics 2018
75 Department of Primary industry and Resources, Northern Territory, <https://dpir.nt.gov.au/__data/assets/pdf_file/0008/505637/Outlook-Overview-2017.pdf

FIGURE 2.31 PRODUCTION AND VALUE: NORTHERN TERRITORY, 2012-13 TO 2016-17



Note: *Production share refers to the proportion of each commodity compared to only the selected commodities listed in the legend, not overall totals across all sectors within agriculture. Milk not included because it is a different unit type. Share of total value refers to total agricultural value not just total from selected commodities listed. Regarding Production and Value charts: series break in 2015–16. Prior to 2015–16 figures are based on establishments with an estimated value of agricultural operations (EVAO) of $5,000. From 2015–16 (inclusive) figures are based on establishments with an EVAO of $40,000. NP* refers to the amount in which ABS includes in the totals but is not provided for publication for a specific commodity

SOURCE: PRODUCTION: ABARES, VALUE: ABS

Emissions

As shown in **Figure 2.32**, emissions produced by agricultural activity in the Northern Territory are significantly higher than 2005 levels, with about 3,000 kt CO_2-e emitted in 2016 (34 per cent above emissions in 2005). Emissions from land clearing (in order to convert land to cropland and grassland) have been progressively increasing, reaching almost 700 kt CO_2-e in 2016, which is about 20 per cent above 2005 volumes.[76] Assuming that national trends are translated at a state and territory level, the expected change in the Northern Territory's emissions by agricultural activity is shown in **Table 2.10**.

[76] Australia Bureau of Statistics 2011 Basic Community Profile, 2016 General Community Profile

The most significant sources of agricultural emissions for the Northern Territory are highlighted. Emissions from grazing beef are expected to remain stable. Emissions associated with all other agricultural activities are expected to increase.[77]

Employment

Employment in the Agriculture, Forestry and Fishing industry has remained relatively steady since 2011.[78]

FIGURE 2.32 EMPLOYMENT AND EMISSIONS: NORTHERN TERRITORY, 2012-13 TO 2016-17

Note: Land conversions refer to land converted to grassland and cropland only. Land conversion to forest and other sinks and the associated net impact are not shown

SOURCE: EMPLOYMENT: ABS, EMISSIONS: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

TABLE 2.10 EMISSIONS PROJECTIONS: CHANGE BY 2030 IN NORTHERN TERRITORY

Agricultural activity	Change by 2030
Grazing beef	●
Grain fed beef	↑
Pigs	↑
Crop	↑
Other animals	↑
Fertilisers	↑
Lime and urea	↑

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY

77 Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*

78 Department of the Environment and Energy, 2018, State and Territory Greenhouse Gas Inventories 2016, Commonwealth of Australia 2018

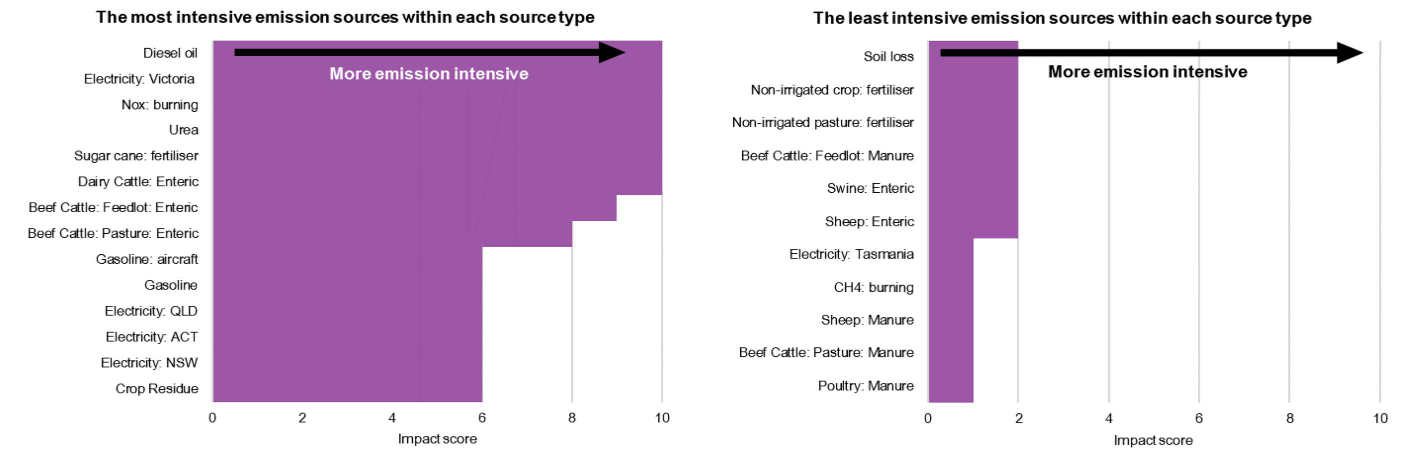
2.4 Emissions factors in agriculture

The emission sources directly applicable to agriculture cover both the range of agricultural sectoral activities and two significant direct inputs: on-farm and transport use of energy, and liquid fuels. Other significant, but diverse emissions sources arising from the use of manufactured products (i.e. packaging, synthetic fertiliser etc) by the agricultural sector are excluded from the following analysis. The energy and transport industries are the most emissions intensive industries nationally, followed by agriculture. Action to reduce emissions from energy and transport are likely to have an impact on the cost of these key inputs, which will have flow-on effects for the agricultural sector.

The logical response by producers in the agricultural sector will be to reduce consumption of these inputs where they can and/or increase sale prices to cover the increased electricity or fuels costs. Information about the spread of emission intensities across these inputs provides a greater understanding to inform the response and pro-active measures the agricultural industry can take to prepare for changes that will occur in these sectors.

Figure 2.33 shows agricultural emissions source intensities. For each unit type, as set out in **Table 2.11** (that is kg CH_4/head, Gg N_2O-N/ Gg N, CO_2-e/ tonne, etc), the relative intensities are compared. The most intensive sources for each unit type are then ranked. Cross referencing this figure to **Table 2.11** is important for context, given a common unit of measurement across all emission sources is not reflected in the comparison.

FIGURE 2.33 COMPARISON OF EMISSION INTENSITY BY SOURCE



Note: Emission sources have been compared within each unit type and scored in terms of their emission intensity. These charts only show the highest and lowest emission intensities by the sources' unit of measurement. There are a number of emission sources that fall in between, such as Dairy: manure. This source of emissions is not as low as Sheep: manure but not as high as Enteric sources. NO_x: burning refers to nitrogen oxide released during the burning process.

SOURCE: ACIL ALLEN FROM: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, NATIONAL INVENTORY REPORT 2016, IPPC GUIDELINE FOR NATIONAL GREENHOUSE GAS INVENTORIES, VOLUME 4, 2006, Department of the Environment and energy, national greenhouse accounts factors July 2018

Table 2.11 shows emission factors for key agricultural sectors as reflected in DoEE's national inventory work. Following from **Table 2.11**, **Figure 2.34** displays the emission factors for the agricultural activities by category, from most to least emission intensive. For each category and corresponding unit of measurement, the relative intensities are highlighted. For example, under enteric fermentation, the notable differential in emission intensities between dairy cattle and beef cattle are displayed, and the even greater differential to sheep can be observed.

The most emission intensive sources in the agricultural sector include enteric fermentation, particularly for both dairy and beef cattle. Enteric fermentation refers to the fermentation of feed as part of the normal digestive processes of livestock which produce methane. The estimation of manure management emissions takes into account the multiple treatments stages of manure from intensive livestock industries, where a tier 3 mass flow approach is used to estimate emissions.[79] This includes

[79] Department of the Environment and Energy, 2016, National Inventory Report 2016 Volume 1, Figure 5.3.

the facilities capable of sustaining anaerobic conditions to process manure, such as lagoons, pits, and tanks. In terms of manure management, swine has the largest emission factor.

The emissions of nitrous oxide (N_2O) from soils arise from microbial and chemical transformations that produce and consume N_2O in the soil. The application of synthetic fertilisers is adding nitrogen to the soil and the resulting emissions produced differs between crop types. The most emission intensive crop type is sugar cane, followed by irrigated crop, and horticulture. Emissions from the application of crop residues (as a form of nitrogen added to the soil) also has a relatively high emissions factor.

Adding urea to soils for fertilisation leads to a loss of the CO_2 that was fixed during the manufacturing process. Similar to the reaction following the addition of lime, the bicarbonate that is formed evolves into CO_2 and water.

TABLE 2.11 EMISSION FACTORS FOR AGRICULTURAL ACTIVITIES; 2016

Emission source	Units	Implied EF
Enteric Fermentation		
Dairy Cattle	kg CH_4 /head/year	92
Beef Cattle: Feedlot	kg CH_4 /head/year	67
Beef Cattle: Pasture	kg CH_4 /head/year	51
Sheep	kg CH_4 /head/year	6.7
Swine	kg CH_4 /head/year	1.6
Poultry	kg CH_4 /head/year	NE
Manure Management		
Swine	kg CH_4 /head/year	23.3
Dairy Cattle	kg CH_4 /head/year	15
Beef Cattle: Feedlot	kg CH_4 /head/year	3.5
Poultry	kg CH_4 /head/year	0.04
Beef Cattle: Pasture	kg CH_4 /head/year	0.02
Sheep	kg CH_4 /head/year	0.0015
Rice Cultivation*	kg CH_4 /ha/day	132.6
Crop Residue	Gg N_2O-N/ Gg N	0.01
Leaching and run-off	Gg N_2O-N/ Gg N	0.0075
Synthetic fertiliser		
Sugar cane	Gg N_2O-N/ Gg N	0.0199
Irrigated crop	Gg N_2O-N/ Gg N	0.0085
Horticulture	Gg N_2O-N/ Gg N	0.0085
Cotton	Gg N_2O-N/ Gg N	0.0055
Irrigated pasture	Gg N_2O-N/ Gg N	0.004
Non-irrigated pasture	Gg N_2O-N/ Gg N	0.002
Non-irrigated crop*	Gg N_2O-N/ Gg N	0.002
Soil loss: mineralisation of nitrogen	Gg N_2O-N/ Gg N	0.002
Cultivation of histosols	kg N_2O-N/ ha	8
Liming		
Dolomite	CO_2-e/ tonne/year*	0.13
Limestone	CO_2-e/ tonne/year*	0.12
Urea	CO_2-e/ tonne/year*	0.2
Burning of agricultural residues		
NO_x	Gg element in species/ Gg element in fuel burnt	0.21
CO	Gg element in species/ Gg element in fuel burnt	0.078

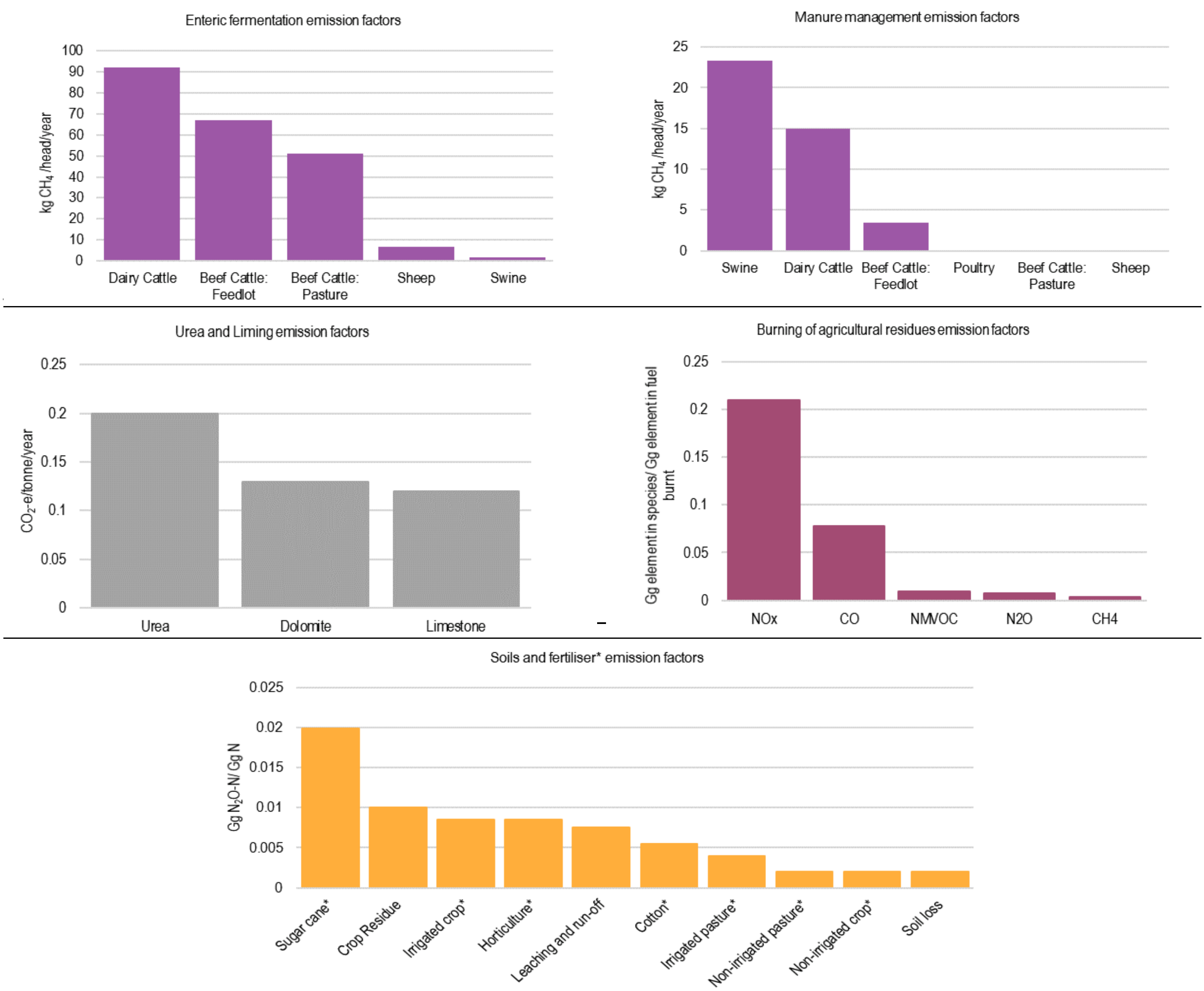
Emission source	Units	Implied EF
NMVOC	Gg element in species/ Gg element in fuel burnt	0.0091
N_2O	Gg element in species/ Gg element in fuel burnt	0.0076
CH_4	Gg element in species/ Gg element in fuel burnt	0.0035

Note: NE: Not estimated. *Rice Cultivation Full formula is the IPCC baseline multiplied by country specific scaling factors = 1.3 x 150 x 1 x 0.68. *Non-irrigated crop: weighted EF assuming 80% occur on low rainfall areas (EF = 0.0005). Gg: gigagrams of annual emissions. N: mass of Nitrogen fertiliser

* /year pertains to the year being referenced (2016), not ongoing emissions over an unspecified period

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, NATIONAL INVENTORY REPORT 2016, IPPC GUIDELINE FOR NATIONAL GREENHOUSE GAS INVENTORIES, VOLUME 4, 2006,

FIGURE 2.34 EMISSION FACTORS FOR AGRICULTURAL ACTIVITIES; 2016



Note: *Refers to the emissions from the application of synthetic fertiliser on crop. Cultivation full formula is the IPCC baseline multiplied by country specific scaling factors = 1.3 x 150 x 1 x 0.68. *Non-irrigated crop: weighted EF assuming 80% occur on low rainfall areas (EF = 0.0005). Gg: gigagrams of annual emissions. N: mass of Nitrogen fertiliser

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, NATIONAL INVENTORY REPORT 2016, IPPC GUIDELINE FOR NATIONAL GREENHOUSE GAS INVENTORIES, VOLUME 4, 2006

The average emission factors in relation to the main energy sources used by the agricultural industry are shown in **Table 2.12**. The emissions produced from these inputs are not included in emissions classified as ‘agriculture’ by DoEE, as they are primarily off-farm transport and electricity emissions (i.e. they do not form part of the 13.2 per cent of total national emissions from agriculture).[80] Detailed figures are provided in Appendix **A**. Fuel switching to natural gas may increase input costs, as prices are projected to increase according to the Australia Energy Regulator. However, gas also has a lower emissions intensity (compared to coal-based electricity), so switching to gas could be a way to reduce emissions, where it is an option.[81]

TABLE 2.12 ELECTRICITY, GAS AND TRANSPORT FUEL AVERAGE EMISSION FACTORS (EF) 2018

Emissions source	Units	Implied EF
Average electricity EF	kg CO_2-e/ kWh	0.67
Average pipeline gas EF	kg CO_2-e/ GJ	51.4
Average transport fuel EF	kg CO_2-e/ GJ	63.2

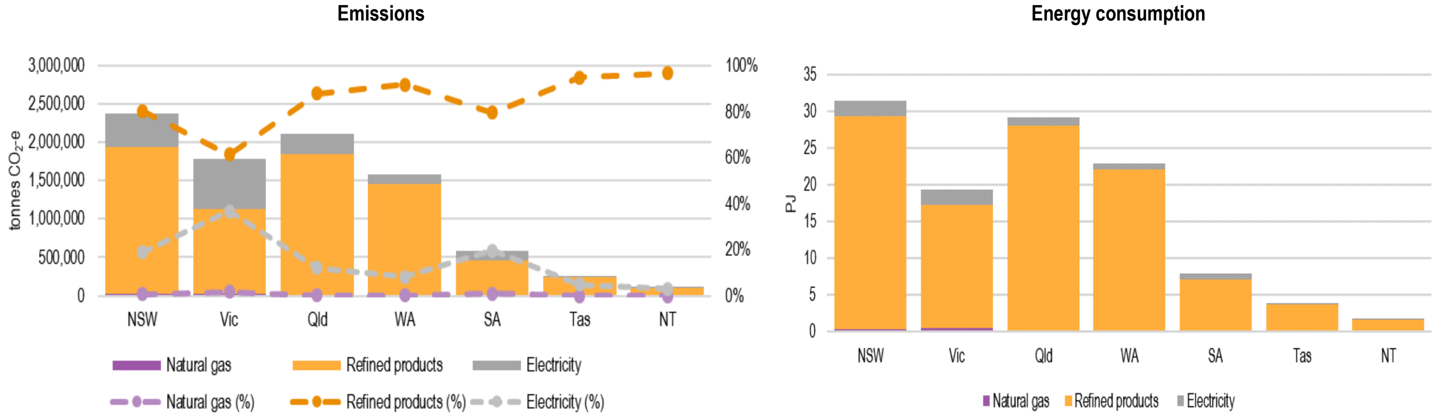
Note: The EF for pipeline gas is the figure for CO_2 only; it does not include CH_4 and N_2O. Average electricity emission factors is the average of all state and territory grids. Average fuel emission factors is the average of diesel oil, gasoline, gasoline for aircraft, LPG and compressed natural gas. In practice. In practice, most transport fuel used in the agricultural sector is diesel; this average EF is considerably lower than that for diesel alone. It should be noted that in comparing gas and electricity emissions factors 1GJ is equivalent in energy terms to about 278kWh.

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, NATIONAL GREENHOUSE ACCOUNTS FACTORS JULY 2018

Energy consumption and estimated emissions in the agricultural sector in 2016-17 are shown at **Figure 2.35**. Out of the three selected energy sources, liquid fuels were consumed the most in all states and territories. However, given the consumption level, the emissions associated from electricity consumption is disproportionally higher. This reflects the relatively high emission intensive generation fleet currently connected to the electricity grid in Victoria, Queensland, New South Wales and Western Australia.

The easiest opportunity to lower emissions is by reducing the consumption of transport fuels, as this is the largest input. However, there is relatively little flexibility to switch energy sources in the agricultural sector. While this provides some level of certainty in planning terms, it also leaves the industry vulnerable to pressures imposed on these inputs, such as policy regulation and increased costs.

FIGURE 2.35 ENERGY CONSUMPTION AND ESTIMATED EMISSIONS IN THE AGRICULTURAL SECTOR: 2016-17



Note: For WA, an average for the emissions factor was used for WA SWIS and WA NWIS. Similarly, for NT and NT DKIS. The ACT is not reported separately. Natural gas: pipeline emission factor used. Refined products: emission factor is the average of diesel oil, gasoline, gasoline: aircraft, LPG.

SOURCE: ACIL ALLEN FROM DEPARTMENT OF THE ENVIRONMENT AND ENERGY, 2018, AUSTRALIA ENERGY UPDATE, 2018

2.4.1 Land use: carbon sinks

The LULUCF sector includes both sources of emissions and sinks that remove CO_2 from the atmosphere and sequester it as carbon in living biomass, debris and soils. Land converted to forest via plantations, natural regeneration or regrowth, acts as a carbon sink for the environment and helps

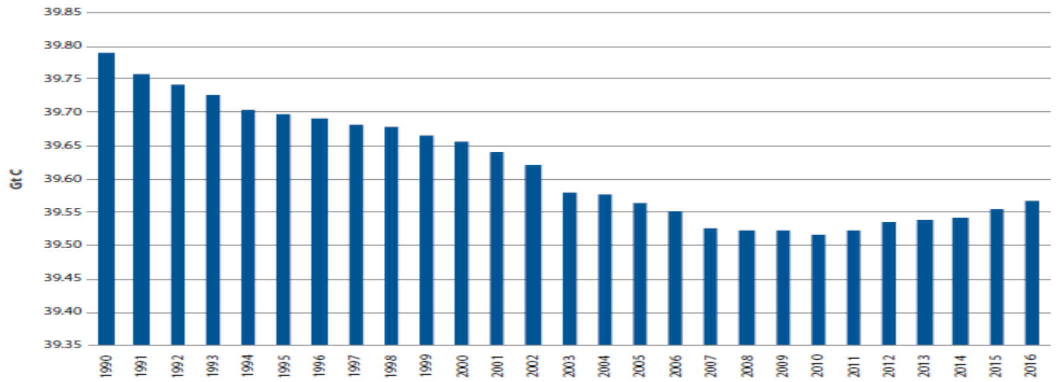
80 Department of the Environment and Energy, 2018, *Australia's emissions projections, 2018*
81 Australia Energy Regulator, 2018, *State of the Energy Market Report*

to off-set emissions. Typically, farmers and growers clear land to undertake agricultural activities, but the opportunity exists for landholders to convert/revegetate the land to act as a carbon sink.

The emissions associated with land use change for agricultural purposes, or on land owned by agricultural producers, are counted under the LULUCF emissions category, not under 'agriculture' emissions. The decisions influencing land use may cross over with multiple industries.

The amount of carbon stocks over time is displayed in **Figure 2.36**. In 2016, 39.57 gigatonnes of carbon stocks was contained in the land sector, which is a about 1 per cent drop since 1990, but an increase from the lows of 2010.

FIGURE 2.36 CHANGES IN LAND CARBON STOCKS (GIGATONNES OF CARBON): 1990 TO 2016

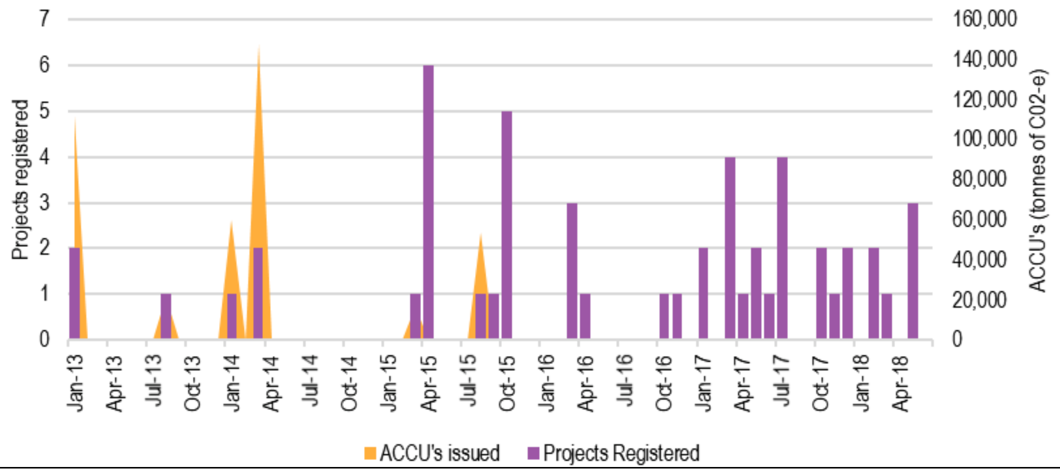


Note: GT C refers to gigatons of carbon

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, NATIONAL INVENTORY REPORT 2016, VOLUME 1, SECTION 2.5

As at June 2018, there was around 60 projects within the 'Agriculture projects' classification under the Emissions Reduction Fund (ERF), with the majority of these projects described as increasing carbon in the soil and sequestration activities. This policy has incentivised a change in land use within the sector to boost carbon stocks. Whilst the carbon abatement contracts have been secured, payment for the abatement (in the form of Australia Carbon Credit Units (ACCUs)) has not occurred for all projects listed because not all the emissions reductions have been measured and/or delivered (see **Figure 2.37**). However, the acquisition of ACCUs provides an alternative (and possibly additional) income stream for producers and can be subsequently traded on the secondary market.

FIGURE 2.37 EMISSIONS REDUCTION FUND PROJECTS AND ACCU'S



Note: Within the 'Agriculture projects' classification

SOURCE: ACIL ALLEN BASED ON HTTP://WWW.CLEANENERGYREGULATOR.GOV.AU/MAPS/PAGES/ERF-PROJECTS/INDEX.HTML

3
CLIMATE CHANGE MODELLING

3.1 Overview of national and regional climate change scenarios

3.1.1 Introduction

This chapter provides a high-level overview of the national and regional impacts of climate change, based on both historical records/data and projections scenarios.[82] The analysis of global impacts is based on the most authoritative work available, namely the current assessments of the IPCC.[83] For Australian projections, the chapter draws on the National Projections for Australia 2015 and the climate simulation tool kit available at the Climate Change in Australia website produced through the collaborative work of BoM and CSIRO.[84]

The future climate will be primarily determined by three factors: the emissions scenario that is being most closely tracked (the scenarios are described by RCPs), the response of the climate system to that scenario, and natural variability.

The IPCC Fifth Assessment Report 2014 and the 2018 Special Report provide the global context for climate change. The scenarios used to develop their projections are based on four RCPs.

The CSIRO and BoM's 2015 projections draw on the IPCC Reports to provide detailed projections for Australia as a whole and regionally under three RCPs scenarios.[85] Projections are provided for modelled climate variables, such as temperature, rainfall, and wind, and derived variables such as indices of climatic extremes, fire weather, and soil moisture.

The analyses are provided at a regional level based on climatic zones and NRM regions. There are four NRM super clusters, with finer detail at the eight NRM cluster and fifteen sub cluster levels. Further detail is contained in Section 3.5. The simulation tool kit provides advanced capabilities to project climate change impacts down to on-farm scale.

In addition to the above sources, there are an increasing number and variety of resources available from states and territories that enable projections and analysis at a regional and local level (see **Box 3.1**). A good example is NARCliM, a partnership of the New South Wales and the Australian

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82 It is important to recognise that projections based on scenarios are a means of exploring possible futures and are not predictions.

83 `*IPCC (Working Group ii) Fifth Assessment Report, Impacts Adaptation and Vulnerability* (2014) https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/, and *IPCC (Working Group ii) Special Report Global Warming of 1.5°C.* (2018) https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf) accessed January 2019.

84 *Climate change in Australia* https://www.climatechangeinaustralia.gov.au/en/; *Climate projections* https://www.climatechangeinaustralia.gov.au/en/climate-projections/; *Climate change in Australia's NRM Regions* https://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/regional-climate-change-explorer/super-clusters/; *Climate Change in Australia Technical Report* 2015 https://www.climatechangeinaustralia.gov.au/en/publications-library/technical-report/, accessed January 2019.

85 ibid.

Capital Territory governments and the Climate Change Research Centre at the University of NSW.[86] The NARCliM project began in 2011 and provides climate change information at a scale that can be used for localised decisions. It has developed 'Climate Change Snapshots' for New South Wales and each of the State's 12 Planning Regions. NARCliM uses the SRES A2 emissions scenario, which is a scenario used in the IPCC's Third Assessment Report, 2001 and the Fourth Assessment Report, 2007.[87] The SRES A2 scenario was selected because it most closely matches the actual global emissions trajectory. The SRES A2 scenario is very similar to the RCP8.5 scenario, described in section 3.1.2 below, used in the IPCC Fifth Assessment Report and in the CSIRO and BoM's 2015 projections.

BOX 3.1 JURISDICTIONS' CLIMATE CHANGE IMPACT SUPPORT TOOLS

The key State and Territory resources on modelling and analysing the impacts of climate change are:

- New South Wales and the Australian Capital Territory - NARCliM https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM) and AdaptNSW https://climatechange.environment.nsw.gov.au/
- South Australia – SA Climate Ready https://data.environment.sa.gov.au/Climate/SA-Climate-Ready/Pages/default.aspx
- Queensland - Queensland Future Climate https://app.longpaddock.qld.gov.au/
- Victoria - Climate Ready Victoria https://www.climatechange.vic.gov.au/
- Western Australia – Climate Change Projections for Western Australia https://www.agric.wa.gov.au/climate-change/climate-projections-western-australia
- Tasmania - Tasmanian Climate Change Office http://www.dpac.tas.gov.au/divisions/climatechange
- Northern Territory – Climate change Science for Northern Australia http://nespclimate.com.au/wp-content/uploads/2017/06/A4-2p-stakeholder-NAus-web.pdf. See also https://www.climatechangeinaustralia.gov.au/en/

SOURCE: ACIL ALLEN CONSULTING

3.1.2 Climate modelling scenarios

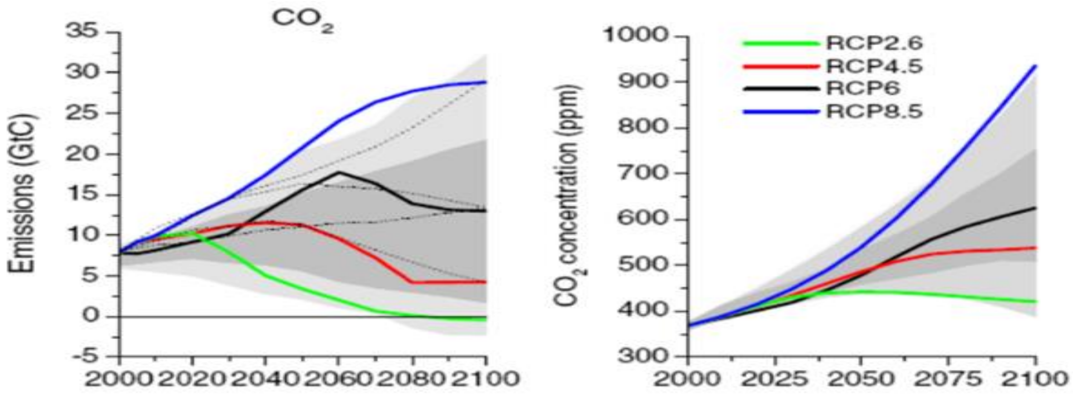
Internationally, and in Australia, the accepted approach to climate modelling is to develop credible projections based on RCP scenarios. **Figure 3.1** outlines the four IPCC RCP scenarios:

- RCP8.5: - a future with little effort to curb emissions. In this scenario, atmospheric CO_2 concentrations continue to rise rapidly, reaching 940 ppm by 2100.
- RCP6.0: – a scenario with slightly lower emissions, achieved by application of some mitigation strategies and technologies. CO_2 concentration rises less rapidly than RCP8.5, but still reaches 660 ppm by 2100, and total radiative forcing stabilises shortly after 2100.
- RCP4.5: – in this scenario, CO_2 concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO_2 concentration only reaches 540 ppm by 2100.
- RCP2.6: - the most ambitious mitigation scenario, with emissions peaking early in the century (around 2020), then rapidly declining. The CO_2 concentration reaches 440 ppm by 2040, then slowly declines to 420 ppm by 2100. This scenario would require early participation from all emitters, including developing countries, as well as the application of technologies for actively removing CO_2 from the atmosphere.

86 https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM

87 The Special Report on Emissions Scenarios (SRES) is a report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000. The greenhouse gas emissions scenarios described in the Report have been used to make projections of possible future climate change. In IPCC Fifth Assessment Report released in 2014, SRES projections were superseded by Representative Concentration Pathways (RCPs) models. SRES A2 is one of the scenarios developed in the report. IPCC SRES (2000), Nakićenović, N.; Swart, R., eds., Special Report on Emissions Scenarios: A special report of Working Group III of the Intergovernmental Panel on Climate Change Cambridge University Press, ISBN 0-521-80081-1

FIGURE 3.1 REPRESENTATIVE CONCENTRATION PATHWAY SCENARIOS



Note: Grey area indicates the 98th and 90th percentiles (light/dark grey) of the values from the literature). The dotted lines indicate four of the SRES marker scenarios

SOURCE: VAN VUUREN ET AL. (2011)

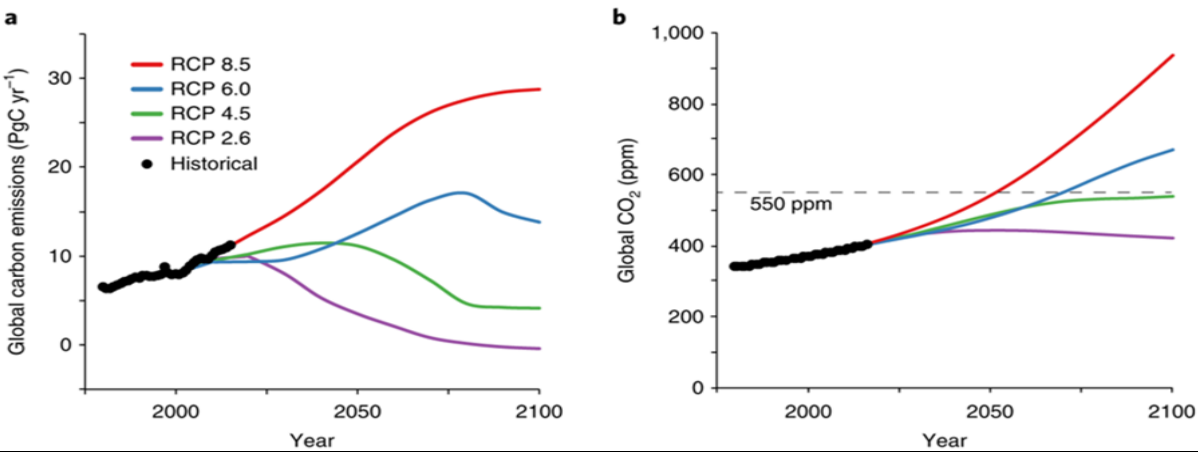
Current Trajectory of Emissions

Figure 3.2 shows historical trends in CO_2 emissions and atmospheric concentrations, compared with model forecasts to 2100. The two graphs are:

a) Historical CO_2 emissions since 1980 and models of carbon emissions until 2100. The current global level of emissions aligns with the most extreme model forecast (RCP8.5).

b) Annual surface global CO_2 concentrations. On the current model trajectory of RCP8.5, 550 ppm concentrations are attained by the middle of the century.

FIGURE 3.2 CURRENT EMISSIONS TRAJECTORIES



SOURCE: SMITH, MR AND SS MYERS (2018) IMPACT OF ANTHROPOGENIC CO2 EMISSIONS ON GLOBAL HUMAN NUTRITION. NATURE CLIMATE CHANGE, 8, 834–839.

3.1.3 The IPCC Special Report

The IPCC (Working Group ii) Special Report Global Warming of 1.5°C, 2018 concluded that human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. The IPCC report also found, with high confidence, that global warming is likely to reach 1.5°C between 2030 and 2052, if it continues to increase at the current rate. The IPCC further concluded that global-mean surface warming by the end of the 21st century is likely to exceed 1.5°C relative to 1850-1900 for all RCPs except RCP2.6. It is likely to exceed 2.0°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2.0°C for RCP4.5. Warming will continue beyond 2100 under all RCPs except RCP2.6; will exhibit interannual-to-decadal variability; and will not be regionally uniform. There will be more hot days and fewer cold days over most land areas. Heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur.

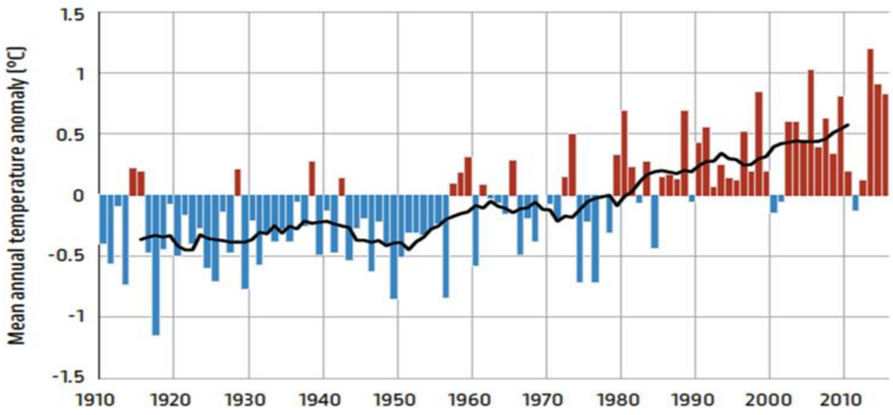
3.1.4 Australia – past climate

Australia's climate has changed significantly during the 20th century and it is important to understand these emerging trends, and the extent of natural variability. The projections suggest that these trends will continue, and intensify, towards the end of the 21st century, with the extent of change dependent upon the scenario.

Temperature increase since 1910

Australia's climate has warmed by just over 1.0°C since 1910. **Figure 3.3** shows the Australia's mean annual surface air temperature anomalies (bars) relative to the 1961-1990 average. The 11-year running average (black line) shows some variability but has a gradual upward trend.

FIGURE 3.3 TEMPERATURE INCREASE SINCE 1910

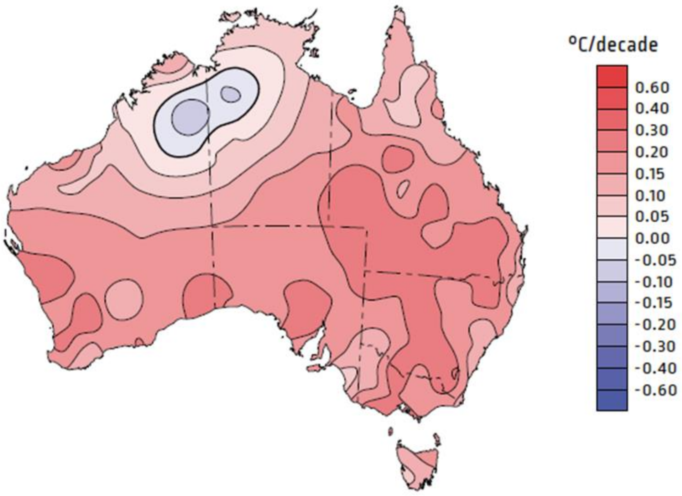


SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Temperature increase across Australia since 1950

Figure 3.4 illustrates the trend in annual mean temperature (°C/decade) from 1950–2015. It shows that most of the continent has warmed over that period.

FIGURE 3.4 TEMPERATURE INCREASE ACROSS AUSTRALIA SINCE 1950

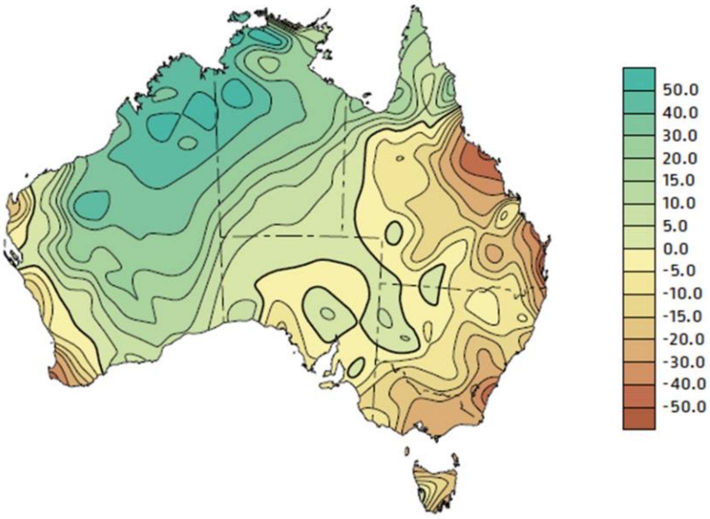


SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall patterns since 1950

Figure 3.5 illustrates the trend in annual-average rainfall (mm/decade) from 1950–2015. In the southwest of Australia, May–July rainfall has decreased by around 20 per cent since 1970. In the southeast of Australia there has been a decline of around 11 per cent in April–October rainfall since the late 1990s. Streamflow has decreased across southern Australia. However, rainfall has increased across parts of northern Australia since the 1970s and streamflow has increased.

FIGURE 3.5 RAINFALL PATTERNS SINCE 1950

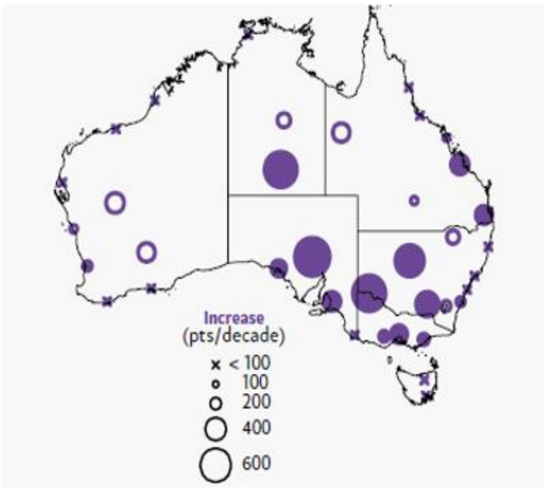


SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Fire danger since 1978

There has been a long-term increase in extreme fire weather, and in the length of the fire season, across large parts of Australia. **Figure 3.6** illustrates the trends in average fire weather days over the last four decades, to 2018. It shows the increase in the MacArthur Forest Fire Danger Index (FFDI) at 38 Reference Sites in points per decade.

FIGURE 3.6 CHANGES IN FIRE DANGER SINCE 1978



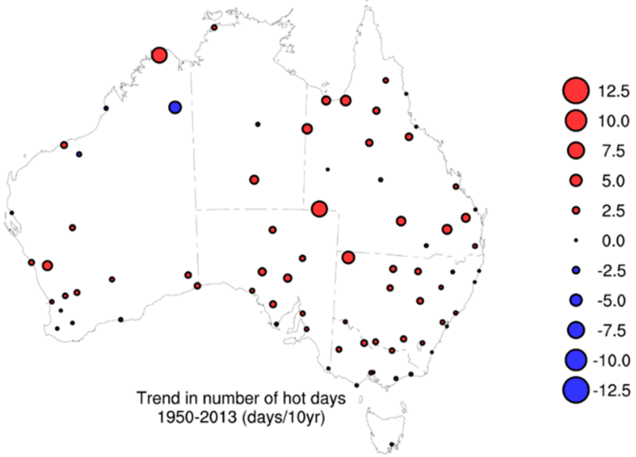
Note: Pts: annual cumulative values of the McArthur Forest Fire Danger Index (FFDI). Filled circles represent trends that are statistically significant. The larger the circle, the larger the trend in terms of Forest Fire Danger Index per decade

SOURCE: THE SCIENCE OF CLIMATE CHANGE – ACADEMY OF SCIENCE 30/12/2018 HTTPS://WWW.SCIENCE.ORG.AU/LEARNING/GENERAL-AUDIENCE/SCIENCE-BOOKLETS/SCIENCE-CLIMATE-CHANGE/7-WHAT-ARE-IMPACTS-CLIMATE-CHANGE

Hot days trend - 1950 to 2013

The trend in the number of hot days (greater than 35°C) in Australian mean temperature is shown in **Figure 3.7**. The data is from the Australian Climate Observations Network of Air Surface Temperature (ACORN SAT) from 1950 to 2013.

FIGURE 3.7 HOT DAYS 1950 TO 2013



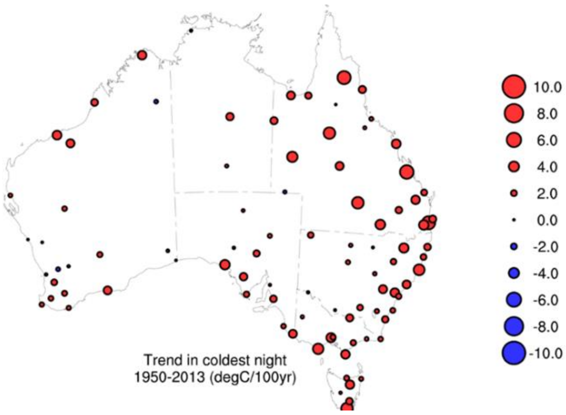
Note: The circles reflect the temperature difference from the mean temperature with the larger circles representing a greater differential to the mean.

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Cold nights trend - 1950 to 2013

The trend in the coldest night (°C) in Australian mean temperature based on the ACORN SAT from 1950 to 2013 is shown in **Figure 3.8**.

FIGURE 3.8 COLD NIGHTS 1950 TO 2013



Note: The circles reflect the temperature difference from the mean temperature with the larger circles representing a greater differential to the mean.

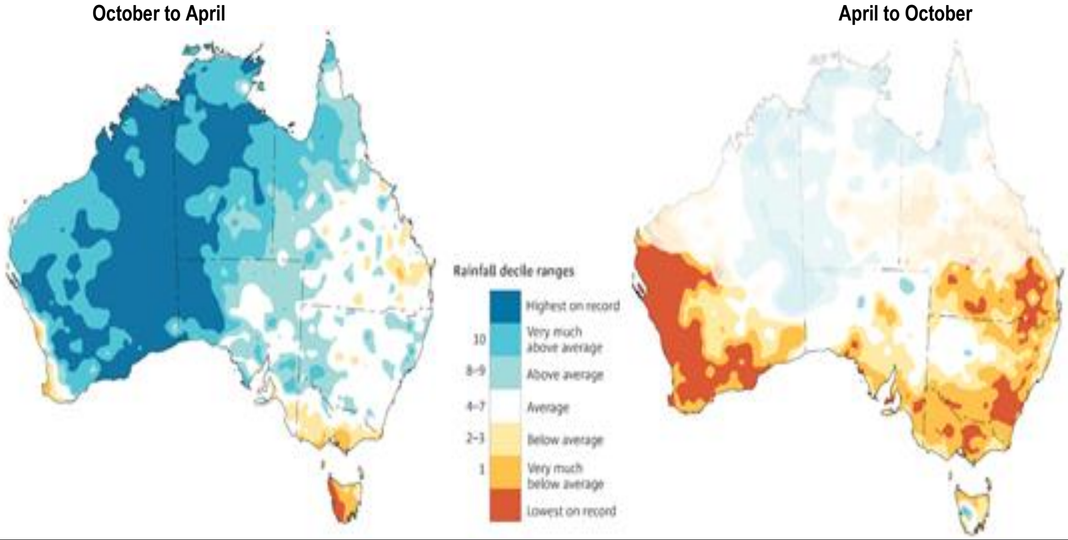
SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall seasonal changes 1900 to 2018

Australian rainfall is highly variable and is strongly influenced by phenomena such as El Niño/La Niña. Despite this large natural variability, underlying long-term trends are evident. There has been a shift towards drier conditions across south western and south eastern Australia during April to October. Northern Australia has been wetter across all seasons, but especially in the northwest during the tropical wet season.

Year-to-year variability occurs against the background drying trend across much of the southern half of Australia, that is south of 26° S. In 17 of the last 20 April to October periods since 1999, southern Australia has had below average rainfall.[88] ***Figure 3.9*** shows the rainfall deciles for October to April (left image) and April to October (right image) 1999 to 2018 relative to the reference period 1900 to 2018.

FIGURE 3.9 *RAINFALL SEASONAL CHANGES 1900 TO 2018*



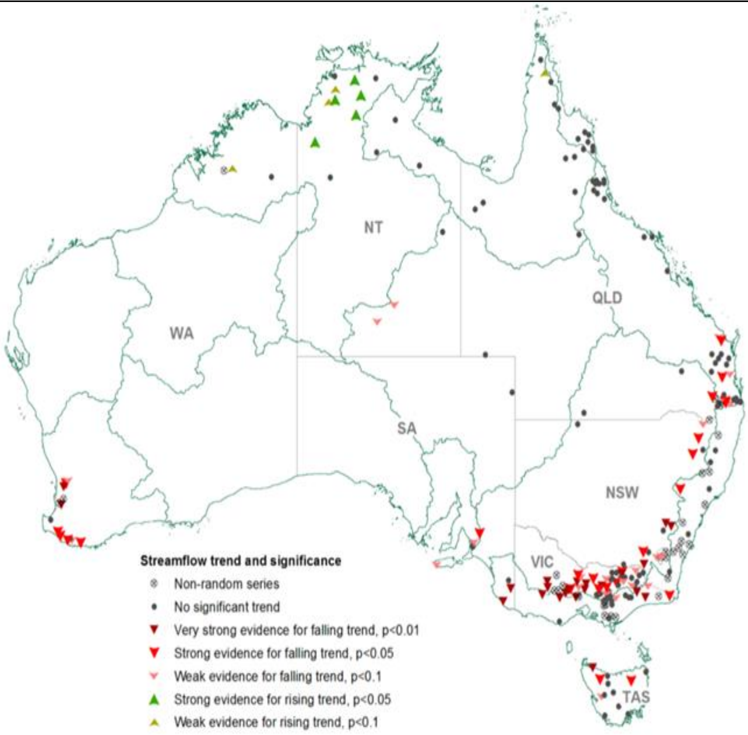
SOURCE: CSIRO AND BOM 2018, STATE OF THE CLIMATE 2018 CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

88 CSIRO and BoM 2018, State of the Climate 2018. http://www.bom.gov.au/state-of-the-climate/future-climate.shtml

Stream flow

Stream flow stations located in the southern part of the country have displayed a decreasing trend and step change persistently. These stations include the Australian Capital Territory, South Australia, Tasmania, the southwest of Western Australia, New South Wales and Victoria. Upward changes were only observed in the northern part of continent. Xiaoyong et al. (2016) undertook a nationwide assessment of the long-term trends in observed streamflow data from 222 stations with more than 30 years of data (some back to 1952).[89] **Figure 3.10** shows the spatial variation and significance of trend results of annual total streamflow. **Figure 3.11** shows the analysis of stations with an upward or downward trend or step change in each of the eight regions investigated.

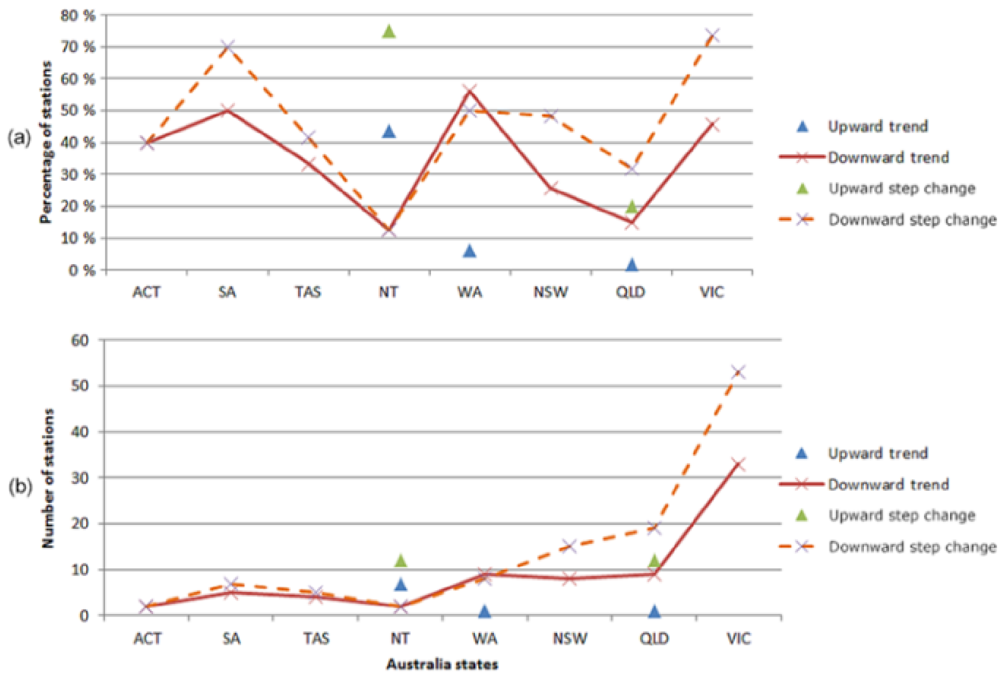
FIGURE 3.10 SPATIAL VARIATION OF TOTAL ANNUAL FLOW



SOURCE: XIAOYONG ET AL. 2016. HOW STREAM FLOW HAS CHANGED ACROSS AUSTRALIA SINCE THE 1950S: EVIDENCE FROM THE NETWORK OF HYDROLOGIC REFERENCE STATIONS. XIAOYONG SOPHIE ZHANG, GNANATHIKKAM E. AMIRTHANATHAN, MOHAMMED A. BARI, RICHARD M. LAUGESEN, DAEHYOK SHIN, DAVID M. KENT, ANDREW M. MACDONALD, MARGOT E. TURNER, AND NARENDRA K. TUTEJA. HYDROL. EARTH SYST. SCI., 20, 3947–3965, 2016 WWW.HYDROL-EARTH-SYST-SCI.NET/20/3947/2016/ DOI:10.5194/HESS-20-3947-2016

89 Xiaoyong Sophie Zhang, Gnanathikkam E. Amirthanathan, Mohammed A. Bari, Richard M. Laugesen, Daehyok Shin, David M. Kent, Andrew M. MacDonald, Margot E. Turner, and Narendra K. Tuteja. Hydrol. Earth Syst. Sci., 20, 3947–3965, 2016 www.hydrol-earth-syst-sci.net/20/3947/2016/ doi:10.5194/hess-20-3947-2016

FIGURE 3.11 STREAMFLOW TRENDS



Note: Chart (a) shows percentage change; chart (b) absolute numbers of stations. Percentage and number of stations showing significant upward and downward trends or step changes in Australian states and territories

SOURCE: XIAOYONG,) ET AL. 2016

These trend patterns are spatially consistent with trends in annual total rainfall, where most of east and southwest of Australia has experienced substantial rainfall declines since 1970, while the northwest of Australia has become wetter over this period. This similarity implies that hydrological variability is closely related with changes in rainfall patterns, although it is not explicit that climate change is the only cause of significant trends in stream flow. There are other factors such as natural catchment changes and climate variability that may also have an effect.[90]

3.2 Understanding Australia's 2015 Climate Projections Modelling and Baselines

Confidence levels are assigned to individual projections to deal with remaining uncertainty due to:

- uncertainty around future emissions and concentrations of GHGs and aerosols
- response uncertainty resulting from limitations in our understanding of the climate system and its representation in climate models
- natural variability uncertainty stemming from unperturbed variability in the climate system.

Where there is good agreement between ensemble models the confidence, level is generally higher.

The projections are presented as ranges of change for different 20-year time periods in the future, centred on 2030, 2050, and 2090, with respect to the reference period,1986-2005, in accordance with results reported in the fifth Assessment Report of the IPCC (IPCC 2013). Time series charts of simulated climate change (1901 to 2099) against a longer baseline (1950-2005) are also provided to show the interplay between the slowly emerging climate change signal and natural variability. It should be noted that the reference period is different to the 1980-1999 period used in Climate Change in Australia 2007 (CSIRO and BoM, 2007).

90 Ibid

The Paris Agreement aims to 'strengthen the global response to the threat of climate change', and its stated goal, in Article 2 of the Agreement, is to limit the increase in the global average temperature to 'well below 2 °C' above pre-industrial levels. The 'base line' of the pre-industrial era is generally taken to be 1850-1900.

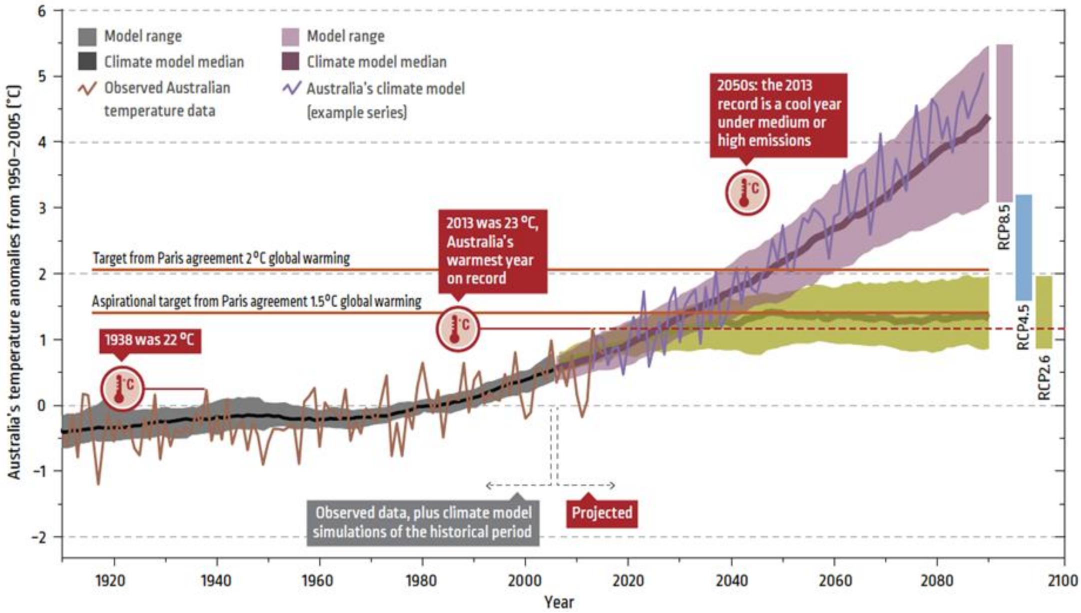
3.3 Australia's national climate change projections – a snapshot

The extent and intensity of projected changes in climate is scenario dependent. Australia's national climate projections are modelled on RCP8.5, RCP4.5 and RCP2.6.

Figure 3.12 shows the modelled temperature outcomes for Australia under different RCP pathways. The trajectories for the RCP pathways diverge from 2030 onwards with RCP8.5 showing a rapid and intense increase. The 2018 IPCC Special Report states that:

> *"Estimated anthropogenic global warming is currently increasing at 0.2°C per decade due to past and ongoing emissions. Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic. Trends in intensity and frequency of some climate and weather extremes have been detected over time spans during which about 0.5°C of global warming occurred."*

FIGURE 3.12 AUSTRALIA'S MEAN ANNUAL SURFACE WARMING FOR THE PAST AND FUTURE EMISSIONS PATHWAYS



Series are relative to the 1950–2005 average: brown is observations, shading is the range of 20-year averages from up to 40 climate models, thick lines are the median of the models, purple is a simulation from Australia's community climate model (ACCESS) showing what a future time series may look like for high emissions including year-to-year variability. Global warming targets from the Paris Agreement are shown relative to pre-industrial temperature and converted to a relevant temperature band for Australia.

SOURCE: CSIRO & BUREAU OF METEOROLOGY 2016; AUSTRALIA'S CHANGING CLIMATE

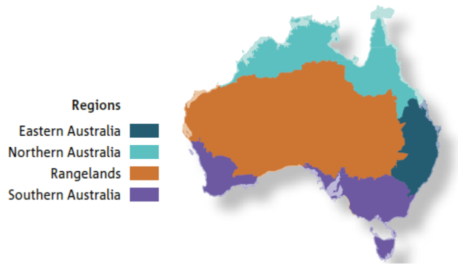
The IPCC (Working Group ii) Special Report Global Warming of 1.5°C, 2018 indicates that the world is currently on a pathway similar to RCP8.5. The projections for this pathway suggest that the trends in Australia's climate experienced to date will continue and intensify towards the end of the 21st century. The analysis provides a clear picture of the short to medium-term projections across three emissions scenarios, out to 2030, with a high degree of confidence. The analysis also covers the period to 2090 as it is important to understand the range of possible futures and their implications over the longer time horizon, even though the extent and direction of change is less certain across some regions.

Based on Australia's 2015 National Projections by CSIRO and BoM, Australia is projected to experience:

— further increases in medium sea and air temperatures
— more extremely hot days and fewer extremely cool days
— more frequent, extensive, intense and longer-lasting heatwaves
— further sea level rise and ocean acidification
— fewer tropical cyclones, but a greater proportion of high-intensity storms, with ongoing large variations from year-to-year
— an increase in intense heavy short duration extreme rainfall events
— an increase in the number of high fire weather danger days
— a longer fire season for southern and eastern Australia.[91]

Figure 3.13 provides an overview of the range, variability, distribution and seasonality of changes in key climate parameters projected by 2090 (relative to 1995) for the RCP scenarios modelled at the super cluster level. The projected variations in key climate parameters are discussed more detail in the following section.

FIGURE 3.13 OVERVIEW OF MODELLED CHANGES IN CLIMATE PARAMETERS BY PATHWAY



	SOUTHERN	EASTERN	NORTHERN	RANGELANDS
Annual temperature	2.7 to 4.2 °C 0.5 to 1.4 °C	2.8 to 5 °C 0.6 to 1.6 °C	2.7 to 4.9 °C 0.5 to 1.6 °C	2.9 to 5.3 °C 0.6 to 1.8 °C
Sea level rise	Geelong 0.38 to 0.82 cm 0.22 to 0.53 cm	Newcastle 0.46 to 0.88 cm 0.22 to 0.54 cm	Darwin 0.41 to 0.85 cm 0.22 to 0.55 cm	Port Hedland 0.40 to 0.84 cm 0.22 to 0.55 cm
Annual rainfall	-26 to 4 % -15 to 3 %	-25 to 12 % -19 to 6 %	-26 to 23 % -12 to 3 %	-32 to 18 % -21 to 3 %
Summer rainfall	-13 to 16 % -22 to 6 %	-16 to 28 % -20 to 13 %	-24 to 18 % -16 to 4 %	-22 to 25 % -22 to 8 %
Autumn rainfall	-25 to +13 % -17 to 11 %	-33 to 26 % -25 to 15 %	-30 to 26 % -18 to 11 %	-42 to 32 % -26 to 18 %
Winter rainfall	-32 to -2 % -9 to 4 %	-40 to 7 % -24 to 9 %	-48 to 46 % -32 to 13 %	-50 to 18 % -31 to 12 %
Spring rainfall	-44 to -3 % -23 to +4 %	-41 to 8 % -26 to 11 %	-44 to 43 % -32 to 13 %	-50 to 23 % -32 to 15 %
Evapotranspiration	8 to 17 % 2 to 5 %	9 to 18 % 3 to 7 %	8 to 17 % 2 to 6 %	6 to 16 % 0 to 4 %
Extreme rainfall (20-year average recurrence interval)	5 to 30 % 1 to 19 %	13 to 45 % 0 to 28 %	3 to 65 % 0 to 31 %	8 to 42 % 4 to 20 %
Fire weather – days over McArthur forest fire danger index 50	Baseline: 2.8 5.3 3.8	Baseline: 1.2 3.2 1.9	Changes less clear	Changes less clear

RCP8.5 RCP2.6 RCP4.5

Note: Projected climate changes by 2090, relative to 1995, averaged over the four regions shown in the map: Northern, Southern, Eastern and Rangelands for RCP8.5 (purple), RCP2.6 (Yellow), or where RCP2.6 results are not available, RCP4.5 (blue). Results are the range of change from the available climate models (the 10–90% range, so excluding the 10% outliers), emphasising the range of possibilities rather than a single 'best estimate'

SOURCE: CSIRO AND BOM 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BOM AUSTRALIA

[91] www.climatechangeinaustralia.gov.au accessed January 2019

3.4 Australian national climate change projections – detail on key parameters

This section describes, in more detail, the distributional and seasonal climate changes of the following parameters:

- Temperature – annual mean, minimum, maximum, number of hot and cold days
- Rainfall - annual, seasonal and extreme rainfall and time in drought
- Potential Evapotranspiration and Soil Moisture
- Fire Danger.

3.4.1 Temperature

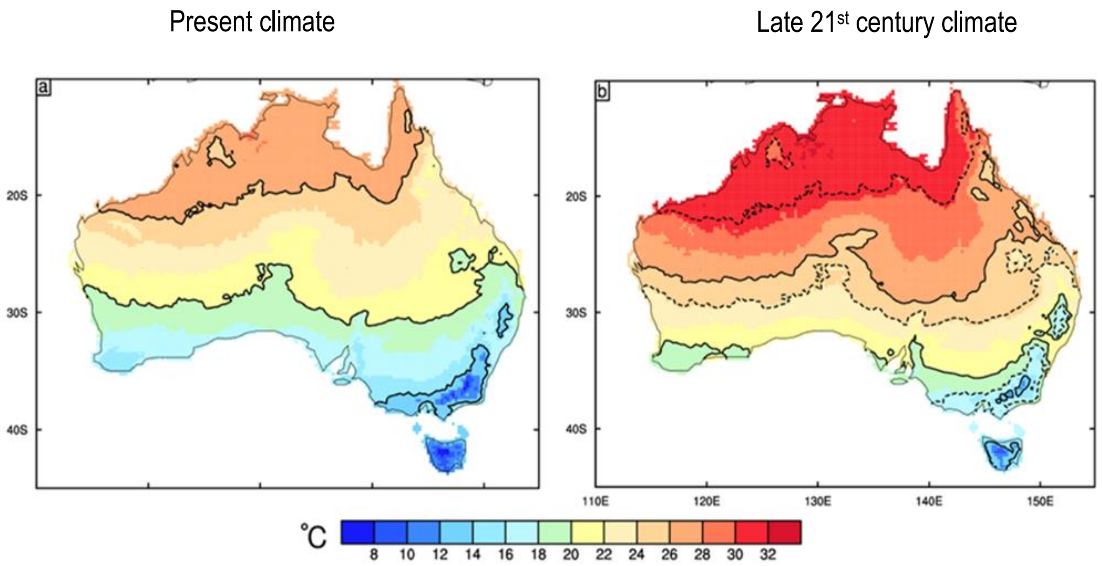
CSIRO and BoM's 2015 projections suggest that there will be increases in mean, daily minimum and daily maximum temperatures throughout this century for all regions in Australia. By 2030 Australia's annual average mean temperature is projected to increase by between 0.6 and 1.3°C above the climate of 1986-2005 under RCP4.5, with little difference in warming between RCPs. However, by 2090 there are larger differences between RCPs, with increases of 0.6 to 1.7°C for RCP2.6, 1.4 to 2.7°C for RCP4.5 and 2.8 to 5.1°C for RCP8.5. Mean warming is projected to be greater than average in inland Australia, and less in coastal areas, particularly in southern coastal areas in winter.

The projections suggest that there will be more frequent hot days. For example, under RCP4.5, in Perth, the average number of days per year with temperatures above 35°C or above 40°C by 2090 is projected to be 50 per cent greater than present. Similarly, the number of days above 35°C in Adelaide are projected to increase by about 50 per cent by late in the century, while the number of days above 40°C more than doubles.

Temperature change by 2100 for RCP8.5

Figure 3.14 shows the annual mean temperature (in °C) for the present climate (left image) and for late 21st century (right image) under RCP 8.5. In each panel the 14°C, 20°C and 26°C contours are shown with solid black lines (in the second image the same contours are shown as dotted lines).

FIGURE 3.14 ANNUAL MEAN TEMPERATURE NOW AND IN 2100 UNDER RCP8.5



SOURCE: CSIRO AND BOM 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BOM, AUSTRALIA

Number of days with temperatures over 35°C and 40°C

Table 3.1 shows the current (average number of days per year with maximum temperature above 35°C and above 40°C in several Australian locations. The projected number of such days in 2030 and 2090 under different pathways are also shown (the brackets show the 10th and 90th percentiles).

TABLE 3.1 NUMBER OF DAYS WITH TEMPERATURE OVER 35°C AND 40°C

THRESHOLD 35 °C	1995	2030 RCP4.5	2090 RCP2.6	2090RCP4.5	2090 RCP8.5
Adelaide[1]	20	26 (24 to 29)	28 (24 to 31)	32 (29 to 38)	47 (38 to 57)
Alice Springs[2]	94	113 (104 to 122)	119 (104 to 132)	133 (115 to 152)	168 (145 to 193)
Amberley[3]	12	18 (15 to 22)	18 (14 to 30)	27 (21 to 42)	55 (37 to 80)
Broome[2]	56	87 (72 to 111)	95 (70 to 154)	133 (94 to 204)	231 (173 to 282)
Cairns[2]	3	5.5 (4.4 to 7.9)	5.5 (4.4 to 14)	11 (7.4 to 22)	48 (24 to 105)
Canberra[2]	7.1	12 (9.4 to 14)	13 (10 to 16)	17 (13 to 23)	29 (22 to 39)
Darwin[2]	11	43 (25 to 74)	52 (24 to 118)	111 (54 to 211)	265 (180 to 322)
Dubbo[2]	22	31 (26 to 37)	34 (26 to 43)	44 (36 to 54)	65 (49 to 85)
Hobart[4]	1.6	2.0 (1.9 to 2.1)	2.0 (1.8 to 2.5)	2.6 (2.0 to 3.1)	4.2 (3.2 to 6.3)
Melbourne	11	13 (12 to 15)	14 (12 to 17)	16 (15 to 20)	24 (19 to 32)
Mildura[2]	33	42 (37 to 46)	44 (39 to 50)	52 (45 to 61)	73 (60 to 85)
Perth[2]	28	36 (33 to 39)	37 (33 to 42)	43 (37 to 52)	63 (50 to 72)
St. George[2]	40	54 (48 to 62)	58 (47 to 69)	70 (59 to 87)	101 (79 to 127)
Sydney[5]	3.1	4.3 (4.0 to 5.0)	4.5 (3.9 to 5.8)	6.0 (4.9 to 8.2)	11 (8.2 to 15)
Wilcannia	47	57 (53 to 62)	60 (54 to 66)	67 (59 to 75)	87 (72 to 100)
THRESHOLD 40 °C	**1995**	**2030 RCP4.5**	**2090 RCP2.6**	**2090RCP4.5**	**2090 RCP8.5**
Adelaide[1]	3.7	5.9 (4.7 to 7.2)	6.5 (5.2 to 8.5)	9.0 (6.8 to 12)	16 (12 to 22)
Alice Springs[2]	17	31 (24 to 40)	37 (24 to 51)	49 (33 to 70)	83 (58 to 114)
Amberley[3]	0.8	1.2 (1.1 to 1.6)	1.2 (1.1 to 2.5)	2.1 (1.5 to 3.9)	6.0 (2.9 to 11)
Broome[2]	4.1	7.2 (6.0 to 9.3)	7.7 (5.7 to 13)	11 (7.7 to 22)	30 (17 to 61)
Cairns[2]	0	0.1 (0.1 to 0.2)	0.1 (0.1 to 0.3)	0.3 (0.2 to 0.4)	0.7 (0.5 to 2.0)
Canberra[2]	0.3	0.6 (0.4 to 0.8)	0.7 (0.5 to 1.3)	1.4 (0.8 to 2.8)	4.8 (2.3 to 7.5)
Darwin[2]	0	0.0 (0.0 to 0.0)	0.0 (0.0 to 0.0)	0.0 (0.0 to 0.2)	1.3 (0.2 to 11)
Dubbo[2]	2.5	3.9 (3.2 to 5.6)	5.0 (3.2 to 8.0)	7.8 (5.1 to 12)	17 (9.9 to 26)
Hobart[4]	0.1	0.2 (0.2 to 0.4)	0.2 (0.1 to 0.4)	0.4 (0.2 to 0.5)	0.9 (0.5 to 1.4)
Melbourne	1.6	2.4 (2.1 to 3.0)	2.7 (2.3 to 3.7)	3.6 (2.8 to 4.9)	6.8 (4.6 to 11)
Mildura[2]	7.2	10 (8.8 to 12)	11 (9.4 to 14)	15 (12 to 20)	27 (19 to 35)
Perth[2]	4	6.7 (5.4 to 7.5)	6.9 (5.6 to 9.0)	9.7 (6.9 to 13)	20 (12 to 25)
St. George[2]	5.1	8.2 (6.3 to 11)	10 (6.1 to 16)	15 (11 to 23)	31 (20 to 49)
Sydney[5]	0.3	0.5 (0.5 to 0.8)	0.7 (0.5 to 0.9)	0.9 (0.8 to 1.3)	2.0 (1.3 to 3.3)
Wilcannia[1]	11	16 (14 to 20)	18 (15 to 25)	23 (18 to 31)	40 (27 to 53)

Notes: 1. CBD, 2. at AIRPORT, 3. AMBERLY RAAF, 4. BATTERY POINT, 5. THE ROCKS

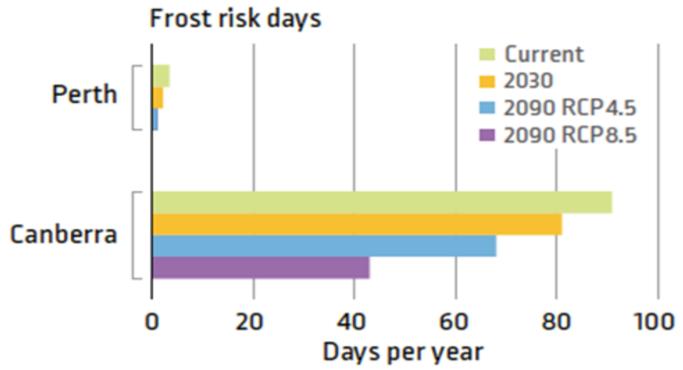
SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA:

Frost days

Fewer frost days are projected. Locations where frost occurs only a few times a year under current conditions, become nearly frost-free by 2030. Under RCP8.5, coastal areas are projected to be free of frost by 2090, while frost is still projected to occur inland. For example, for Canberra the number of frost days drops by a third by 2090 under the RCP4.5 pathway, and more than half under RCP8.5.

Figure 3.15 shows the projected changes in the annual average number of frost risk days (nights below 2.0°C) for Perth and Canberra stations relative to the 1981–2010 period for 2030 (when all emissions scenarios produce similar results), and for 2090 for the medium and high emissions scenarios.

FIGURE 3.15 PROJECTED CHANGES IN THE ANNUAL-AVERAGE NUMBER OF FROST RISK DAYS



SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2016, AUSTRALIA'S CHANGING CLIMATE

3.4.2 Rainfall

Out to 2030 natural variability in Australian rainfall will mask any long-term changes due to climate change. **Table 3.2** shows projected median and 10th to 90th percentile range of projected rainfall change for various regions, compared to 1986-2005 baseline. Colours show the extent of agreement on change across models - medium over 60 per cent of models; high over 75 per cent of models; very high over 90 per cent of models; and 'substantial' change outside the 10 to 90 per cent range of model natural variability.

Under all RCP scenarios, overall cool season (winter and spring) rainfall is projected to decrease in southern Australia, though there may be little change, or some increase in Tasmania during winter. The winter decline in rainfall may be as great as 50 per cent in the southwest of Australia in the highest emission scenario (RCP8.5) by 2090. The direction of change in summer and autumn rainfall in southern Australia cannot be reliably projected, although a decrease in the southwest of Victoria in autumn, and in western Tasmania in summer, is likely. By 2090, a decrease in winter rainfall is likely in eastern Australia. For northern Australia and northern inland areas, the direction of future rainfall change by 2090 is uncertain, but substantial changes to wet-season and annual rainfall cannot be ruled out.

Under RCP8.5, there is an emerging drying trend evident in southern and eastern Australia, and in southern Australia this is also evident under the lower RCPs. The range of projected changes in rainfall in 2030, relative to 1995 (under RCP4.5), are around minus 10 per cent to little change in southern Australia, and minus 10 to plus 5 per cent in the other regions. In 2090, under RCP8.5, the projected rainfall changes are minus 25 to plus 5 per cent in southern Australia, around minus 25 to plus 10 per cent in eastern Australia, around minus 30 to plus 20 per cent in the Rangelands and minus 25 to plus 25 per cent for northern Australia. As shown in **Table 3.2**, changes are generally much more moderate in 2090 under RCP2.6.

Extreme rainfall events (i.e. wettest day of the year and wettest day in 20 years) are projected to increase in intensity, with this tendency more strongly evident in southern Australia. However, this is less certain for the southwest of Western Australia, where the reduction in mean rainfall may be so strong that it significantly weakens this tendency. The increases in the magnitude of extreme rainfall events are projected to be around 25 per cent under RCP8.5 in 2090.

While tropical cyclones are projected to become less frequent, there will be a greater proportion of high intensity storms, with stronger winds and greater rainfall, which may occur as far south as 25° S.

TABLE 3.2 PROJECTED RAINFALL UNDER DIFFERENT RCP PATHWAYS

Season	2030 RCP4.5	2090 RCP2.6	2030 RCP4.5	2090 RCP8.5
Rainfall Change in Northern Australia (%)				
Annual	0 (-9 to +4)	-4(-12 to +3)	-1 (-14 to +6)	0 (-26 to +23)
DJF	-1 (-8 to +8)	-2 (-16 to +4)	-1 (-18 to +8)	+2 (-24 to +18)
MAM	0 (-17 to +7)	-4 (-18 to +11)	-2(-17 to +12)	-2 (-30 to +26)
JJA	-5 (-26 to +16)	-8 (-41 to +16)	-14 (-35 to +20)	-15 (-48 to +46)
SON	-4 (-26 to +20)	-7 (-32 to +13)	-7 (-32 to +27)	-13 (-44 to +44)
Rainfall Change in Eastern Australia (%)				
Annual	-1 (-13 to +5)	-4 (-19 to +6)	-7 (-16 to +6)	-10 (-25 to +12)
DJF	-2 (-12 to +13)	-6 (-20 to +13)	-2 (-15 to +13)	+4 (-16 to +28)
MAM	-4 (-22 to +13)	-8 (-25 to +15)	-7(-28 to +18)	-8 (-33 to +26)
JJA	-3 (-19 to +9)	-4 (-24 to +9)	-10(-25 to +8)	-16 (-40 to +7)
SON	-2 (-18 to +11)	-3 (-26 to +11)	-10 (-27 to +9)	-16 (-41 to +8)
Rainfall Change in Rangelands (%)				
Annual	-2 (-11 to +6)	-6 (-21 to +3)	-5 (-15 to +7)	-4 (-32 to +18)
DJF	-1 (-16 to +7)	-6 (-22 to +8)	2 (-16 to +10)	+3 (-22 to +25)
MAM	+0 (-23 to +21)	-6 (-26 to +18)	0 (-23 to +27)	-9 (-42 to +32)
JJA	-7 (-20 to +14)	-4 (-31 to +12)	-11(-34 to +7)	-20 (-50 to +18)
SON	-3 (-21 to +19)	-5 (-32 to +15)	-10 (-26 to +11)	-11 (-50 to +23)
Rainfall Change in Southern Australia (%)				
Annual	-4 (-9 to +2)	-3 (-15 to +3)	-7 (-16 to +2)	-8 (-26 to +4)
DJF	-1 (-17 to +9)	-5 (-22 to +6)	-2 (-13 to +8)	+1 (-13 to +16)
MAM	-2 (-18 to +8)	-5 (-17 to +11)	-2 (-19 to +10)	-1 (-25 to +13)
JJA	-4 (-12 to +3)	-3 (-9 to +4)	-9 (-19 to +2)	-17 (-32 to +2)
SON	-4 (-13 to +5)	-5 (-23 to +4)	-10 (-23 to +1)	-18 (-44 to +3)

- High agreement on decrease
- High agreement on substantial decrease
- High agreement on little change
- Medium agreement on decrease
- Medium agreement on substantial decrease
- Medium agreement on increase
- Low agreement on direction of change
- Very high agreement on substantial decrease
- Medium agreement on little change

NOTE: The 4 plots illustrate 4 seasons. (DJF=Dec-Feb, MAM=Mar-May,. JJA=Jun-Aug, SON=Sep-Nov)

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

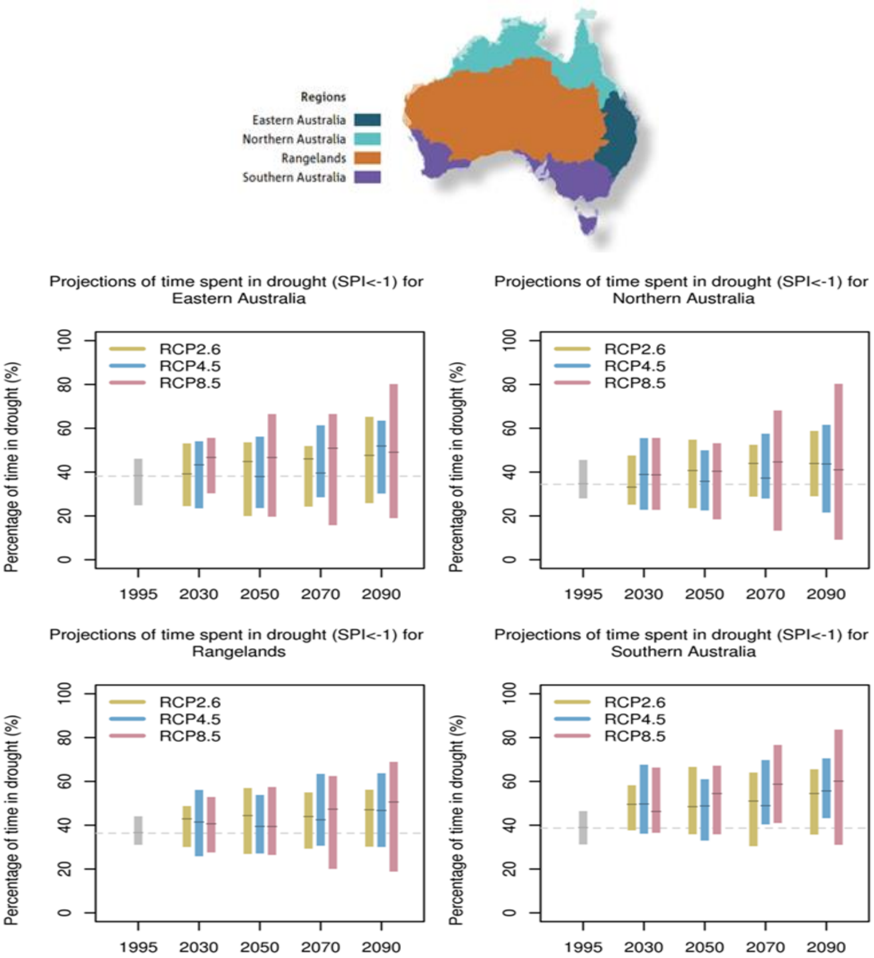
Time spent in drought

The time in drought is projected to increase over southern Australia, consistent with the projected decline in mean rainfall. The nature of droughts is also projected to change with a greater frequency of extreme droughts, and less frequent moderate to severe droughts projected for all regions.

For the 20-year period centred on 1986-2005, the drought proportion is around 35 per cent in Rangelands and northern Australia and 39 per cent in eastern Australia and southern Australia. This will increase by roughly 5 to 20 per cent in the future, depending on the RCP. There is high agreement between the models as to an increase in the proportion of the southern Australia region in drought.

Figure 3.16 shows the projected change in the proportion of time spent in drought (median, 10th and 90th percentile range) for five 20-year periods. Natural variability is depicted in grey, RCP2.6 in green, RCP4.5 in blue, and RCP8.5 in purple, for NRM super cluster regions. The proportion of time in drought is defined as any time the Standard Precipitation Index[92] is continuously, for three or more months, negative and reaches an intensity of -1.0 or less.

FIGURE 3.16 PROJECTED CHANGE IN PROPORTION OF TIME SPENT IN DROUGHT



SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

3.4.3 Evapotranspiration and soil moisture

Potential evapotranspiration[93] (atmospheric moisture demand) is projected to increase. The potential evapotranspiration change for 2030 and 2090 shows a strong tendency for increases throughout Australia in all four seasons. By 2030, the increases are already large, compared to natural variability,

[92] Standardised Precipitation Index is a widely used index to characterise meteorological drought on a range of timescales

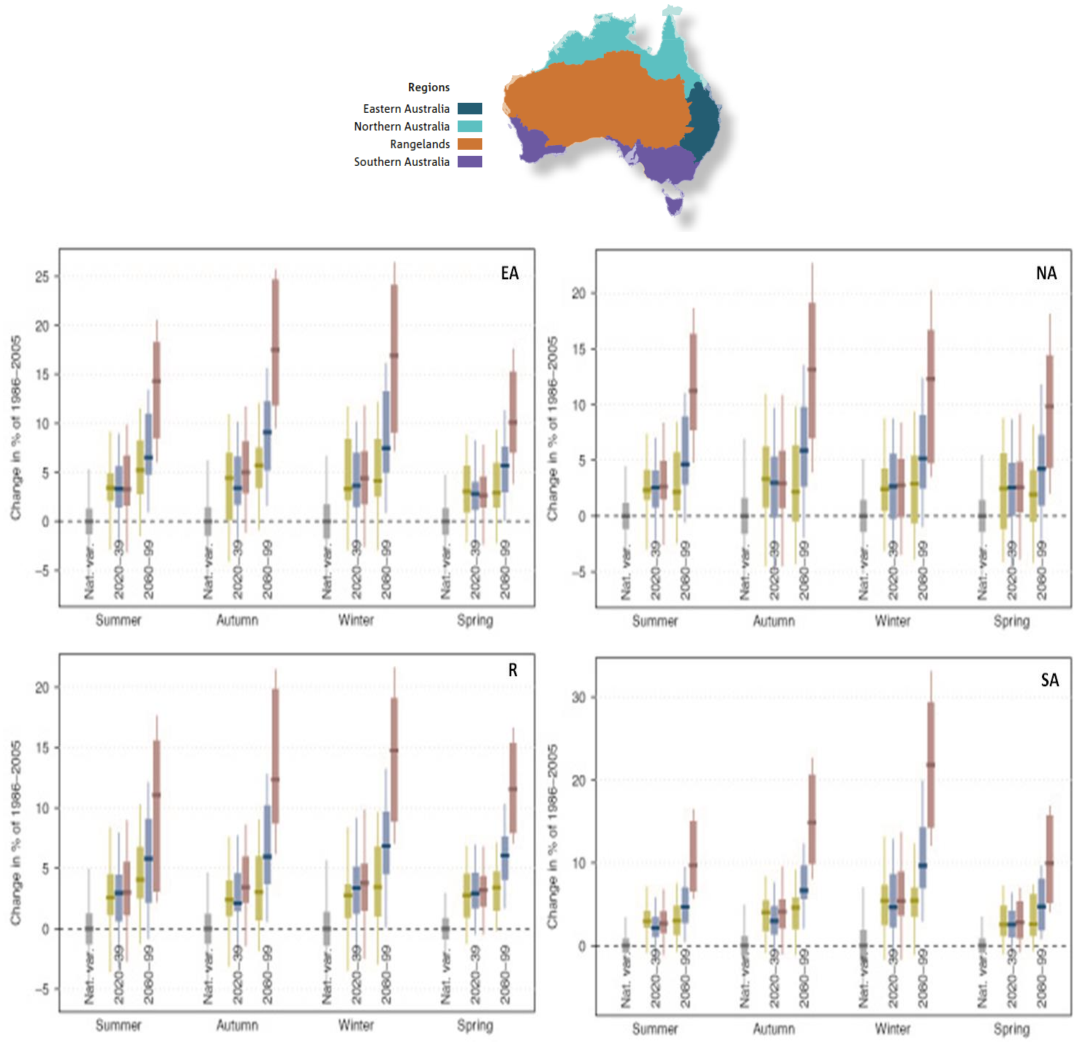
[93] Evapotranspiration is a collective term for the transfer of water vapour to the atmosphere from both vegetated and unvegetated land surfaces. It is a key component in the water balance of a system such as a landscape, catchment or irrigation region. In practice, actual evapotranspiration is rather difficult to measure, and its estimate is often based on information about potential evapotranspiration and soil moisture. Potential evapotranspiration is often regarded as the maximum possible evaporation rate that would occur under given meteorological conditions if water sources were available.

although less than 5 per cent in magnitude. The increases are very significant in 2090 under RCP8.5, around 10-20 per cent increase seasonally, as well as annually.

Figure 3.17 shows the projected change in potential evapotranspiration for 2030 and 2090 under different emissions scenarios. Median and the 10th to 90th percentile range of projected changes in seasonal potential evapotranspiration are shown for 2020-2039 and 2080-2099, relative to 1986-2005 period (grey bar) for the RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple) pathways for the super cluster regions. Fine lines show the range of individual years and solid bars for 20 year running means.

Soil moisture, at the broad-scale, generally reflects the time lag of rainfall accumulated over several months. The projections of changes to soil moisture are influenced by the projected changes in rainfall and higher evaporative demand. Under all time frames and emissions scenarios, a decreasing tendency in soil moisture is evident across all regions. While this remains relatively small compared to natural variability out to 2030, it is more significant in winter in eastern Australia and the Rangelands, and in winter and spring in southern Australia. Changes are larger in 2090, with projected decreases of up to 15 per cent in winter in southern Australia. Decreased soil moisture elsewhere in Australia is not certain as the direction of rainfall change is uncertain.

FIGURE 3.17 PROJECTED CHANGE IN SEASONAL POTENTIAL EVAPOTRANSPIRATION FOR 2020-2039 AND 2080-2099



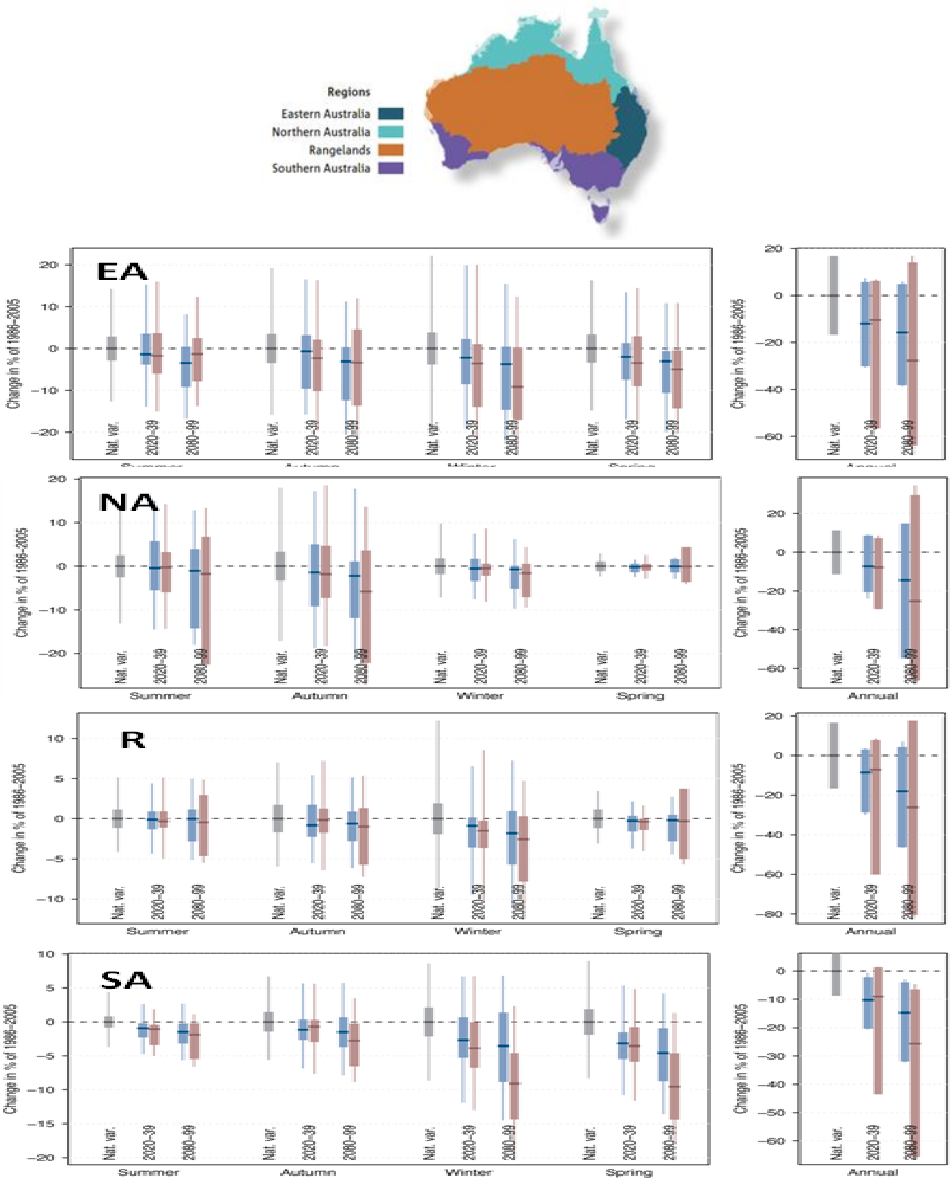
SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Soil moisture

Figure 3.18 shows the median and 10th to 90th percentile range of the projected changes in seasonal soil moisture (left column) and annual run off (right column) for 2020-2039 and 2080-2099 with respect to 1986-2005 associated with natural variability only (Grey), RCP4.5 (Blue), and RCP8.5 (Purple). Fine lines show the range of individual years and solid bars for 20-year running means.

Projected changes to soil moisture are influenced by the projected changes in rainfall and higher evaporation. Soil moisture decreases in the southern regions (particularly in winter and spring) are driven by the projected decrease in rainfall and higher evaporative demand. In 2030 this is mostly small compared to natural variability, but more marked in winter in eastern Australia and the Rangelands, and in winter and spring in southern Australia. Changes are larger in 2090, with decreases of up to 15 per cent in winter in southern Australia.

FIGURE 3.18 PROJECTED CHANGE IN SEASONAL SOIL MOISTURE AND ANNUAL RUN OFF



SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

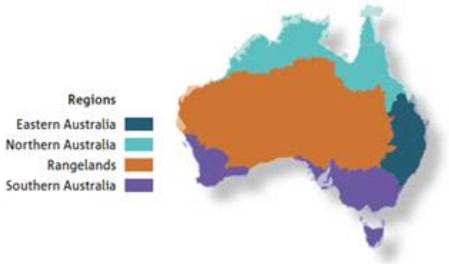
3.4.4 Fire danger

Projected warming and drying in southern and eastern Australia will lead to fuels that are drier and more ready-to-burn, with increases in the average forest fire danger index (FFDI) and a greater number of days with severe fire danger. Little change in fire frequency in tropical and monsoonal northern Australia is projected. The fire risk is uncertain in the arid inland areas where it is dependent upon the availability of fuel, which is driven by episodic rainfall.

Across southern Australia and eastern Australia, the projected number of severe fire days increases by 160-190 per cent by 2090 in the worst case under RCP8.5. Increases of 30-35 per cent in annual total FFDI (i.e. the sum of FFDI from July to June) are also projected by 2090 under RCP8.5. The number of fire danger days rated as 'very high' could double by 2050 in the southeast of Australia under high emissions scenarios.[94]

Figure 3.19 shows the projected changes in mean annual values of maximum temperature (T; °C), Rainfall (R; mm), Drought factor (DF), the number of severe fire danger days per year (SEV; FFDI greater than 50) and cumulative annual FFDI (Cum. FFDI) for the 1995 baseline and projections for 2030 and 2090 for RCP4.5 and RCP8.5 scenarios.

FIGURE 3.19 PROJECTED REGIONAL CHANGES IN KEY CLIMATE VARIABLES AND FIRE DANGER



SUPER CLUSTER	VARIABLE	1995 BASELINE	2030 RCP4.5	2030 RCP8.5	2090 RCP4.5	2090 RCP8.5
SOUTHERN AUSTRALIA	T	21.1	22.3	22.2	23.2	24.8
	R	614	507	521	509	468
	DF	6.4	6.7	6.6	6.8	7.3
	SEV	2.8	3.6	3.4	3.8	5.3
	cum. FFDI	2772	3043	2978	3132	3638
EASTERN AUSTRALIA	T	25.0	26.1	26.4	27.3	29.0
	R	968	856	830	828	809
	DF	6.4	6.6	6.7	6.8	7.1
	SEV	1.2	1.5	1.8	1.9	3.2
	cum. FFDI	2692	2859	3037	3103	3584
NORTHERN AUSTRALIA	T	30.3	31.2	31.5	32.3	33.8
	R	1235	1193	1194	1256	1217
	DF	7.2	7.3	7.3	7.2	7.3
	SEV	2.5	3.1	3.4	3.6	5.3
	cum. FFDI	3568	3726	3762	3829	4168
RANGELANDS	T	28.4	29.8	29.9	30.8	32.7
	R	318	273	293	293	285
	DF	8.6	8.8	8.7	8.8	8.9
	SEV	12.7	18.6	17.1	18.8	27.6
	cum. FFDI	6949	7784	7530	7763	8709

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

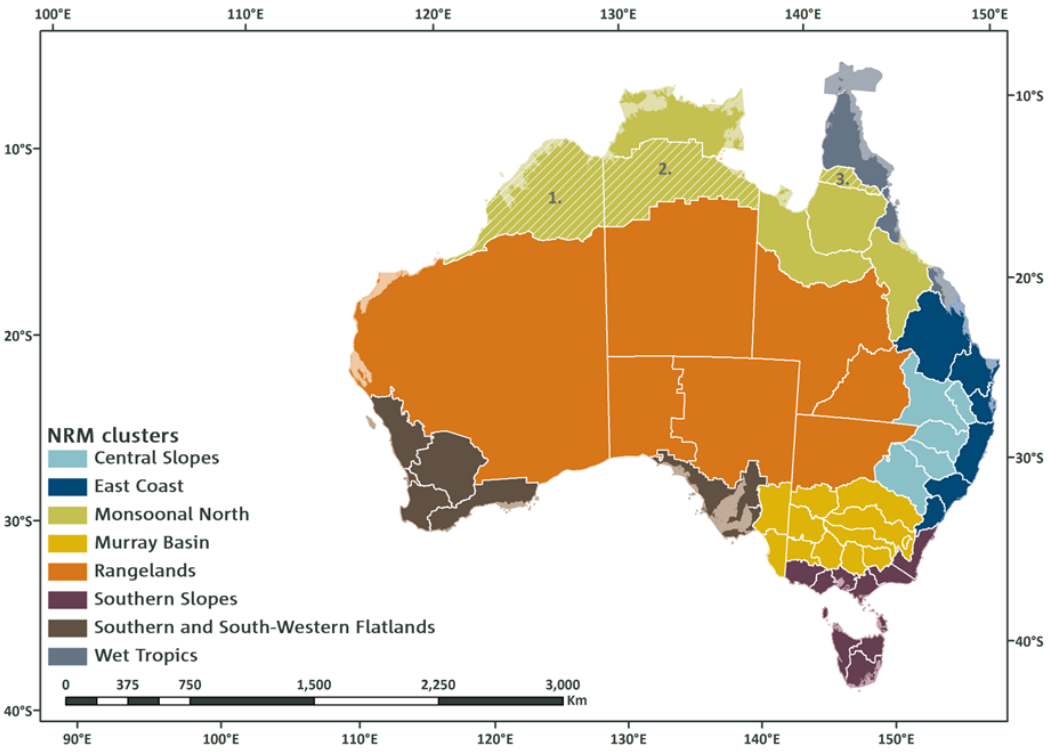
94 State of the Climate, 2018, BoM, http://www.bom.gov.au/state-of-the-climate/State-of-the-Climate-2018.pdf

3.5 Regional climate change projections for Australia

3.5.1 Introduction

This section provides a synopsis of the 2015 regional climate change projections for Australia to 2090, prepared by CSIRO and BoM. These projections are for eight regions of Australia shown at **Figure 3.20**. These regions are based on NRM regional boundaries in each jurisdiction and climatic and biophysical properties. The cluster boundaries were set in 2014. The map also shows the sub cluster boundaries.

FIGURE 3.20 THE NRM CLUSTERS USED FOR THE 2015 REGIONAL CLIMATE CHANGE PROJECTIONS



SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: TECHNICAL REPORT, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

3.5.2 Regional projections for NRM clusters

Central Slopes cluster

The Central Slopes cluster comprises regions to the west of the Great Dividing Range from the Darling Downs in Queensland to the central west of New South Wales. The area features several important headwater catchments for the Murray-Darling Basin and is extensively developed for dryland and irrigated agriculture and grazing. The cluster area has a range of climates, from sub-tropical in the north, through to temperate in the south, with a typically drier winter and wetter summer. Key messages from the modelling of the impacts of climate change on this cluster are shown in **Box 3.2**. More detailed information on the modelling results can be found in Appendix B.

BOX 3.2 KEY MESSAGES FROM THE MODELLING FOR THE CENTRAL SLOPES CLUSTER

- Average temperatures will continue to increase in all seasons (*very high confidence*).
- More hot days and warm spells are projected with *very high confidence*. Fewer frosts are projected to occur (*high confidence*).
- Average winter rainfall is projected to decrease with *high confidence*. There is only *medium confidence* in spring decrease. Changes in summer and autumn are possible but unclear.
- Increased intensity of extreme rainfall events is projected, with *high confidence*.
- Mean sea level will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).
- A harsher fire-weather climate in the future (*high confidence*).
- On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly over the next 20 years (particularly for rainfall).

SOURCE: HTTPS://WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU/EN/CLIMATE-PROJECTIONS/FUTURE-CLIMATE/REGIONAL-CLIMATE-CHANGE-EXPLORER/CLUSTERS/?CURRENT=CSC&TOOLTIP=TRUE&POPUP=TRUE ACCESSED JANUARY 2019

East Coast Cluster

The East Coast cluster comprises NRM regions in the central part of the eastern seaboard of Australia. The area encompasses important headwater catchments for a high proportion of Australia's population. The area has a predominantly sub-tropical climate, with regional variations such as some tropical influences in the north and some temperate influences in the south. Key messages from the modelling of the impacts of climate change on this cluster are shown in **Box 3.3**. More detailed information on the modelling results can be found in Appendix B.

BOX 3.3 KEY MESSAGES FROM THE MODELLING FOR THE EAST COAST CLUSTER

- Average temperatures will continue to increase in all seasons (*very high confidence*).
- More hot days and warm spells are projected with *very high confidence*. Fewer frosts are projected with *high confidence*.
- Decreases in winter rainfall are projected for south of the east coast with *medium confidence*. Other changes are possible but unclear.
- Increased intensity of extreme rainfall events is projected, with *high confidence*.
- Mean sea level will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).
- A harsher fire-weather climate in the future (*high confidence*).
- On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall.

SOURCE: HTTPS://WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU/EN/CLIMATE-PROJECTIONS/FUTURE-CLIMATE/REGIONAL-CLIMATE-CHANGE-EXPLORER/CLUSTERS/?CURRENT=ECC&TOOLTIP=TRUE&POPUP=TRUE ACCESSED JANUARY 2019

Monsoonal North cluster

The Monsoonal North comprises NRM regions in Western Australia, Northern Territory and Queensland, commonly known as the tropical 'top end'. This region experiences a pronounced wet and dry season, with differences in the timing between eastern and western parts. The Monsoonal North-West covers tropical rainforests, wetlands and arid rangelands of the Northern Territory, and the steep mountain ranges of the Ord and Fitzroy River catchments of the Kimberley. The Monsoonal North-East covers relatively intact savannah woodland and important rainforest areas as well as the Mitchell, Gilbert, Norman, Burdekin and Staaten River catchments, all of which flow into the Gulf of Carpentaria (except Burdekin). Key messages from the modelling of the impacts of climate change on this cluster are shown in **Box 3.4**. More detailed information on the modelling results can be found in Appendix B.

BOX 3.4 KEY MESSAGES FROM THE MODELLING FOR THE MONSOONAL NORTH CLUSTER

— Average temperatures will continue to increase in all seasons (*very high confidence*).
— More hot days and warm spells are projected with *very high confidence*.
— Changes to rainfall are possible but unclear.
— Increased intensity of extreme rainfall events is projected, with *high confidence*.
— Mean sea level will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).
— Fewer but more intense tropical cyclones are projected (*medium confidence*).
— On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall.

SOURCE: HTTPS://WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU/EN/CLIMATE-PROJECTIONS/FUTURE-CLIMATE/REGIONAL-CLIMATE-CHANGE-EXPLORER/CLUSTERS/?CURRENT=MNC&TOOLTIP=TRUE&POPUP=TRUE ACCESSED JANUARY 2016

Murray Basin cluster

The Murray Basin cluster comprises NRM regions across New South Wales, Victoria and South Australia. The cluster extends from the flatlands of inland New South Wales to the Great Dividing Range along the southern and eastern boundaries and includes Australia's highest mountain; Mt Kosciuszko, at 2,228m. The cluster is relatively dry and temperate, with a warm and dry grassland climate in the north-west ranging to temperate with hot summers further east. Key messages from the modelling of the impacts of climate change on this cluster are shown in **Box 3.5**. More detailed information on the modelling results can be found in Appendix B.

BOX 3.5 KEY MESSAGES FROM THE MODELLING FOR THE MURRAY BASIN CLUSTER

— Average temperatures will continue to increase in all seasons (*very high confidence*).
— More hot days and warm spells are projected with *very high confidence*. Fewer frosts are projected with *high confidence*.
— By late in the century, less rainfall is projected during the cool season, with *high confidence*. There is *medium confidence* that rainfall will remain unchanged in the warm season.
— Even though mean annual rainfall is projected to decline, heavy rainfall intensity is projected to increase, with *high confidence*.
— Mean sea level will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).
— A harsher fire-weather climate will prevail in the future (*high confidence*).
— On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall.

SOURCE: HTTPS://WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU/EN/CLIMATE-PROJECTIONS/FUTURE-CLIMATE/REGIONAL-CLIMATE-CHANGE-EXPLORER/CLUSTERS/?CURRENT=MBC&TOOLTIP=TRUE&POPUP=TRUE ACCESSED JANUARY 2019

Rangelands cluster

The Rangelands comprises NRM regions in four States and the Northern Territory. This vast region contains many varied landscapes, including the Flinders Ranges, the ranges of the Pilbara and 'The Centre' (the outback). Cattle and sheep grazing are important agricultural activities. Rainfall systems vary from seasonally reliable monsoonal influences in the far north through to very low and variable rainfall patterns in much of the centre and south. Key messages from the modelling of the impacts of climate change on this cluster are shown in **Box 3.6**. More detailed information on the modelling results can be found in Appendix B.

BOX 3.6 KEY MESSAGES FROM THE MODELLING FOR THE RANGELANDS CLUSTER

- Average temperatures will continue to increase in all seasons (*very high confidence*).
- More hot days and warm spells are projected with *very high confidence*. Fewer frosts are projected with *high confidence*.
- Changes to summer rainfall are possible but unclear. Winter rainfall is projected to decrease in the south with *high confidence*.
- Increased intensity of extreme rainfall events is projected, with *high confidence*.
- Mean sea levels will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).
- On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall.

SOURCE: HTTPS://WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU/EN/CLIMATE-PROJECTIONS/FUTURE-CLIMATE/REGIONAL-CLIMATE-CHANGE-EXPLORER/CLUSTERS/?CURRENT=RA&TOOLTIP=TRUE&POPUP=TRUE ACCESSED JANUARY 2019

Southern Slopes cluster

The Southern Slopes comprises nine NRM regions in Tasmania, southern Victoria and south-east New South Wales. This region has an extensive coastal zone and a diversity of local climates across its relatively small area. The dominant rain-bearing weather systems are cold fronts and troughs coming from the west. Key messages from the modelling of the impacts of climate change on this cluster are shown in **Box 3.7**. More detailed information on the modelling results can be found in Appendix B.

BOX 3.7 KEY MESSAGES FROM THE MODELLING FOR THE SOUTHERN SLOPES CLUSTER

- Average temperatures will continue to increase in all seasons (*very high confidence*).
- More hot days and warm spells are projected with *very high confidence*. Fewer frosts are projected with *high confidence*.
- Generally, less rainfall in the cool season is projected with *high confidence*, but with strong regional differences. Changes to summer and autumn rainfall are possible but less clear.
- Increased intensity of extreme rainfall events is projected, with *high confidence*.
- Mean sea level will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).
- A harsher fire-weather climate in the future (*high confidence*).
- On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall.

SOURCE: HTTPS://WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU/EN/CLIMATE-PROJECTIONS/FUTURE-CLIMATE/REGIONAL-CLIMATE-CHANGE-EXPLORER/CLUSTERS/?CURRENT=SSC&TOOLTIP=TRUE&POPUP=TRUE ACCESSED JANUARY 2019

Southern and Southwestern Flatlands cluster

The Southern and South-Western Flatlands (SSWF) region comprises NRM regions in southwest Western Australia and southern South Australia. Iconic features include the Western Australian wheat and sheep belt, Eyre Peninsula and Kangaroo Island. The SSWF area has a predominantly Mediterranean climate, with high winter rainfall and little summer rainfall in both the east and west of the region. Key messages from the modelling of the impacts of climate change on this cluster are shown in **Box 3.8**. More detailed information on the modelling results can be found in Appendix B.

BOX 3.8 KEY MESSAGES FROM THE MODELLING FOR THE SSWF CLUSTER

— Average temperatures will continue to increase in all seasons (*very high confidence*).
— More hot days and warm spells are projected with *very high confidence*. Fewer frosts are projected with *high confidence*.
— A continuation of the trend of decreasing winter rainfall is projected with *high confidence*. Spring rainfall decreases are also projected with *high confidence*. Changes in other seasons unclear.
— More time in drought is projected with *high confidence*
— Mean sea level will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).
— A harsher fire-weather climate in the future (*high confidence*).
— On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall.

SOURCE: HTTPS://WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU/EN/CLIMATE-PROJECTIONS/FUTURE-CLIMATE/REGIONAL-CLIMATE-CHANGE-EXPLORER/CLUSTERS/?CURRENT=SSWS&TOOLTIP=TRUE&POPUP=TRUE ACCESSED JANUARY 2019

Wet Tropics cluster

The Wet Tropics comprises four NRM regions in northern Queensland. The region contains considerable biodiversity assets, for example within national parks and the Great Barrier Reef World Heritage area. The climate of this cluster is characterised by two seasons; the monsoonal wet season (from around December to April), which is dominated by prevailing north-westerly winds, and the dry season (May to November), when south-easterly trade winds dominate. Key messages from the modelling of the impacts of climate change on this cluster are shown in **Box 3.9**. More detailed information on the modelling results can be found in Appendix B.

BOX 3.9 KEY MESSAGES FROM THE MODELLING FOR THE WET TROPICS CLUSTER

— Average temperatures will continue to increase in all seasons (*very high confidence*).
— More hot days and warm spells are projected with *very high confidence*.
— Changes to rainfall are possible but unclear.
— Increased intensity of extreme rainfall events is projected, with *high confidence*.
— Mean sea level will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).
— Fewer but more intense tropical cyclones are projected (*medium confidence*).
— On an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall.

SOURCE: HTTPS://WWW.CLIMATECHANGEINAUSTRALIA.GOV.AU/EN/CLIMATE-PROJECTIONS/FUTURE-CLIMATE/REGIONAL-CLIMATE-CHANGE-EXPLORER/CLUSTERS/?CURRENT=WTC&TOOLTIP=TRUE&POPUP=TRUE ACCESSED JANUARY 2019

4

IMPLICATIONS OF CLIMATE CHANGE FOR AGRICULTURAL ACTIVITY

An assessment of the impacts of climate change projections on Australian agricultural production needs to consider a number of factors.

1. The range of agricultural commodities produced in Australia and which are the main commodities in terms of total agricultural value.
2. The different mix of agricultural commodities in each jurisdiction and the differences in the relative importance of commodities to that economy.
3. The drivers of production, productivity and profitability in the agricultural sector and the range of risks that that need to be managed, of which climate change is only one.
4. The scale and diversity of the climatic regions in Australia which range from monsoonal to desert, temperate and alpine.
5. The changes in climate already experienced and the extent to which agriculture has demonstrated an ability to adapt.
6. The nature, extent and rate of change projected under the three RCP scenarios (RCP8.5 - high emissions little action, RCP4.5 - moderate emissions some action, RCP2.6 - low emissions intensive action).

4.1 Highest value agricultural commodities by jurisdiction

The Australian agricultural sector produces a very wide variety of commodities, across a broad range of climatic zones, from monsoonal to temperate conditions. The assessment of the implications of climate change has focused on those commodities that contribute most to the national gross value of production and also contribute most to each jurisdiction.

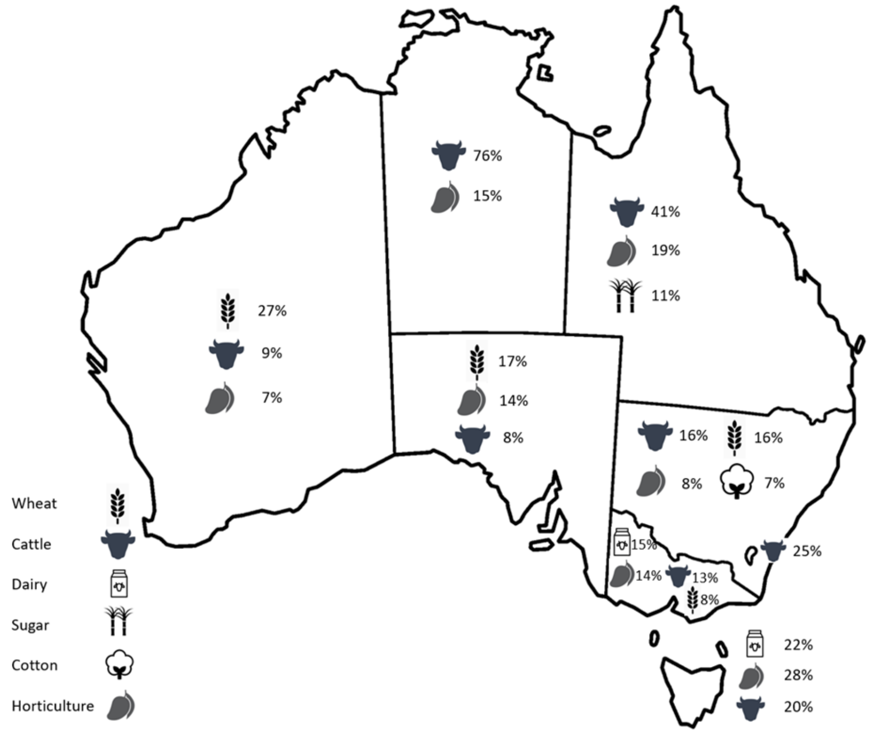
The gross value of agricultural production in Australia for 2016-17 was almost $61 billion. The commodities that contribute the most to this total are cattle $12.1 billion, wheat $7.4 billion and milk $3.7 billion. Horticulture, which comprises a great variety of different commodities (fruit, vegetables and nuts), is also a significant component, with fruit at $4.2 billion and vegetables $3.9 billion.

A total of nine commodities are assessed; the top commodities by value of production, plus some additions which make a major contributor to one of more jurisdictions. These are cattle, milk (dairy), wheat, sugar cane, cotton, potatoes, wine, mangoes and melons.

Cattle, including dairy, are a significant contributor to the value of production in each jurisdiction. For cattle this ranges from 76 per cent in the Northern Territory to just over 8 per cent in South Australia. In South Australia and Western Australia, wheat is the dominant commodity. Milk and cattle together make a significant contribution of over 42 per cent in Tasmania.

Other major commodities for individual jurisdictions include sugar cane in Queensland, cotton in New South Wales, oilseeds and coarse grains in Western Australia, potatoes in Tasmania and mangoes and melons in the Northern Territory. In Victoria, milk, cattle, horticulture and wheat are all important. Wine is also included as it is a high profile commodity for South Australia, New South Wales, Victoria, Western Australia and Tasmania, with domestic wine sales worth $3.5 billion and exports $2.8 billion in 2017-18).[95] The values and percentage breakdown of the major commodities by jurisdiction are shown in **Figure 4.1**, **Table 4.1** and **Table 4.2** .

FIGURE 4.1 MAJOR COMMODITIES BY JURISDICTION



SOURCE: ACIL ALLEN CONSULTING

95 Wine Australia providing insights on Australian Wine; *Australian wine sector 2017 at a glance*; accessed 3 March 2019https://www.wineaustralia.com/getmedia/ba012fa8-3e20-44e9-a783-e8d137a2c74d/MI_SectorReport_Jan2018_F.pdf

TABLE 4.1 GROSS VALUE OF AGRICULTURAL PRODUCTION AND MAJOR COMMODITIES BY JURISDICTION; 2016-17: $ MILLION

	Total	Cattle	Wheat	Milk	Coarse grains	Sheep and lambs	Wool	Pulses	Oilseeds	Cotton	Pigs	Sugar	Fruit	Vegetables
	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17	$million, FY17
NSW	$14,501	$2,364.2	$2,259.7	$548.8	$909.5	$832.6	$1,095.0	$816.4	$714.5	$1,059.5	$224.4	$97.2	$723.4	$507.4
Vic	$14,016	$1,839.4	$1,062.8	$2,196.2	$736.1	$1,532.5	$857.7	$447.6	$344.4	$0.0	$306.3	$0.0	$1,086.3	$943.9
Qld	$14,014	$5,731.2	$361.4	$250.9	$302.7	$9.1	$76.5	$744.0	$9.2	$621.8	$293.1	$1,527.3	$1,457.9	$1,265.8
SA	$7,230	$609.4	$1,226.2	$180.8	$564.5	$579.1	$493.0	$496.0	$208.8	$0.0	$347.0	$0.0	$445.6	$561.1
WA	$8,991	$833.1	$2,442.1	$192.1	$1,084.9	$551.2	$825.5	$221.0	$1,178.9	$0.0	$162.9	$0.0	$320.9	$317.3
Tas	$1,470	$294.7	$13.6	$326.0	$10.7	$58.7	$107.9	$0.0	$4.6	$0.0	$8.3	$0.0	$153.9	$264.4
NT	$610	$464.6	$0.0	$0.0	$0.2	$0.0	$0.0	$0.2	$0.0	$0.0	$0.0	$0.0	$46.0	$43.8
ACT	$11	$2.8	$0.0	$0.0	$0.0	$1.7	$2.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Total	**$60,842**	**$12,139**	**$7,366**	**$3,695**	**$3,608**	**$3,565**	**$3,458**	**$2,725**	**$2,460**	**$1,681**	**$1,342**	**$1,624**	**$4,234**	**$3,904**

Note: Figures are based on establishments with an estimated value of agricultural operations of $40,000 and above.

SOURCE: AUSTRALIAN BUREAU OF STATISTICS

TABLE 4.2 GROSS VALUE OF AGRICULTURAL PRODUCTION AND MAIN COMMODITIES BY JURISDICTION: 2016-17; PER CENT

	Total	Cattle	Wheat	Milk	Coarse grains	Sheep and lambs	Wool	Pulses	Oilseeds	Cotton	Pigs	Sugar	Fruit	Vegetables
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
NSW	23.8 per cent	16.3 per cent	15.6 per cent	3.8 per cent	6.3 per cent	5.7 per cent	7.6 per cent	5.6 per cent	4.9 per cent	7.3 per cent	1.5 per cent	0.7 per cent	5.0 per cent	3.5 per cent
Vic	23.0 per cent	13.1 per cent	7.6 per cent	15.7 per cent	5.3 per cent	10.9 per cent	6.1 per cent	3.2 per cent	2.5 per cent	0.0 per cent	2.2 per cent	0.0 per cent	7.8 per cent	6.7 per cent
Qld	23.0 per cent	40.9 per cent	2.6 per cent	1.8 per cent	2.2 per cent	0.1 per cent	0.5 per cent	5.3 per cent	0.1 per cent	4.4 per cent	2.1 per cent	10.9 per cent	10.4 per cent	9.0 per cent
SA	11.9 per cent	8.4 per cent	17.0 per cent	2.5 per cent	7.8 per cent	8.0 per cent	6.8 per cent	6.9 per cent	2.9 per cent	0.0 per cent	4.8 per cent	0.0 per cent	6.2 per cent	7.8 per cent
WA	14.8 per cent	9.3 per cent	27.2 per cent	2.1 per cent	12.1 per cent	6.1 per cent	9.2 per cent	2.5 per cent	13.1 per cent	0.0 per cent	1.8 per cent	0.0 per cent	3.6 per cent	3.5 per cent
Tas	2.4 per cent	20.0 per cent	0.9 per cent	22.2 per cent	0.7 per cent	4.0 per cent	7.3 per cent	0.0 per cent	0.3 per cent	0.0 per cent	0.6 per cent	0.0 per cent	10.5 per cent	18.0 per cent
NT	1.0 per cent	76.1 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	7.5 per cent	7.2 per cent
ACT	0.0 per cent	25.1 per cent	0.1 per cent	0.0 per cent	0.0 per cent	14.9 per cent	19.7 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent	0.0 per cent
Overall		**20.0 per cent**	**12.1 per cent**	**6.1 per cent**	**5.9 per cent**	**5.9 per cent**	**5.7 per cent**	**4.5 per cent**	**4.0 per cent**	**2.8 per cent**	**2.2 per cent**	**2.7 per cent**	**7.0 per cent**	**6.4 per cent**

Note: Figures are based on establishments with an estimated value of agricultural operations of $40,000 and above.

SOURCE: AUSTRALIAN BUREAU OF STATISTICS

A 2005 study by Nguyen et al. examined the issues of farming risks and risk management strategies in Australia.[96] In the upper Eyre Peninsula of South Australia and southwest Queensland, the study found that climate variability ranked as the most important source of risk. Financial risk, marketing risk, government and personal risk were the other major sources of farming risk. The main management strategies used by farmers included diversifying varieties, minimising tillage, minimising the area of risky crops and maximising the area of the least-risky crop, having high equity, having farm management deposits and other off-farm investments, and obtaining expert marketing advice.

The following sections discuss the implications of climate change for yield for each of the key agricultural commodities for each jurisdiction. The impact of the various measures being used to manage risks to yield are also considered.

4.2 Climate trends affecting agriculture

Australia has warmed just over 1°C since 1910, with most warming since 1950. This warming has seen an increase in the frequency of extreme heat events and increased the severity of drought conditions during periods of below-average rainfall.

Eight of Australia's top-ten warmest years on record have occurred since 2005.[97] Very high monthly maximum temperatures that occurred around 2 per cent of the time in the past i.e. during the period 1951–1980, now occur around 12 per cent of the time (during the period 2003–2017). Very warm monthly minimum, or night-time, temperatures that occurred around 2 per cent of the time in the past (1951–1980) now also occur around 12 per cent of the time (2003–2017). This shift has occurred across all seasons, with the largest change in spring.

Australian rainfall is highly variable and is strongly influenced by phenomena such as El Niño/La Niña. However, this year-to-year variability is occurring against a long-term background drying trend across much of the southern half of Australia (south of 26° S). Since 1999, southern Australia has experienced below average rainfall for 17 of the last 20 periods between April and October. This drying is the most sustained large-scale change in rainfall since national records began in 1900.

The drying trend is particularly strong between May and July over southwest Western Australia, with rainfall since 1970 around 20 per cent less than the average from 1900-1969, with this increasing to 26 per cent less since1999. For the southeast of the continent, April to October rainfall for the period 1999-2018 has decreased by around 11 per cent, when compared to the 1900-1998 period. This period encompasses the 'Millennium Drought', which saw low annual rainfall totals across the region from 1997-2010. Northern Australia has been wetter across all seasons, but especially in the northwest during the tropical wet season.

There has also been a higher proportion of total annual rainfall in recent decades from heavy rain days. Total rainfall from heavy rain days is expected to increase by around 7 per cent per degree of warming.

This decrease of winter and spring rainfall has occurred at an agriculturally and hydrologically important time of the year and is combined with warming day and night temperatures. The reduction in rainfall across southern Australia has led to even greater reductions in stream flows. For example, the mean annual stream flow into Perth water storages has dropped from 338 gigalitres (GL) during the period 1911-1974 to 47 GL for the six years from 2012-2017. Declines in stream flow have also been observed in four drainage divisions: the Murray–Darling Basin, South East Coast (Victoria) and South East Coast (New South Wales) (which include Sydney and Melbourne), and the South Australian Gulf (which includes Adelaide). In each of these drainage divisions, between two thirds and three quarters of streamflow records show a declining trend since the 1970s.

On top of these trends, there are further risks placed on the agricultural sector from the increase in extreme weather events.

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96 Nam Nguyen, Malcolm Wegener, Iean Russell, Donald Cameron, David Coventry, Ian Cooper 2005. Risk management strategies by Australian farmers. 15th Congress - Developing Entrepreneurship Abilities to Feed the World in a Sustainable Way. IFMA Brazil 2005

97 CSIRO and BoM 2018. State of the Climate 2018 http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml

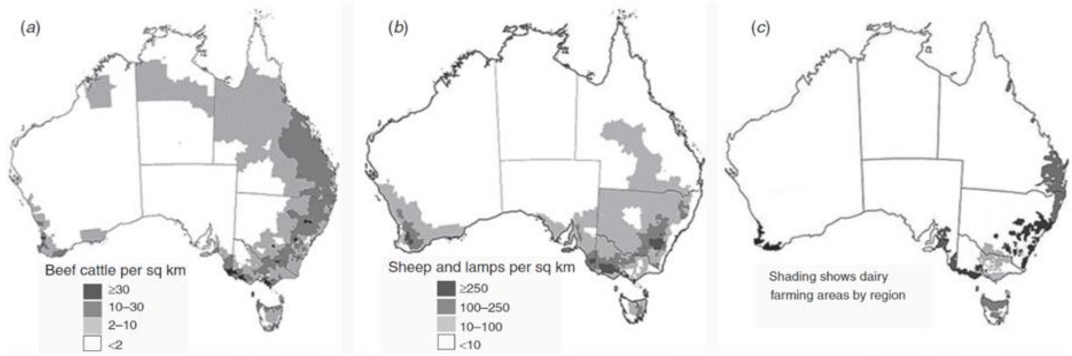
4.3 Livestock – Cattle and Dairy

The gross value of agricultural production from the cattle and dairy (milk) sector in Australia was $15.8 billion in 2016-17. This sector is the highest contributor to the value of production in each jurisdiction, except South Australia and Western Australia. In Queensland, cattle contribute $5.7 billion, or 41 per cent of the total value of agricultural production. In the Northern Territory, they contribute $610 million, or 76 per cent of the total value of agricultural production. In the Australian Capital Territory, cattle production accounts for 25 per cent of the total value of agricultural production.

Although sheep and lamb herd numbers are over double that of cattle and calves, the value of the sector is only about a quarter. However, sheep and wool production make a significant contribution to the value of production in certain jurisdiction. In particular, in New South Wales, they contributed $833 million and $1.1 billion respectively in 2016-17, which is about 6 and 8 per cent of total agricultural value). Given the impacts of climate change on sheep and wool production largely parallel those of the cattle industry, this sector has not analysed in detail.

In 2016-17, the cattle and sheep herd consisted of 23.5 million beef cattle and calves, 2.6 million dairy cattle and calves and 72 million sheep and lambs (see **Figure 4.2**). In Australia, livestock production is the primary land use on 47 per cent of the continental land mass.[98]

FIGURE 4.2 DISTRIBUTION OF BEEF CATTLE, SHEEP AND DAIRY CATTLE IN AUSTRALIA 2016-17



SOURCE: BEVERLEY HENRY, ED CHARMLEY, RICHARD ECKARD, JOHN B. GAUGHAN, AND ROGER HEGARTY. LIVESTOCK PRODUCTION IN A CHANGING CLIMATE: ADAPTATION AND MITIGATION RESEARCH IN AUSTRALIA, 2012, CROP & PASTURE SCIENCE, 63, 191–202, HTTP://DX.DOI.ORG/10.1071/CP11169 .

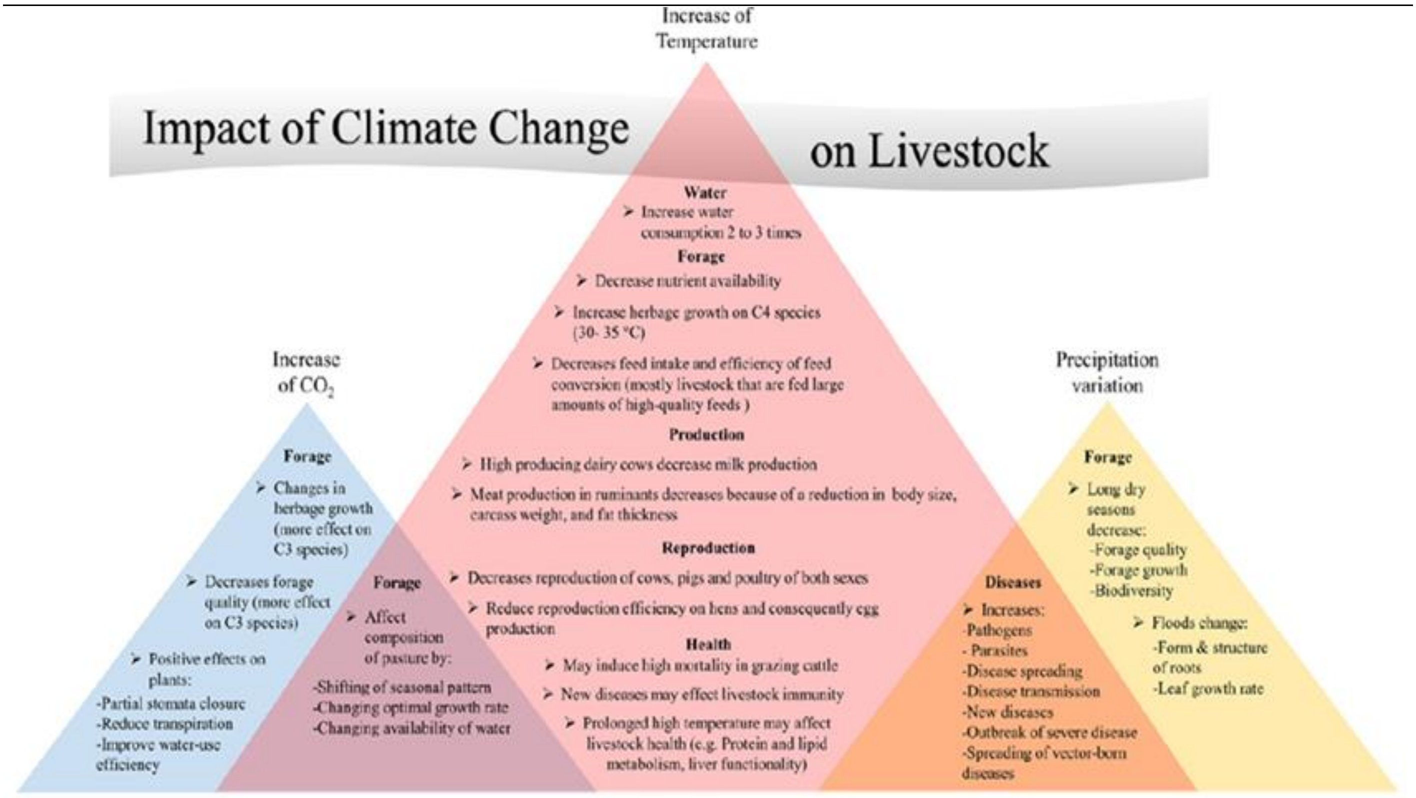
Livestock producers in Australia have, for some time, managed the complex suite of impacts linked to climate change, including higher temperatures; changes in rainfall amounts; intensity and patterns; abatement measures; alternate land uses for food; animal feed, biofuels and carbon sequestration; and increasing input costs due to water pricing and higher energy costs.

A 2018 review of 126 scientific publications examined the impacts of climate change on livestock.[99] The review provides a large and comprehensive information base. The discussion that follows draws on the papers examined in the review.

The interactions between direct and indirect climate effects on livestock and their sources of nutrition are complex and vary across regions. They are summarised in **Figure 4.3**.

98 ABS (2010) Agricultural commodities, Australia. (Australian Bureau of Statistics: Canberra) Available at: http://www.abs.gov.au
99 Jacquelyn F. Escarcha, Jonatan A. Lassa and Kerstin K. Zander. Climate 2018, 6(3), 54; https://doi.org/10.3390/cli6030054 *Livestock Under Climate Change: A Systematic Review of Impacts and Adaptation*

FIGURE 4.3 IMPACTS OF CLIMATE CHANGE ON LIVESTOCK



SOURCE: M.M. ROJAS-DOWNING ET AL. / CLIMATE RISK MANAGEMENT 16 (017) 145-163

The effects of climate change on livestock production systems in Australia will be superimposed on high natural variability in climate. The projected distribution of climate change impacts over the continental land mass shows that regions of ruminant livestock production cover the full range of change under all scenarios (see **Figure 4.4**). The changes in climatic conditions are expected to affect animal agriculture in four main ways: feed-grain production, availability, and price; pasture and forage crop production and quality; animal health, growth, and reproduction; and disease and pest distribution. The combination of these factors could have a significant impact on the economic viability of livestock production systems.

The impacts of climate change on livestock production in Australia have also been examined by CSIRO.[100] The effects of projected increases in temperature, changes to rainfall patterns, and impact of elevated atmospheric CO_2 levels on productivity of grazing systems, will vary regionally and will depend on the combination of changes. Short-term changes due to extremes in weather, such as extended drought, heat waves, and flooding, will further add to these challenges. The effects of higher temperature on livestock and their forage base is the most certain impact. The effects of rainfall are far less certain.

Livestock will normally maintain their body temperature within a fairly narrow range +/-0.5°C over the course of a day.[101] In the event of increases in temperature variability and extremes, normal behavioural, immunological, and physiological functions of animals are all potentially impacted. In addition, when animals are exposed to thermal stress, metabolic and digestive functions are often compromised due to altered or impaired feeding activity. These effects could potentially result in changes in the types of animals and genotypes that are used, changes in the facilities and housing utilised for the care and management of livestock, and eventually, a potential redistribution of livestock and livestock species in a region.

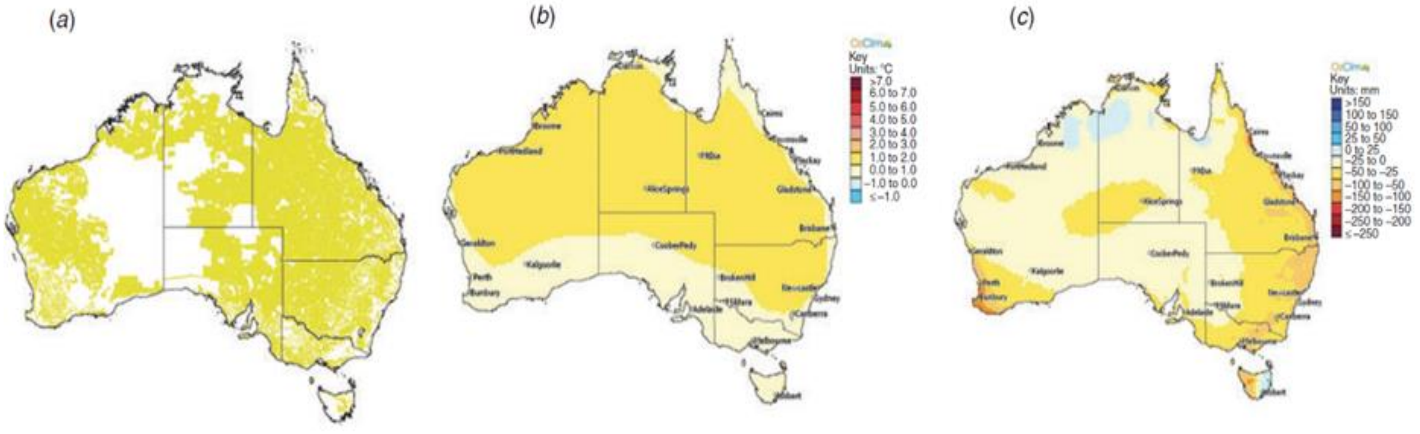
100 Beverley Henry, Ed Charmley, Richard Eckard, John B. Gaughan, and Roger Hegarty. Crop & Pasture Science, 2012, 63, 191–202, http://dx.doi.org/10.1071/CP11169, *Livestock production in a changing climate: adaptation and mitigation research in Australia*

101 ibid

4.3.1 Pasture and forage crop production and quality

The changes in climate and weather are likely to result in more variable pasture productivity and quality, increased livestock heat stress, greater pest and weed effects, more frequent and longer droughts, more intense rainfall events, and greater risks of soil erosion. This may impact grazing systems by altering species composition in mixed swards. For example, warming will favour tropical (C4) species over temperate (C3) species, with associated changes in pasture quality through reduced protein concentration and digestibility, particularly in C3 plants.[102] [103]

FIGURE 4.4 DISTIBUTION OF GRAZING LAND, PROJECTED CHANGE IN TEMPERATURE AND TOTAL RAINFALL IN 2030



Notes: Map A shows 'GRAZING LAND' IN AUSTRALIA, map B shows PROJECTED CHANGE IN MEAN SURFACE TEMPERATURE (°C) AND Map C shows TOTAL RAINFALL (MM) FOR THE YEAR 2030 RELATIVE TO A BASE PERIOD OF 1975–2004 USING THE CSIRO EACHAM5/MPI-OM MODEL (WWW.CSIRO.AU/OZCLIM)

SOURCE: BEVERLEY HENRY, ED CHARMLEY, RICHARD ECKARD, JOHN B. GAUGHAN, AND ROGER HEGARTY. CROP & PASTURE SCIENCE, 2012, 63, 191–202, HTTP://DX.DOI.ORG/10.1071/CP11169, LIVESTOCK PRODUCTION IN A CHANGING CLIMATE: ADAPTATION AND MITIGATION RESEARCH IN AUSTRALIA

In Mediterranean, temperate, and cool temperate climates, increased pasture growth rates in winter and early spring, may be counteracted by a shorter spring growing season. In a cool temperate environment, such as in Tasmania, annual pasture production could increase under scenarios modelled through to 2070. In subtropical regions, lower rainfall and increasing intensities of drought in savannah areas may be partially offset by benefits of higher CO_2 levels, and an associated increased growing season. In northern areas, such as the Kimberley, increased rainfall could result in greater pastoral productivity. Wetter areas, traditionally used for grazing, may shift to cropping if rainfall decreases, a trend noted in the south-west of Victoria.

The results of a study undertaken by CSIRO indicate that there is a real prospect of 15-20 per cent overall reduction in pasture growth across southern Australia by 2030.[104] In the absence of adaptation, reductions in profitability will be larger again. Climate change impacts are likely to be most severe in the lower-rainfall areas of the cereal-livestock zone. The (CSIRO) authors consider that no single alteration to management will be a 'silver bullet' in response to climate change, but combinations of adaptations can probably be found to maintain the productivity of livestock production across southern Australia to 2030. On the other hand, by 2050 and 2070, it is likely that new technologies or systems will need to be found if livestock production at the dry edge of the farming zone is to remain viable.

A recent paper by Perera et al. examined the influence of El-Niño Southern Oscillation and Indian Ocean Dipole (IOD) phases on annual pasture production in south eastern Australia. [105] The authors analysed annual pasture production, simulated at five sites (Wagga Wagga, Dookie, Hamilton,

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102 ibid

103 C3, C4 and CAM are the three different processes that plants use to fix carbon during the process of photosynthesis.

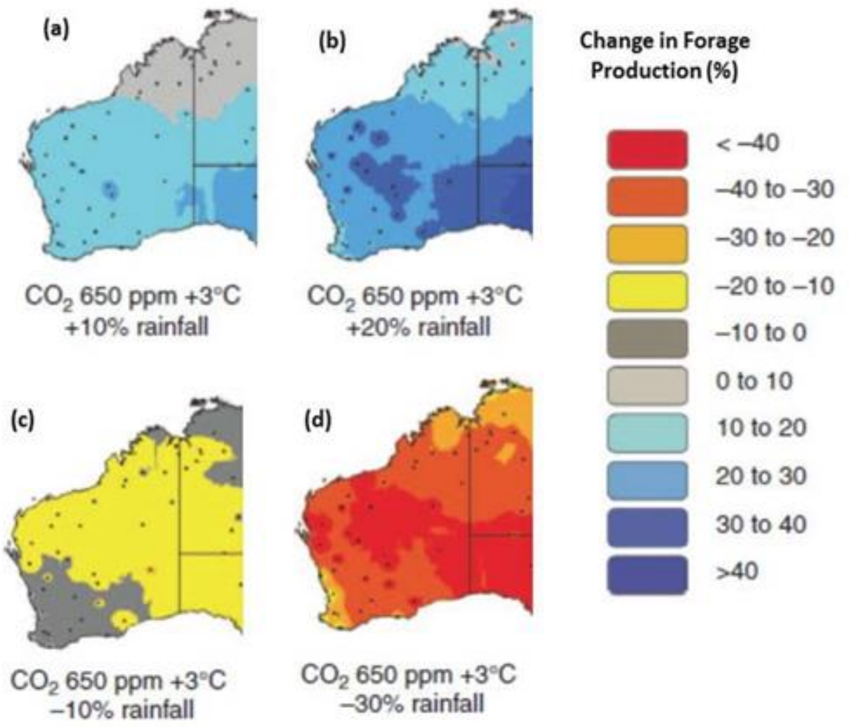
104 CSIRO; Southern Livestock Adaptation 2030. Appendix 1A CSIRO Summary Report on Southern Livestock Adaptation to Climate Change 2012. http://sla2030.net.au/wp-content/uploads/2012/11/Appendix-1A-CSIRO-Summary-Report-on-Southern-Livestock-Adaptation-to-Climate-Change-2012.pdf

105 TMRS Perera, BR Cullen and R Eckard, Influence of El-Niño Southern Oscillation and Indian Ocean Dipole phases on annual pasture production in south eastern Australia, Proceedings of the Australian Dairy Science Symposium, 2018.

Ellinbank and Elliott) using DairyMod.[106] The authors found that mean annual pasture yields were substantially lower during El-Niño years at Wagga Wagga (7 t DM/ha/yr) and Dookie (6.4 t DM/ha/yr) than neutral and La-Niña years (approximately 10 t DM/ha/yr). This is equivalent to a reduction of between 30 and 36 per cent. Similarly, there were lower yields at Wagga Wagga, Dookie and Elliott during IOD positive years.

Projections analysis for Western Australia in Sudmeyer et al. found that reduced rainfall of 10 per cent by 2030 and higher temperatures could reduce forage production by up to 10 per cent over the agricultural areas and southern rangelands and by 10–20 per cent over the rest of the state.[107] Sudmeyer et al. argued that the percentage decline in livestock productivity and profitability would be greater than the decline in pasture growth. Thus, rainfall decline and continued climate variability is likely to place severe stress on rangeland ecosystems, grazing enterprises and rural communities in southern Western Australia (see **Figure 4.5**).

FIGURE 4.5 PROJECTED CHANGES IN FORAGE PRODUCTION FOR A HIGH EMISSIONS SCENARIO



Note: CO_2 concentration of 650 ppm and temperature increase of 3°C with rainfall increasing by (a) 10%, and (b) 20%, and rainfall declining by (c) 10%, and (d) 30%; Dots indicate the sites where forage production was estimated

SOURCE: SUDMEYER ET AL. 2016

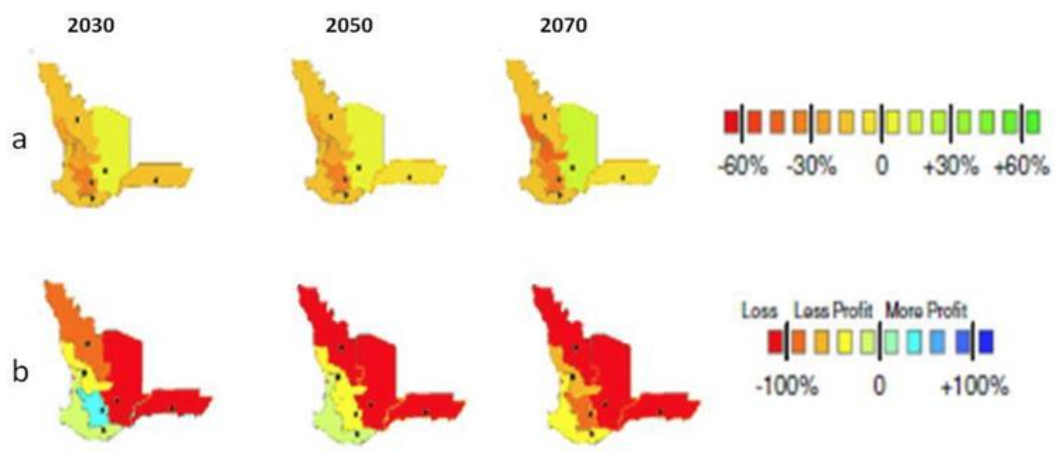
Figure 4.6 shows the modelled changes in (a) above-ground net primary productivity of pastures, and (b) long-term average operating profit from Merino ewe enterprises resulting from climate changes projected by four global climate models under the SRES A2 scenario. Values shown are changes relative to 1970–99 base scenario and are for optimal sustainable stocking rates.[108]

106 DairyMod is a biophysical simulation model of the dairy pasture system, designed to explore dairy pasture management, which incorporates the principal rotational grazing management strategies that are used in Australia

107 Sudmeyer, R A, Edward, A, Fazakerley, V, Simpkin, L, and Foster, I. (2016), Climate change: impacts and adaptation for agriculture in Western Australia. Department of Agriculture and Food, Western Australia, Perth. Bulletin 4870

108 ibid

FIGURE 4.6 MODELLED CHANGES IN NET PRIMARY PRODUCTIVITY OF PASTURES (a), AND LONG-TERM PROFIT FROM MERINO ENTERPRISES (b)



Note: Values were determined at optimal sustainable stocking rate and with a SRES A2 emission scenario

SOURCE: SUDMEYER ET AL. 2016

4.3.2 Weeds

Climate change will alter the occurrence of weeds in grazing areas, with both positive and negative impacts on pasture quality depending on the region (see **Table 4.3**).

TABLE 4.3 POTENTIAL IMPACTS OF CLIMATE CHANGE ON WEEDS SIGNIFICANT TO AGRICULTURE IN SOUTHERN AUSTRALIA

Weed	Impact
Blackberry	Expected to retreat southwards and to higher altitudes because it is sensitive to higher temperatures and drought.
Chilean needle grass	Expected to increase its range because it is highly invasive (long-lived, seed dispersed by wind and water) and drought tolerant.
Gorse	Expected to retreat southwards because it is drought sensitive.
Lantana	Expected to continue its move southwards into the higher rainfall zones of northern New South Wales.
Mesquite	Some risk that it may move into lower rainfall areas because it is very drought tolerant.
Parthenium	Not suited to winter dominant rainfall areas. May move into summer dominant, higher rainfall (>500 mm) regions.
Serrated tussock	Expected to retreat southwards and to higher altitudes because it is sensitive to higher temperatures. As a drought-tolerant plant, it should become more invasive in areas where temperature allows.
Prickly acacia	Expected to move southwards and into arid areas.

SOURCE: SUDMEYER, R A, EDWARD, A, FAZAKERLEY, V, SIMPKIN, L, AND FOSTER, I. (2016), CLIMATE CHANGE: IMPACTS AND ADAPTATION FOR AGRICULTURE IN WESTERN AUSTRALIA. DEPARTMENT OF AGRICULTURE AND FOOD, WESTERN AUSTRALIA, PERTH. BULLETIN 4870

4.3.3 Heat stress

Livestock will normally maintain their body temperature within a fairly narrow range (+/-0.5°C) over the course of a day. Exposure to high temperatures will induce a heat stress response as the animal attempts to maintain its body temperature. As a result of thermal challenges associated with climate variability and change, the normal behavioural, immunological, and physiological functions of animals are all potentially impacted. In addition, when animals are exposed to thermal stress, metabolic and digestive functions are often compromised due to altered or impaired feeding activity. Heat stress can also limit growth and compromise fertility.

Different cattle breeds can cope with heat stress with different magnitudes. Breed, coat colour and type, and body condition all play a role.[109] For example, there is evidence that Braham cattle (*Bos indicus*) can better endure thermal stress than *Bos taurus* (e.g. Angus cattle) and variations also exist within different breeds of *Bos taurus*.[110] [111]

4.3.4 Stock water availability and use

Increased temperatures will increase livestock water requirements. In south-east Queensland, a 2.7°C increase in air temperature is estimated to increase cattle water requirements by 13 per cent, with further nonlinear increases at higher temperatures (see **Table 4.4**). However, if the temperature of stock water becomes too high - more than 27°C for cattle - water and feed intake may decrease, affecting animal productivity. In a 2010 feedlot study by Gaughan et al. mean water intake increased from 32 to 82 litres per steer per day as heat load increased.[112]

TABLE 4.4 WATER REQUIREMENTS OF CATTLE AT VARIOUS AIR TEMPERATURES

Air temperature (°C)	Litres of water per kilogram of dry feed`	Litres of water for a 500kg cow
5	0.55	30.7
16	0.79	38.2
27	1.07	51.5
32	1.51	73.4

SOURCE: HIGGINS SF AND AGOURDIS 2008. DRINKING WATER QUALITY GUIDELINES FOR CATTLE UNIVERSITY OF KENTUCKY EXTENSION SERVICEHTTP://WWW2.CA.UKY.EDU/AGC/PUBS/ID/ID170/ID170.PDF ACCESSED FEBRUARY 2019

4.3.5 Disease and pest distribution

Increasing temperature may also increase exposure and susceptibility of animals to parasites and disease especially vector-borne diseases. However, the potential impact of climate change on parasite populations and subsequent effects on animal production is not yet well understood and therefore difficult to project. This is due to the complex interactions between pathogens, vectors, host, and the multivariate nature of climate change and the non-linear thresholds in both disease and climate processes.

For example, the tropical biting buffalo fly (*Haematobia irritans exigua*), has appeared in Victoria during hot wet summers and during mild winters. These flies may overwinter as far south as Port Macquarie in New South Wales. The spread of tropical parasites south is likely to continue, whereas there could be contractions in some temperate species (e.g. lice). For example, the range of the cattle tick (*Rhipicephalus microplus*) and *Culicoides* vectors of bluetongue virus are likely to extend southwards in areas where summer rainfall increases. Blowfly strike on sheep may also increase where humidity and summer rainfall increase.

4.3.6 Irrigated water availability

Extreme events, such as drought, provide insights into the capability of graziers to adapt. In northern Victoria, the dairy industry underwent major changes to its production systems in response to reduced water allocations following the millennium drought. Before the drought, most farmers in this region used flood irrigation on perennial pastures throughout the dry summer months. However, over a

109 https://www.mla.com.au/research-and-development/feeding-finishing-nutrition/Lotfeeding-intensive-finishing/heat-stress/
110 Summer, A, Lora, I, Formaggioni, P, Gottardo, F, (2019) Impact of heat stress on milk and meat production, Animal Frontiers, Volume 9, Issue 1, 3 January 2019, Pages 39–46, https://doi.org/10.1093/af/vfy026
111 Gaughan, J.B., Mader, T.L., Holt, S.M. et al. *Assessing heat tolerance of 17 beef cattle genotypes*. Int J Biometeorol (2010) 54: 617. https://doi.org/10.1007/s00484-009-0233-4
112 Gaughan JB, Bonner S, Loxton I, Mader TL, Lisle A, Lawrence R (2010). Effect of shade on body temperature and performance of feedlot steers. Journal of Animal Science 88, 4056–4067. doi:10.2527/jas.2010-2987

period of 3 to 5 years, these systems changed to supplementary irrigation of more water-use efficient forages (e.g. maize, annual ryegrass, lucerne/alfalfa) during the less evaporative months of the year.

4.3.7 Impact on livestock productivity – case study Western Australia

The analysis of climate change projections and impacts by Sudmeyer et al. for Western Australia reported that reduced rainfall of 10 per cent by 2030 and higher temperatures could reduce forage production by up to 10 per cent over the agricultural areas and southern rangelands, and by 10–20 per cent over the rest of the state.[113] They argued that the percentage decline in livestock productivity and profitability would be greater than the decline in pasture growth. Thus, rainfall decline and continued climate variability is likely to place severe stress on rangeland ecosystems, grazing enterprises and rural communities in southern Western Australia.

4.3.8 Conclusions: beef

The discussion above suggests that climate change will have a number of negative impacts on livestock productivity. The most serious of these appear to be temperature related, either through impacts on forage growth, or as a result of heat stress on livestock.

In Sudmeyer et al. it was reported that forage production could be reduced by up to 10 per cent across all of Western Australia by 2030. Livestock productivity is expected to decline by more than those percentages. Perera et al. identified likely declines in annual pasture production in south eastern Australia of around 30 per cent. [114]

For the purposes of the analysis it is assumed that livestock productivity gradually drops over the period to 2030. By then productivity is assumed to have declined by 5 per cent. Beyond 2030 the picture is less clear. While the climate change signals will strengthen, placing greater stress on productivity, this may well be offset by new research and the implementation of adaptation measures. Given this lack of clarity it has been assumed that the reduction remains constant. Based on the research reviewed, this is likely to be a conservative estimate.

4.4 Dairy

4.4.1 Impact on dairy production

Much of the discussion around the impact of climate change on pasture productivity in relation to cattle is also relevant to the outlook for dairy cows.

Heat stress is an important factor in dairy production as it can reduce milk production in dairy cattle. The analysis of climate change projections and impacts by Sudmeyer et al. found that the number of heat stress days under a warmer climate in Western Australia would increase by up to 30 per cent in northern parts of the State and by 10 per cent in southern parts of the State.

An analysis by Key and Sneeringer in 2014 of the US dairy industry projected a 0.60 per cent to 1.35 per cent decline in milk production by 2030 due to heat stress, depending upon the climate model used. In southern states of the USA, losses greater than two per cent were predicted.[115]

Garner et al. found that cows exposed to moderate heat stress in a controlled environment-chamber had a milk yield reduction of 53 per cent. However, the fact that this level of impact is seldom observed at an industry level illustrates that operational management adjustments by dairy farmers, in response to experienced climate, over time, increases their resilience to climate 'shocks'.[116]

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113 Sudmeyer, R, Edward, A, Fazakerley, V, Simpkin, L & Foster, I 2016, *Climate Change: Impacts and Adaptation for Agriculture In Western Australia*, Bulletin 4870, Department of Agriculture and Food, Western Australia, Perth

114 op cit

115 Key N and Sneeringer S, 2014. *Potential effects of climate change on the productivity of U.S. dairies*. American Journal of Agricultural Economics 96, 1136–1156.

116 Garner JB, Douglas M, Williams SRO, Wales WJ, Marett LC, DiGiacomo K, Leury BJ and Hayes BJ 2017. *Responses of dairy cows to short-term heat stress in controlled-climate chambers*. Animal Production Science 57, 1233–1241.

Henry et al. analysed milk tanker pick-up data from dairy farms distributed across the state of Victoria, throughout one of the most extreme heat wave events in Australia's history that occurred from 13 to 18 January 2014. The event ranked along with the 2009, 1939 and 1908 heat waves as one of the most significant multi-day heat waves on record. They found that the average drop in milk production across the state was 10 per cent below the average 14-day running mean for the five days before the event.[117]

The impact of projections for warmer, drier and more variable future climate on the dairy industry was recently analysed by Dairy Australia.[118] This analysis examined dairy systems in Victoria, South Australia and Tasmania and explored how farms may perform under predicted climate change, out to 2040, and how adaptation can modify those impacts.

The analysis found that the annual rate of productivity growth required to maintain profitability in 2040, under a high scenario, was an additional 0.6 per cent per year for the Fleurieu Peninsula and Gippsland and 0.3 per cent per year for Tasmania, on top of the current dairy annual productivity growth of 1.6 per cent (as estimated by ABARES). This is a substantial additional challenge on top of 'business as usual'. It should be noted that the study also found that the milk price was the largest single source of variation in profit across regions, out to 2040.

An indicative estimate of the impact of heat stress on dairy cattle derived from an earlier CSIRO study indicated that the impact would be a reduction in milk/cow/year of between 0.6% and 5% (low to high susceptibility cows and scenarios).[119] The study of the Murray Dairy Region analysed past heat stress frequency and duration and projected changes into the future using model estimates of global warming.

Analysis by ABARES showed that in the dairy industry, productivity growth averaged 1.4 per cent per year between 1978–79 and 2015–16.[120] This was a result of a 1.2 per cent per year increase in output and a 0.2 per cent per year decline in input use.

4.4.2 Conclusions: dairy

The research outlined above strongly suggests that the growth in dairy productivity will not be sufficient to keep pace with the productivity declines caused by climate change unless new adaptation approaches are adopted. This means that productivity will gradually decline over the period to 2030. It is assumed that the annual productivity loss is 0.1 per cent per year. There is clearly some uncertainty around assumptions such as these and the impact will vary at differing regional levels. These issues will be explored further in subsequent work.

Based on the information from the research assessed, this is considered an appropriate, but conservative, assumption.

4.5 Wheat

Wheat is the major winter crop grown in Australia, with sowing starting in autumn and harvesting, depending on seasonal conditions, occurring in spring and summer. The largest producing states are Western Australia and New South Wales, producing around $2.3 to $2.4 billion in value, respectively. South Australia and Victoria together produced around $2.3 billion in value in 2016-17. The areas under production by state are Western Australia –5 million hectares; New South Wales – 3.1 million hectares; South Australia – 1.9 million hectares; Victoria – 1.5 million hectares; Queensland – 610,000 hectares; and Tasmania – 7,000 hectares (ABARES).[121]

The majority of Australian wheat, around 80 per cent, is sold overseas, with Western Australia the largest exporting state. The major export markets are in the Asian and Middle East regions and

117 B. K. Henry, R. J. Eckard and K. A. Beauchemin, (Animal, Page 1 of 12 © The Animal Consortium 2018 doi:10.1017/S1751731118001301. *Adaptation of ruminant livestock production systems to climate changes*

118 http://piccc.org.au/Files/DArmstrongper cent20DBFC.pdf accessed January 2019.

119 Nidumolu U, Crimp S, Gobbett D, Laing A, Howden M and Little S 2010. Heat stress in dairy cattle in northern Victoria: responses to a changing climate. CSIRO Climate Adaptation Flagship Working Paper No 10. https://research.csiro.au/climate/wp-content/uploads/sites/54/2016/03/10_CAF_WorkingPaper10_pdf.pdf

120 Boult, C, Valle, H, Zhao, S & Jackson, T 2018, Productivity in Australia's broadacre and dairy industries, ABARES report, Canberra, September

121 ABARES Agricultural Commodities, Australia, 2016-17 https://www.abs.gov.au/ausstats/abs@.nsf/mf/7121.0

include Indonesia, Japan, South Korea, Malaysia, Vietnam and Sudan. Wheat grown for domestic consumption and feedstock is predominately produced on the east coast, even though early indications are that 2019 east coast crop will be insufficient to meet this demand, requiring 'imports' from Western Australia.

Most of the wheat crop in Australia is sown in autumn to early winter depending on the variety, region and rainfall patterns. Wheat is usually sown after a suitable rain event and the sowing 'window' can be across a four to six-week time period from April through to June. However, there is increasing adoption of dry sowing techniques. Wheat varieties differ in the time they take from sowing to flowering. Late-sown (quicker maturing) varieties take fewer days to flower than early-sown (late maturing) varieties. Early-sown varieties flower in late winter when there is the risk that frosts can cause damage to the florets, causing sterility, leading to a reduced yield and grain quality (protein content). Late-sown varieties may not reach their yield potential because late flowering and grain filling can occur under hot, dry and stressful conditions.

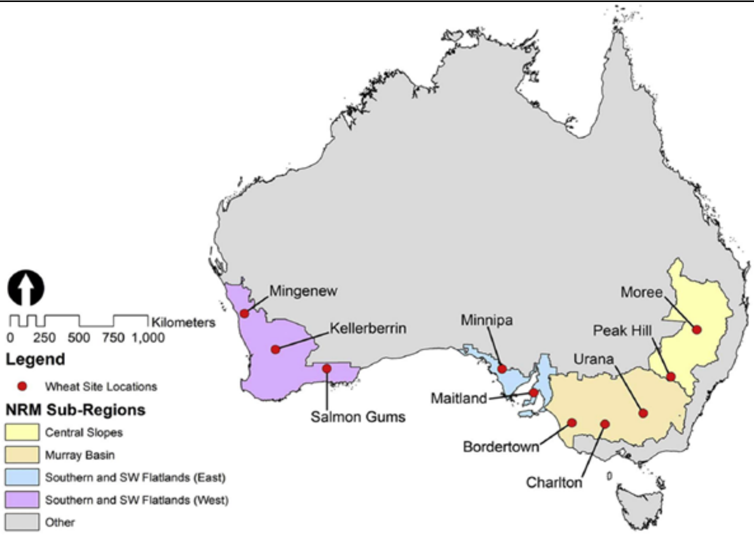
Sowing time is a compromise between having the crop flowering soon after the last heavy frost, but early enough to allow adequate grain fill before the onset of moisture stress and heat in spring. Yield drops 4–7 per cent with each week after the optimum sowing time for a specific variety. Wheat grows on a wide range of soils but has higher yields on well drained soils than clay based. Wheat germination requires temperatures ideally between 12°C and 25°C. However, germination will still occur between 4°C and 37°C.

Global wheat production increased at an annual rate of 0.9 per cent from 1961 to 2008.

4.5.1 Climate change impacts on wheat productivity

The projected change in wheat yields across the major wheat growing regions in southern and eastern Australia has recently been modelled for RCP 4.5 and RCP 8.5 by Taylor et al.[122] The year 2090 was used for the analysis, because the climate signal is considered strongest under both RCPs. The baseline used was from 1980 to 2010, that is 31 years with 1995 as the centred year. This comprehensive study applied the Agricultural Production Systems siMulator (APSIM) and used representative climate futures (RCFs) that represented 'most-likely', 'best' and 'worst' cases for two RCP pathways at 10 sites across the NRM regions of the Southern and SW Flatlands West, the Southern and SW Flatlands East, the Murray Basin and the Central Slopes. The study sites used by Taylor et al. for modelling trends in wheat yields under the RCFs are shown in **Figure 4.7**.

FIGURE 4.7 STUDY SITES FOR WHEAT MODELLING TRENDS 2018



SOURCE: TAYLOR ET AL 2018

[122] Taylor, Chris & Cullen, Brendan & D'Occhio, Michael & Rickards, Lauren & Eckard, Richard, 2018. *Trends in wheat yields under representative climate futures: Implications for climate adaptation*; Agricultural Systems, Elsevier, vol. 164(C), pages 1-10

The RCF approach was developed by Whetton et al.[123] The RCF analysis resulted in eight Global Climate Models (GCMs) being selected for RCP4.5 and nine GCMs for RCP8.5. The RCF projected temperature and rainfall changes modelled for the four regions under RCP8.5 are shown in **Table 4.5**.

TABLE 4.5 PROJECTED TEMPERATURE AND RAINFALL CHANGES IN KEY WHEAT GROWING AREAS

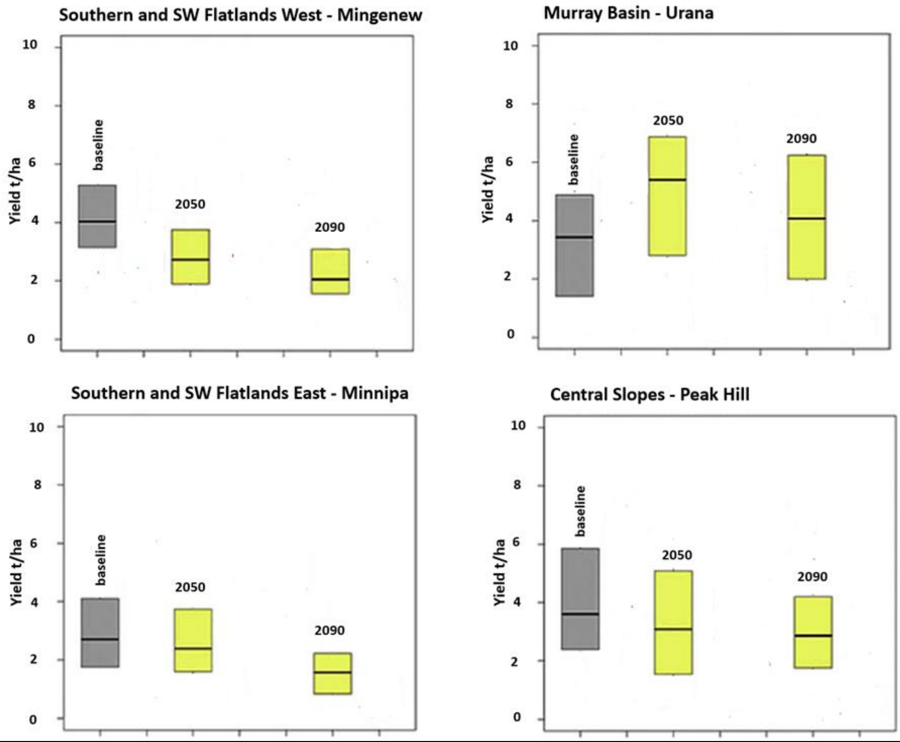
Location	Temperature increase mean Max °C		% Rainfall change	
	2050	2090	2050	2090
Southern and SW Flatlands West (WA)	1.9	3.6	-27	-30
Southern and SW Flatlands East (SA)	1.4	3.2	-11.3	-23.4
Murray Basin (NSW)	1.6	3.9	+13	+0.6
Central Slopes (NSW)	2.4	4.8	-11.6	-16.4

SOURCE: TAYLOR ET AL 2018

Modelling of median wheat yields in south west Western Australia projected declines between 26 per cent and 38 per cent, under a 'most-likely' case for RCP4.5 by 2090, and between 41 per cent and 49 per cent, under a 'most-likely' case for RCP8.5. Median wheat yields declined under RCP8.5 for the 'most-likely' case across the majority of wheat producing regions, with a range of one per cent to 49 per cent. Variability also changed from the baseline under all projected RCFs and across all regions.

Figure 4.8 shows the projected change in wheat yield for one station in each NRM region. In 2050 decreases can be observed for all regions except the Murray Basin where there is an increase. By 2090 there is a marked yield decrease across all regions.

FIGURE 4.8 PROJECTED CHANGES IN WHEAT YIELD UNDER THE RCP 8.5 SCENARIO



SOURCE: TAYLOR ET AL 2018

[123] Whetton, P., Hennessy, K., Clarke, J., McInnes, K., Kent, D., 2012. *Use of representative climate futures in impact and adaptation assessment*. Clim. Chang. 115 (3–4),433–442.

The climate projections point to both likely overall changes in yields and also greater variance in productivity between years. Taylor et al. suggest that incremental adaptations such as new crop variety maturity type, level of nitrogen fertiliser or sowing dates may be necessary to maintain productivity.[124] Broader research findings suggest that, in at least in some regions, the adaptations are likely to include more systemic approaches, such as a change in enterprise mix, or transformational adaptation, such as a shifting out of cropping, or exiting the region altogether.

A recently published study by Hochman et al. also provides an analysis of wheat yields.[125] Their modelling is the first to combine the use of a locally validated cropping simulation model, APSIM[126], that simultaneously accounts for soil moisture, rainfall, temperature and CO_2 concentrations, with high quality observational climate data (rather than projections) from 50 stations across the regions that cover 90 per cent of the winter cereals cropping areas. This is important as studies that focus only on temperature increase are likely to considerably underestimate climate trends in regions that are subject to negative precipitation trends.

The study area covered the wheat growing areas of the southwest of Western Australia, South Australia, New South Wales and Victoria. The southwest of Western Australia has been subject to a 17 per cent decline in average winter rainfall since 1970 and the southeast has experienced a 15 per cent decline in late autumn and early winter rainfall since the mid 1990's, with a 25 per cent reduction in average rainfall across April and May. The mean surface temperature has warmed since 1910 and especially since 1960.

The modelling found that climate effects have reduced the potential wheat yield in Australia by around 27 per cent since 1990, that is a 1.1 per cent decline per annum over a 26-year period. This decline was concurrent with decreasing rainfall of 28 per cent over 26 years and rising maximum daily temperatures of 1.05˚C over 26 years or 0.4˚C per decade. Most of this decline in yield (84 per cent) was attributed to reductions in rainfall, and 17 per cent to rising temperatures. Elevated CO_2 concentrations prevented a further 4 per cent loss. This climate effect was found to be offset by productivity improvements of 23 kg per hectare per year, so that actual yields remained essentially constant. This is a 50 per cent increase in productivity over the previous 26-year period.[127] This assessment is also likely to be an underestimate as the cropping system simulation does not fully capture extreme events including severe frosts and heat waves.

Whilst the analysis focused on wheat, the mechanisms that drive the decline in yield for wheat are quite similar for other temperate grain crops, pulses and oil seeds that grow in the same regions and have similar seasons to wheat. Hence the decline in yield for these crops could reasonably be assumed to be similar to that of wheat.

ABARES have also estimated the recent effect of climate change on wheat yields against the long-term running average and found significant areas experiencing a 10 to 20 per cent reduction (see **Figure 4.9**).

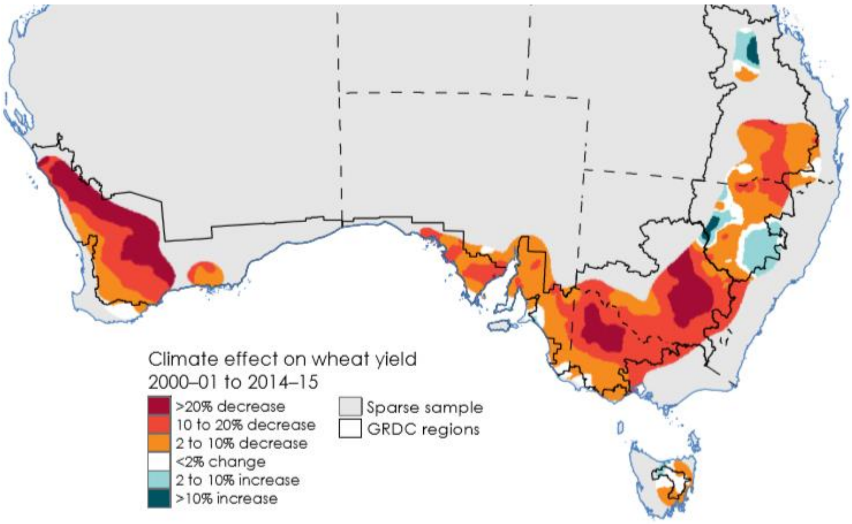
124 op cit

125 Zvi Hochman, David L Gorbett and Heidi Horan, *Climate trends account for stalled wheat yields in Australia since 1990*. Global Climate Change Biology (2017), 23, 2071-2081

126 Holzworth, Dean, N. I. Huth, J. Fainges, H. Brown, E. Zurcher, R. Cichota, S. Verrall, N. I. Herrmann, B. Zheng, and V. Snow. "APSIM Next Generation: Overcoming Challenges in Modernising a Farming Systems Model." Environmental Modelling & Software 103 (May 1, 2018): 43–51. https://doi.org/10.1016/j.envsoft.2018.02.002

127 Ibid

FIGURE 4.9 AVERAGE CLIMATE EFFECT ON WHEAT YIELDS



SOURCE: FARM PERFORMANCE AND CLIMATE 2017 ABARES

A 2016 study by Crimp et al. looked at the implications of frost season length and frost occurrence.[128] Their analysis showed that across southern Australia, despite a warming trend of 0.17°C per decade since 1960, frost season length has increased on average by 26 days across the whole southern portion of Australia, compared to the 1960-1990 long term mean. Some areas of southern Australia now experience their last frost an average of four weeks later than during the 1960's.

This study of the intersection of frost and wheat production risk covered 60 sites across the Australian wheat belt. The results highlighted how frost related production risk had increased by as much as 30 per cent across much of the Australian wheat belt over the last two decades in response to an increase in later frost events. Across 15 Victorian sites, sowing dates to achieve anthesis (flowering) during a period with only a 10 per cent chance of a 0°C night, shifted by 23 days for the short season variety, 20 days for the medium season variety and up to 36 days later for the long season variety. For example, in some areas of southern Australia, the mean last date of frost in the period 1960-1970 was 19 September, compared to 23 October for 2000-2014. For the period 1960-2013, simulated yields decreased by up to two per cent per annum in some regions, for both short and medium-growing season wheat maturity types, due to increased frost risk. This is clearly an important factor in assessing the implications of climate change as the most recent (2015) estimates of frost related loss were between $120 million and $700 million per annum.[129] This is equivalent to between 1.0 and 6.0 per cent of the total value of the wheat crop.

While now dated, the Garnaut Review provided a perspective on the possible scale of impacts of climate change on wheat.[130] Nonetheless, the Review remains useful in that it provides an Australia wide perspective for impacts on wheat against three modelled climate change scenarios. The Review assessed 10 study sites to understand the difference in magnitude of climate impacts on wheat yield between a no-mitigation scenario and 450 and 550 ppm global mitigation.

Table 4.6 shows that there are markedly different yield impacts between regions and scenarios. Under the no-mitigation case, and through adaptive management, much of Australia could experience an increase in wheat production by 2030. This would involve moving planting times in response to warming and selection of optimal production cultivars. Increases would also result from higher CO_2

[128] Steven Crimp, Bangyou Zheng, Nirav Khakassia, David Gobbett, Scott Chapman, Mark Howden and Neville Nicholls, *Recent changes in southern Australian frost occurrence implications for wheat production risk*, Crop and Pasture Science, 2016, 67, 801-811

[129] Steven Jeffery Crimp, Bangyou Zheng, Nirav Khimashia, David Lyon Gobbett, Scott ChapmanB, Mark HowdenA,E, and Neville Nicholls, *Recent changes in southern Australian frost occurrence: implications for wheat production risk*, Crop & Pasture Science, 2016, 67, 801–811 http://dx.doi.org/10.1071/CP16056.

[130] Garnaut, Ross, *Garnaut Climate Change Review: Final Report* © Commonwealth of Australia 2008 (Chapter 6)

concentrations. However, over time, even with adaptive management, a number of regions would experience substantial declines in wheat yield.

In some sites in Western Australia the rainfall changes, with no mitigation, would improve yields as subsoil constraints to growth, for example salinity, respond to declines in rainfall. This beneficial impact would only be associated with modest rainfall declines, that is less than 30 per cent of the long-term annual mean. Yields would be affected negatively with larger declines. Decline in yield would be reduced substantially with global mitigation by 2100. The hot, dry extreme case would have devastating consequences, leading to complete abandonment of production for most regions.

TABLE 4.6 CUMULATIVE YIELD CHANGE (%) FROM 1990 FOR AUSTRALIAN WHEAT UNDER FOUR CLIMATE SCENARIOS

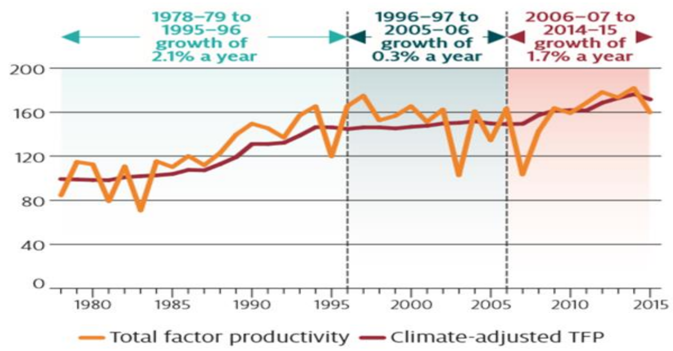
	No-mitigation case		Global mitigation with CO_2-e stabilisation at 550ppm by 2100		Global mitigation with CO_2-e stabilisation at 450ppm by 2100		Hot, dry extreme case (the 'bad-end story')	
	Cumulative yield change (%)							
	2030	2100	2030	2100	2030	2100	2030	2100
Dalby, QLD	8.2	-18.5	4.8	-1.0	1.6	-3.7	-6.6	-100.0
Emerald, QLD	7.2	-10.1	4.4	0.0	1.8	-2.5	-7.6	-100.0
Coolamon, NSW	11.6	1.9	9.9	12.3	8.2	7.4	1.2	-100.0
Dubbo, NSW	8.1	-5.9	6.1	6.7	4.0	2.3	-2.4	-100.0
Geraldton, WA	12.5	22.4	9.7	5.6	6.9	2.6	9.5	-16.9
Birchip, VIC	14.8	-24.1	10.7	1.5	6.8	-0.3	-0.7	-100.0
Katanning, WA	15.6	16.8	14.8	18.9	13.9	14.6	-15.7	-18.7
Minnipa, SA	0.8	-23.9	-3.4	-15.3	-7.4	-15.7	-13.8	-82.0
Moree, NSW	20.6	10.9	17.7	14.1	14.8	10.8	6.4	-79.2
Wongan Hills, WA	16.1	-21.8	13.0	5.5	10.0	4.4	5.5	-100.0

SOURCE: GARNAUT CLIMATE CHANGE REVIEW: FINAL REPORT © COMMONWEALTH OF AUSTRALIA 2008

4.5.2 Productivity Growth for wheat

When examining the impacts of climate change it is also important to look at total factor productivity, rather than merely production weight, or volume per unit area. Analysis by ABARES in 2017 examined the climate adjusted productivity growth for cropping farms over a 36-year period (see **Figure 4.10**). The study found that management and technology changes have, so far, largely offset the impacts of climate variability and climate change.

FIGURE 4.10 CLIMATE ADJUSTED PRODUCTIVITY GROWTH, CROPPING FARMS, 1978–79 TO 2014–15



SOURCE: FARM PERFORMANCE AND CLIMATE 2017 ABARES

Impact of pests and diseases on wheat productivity

Wheat diseases cause an estimated average annual loss of $913 million, or $76.64 per ha, to the Australian wheat industry. This loss is 19.5 per cent of the average annual value of the wheat crop over the past decade. Nationally, five diseases dominate these losses: yellow spot (an average loss of $17.8/ha), stripe rust ($10.6/ha), *Septoria nodorum* blotch ($9.1/ha), crown rot ($6.6/ha) and *Pratylenchus neglectus* ($6.1/ha).[131]

Invertebrate wheat pests have the potential to cause serious losses and, even with control, five pests cost the wheat industry more than $100 million annually. The potential losses that could be caused have been estimated by the Grains Research and Development Corporation (RDC) for the redlegged earth mite ($25 million), blue earth mite ($22.5 million), locusts ($19.7 million) and lucerne flea ($18.6 million).[132] The average total cost of treatment for invertebrate pests in wheat nationally is $77.9 million or $6 per ha grown.

The impact of climate change is not likely to be uniform across all wheat plant pathogens, hosts and locations. Climate change could alter stages and rates of development of the pathogen, modify host resistance, and result in changes in the physiology of host–pathogen interactions.[133] An increase in summer rainfall may enable host plants to survive over summer, allowing pathogens, such as rust, to survive until crops are established in autumn.

Fungal diseases grow best in warm and humid conditions as most fungal spores germinate when leaves are moist. Some spores, such as those of *Septoria* diseases, require rain splash to spread to new leaves and some, such as those of powdery mildew, require only high humidity for infection. Dry summers are important to break the disease cycle of rust diseases, such as stripe rust as these rely on living host plants and do not have a resting stage. Unusually wet summer conditions can greatly increase risk of wheat rusts. Increasing summer rainfall may also increase the severity and incidence of soilborne diseases. Root diseases can often become more evident and induce greater effects on production under drier than normal crop finishing conditions.[134]

Climate change may also alter the stages and rates of development of a wide range of insect pests, and so alter the timing and severity of pest outbreaks.[135] Many pests are restricted geographically and seasonally by climate suitability, so climate change may lengthen the season when certain pests are active and expand their geographical range. It may also open opportunities for greater weed infestations in crops.

4.5.3 Conclusions: wheat

The R&I work being done by Rural Research and Development Corporations (Rural RDCs) and other researchers has, to date, managed to largely offset yield losses due to climate change. However, initial discussions with both researchers and policy makers suggest that there is an expectation that in a scenario where R&I continues in a business-as-usual manner, it is increasingly likely that future productivity gains will fail to keep pace with the reductions in yield caused by climate change.

For the purposes of the analysis it is assumed that the gap will be around 0.1 per cent in 2020 and that it will increase by 0.1 per cent a year out to 2030, after which it will remain constant. Beyond 2030 the picture is less clear. While the climate change signals will strengthen, placing greater stress on productivity, this may well be offset by new research and the implementation of adaptation measures. Given this lack of clarity it has been assumed that the reduction in productivity remains constant. There is clearly some uncertainty around assumptions such as these. Based on the information from the research assessed, this is considered an appropriate, but conservative, assumption.

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131 Grains Research and Development Corporation 2009 The Current and Potential Costs from diseases of Wheat in Australia. https://grdc.com.au/__data/assets/pdf_file/0026/203957/disease-loss-wheat.pdf.pdf

132 GRDC (2013); *The Current and Potential Costs of Invertebrate Pests in Australia*. GRDC Project Code: AEP00001. https://grdc.com.au/__data/assets/pdf_file/0026/159281/grdcreportcurrentpotentialcostsinvertebratepests-feb2013pdf.pdf.pdf)

133 Garrett KA, Dendy SP, Frank EE, Rouse MN and Travers SE (2006) *Climate change effects on plant disease: Genomes to Ecosystems*. Annual Review Phytopathology 44: 489–509

134 Anderson, WK and Garlinge JR (2000) *The Wheat book: principles and practice*. Western Australian Agriculture Authority, Perth Western Australia

135 ibid

4.6 Cotton

The area of cotton planted in Australia increased by 2.5 times between 2014-15 and 2017-18. As shown in **Table 4.7**, the total gross value for both lint and seed in 2016-17 was $1.68 billion. In 2015-16, the area of cotton grown was 280,442 ha, with around 75 per cent of the area being irrigated, with 1,432,093 megalitres (ML) of water applied.[136] There are around 1,200 cotton farms, with two thirds in New South Wales and one third in Queensland (see **Figure 4.11**). The gross value of the cotton crop in New South Wales is just over $1 billion (lint only). Australia produces around 3 per cent of the world's cotton and is the third largest exporter, behind the USA and India.

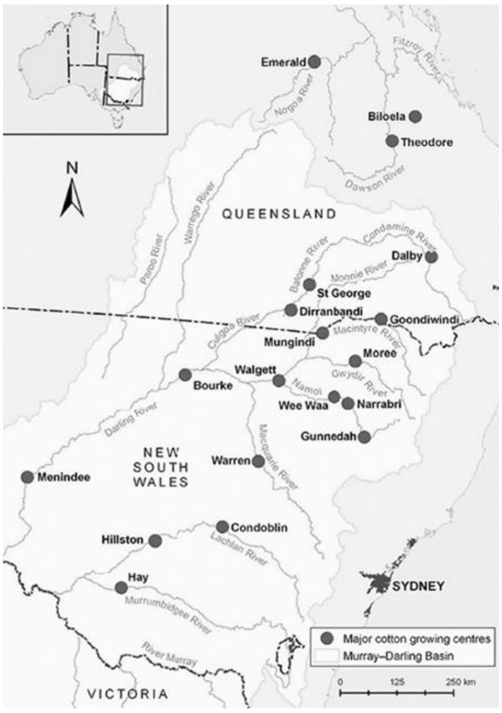
TABLE 4.7 COTTON PRODUCTION IN 2016-17

Jurisdiction	Area harvested*	Gross value	Production	Yield
	ha	$ million	t	t/ha
NSW	315,489	$1,059	490,772	1.56
Qld	203,100	$622	283,717	1.40
Australia	518,589	$1,681	774,489	1.49

Note: *irrigated and non-irrigated

SOURCE: AUSTRALIA BUREAU OF STATISTICS

FIGURE 4.11 MAJOR COTTON AREAS IN NEW SOUTH WALES AND QUEENSLAND



SOURCE: CLIMATIC CHANGE DOI 10.1007/S10584-014-1305-Y. QUANTIFYING THE RESPONSE OF COTTON PRODUCTION IN EASTERN AUSTRALIA TO CLIMATE CHANGE ALLYSON WILLIAMS & NEIL WHITE & SHAHBAZ MUSHTAQ & GEOFF COCKFIELD & BRENDAN POWER & LOUIS KOUADIO. 2014. (TAKEN FROM NATIONAL WATER COMMISSION 2011)

The area planted to cotton is forecast to fall by 44 per cent in 2018–19, to 280,000 hectares – that is the same level as in 2015-16. This is because below average rainfall in 2018 resulted in a significant fall in water levels in irrigation dams serving cotton growing regions and in low soil moisture levels.

[136] ABS 2015-16 commodities information summary available at file:///H:/Di'sper cent20Data/work/ACILper cent20Allen/AgCCper cent20project/modelling/ABS-per cent202015-16per cent20censusper cent20commodityper cent20summaryper cent20informationper cent20sheets.pdf

Cotton production is forecast to fall by 42 per cent to around 581,000 tonnes of cotton lint and 822,000 tonnes of cottonseed.[137]

Cotton is mostly grown in the 400-800 mm summer rainfall zone in Queensland and New South Wales. Several studies have identified that, in general, the region is likely to have reduced water availability in the future due to likely decreases in rainfall, higher temperatures and net evaporation, and decreased inflows. The reduction in water availability is the combined result of climate change, government buybacks of environmental water under the Murray-Darling Basin Plan and water trading to non-agricultural purposes.

Compared with many other field crops, identifying the sensitivity of particular aspects of cotton production to different climate variables is relatively complex. This is because of cotton's indeterminate growth habit - vegetative and reproductive growth can occur simultaneously according to environmental factors. The key influences are CO_2 fertilisation effects, water availability, in the form of both rainfall and evaporative demand, and temperature.

Recent modelling by CSIRO has used APSIM to evaluate the effect of future climate change scenarios on cotton yield in southern Queensland and northern New South Wales.[138] Previous studies have identified that optimum growth and yields occur when mean temperatures are between 26 and 28°C,[139] but yields start decreasing dramatically when daily maximums exceed 32°C.[140] CSIRO's analysis identified an increase in minimum and maximum temperatures by 2050 (with maximum temperatures increasing more than the minimums). The occurrence of more days with temperatures over 40°C will have a negative impact on yield through a range of impacts, including decreasing photosynthesis, increasing respiration, and direct damage to plant tissue. Offsetting this is a decrease in the number of days with temperatures less than 11°C, the temperature at which the incidence of growth-limiting 'cold shock' occurs.

The analysis of future climate scenarios suggests a less favourable cotton growing environment, with higher temperatures and generally less annual rainfall, by 2050. The modelling suggests that, in addition to a large decrease in median rainfall (20 per cent), the risks of not receiving the required rainfall of 300 mm in the key growing season are also greater. There is a 15 per cent chance of not receiving this amount in 2050 compared with a 3 per cent chance over the past 100 years.

The simulations of cotton production showed that changes in the influential meteorological parameters caused by climate change would lead to decreased future cotton yields without the effect of CO_2 fertilisation. By 2050, the yields would decrease by 17 per cent. Including the effects of CO_2 fertilisation ameliorates the effect of decreased water availability, with yields increasing by 5.9 per cent by 2030, but then decreasing by 3.6 per cent in 2050. Importantly, irrigation volumes would need to increase by almost 50 per cent to maintain adequate soil moisture levels. In addition, the study advises that the physiological response of plants to climate change needs to be better understood to avoid making inaccurate projections of yield, and potentially constraining investment or increasing risk.

In general, cotton production enterprises are relatively adaptable in years of water limitations as they already practise a high degree of water efficiency. However, a combination of increased incidence of drought and reduced stream flows is likely to impact on production going forward. These implications will be explored further in Stream 2.

137 http://www.agriculture.gov.au/abares/research-topics/agricultural-commodities/australian-crop-report/overview accessed January 2019.

138 Allyson Williams & Neil White & Shahbaz Mushtaq &Geoff Cockfield & Brendan Power & Louis Kouadio, Climatic Change DOI 10.1007/s10584-014-1305-y, *Quantifying the response of cotton production in eastern Australia to climate change,* 2014

139 Reddy KR, Hodges HF, Kimball BA (2000) Crop ecosystem responses to global climate change: cotton. In: Reddy KR, Hodges HF (eds) Climate change and global crop productivity. CAB International, Wallingford,) pp 162–187

140 Schlenker W, Roberts MJ (2009) Nonlinear temperature effects indicate severe damages to US crop yields under climate change. Proc Natl Acad Sci 106(37):15594–15598

4.6.1 Conclusions: cotton

Yields are projected to increase by almost 6 per cent in 2030 (due to the effects of CO_2 fertilisation offsetting what would otherwise be a decline) before declining by 3.6 per cent by 2050.

However, the projection that the risk of not receiving the required rainfall of 300 mm in the key growing season will be five times greater by 2050 due to the impacts of climate change, coupled with the finding that the amount of water needed for irrigation is projected to increase by around 50 per cent, suggest that access to and affordability of water is likely to be a major challenge, particularly given the scope for cotton farmers to further improve their water efficiency may be limited.

For the purposes of the analysis we have assumed that cotton yield in 2030 will be the same as it is now. While projected yield is expected to increase over this time frame due to CO_2 fertilisation effects, this is likely to be offset by the projected increased incidence of drought and reduced stream flows.

Based on the information from the research assessed, this is considered an appropriate, but conservative, assumption.

4.7 Sugar cane

Australia is the largest raw sugar supplier in the world, with 80 per cent of production being exported. Sugar cane production in Australia had a gross value of $1.6 billion in 2016-17 (see **TABLE 4.8**). In 2017, AgriFutures Australia estimated there were around 4,000 cane farming enterprises in Australia, suppling 24 mills that were run by seven milling companies. The major product in Australia is raw crystal sugar; this is sold to refineries both domestically and internationally.[141]

TABLE 4.8 SUGAR CANE PRODUCTION IN 2016-17

Area harvested*	Gross value	Production	Yield
ha	$ million	t	t/ha
402,435	$1,624	36,561,497	90.9

Note: *area for crushing only

SOURCE: AUSTALIAN BUREAU OF STATISTICS

Sugar cane is grown in pockets along a 2,100 km zone in eastern Australia, mostly within 50 km of the coastline, with 94 per cent of production occurring in Queensland (see **Figure 4.12**). The large spatial coverage of the sector means that the sugar industry is growing cane in a range of climate zones which will all experience different impacts of climate change. Sugar production is sensitive to many aspects of climate. However, the primary climate drivers are water availability, solar radiation, and temperature, specifically the minimum temperature at which growth starts and the maximum temperature when growth stops.

[141] https://www.agrifutures.com.au/farm-diversity/sugarcane/ accessed 21 July 2019

FIGURE 4.12 AUSTRALIA'S SUGAR CANE AREAS

SOURCE: WWW.CANEGROWERS.COM.AU ACCESSED JANUARY 2019

Sugar cane is a tall tropical perennial grass and a C4 plant[142], which is efficient at photosynthesis, allowing the plant to store sugar (sucrose) in its stems. Sugar cane in Australia is grown as a dryland or irrigated crop, requiring approximately 1,500 mm of water per season (as rain and/or irrigation) Irrigation requirements are around 5ML/ha.[143] The optimum growing temperature for sugar cane is between 32°C and 38°C. Temperatures above 38°C reduce the rate of photosynthesis and increase respiration, leading to less accumulation of sugars.

Sugarcane is usually grown on a four-year cycle. In the first year, sugar cane is planted and harvested by cutting the cane off at ground level. From this stubble, a 'ratoon' crop emerges, which grows from the remaining buds and once mature, is similarly harvested. Typically, three 'ratoon' crops will be grown from one planting. After the sugar cane crop-cycle has completed, growers may choose to fallow the paddock, or plant a break or complementary crop, to improve soils and manage weeds, pests and disease. The sugar cane harvest season occurs from June to December. Many factors influence harvest timing including farm site, climatic conditions, timing of planting and the difference in time to maturity between plant and 'ratoon' crops.

There are regional variations in the significance of climate drivers on production. For example, in the most northern growing region in far north Queensland, sugar production is constrained by low radiation when it's cloudy, and when excessive rainfall causes waterlogged paddocks. In the central

142 C4 plants are those which photosynthesise following the mechanism called C4 Photosynthesis
143 http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1318.3Feature%20Article14Sep%202009

and southern regions, excessive rainfall and waterlogging is a lower risk to production, compared with risks arising from limited irrigation water supply and/or high temperatures.

The impact of increased atmospheric CO_2 and climate change will also create different risks in the various growing regions. All regions will see an increase in growth due to higher atmospheric CO_2 concentrations. Regions are projected to experience an increase in temperature, rainfall intensity, sea level, and tropical cyclone intensity.

Table 4.9 summarises a recent report by Williams examining the impacts of climate change on sugar production.[144] Whilst the change in summer rainfall under all climate change scenarios cannot be projected with confidence, winter rainfall is likely to decrease and, in the Northern Australian zone, summer rainfall may vary by between -20 per cent and +10 per cent.

In general, if rainfall decreases in the northern growing region, yields may increase in response to increased solar radiation. In southern growing regions, a reduction in rainfall would reduce yields and increase demands for irrigation water. For the northern region production systems, the potential impacts of climate change include increased crop damage from wind and tropical cyclones; poorer crop establishment if spring rain decreases; and increased waterlogging if growing season rainfall increases. There may also be secondary impacts such as increased nutrient and sediment runoff from high intensity rainfall events.

TABLE 4.9 KEY IMPACTS ON SUGAR INDUSTRIES IN THE COASTAL REGIONS OF AUSTRALIA

Industry	Region	Regional impacts
Sugarcane	Northern areas	Sea level rise will exacerbate tidal intrusion of flood plains. It may also impact salinity issues. An increase in extreme rain events will increase already high erosion risks causing sediment loading of the Great Barrier Reef, and increased pest and disease risk. The increased risk of extreme winds and intense tropical cyclonic activity is likely to increase the risk of crop damage.
	Southern areas	A decrease in rainfall may increase yields due to increased solar radiation. A decrease in rainfall would increase pressure on water availability for irrigation. Increased temperatures will increase the length of the growing season. Increased land use pressure from horticultural crops.

SOURCE: WILLIAMS 2016

An earlier analysis reported by the Sugar RDC used the crop growth model, APSIM to quantify the impacts of a change in temperature and rainfall on cane fresh weight.[145] The best potential outcome for 2030, assuming no implementation of adaptation response strategies, was projected to be an increase in yield of around seven per cent, whilst the worst, a reduction of around four per cent. By 2070, it projected any potential increases in yield would be around eight per cent, whilst potential reductions could be up to 47 per cent.

A more recent crop model and climate projections analysis was undertaken by Everingham et al. in 2015.[146] This analysis assessed climate change impacts on sugarcane productivity for three major sugar cane-growing regions in Australia - Burdekin, Mackay and New South Wales. The simulations under a high (slightly below the current emissions trajectory) and low emissions scenario projected increases in yields in the medium term (2050). In particular, higher yields in the New South Wales regions were projected to occur under the high emissions scenario.

144 Williams, A., 2016: *Climate change impacts on coastal agriculture*. CoastAdapt Impact Sheet 11, National Climate Change Adaptation Research Facility, Gold Coast

145 Global change: informing the Australian Sugar Industry on potential impacts, possible strategies for adaptation and best-bet directions for future R&D, May 2007 SRDC Final Report Project: CSE019.

146 Yvette Everingham, Geoff Inman-Bamber, Justin Sexton, Chris Stokes, A Dual Ensemble Agroclimate Modelling Procedure to Assess Climate Change Impacts on Sugarcane Production in Australia. Agricultural Sciences, 2015, 6, 870-888

Given the broad spatial range of sugar cane and the wide range of physiological effects of climate change on the plant and farm management practices, the assessment of impacts is complex and the quantum and range of results vary. This topic was examined in a 2018 review by Linnenlueke et al.[147] The review draws together research on how climate change impacts sugar cane production. The findings are very diverse as the various research studies use different assumptions and approaches making it difficult for stakeholders to interpret and synthesise the results.

In particular, the authors drew attention to the concerns of researchers that current studies might significantly overestimate the potential benefits of climate change (and underestimate adaptation needs) by not taking full account of the range of climate change threats. In the past, sugar cane yields have been significantly impacted by extreme weather events such as drought and tropical cyclones. Changes in the frequency and/or intensity of weather extremes could exacerbate this. Given flooding can preclude harvesting, coastal inundation, due to sea level rise and extreme weather events, poses a significant threat (these implications will be explored further in Stream 2).

In terms of extreme weather, it is estimated that Cyclone Larry, which made landfall in Queensland in 2006, affected over 60 per cent of all sugar growers in its path, and led to a loss of A$111 million in raw sugar output in the 12 months following the initial impact. The cyclone led to the decision not to open the Mourilyan sugar mill for the 2006 crushing season and the mill has subsequently remained closed.[148] The same region was also affected by Cyclone Yasi (2011) and Cyclone Debbie (2017).

4.7.1 Conclusions: sugar cane

The range of outcome for yield is currently quite broad and there is considerable uncertainty surrounding existing projections. There is the potential for productivity to improve in the south (i.e. northern New South Wales) but decrease in northern Queensland.

For the purposes of the analysis it is assumed that sugar cane yield in 2030 will be the same as it is now. Based on the information from the research assessed, this is considered an appropriate, but conservative, assumption.

4.8 Horticulture

Horticulture embraces a wide range of agricultural produce covering fruit and vegetables and tree crops which are grown in every state and territory. The impacts of climate change will thus be highly variable according to the produce and location. Nationally horticulture (fruit, vegetables and nuts) comprise $8.1 billion, or 13.3 per cent of the total value of production (with a relatively even split between fruit and vegetables).[149] In Tasmania in 2016–17, potatoes were the third most important agricultural commodity, with a value of $111 million (after milk ($326 million), followed by cattle and calves ($295 million)).

The Australian wine sector has 65 wine growing regions, 6,251 grape growers, 136,113 ha of vineyards, 2,468 vineyards and produced 1.98 million tonnes of wine grape crush in 2016-17.[150] Total wine sales for Australia were valued at $6.3 billion in 2017-18, with 63 per cent of production exported with a value of was $2.8 billion, and 37 per cent sold domestically with a value of $3.5 billion.

In terms of the relative importance of horticulture to a jurisdiction, the Northern Territory and Tasmania stand out. Potatoes are the largest vegetable commodity grown (by volume) in Australia. For Tasmania, in particular, potatoes are a significant contributor to the State with a gross value of production of $111 million, which is greater than the contribution from sheep and lambs.[151] For the Northern Territory, whilst cattle dominates the agricultural sector, the next most significant products are mangoes and melons, which, in 2016-17, contributed $40 million and $36 million, respectively.[152]

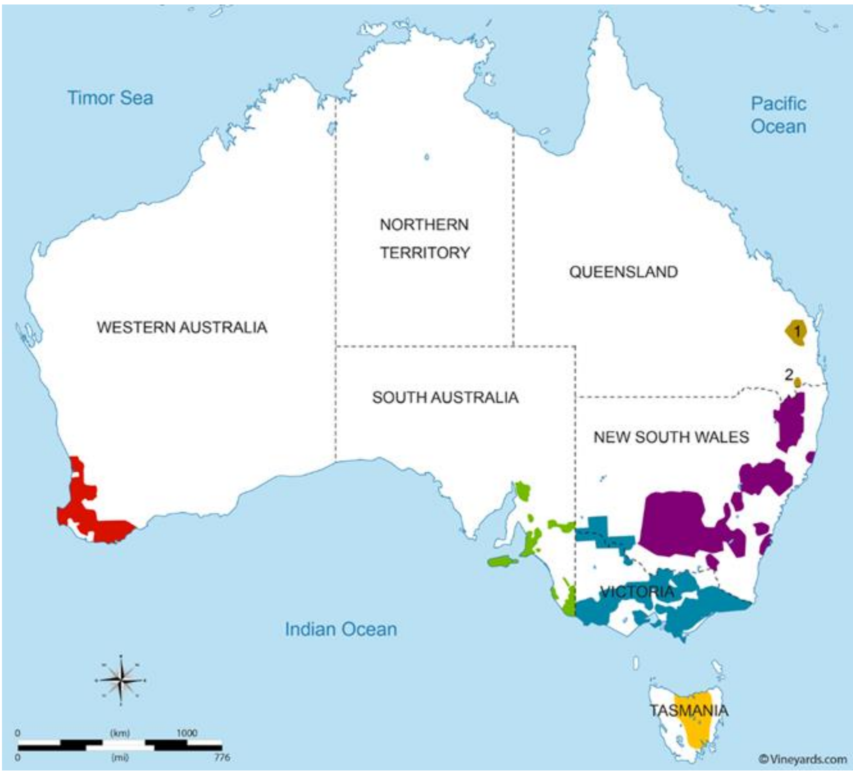
[147] Martina K. Linnenluecke, Natalie Nucifora and Nicole Thompson, *Implications of climate change for the sugarcane industry*, Wiley Interdisciplinary Reviews: Climate Change. 9. e498. 10.1002/wcc.498
[148] ibid
[149] Australian Bureau of Statistics, 2016-17, Value of Agricultural Commodities Produced
[150] Wine Australia 2018, https://www.wineaustralia.com/getmedia/ba012fa8-3e20-44e9-a783-e8d137a2c74d/MI_SectorReport_Jan2018_F.pdf
[151] ABARES - http://www.agriculture.gov.au/abares/research-topics/aboutmyregion/tas#farm-financial-performance
[152] Australian Bureau of Statistics, 2016-17, Value of Agricultural Commodities Produced

According to the Department of Primary Industry and Resources in the Northern Territory, these values are closer $88.3 million for mangoes, and $50.3 million for melons.[153] These are important fruit crops to that jurisdiction and are used as one example to explore some of the impacts of climate change on the horticulture sector.

4.8.1 Viticulture

The key wine growing regions are shown at **Figure 4.13** and the 2017 harvest figures (wine grape crush) in **Table 4.10**.

FIGURE 4.13 AUSTRALIAN WINE GROWING REGIONS



SOURCE: HTTPS://VINEYARDS.COM/WINE-MAP/AUSTRALIA

TABLE 4.10 2017 WINE GRAPE CRUSH

Region	Percentage	Tonnes
South Australia	51	984,000
Murray Darling Basin-Swan Hill	21	410,000
New South Wales	21	398,000
Victoria	5	87,000
Western Australia	2	40,000
Tasmania	1	11,000
Australia	100	193,000,000

SOURCE: WINE AUSTRALIA (HTTPS://WWW.WINEAUSTRALIA.COM/GETMEDIA/BA012FA8-3E20-44E9-A783-E8D137A2C74D/MI_SECTORREPORT_JAN2018_F

153 Department of Primary industry and Resources. Overview and Outlook 2017 https://dpir.nt.gov.au/__data/assets/pdf_file/0008/505637/Outlook-Overview-2017.pdf

The impact of a changing climate on viticulture can be assessed both by looking at past trends and modelled projections against possible future scenarios as shown by several studies. The timing of the grapevine phenology is temperature driven.[154] Webb et al. undertook an extensive assessment of observed trends in wine grape maturity dates in relation to temperature from 44 vineyard blocks located in geographically diverse wine grape growing regions, representing a range of varieties.[155] A statistically significant trend to earlier maturity of wine grapes was observed in 43 of the 44 vineyard blocks. There was a more rapid advance the more recent 1993-2009 period, where the average advance was 1.7 days, whereas for the period 1985–2009 the rate of advance was 0.8 days on average.

A recent study Jarvis et al. provides an updated assessment of the trend to earlier maturity. [156] This study used vineyard records from 31 vineyard blocks in 13 Australian wine regions, in conjunction with gridded temperature data, to assess changes to maturity timing and mean growing season temperature. A trend towards earlier maturity and warmer growing season temperature was found for all vineyard blocks and all regions, supporting results found in Webb et al., with the magnitude of the trend varying by region and cultivar.

Changes to the timing of maturity can compress the harvest period, where the time between when the first and last cultivars reach maturity is shortened.[157] Warm temperatures can hasten the time between phenological phases, such as from budburst to flowering, resulting in maturity occurring earlier in the season. Generally, early-ripening cultivars, such as Chardonnay and Pinot Noir, reach maturity several weeks before later ripening cultivars, such as Cabernet Sauvignon. This can place pressure on vineyard and winery logistics, with the grapes needing to be harvested and processed over a shorter period. Jarvis et al. argued that should different cultivars all ripen around the same time, there may be insufficient resources to pick the fruit at the optimum time, leading to suboptimal grape composition.

Hayman and Thomas (2013) have undertaken modelling to assess the vulnerability to climate change across Australia's wine growing regions, looking at historic trends and projections to 2030 and 2050, for medium and high emissions scenarios and rainfall projections.158 The study assessed growing season temperature trends across 21 regions from the Barossa, Riverina, Yarra, Mornington Peninsula to the Tasmanian wine area. The study found, that compared to the 30-year period 1961 to 1990, for the period 2000 to 2013 between eight and 13 seasons were warmer than average and up to seven were warmer than the previous maximum.

The study then modelled the impact of a 1°C warmer future on the percentage of years with a growing season temperature cooler than the average; warmer than the average; and warmer than the maximum in the base period (see **Figure 4.14**). In terms of adaptation approaches, the study concluded the choice of varieties would be important, as would root stock in relation to drought tolerance.

The study showed that the percentage of years cooler than the base period ranged from 0 to 12 per cent across the 17 regions, with the lowest figure being for Robe on the Limestone Coast and the highest for Mornington Peninsula. For warmer than the average, the range was from 18 percent on the east coast of Tasmania to 69 percent in the Clare Valley and Limestone Coast. The percentage of years projected to be warmer than the maximum ranged from 12 per cent at Mornington Peninsula to 80 per cent on the east coast of Tasmania, with the Barossa Riverina-Griffith and McLaren Vale around 50 per cent.

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154 Pearce, I, Coombe, B, (2004); *Grapevine Phenology*. In: Dry, P.; Coombe, B.G. (eds) Viticulture Volume 1 – Resources. Winetitles; Adelaide, SA:150–166

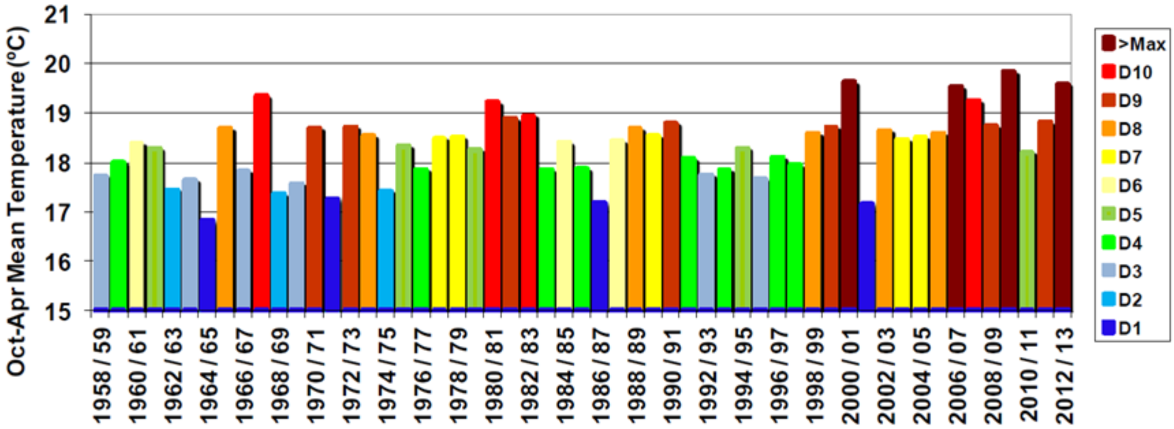
155 Webb, L, Whetton, P, and Barlow, E, (2011); *Observed trends in wine grape maturity in Australia*. Global Change Biology 17, 2707–2719

156 Jarvis, C, Darbyshire, R, Goodwin, I, Barlow, E, and Eckard, R, (2019); *Advancement of winegrape maturity continuing for winegrowing regions in Australia with variable evidence of compression of the harvest period* Australian Journal of Grape and Wine Research 25, 101–108, 2019. doi: 10.1111/ajgw.12373

157 Webb, L, Whetton, Barlow, E, (2007); *Climate change impacts on Australian viticulture*. Proceedings of the Thirteenth Australian Wine Industry Technical Conference

158 Hayman, P, & Thomas, D, (2013); *Assessment of vulnerability to climate change across Australia's wine regions*. Final Report to Grape and Wine Research and Development Corporation, GWRDC Project No SAR 1002. South Australian Research and Development Institute

FIGURE 4.14 MEAN GROWING SEASON TEMPERATURE (°C) 1958-59 TO 2012-13



Note: Bar colour shows 30-year decile for the period 1960 to 1989- cooler growing seasons - blue to green and warmer growing seasons - yellow to red. The brown bars growing seasons that were hotter than any during the 30-year period

SOURCE: HAYMAN AND THOMAS 2013

In relation to future impacts, a comprehensive assessment of the effect of projected temperature on the timing of grapevine phenology was also undertaken by Webb et al.159 The study modelled low, mid and high emissions scenarios for projections to 2030 and 2050 (with a baseline year of 2000) and analysed 35 wine growing regions using the OzClim database. The analysis showed that for all regions the season duration (i.e. the time from budburst to harvest) is compressed, and highlighted the dual impacts of climate change on the temperature of the ripening period (see Table 4.11). For example, in the Coonawarra wine region, grapes are projected to be harvested earlier in the year in 2030, relative to the current harvest date.

TABLE 4.11 CHANGES IN TIMING OF BUD BURST AND HARVESTING

Bub burst day	2030	2050
Coonawarra	4 to 8 days earlier	6 to 11 days earlier
Riverina	4 to 7 days earlier	5 to 12 days earlier
Margaret River	4 to 10 days later	6 to 26 days later

Harvest day	2030	2050
Coonawarra	15 to 23 days earlier	21 to 45 days earlier
Riverina	6 to 12 days earlier	7 to 14 days earlier
Margaret River	10 days earlier to 4 days later	0 to 14 days earlier

Note: Changes in timing (days) of budburst and harvest for Cabernet Sauvignon for two future periods

SOURCE: WEBB ET AL (2007)

Webb et al. also assessed the impact of changes in temperature on the future suitability of the regions for wine grape varieties. There are several dominant varieties of grapes grown in each region, as some states have more warm grape growing regions, and other states, mostly cooler regions, giving a preference of production of a particular variety within a temperature category (MJT - Mean January Temperature °C). This is shown in the **Table 4.12**.

159 op cit

TABLE 4.12 SHIFTS IN REGIONAL SUITABILITY

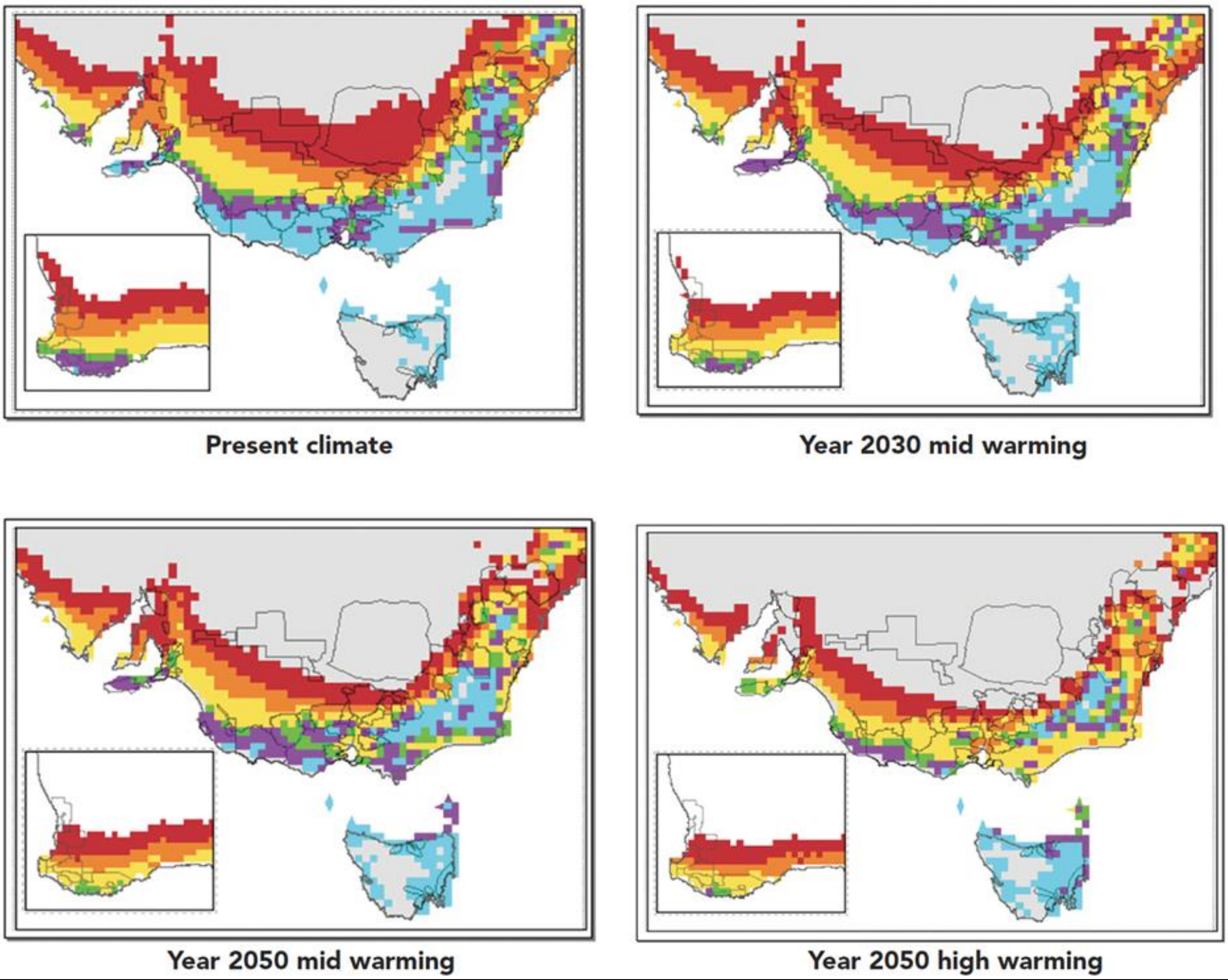
Group	Grape types	MJT	2007 Distribution	Shift in areas suitable by 2030	Shift in areas suitable by 2050
Group 1 (Blue)	Pinot Noir, Chardonnay, Sauvignon Blanc	15.8-19.1°C	Most southern part of the continent and northern Tasmania		Suitability increased to a greater degree in Tasmania. Mainland, suitability moves into the more elevated sites of the Gippsland region
Group 2 (Purple)	Cabernet Sauvignon, Merlot, Cabernet Franc	19.1-20.1°C	South Australia and the Coonawarra, and central Victoria Pyrenees and Bendigo	South Australia suitable and suitability increases in the mid part of the Victorian grape growing regions.	Hunter Valley, South Burnett, Swan Valley, Riverland and Riverina. Projected temperature not previously experienced in Australian wine growing regions.
Group 3 (Green)	Mixed varieties	20.2-20.6°C			
Group 4 (Yellow)	Shiraz, Semillon, Muscadelle	20.7-22°C			Most of the southern part of Victoria
Group 5 (Orange)	Malbec Traminer, Riesling, Verdelho	22.3-23.3°C			
Group 6 (Red)	Ruby Cabernet, Chenin Blanc, Colombard	23.4-24.8°C	Riverina Swan Valley and Victorian and NSW Murray Valley	Southern part of the Riverina and Victorian and NSW Murray Valley and South Burnett Qld	Hunter Valley, South Burnett, Swan Valley, Riverland and Riverina. Projected temperature not previously experienced in Australian wine growing regions.

SOURCE: WEBB ET AL (2007)

As indicated in the maps at Figure 4.15, under the projected temperature change scenarios, the potential shift of the variety suitability bands is towards more coastal areas of south-east Victoria, into the highlands of the Great Dividing Range, and more towards the south-east part of Tasmania. Suitability reduces in parts of south western Victoria and mid New South Wales by 2030 with greater shifts by 2050. By the year 2030 there may be a reduction of more than 10 per cent of land with temperatures suitable for grape growing. By 2050, the reduction may exceed 27 per cent (mid warming) or as high as 44 per cent (high warming).[160]

[160] The impact on grape production was investigated using a range of emission scenarios and climate models of differing sensitivity (IPCC 2000, 2001) – it pre-dates the development of the RCP scenarios

FIGURE 4.15 SUITABILITY FOR GROWING GRAPEVINES IN SOUTHERN AUSTRALIA



Note: The maps indicate the projected shifting of suitability zones by 2030 and 2050 with a mid-climate warming and a 2050 result from a high warming scenario. Colours indicate varieties suited to different climates from cool (blue) to warmer (red), see **Table 4.12** above -Group 1 Blue. Group 2 Purple, Group 3, Green, Group 4 Yellow, Group 5 Orange, Group 6 Red

SOURCE: WEBB ET AL (2007)

The potential impact of projected regional temperature increases on wine grape quality by 2030 and 2050 has also been assessed by Webb et al.[161] [162] **Figure 4.16** shows the range in projected regional cost to quality for Australian wine regions by 2030 and 2050. Overall, the potential impact on grape quality was estimated to be a decrease of seven to 23 per cent by 2030 and 12 to 57 per cent by 2050, assuming no adaptive strategies or CO_2 fertilisation effect.

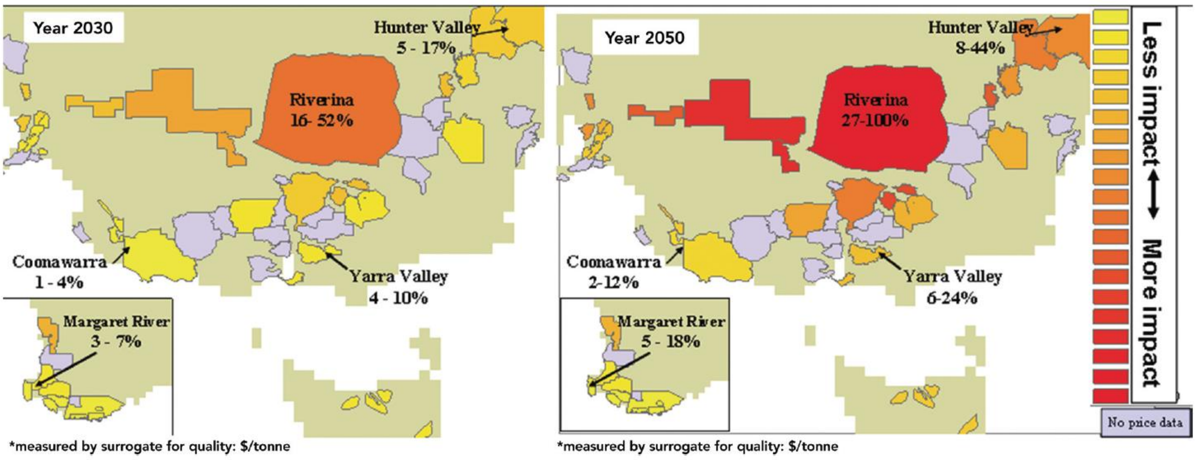
Impact models, based upon existing viticultural practices and wine grape market data from the annual Australian regional wine grape crush survey, were applied. The regional impacts of warming on wine grape quality were calculated by weighting the varietal impact by the proportion of each variety produced in a region. The impact is described as per cent impact to quality, or per cent cost to quality. For example, a 10 per cent impact means 10 per cent less suitable for winemaking, and, at the extreme, a 100 per cent impact would mean the wine grape would not be usable for the purpose of making wine.

161 Webb, L, Whetton, Barlow, E, (2007); Climate change impacts on Australian viticulture. Proceedings of the Thirteenth Australian Wine Industry Technical Conference

162 Webb L, Whetton P, Barlow E (2008a); Climate change and wine grape quality in Australia. Climate Research, 36, 99–11

The analyses found that the reduction to wine grape quality varied regionally, with greater quality reductions in the inland regions. For the year 2030, the study showed a median reduction in quality for the Riverina, Hunter Valley, Yarra Valley, Margaret River and Coonawarra wine regions of 16 per cent, five per cent, four per cent, three per cent and 1.2 per cent respectively under a low impact scenario.. This rose to 52 per cent, 17 per cent, 10 per cent, seven per cent, and four per cent, respectively under a high impact scenario. National impacts were obtained by summing the production-weighted cost to quality across each region.

FIGURE 4.16 PROJECTED REGIONAL COST TO WINE GRAPE QUALITY



Note: Projected regional cost to quality for Australian wine regions by 2030 and 2050. Lower number in each range is for low emissions scenario and top of range is high emissions scenario.
SOURCE: WEBB ET AL (2007)

Adaptation approaches for addressing the impact of projected warming on wine grape quality by Webb et al. (2007) include yield compensation strategies that increase wine grape yield using grapevine management techniques for a given region; shifting the sites of vineyards to maintain, as far as possible, the same climate as currently utilised; and variety substitution, especially in cooler climates where a positive impact of climate change for some varieties could be realised.

Conclusion: viticulture

Analysis of historic trends in growing season temperature indicate a warming across Australia's wine growing regions leading to earlier maturity and compression of harvesting. Projections indicate clear impacts on wine grape quality by 2030, which will become more pronounced by 2050. In the absence of adaptation, some areas would become unsuitable for current varieties and some areas unsuitable for wine grape growing. However, changes in varieties and shifting of growing areas, to the south and into higher country on the mainland, and to Tasmania, may ameliorate these effects.

4.8.2 Tasmanian example of potato production impacts

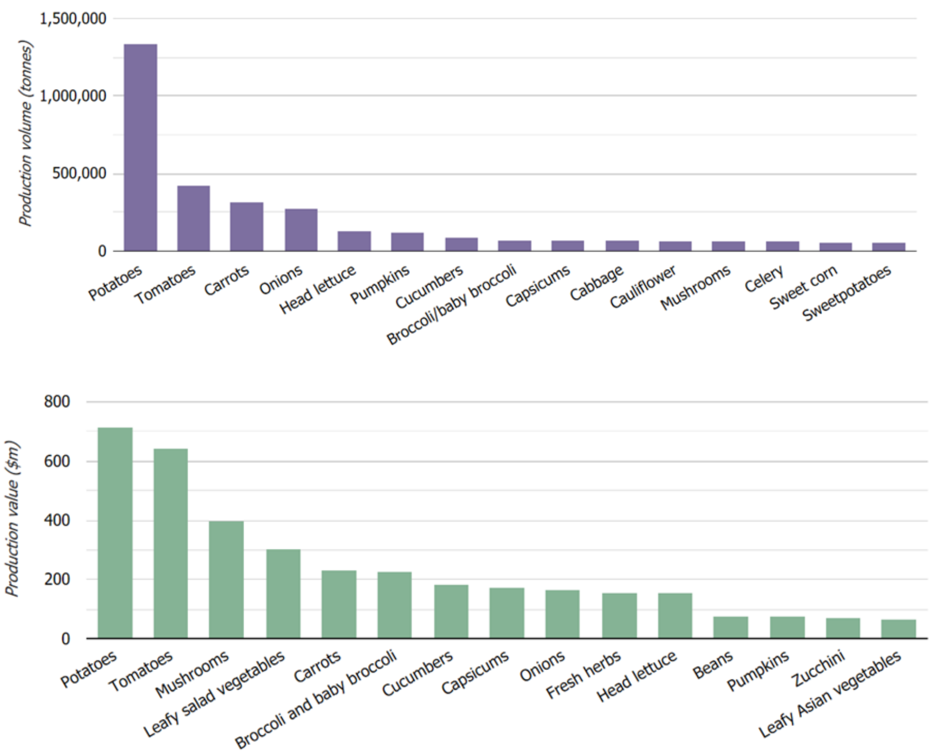
Potatoes are by far the biggest vegetable commodity grown in Australia by volume, with over 1.3 million tonnes of potatoes grown for human consumption and processing in 2016-17. The next-largest crops were tomatoes (426,000 tonnes), carrots (318,000 tonnes), onions (277,000 tonnes) and head lettuce (128,000 tonnes). Potatoes are also the most valuable crop grown in terms of value of production, at $717 million in 2016-17 (see **Figure 4.17**).[163]

The Tasmanian potato industry comprises of three sectors; the processing sector, fresh market sector and seed sector. The large majority (80 per cent) of production flows into the processing market, 10 per cent is supplied for the fresh market (to be sold in fresh form) and 10 per cent to seed. Fresh potatoes are not permitted entry into Tasmania due to potential pest and disease risks.

The main growing area for potatoes in Tasmania is the Cradle Coast Region (see Figure 4.18).

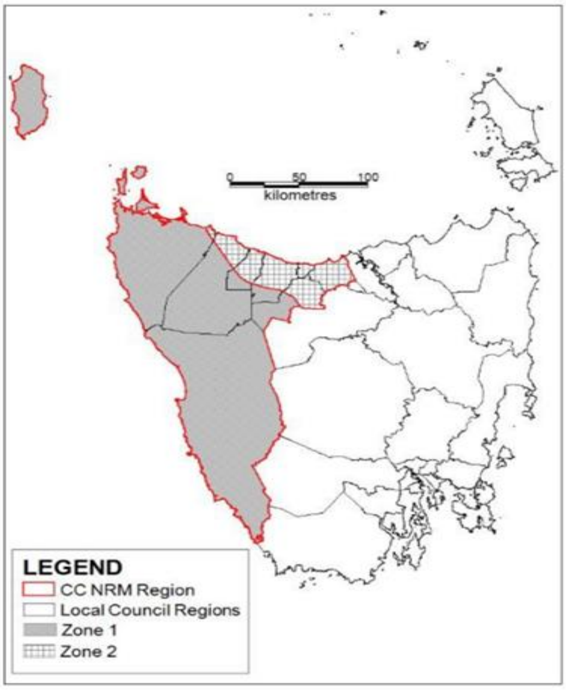
163 ABARES; available at https://ausveg.com.au/resources/economics-statistics/australian-vegetable-production-statistics/#majorcrops

FIGURE 4.17 TOP 15 VEGETABLES PRODUCED IN AUSTRALIA BY VOLUME AND VALUE



SOURCE: AUSTRALIAN HORTICULTURE STATISTICS HANDBOOK, 2016/17

FIGURE 4.18 CRADLE COAST POTATO GROWING REGION



SOURCE: CLIMATE CHANGE ADAPTATION-FACT SHEET POTATO PRODUCTION, 2014, CRADLE COAST NRM[164]

164 Climate change and agriculture in the North-West of Tasmania, Samantha Gadsby and Astrid Ketelaar, AK Consultants, 28 April 2014. Cradle Coast NRM; North West Tasmania - Climate Change Adaptation-FACT Sheet Potato Production, 2014 Cradle Coast NRM

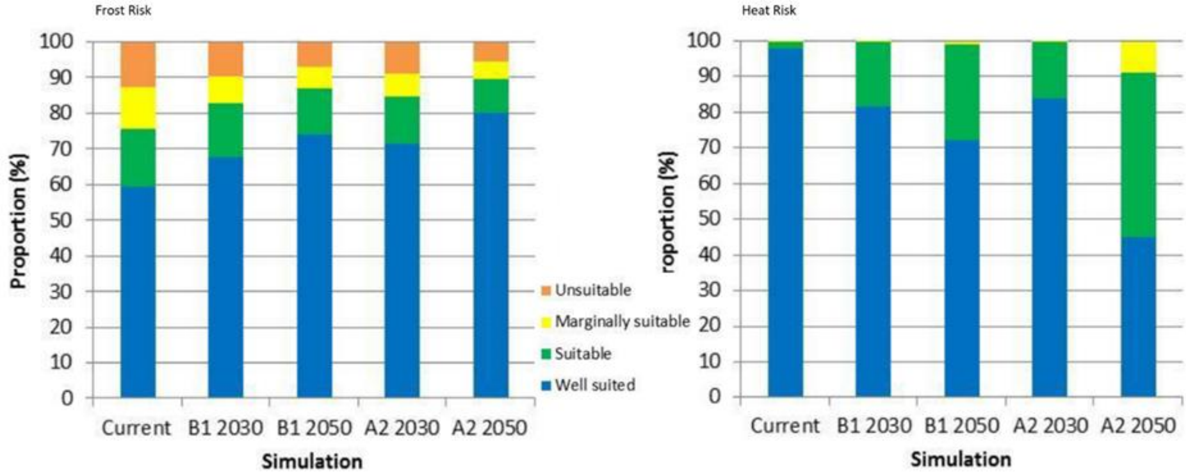
Potatoes grown for processing and seed require more than 130 and 90 frost free days, respectively. Potatoes also need more than 1125 growing degree days[165] (a measure of the heat to grow and ripen crops) and require overnight temperatures to drop below 20°C for at least four hours each night. [166]

The Climate Futures for Tasmania projections show that, under a high emissions scenario, the entire Cradle Coast NRM region is projected to have an increase in temperature of 2.6 to 3.3°C.[167] Rainfall changes vary across the potato growing region. Frost risk days are projected to decrease significantly across the entire region and the number of tropical nights (where the minimum temperature is greater than 20°C) is projected to increase by six nights per year by 2085 (Holz et al., 2010).[168]

These projections have recently been combined with the ability to model the suitability of crops for Tasmanian soil and climatic conditions – 'enterprise suitability modelling' (by the Department of Primary Industries, Parks, Water and Environment, Tasmania). The modelling is based on digital soil and climate mapping, validated by extensive field work. This project has mapped State-wide changes in enterprise suitability for five crops, including potatoes, for A2 (higher emissions scenario) and B1 (lower emissions scenario) simulations, and for the 2030 and 2050 timeframes.[169]

The findings show a marked increase of suitable land available for potato production, with most change to occur in 2050 under the A2 scenario. Unsuitable land is expected to decrease by at least six per cent (B1 scenario at 2030) to 10 per cent (A2 scenario at 2050). Over time, frost risk gradually reduces in severity and, with that, there is a notable increase in the availability of suitable land. However, the increase in the proportion of minimum temperature days above 20°C results in land areas gradually becoming less suitable. Overall, the decrease in frost severity is expected to outweigh the increase in prolonged warming in late spring/summer and result in more areas becoming suitable for potato growing under either emissions scenario. The outcomes of the research are shown in **Figure 4.19**.

FIGURE 4.19 CHANGES IN AVAILABILITY OF SUITABLE LAND FOR POTATO PRODUCTION



Note: Proportion (%) of land area change with respect to frost risk [risk of having a day where Tmin <0°C (1 November to 28 February) and heat risk [risk of having a day where Tmin >20°C (1 November to 28 February) - classified to their suitability categories: <20% = Well suited, 20-40%= Suitable; >40%= Marginally suitable

SOURCE: WEBB 2015

165 a measure of the heat required to grow and ripen crops. Crop 'growing degree days' are accumulated over the potato growing season beginning May 1 using the average daily air temperature.

166 Cotching B., 2011, *Potato growing in Tasmania, Wealth from Water factsheet*, Tasmanian Institute of Agriculture

167 Holz GK, Grose MR, Bennett JC, Corney SP, White CJ, Phelan D, Potter K, Kriticos D, Rawnsley R, Parsons D, Lisson S,Gaynor SM & Bindoff NL 2010, Climate Futures for Tasmania: impacts on agriculture technical report, Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania

168 ibid

169 Webb, M (2015) Incorporating Climate Futures into Enterprise Suitability Mapping - Technical report. Department of Primary Industries, Parks, Water and Environment. Launceston, Tasmania

This assessment is supported by a more recent study by Borus using APSIM-potato to investigate and quantify the potential impact of future climate scenarios on potato productivity.[170] The data used to simulate future climates included dynamically downscaled bias-corrected climate projections for Tasmania from Climate Futures Tasmania. Temperature projections from the simulation indicated a 1.2°C increase for maximum temperature and 1.3°C for minimum temperature by 2050. Annual rainfall increases by 4.5 to 9 per cent, relative to the baseline (1981-2010) by 2085 and seasonal rainfall intensity also increases.

Although temperature is projected to increase, the modelling showed that duration of crop exposure to temperatures outside the crops optimal range is negligible. Thus, climate change would have little influence on projected future tuber yield under current farmer practice (based on evidence from the period 2012-16). However, the time to crop maturity shortening by 10 days in 2050, and 15 days by 2085, could potentially translate to less irrigation and pesticide use. Conversely, shifts in climate may allow the establishment of pests and diseases. Extreme events leading to waterlogging could destroy crops.

Conclusion: potatoes

With increasing temperatures and growing degree days and a reduction in frost risk, the potato industry could expand into new areas in Tasmania. The increased intensity in rainfall, as well as longer dry periods, will bring the need for increased erosion control and create water management challenges for growers.

The impacts in other potato growing regions (South Australia and Victoria) have not been examined in detail, given the relatively small contribution of potatoes to the economies of those jurisdictions. Nevertheless, the Tasmanian findings have implications for these areas, which are located further north. Here the impact of heat risk and reduced winter-spring rainfall is less clear, but it is likely to outweigh the reduction in frost risk, with productivity plateauing to 2050.

4.8.3 Northern Territory and Western Australia examples of mango production impacts

In 2017-18 the Northern Territory produced almost half the national mango crop and around 30 per cent of the nation's melons. The main cropping areas in the Northern Territory are Darwin and Katherine. Queensland produces a further 47 per cent of the nation's mangoes, with the final 5 per cent spread across the remaining states, excluding Tasmania. National mango production was 43.7 tonnes in 2016-17, harvested from 1.178 million fruit bearing trees, with an average yield per tree of 37 kg (ABS).[171] There have been an increasing number of mango trees planted over the last 10 to 15 years and these are now starting to come into full production.

Mangoes thrive in the heat and are well suited to the tropical and subtropical areas. A warming climate could well increase growth rates, pollen viability and fruit set. Mangoes fruit best in areas of low rainfall and low relative humidity at flowering, fruit setting and harvest, and with a warm to hot climate during fruit development. The mango is susceptible to cold. Young trees may be killed by temperatures below 0.5°C. Older trees will survive a few degrees of frost but may be severely damaged. Mangoes will tolerate temperatures up to 48°C without serious damage to established, irrigated trees. Mature trees can tolerate prolonged periods of moisture stress, as well as having a high tolerance to flooding.

However, some mango varieties need a cool period with nights below 20°C for flowering to occur and temperatures above 45°C will affect fruit development, particularly induction, size and number of flowers. During ripening, sun-damaged fruit and fruit drop can be caused by excessively high temperatures, combined with low humidity. Unpredictable rainfall during pre-flowering and flowering periods may cause poor fruit set, while any increase in tropical cyclone intensity will damage crops. In the southern growing areas, cool weather in spring or early summer can delay flowering and reduce yield. Climate change could see mango growing move further south. Conversely, traditional growing areas will experience risks of abnormal flowering and fruit set, with reduced quality and yield.

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[170] Borus, DJ (2017); *Impacts of climate change on the potato (Solanum Tuberosum L.) productivity in Tasmania, Australia and Kenya*, PhD thesis, University of Tasmania

[171] ABS 7121.0 - Agricultural Commodities, Australia, 2016-17. available at: http://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/7121.0Mainper cent20Features512016-17

In Western Australia, the spring and early summer of 2016 were considerably cooler than the long-term average temperatures for this period. Mango flowering was two months later than the previous year. Yields in the region were about 10 to 20 per cent of the typical yields (i.e. an 80 per reduction compared to normal yield).[172] In the Northern Territory, during the 2016-17 season, there were enough cool nights to promote mango flowering. However, the period immediately following flowering was excessively hot and this scorched the buds and reduced the total crop yield by 30 per cent, equivalent to a loss in value of $12 million. With the projected increase in climate variability and extreme weather events these types of impacts are likely to increase.

Conclusion: mangos

Mango growers are faced with key climate change adaptation decisions in the near future. There is anecdotal evidence of a significant drop in productivity in some mango varieties in the Carnarvon region of Western Australia due to rising temperatures This impact is expected to be seen in the mango growing areas of the Northern Territory within 20 years. Given the average productive life of a mango tree is 10 to 15 years, growers are now facing key crop replacement decisions around which variety to use in renewing their crops.

4.8.4 Western Australia example of vegetable production impacts

A 2013 study for Horticulture Australia found that increased temperatures at Manjimup in the far southwest of Western Australia (300km south of Perth) would alter development and harvest times of vegetable crops. This would allow alternative crops, such as capsicum, to be grown; extend the growing season of some varieties; and preclude the growing of others (**Table 4.13**).[173] It also found that 4°C temperature increase, or an increase in the number of days over 35°C, would reduce both quality and yield. The study also projected that the amount of time that the critical temperature threshold for lettuce (28°C) is exceeded could increase by two weeks at Gingin (70 km north of Perth) by 2030. Increasing temperatures will decrease lettuce quality and could stop summer production, unless more heat-tolerant lettuce cultivars are available.

TABLE 4.13 EFFECT OF INCREASED TEMPERATURES ON HORTICULTURAL PRODUCTION AT MANJIMUP

Crop	Current conditions	1°C increase	2°C increase	3°C increase	4°C increase	5 days over 35°C
Lettuce	Harvested from December to May	2-3 days quicker to harvest	Change to summer-type varieties, increased tip burn	May require protective shading during summer, transition period becomes longer	Avoid growing lettuce in summer. Harvesting during winter possible	Decline in quality and yield
Baby leaf lettuce, spinach, rocket	Harvested from October to June	2-3 days quicker to harvest	3-5 days quicker to harvest, change varieties, extended harvest period	6-7 days quicker to harvest, new varieties, all year round production	8-9 days quicker to harvest, new varieties, all year round production	Germination problems in summer if >35°C, fringe burn reduces leaf quality
Capsicum	Not suitable area for production	Harvesting possible from January to March	Harvesting possible from January to April	Harvesting possible from mid-December to May	Harvesting possible from December to late May	Sunscald and blossom end rot
Broccoli and cauliflower	Harvested all year round	Earlier maturity	Use varieties adapted to warmer conditions	Less cool- season varieties in schedule	Increased 'buttoning', premature heading, tip burn, hollow stem and white blister, harvest window reduced to June to October	Quality decreases

SOURCE: ROGERS 2013:

[172] Adapting mango growing to a Mediterranean climate Factsheet. Neil Lantzke Horticultural Consultant Western Australia, for Northern Agricultural Catchments Council (NACC) 2017. https://www.nacc.com.au/wp-content/uploads/2017/11/1612-05-12-Adapting-mango-growing-to-a-Mediterranean-climate-Factsheet.pdf

[173] Rogers G., 2013, Understanding and managing impacts of climate change and variability on vegetable industry productivity and profits, Project Number: VG12041. Horticulture Australia Ltd, Sydney

As shown at **Table 4.14**, the optimal temperature range for many horticulture crops is narrow, with the upper threshold also relatively low. This makes their growing regions and seasons quite susceptible to relatively small temperature increases. Extreme weather events can also impact productivity. A recent assessment shows that perennial and annual horticultural crops are particularly vulnerable to the impact from heatwave stress, which can include damage to trees/vines; yield losses; damaged products; reduced product quality; and increased input requirements.[174]

TABLE 4.14 OPTIMAL GROWING TEMPERATURES AND TEMPERATURE THRESHOLDS ABOVE WHICH YIELD DECLINES FOR VARIOUS HORTICULTURAL CROPS

Crop type	Optimal temperature range for growth (°C)	Upper threshold (°C)
Chilli	21-30	35
Eggplant	21-30	35
Babyleaf - rocket	16-24	32
Capsicum	20-25	32
Cauliflower	15-18	32
Cucumber	18-24	32
Pumpkin	18-24	32
Sweet corn	24-30	32
Zucchini & butterscotch	18-24	32
Broccoli	15-18	30-32
Baby leaf - spinach	15-18	30
Carrot	15-18	30
Garlic	13-24	30
Leek	13-24	30
Shallot	13-24	30
Tomato	18-24	29
Bean	15-21	27
Beetroot	15-18	27
Artichoke	15-18	24
Babyleaf - chard	15-18	24
Brussel sprout	15-18	24
Cabbage	15-18	24
Celery	15-18	24
Herbs	15-18	24
Lettuce - cos	12-21	24
Lettuce – fancy and babyleaf	12-21	24
Lettuce - iceberg	12-21	24
Parsnip	15-18	24
Pea	15-18	24
Silverbeet	15-18	24
Snow pea & sugar snap pea	15-18	24
Swede and turnip	15-18	24

Note: vegetable crops only (excludes fruit and nuts)

SOURCE: ROGERS 2013

[174] Natural Capital Economics (2018). Heatwaves in Victoria: a vulnerability assessment. Report prepared for the Department of Environment, Land, Water and Planning, VIC https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0029/399440/Heatwaves_VulnerabilityAssessment_2018.pdf

4.8.5 Biosecurity risks

An example of how a pest or disease incursion can write off a commodity overnight is provided by the recent incursion and impact of the Cucumber Green Mottle Mosaic Virus (CGMMV) on watermelons, although this incursion is not climate change related. Australia's melon crop is worth $60 million annually. The Northern Territory produces around 30 per cent of Australia's melons.

New Zealand authorities detected CGMMV on a batch of watermelons from the Northern Territory and suspended cucurbit imports in August 2018. CGMMV is a soil-borne plant virus which affects cucurbit crops such as watermelons, pumpkins, zucchinis and cucumbers. The virus was first detected the Northern Territory's Katherine region in 2014, where it almost wiped out the watermelon industry. It has since been found on farms in Queensland and Western Australia. It is thought to have entered Australia on seeds and is extremely difficult to eradicate. The farm where the initial infection was detected is still experiencing outbreaks.

This single incursion of a pest on cucurbit crops is used to highlight the potential vulnerability of the industry. There is only limited research as to how a warming trend may impact the incursion risk or spread of a disease or pest. However, there is growing evidence of the potential risks of tropical pests and diseases spreading to areas previously immune from such outbreaks, as well as an increase in the frequency of such outbreaks appearing in the more southern horticulture regions of Australia.

Furthermore, the potential risk to industry is not restricted to the horticulture sector. There is a significant risk across all agricultural commodities in relation to pests and diseases changing distribution under a changing climate; the introduction of novel pests; changes insect pest generation times etc. With these risks come potentially greater management costs; chemical use issues; and implications for marketability and market access. Biosecurity is a key issue for industry going forward and an analysis of risks and their management will be addressed under Stream 2 work.

4.8.6 Conclusions: horticulture

Australia's fruit and vegetable growers already deal with a highly variable environment. A large proportion of fruit and vegetable production in Australia is irrigated. Many crops are susceptible to small changes in temperature which will affect overall productivity and quality, as well as the growing season. However, that proportion of the produce which is grown in closed greenhouse environments will be less exposed to climate change impacts, provided energy and water remain available, and are priced at a level that allows the crop to be economically viable.

Annual horticultural crops also have the potential to 'migrate' with temperature change, subject to land and water availability, but 'tree' crops (which have an average productive life generally measured in decades) have less flexibility. As a high-value per hectare crop, horticulture is likely to displace other agricultural sectors, but will be faced with encroachment challenges from urbanisation etc.

Accordingly, there are many factors in production that may influence the overall impact on yield and productivity. For many products, the one-off impact of climate variability over a single growing season, or disease, can cause major losses of 30 to 100 per cent. Rogers modelled the impacts of a high temperature climate scenarios on vegetable gross margins and determined that reductions in yields (against the 2010-12 baseline) were between 20 to 50 per cent.[175]

For the purposes of the analysis it has been assumed that horticulture yield will remain constant. This reflects a slowing compared to the current upward growth trajectory.

175 ibid

4.9 Productivity impact snapshot

A snapshot summary of potential impacts of climate change on productivity in relation to each of the agricultural commodities examined in detail is shown in **Table 4.15**.

TABLE 4.15 CLIMATE CHANGE IMPACTS ON PRODUCTIVITITY FOR SELECTED COMMODITIES

Commodity	Productivity impact to 2030	Key climatic factors considered
Cattle	5.0% decline in productivity by 2030	Pasture impacts only (from temperature and rainfall)
Wheat	1.1% decline in productivity by 2030	Less rainfall and higher temperatures
Dairy	1.2% decline in productivity by 2030	Pasture and heat stress
Sugar	Estimates vary from -4.0% to +7.5% change	Highly variable; QLD down, NSW up
Cotton	Up to 6.0% increase in productivity by 2030, but then declines	Temperature and CO_2 effect only; access to water critical
Horticulture	May be significant at the crop level	Highly variable, localised, extreme weather related

SOURCE: ACIL ALLEN CONSULTING

5 ECONOMIC IMPLICATIONS FOR JURISDICTIONS

As discussed in chapter 2, Australia is a world leading producer and exporter of agricultural commodities with the total production of agricultural products valued at over $60 billion in 2016-17. Exports were worth an estimated $50 billion. The agricultural sector employs around a quarter of a million people. Agriculture is an important component of the economy in all jurisdictions.

This chapter assesses the economic implications for each jurisdiction arising from the impacts of climate change on the productivity/yield of a range of agricultural commodities. It draws upon the assumptions and conclusions in chapters 3 and 4. The analysis has focused on the key agricultural commodities produced in each jurisdiction.

The agricultural sectors examined include those with largest and highest value. Sectors have been selected on the basis that they are common to many jurisdictions (i.e. cattle, wheat) and because they have strong similarities to other sectors (i.e. wheat to coarse grains). The sectors examined are also particularly susceptibility to climate change impacts, given their specific growing requirements (i.e. cotton, given high water use) and because some have specific, but more generalised, growing parameters (i.e. sugar, horticulture). Importantly, the results of the assessment exemplify the trends which might be anticipated across the agricultural sector more broadly.

As with any analysis of this kind, it is important to recognise that different assumptions will produce different outcomes. The assessment draws on the productivity impacts explored in Chapter 4, which, based on the information from the research assessed, are considered an appropriate, but conservative, assumptions. Sensitivity analysis is included to provide an indication of the impact of different assumptions. The economic implications are nationally focused and do not take account of global impacts of climate change (for example, increased wheat production in Black Sea region/Canada might result in global oversupply and decline in wheat export prices).

The availability of substantial economic modelling results, such as computed partial and general equilibrium modelling, of climate change impacts across all agricultural commodities and regions is very limited. Economic modelling of climate change from an economy wide perspective is available. However, there is a significant gap in relation to work that is focused on the specifics of the agricultural sector, and that incorporates more sophisticated assumptions and regional changes highly relevant to key agricultural commodities.

Accordingly, a conservative and simplified approach has been adopted to provide some insights as to possible economic impacts and potential consequences of climate change for key commodities. A brief summary of what has, and has not, been assumed is provided in **Table 5.1**. This approach oversimplifies because of the assumption of direct causal relationships, which means that changes in production are directly proportional to changes in value. The analysis is essentially an extrapolation of biophysical impacts rather than economic modelling per se.

TABLE 5.1 ECONOMIC IMPLICATIONS ANALYSIS ASSUMPTIONS AND GAPS

Assumption	Description	Included	If not included, what is needed
Projections of changes detailed in Chapter 4 for selected commodities	Chapter 4 details projected changes in production due to climate change impacts	Y	
Production and value reduction are directly proportional	A 10 per cent reduction in production equals a 10 per cent drop in value, for example	Y	
The relative share of the commodities in each jurisdiction remains the same as it was in 2016-17	No opportunistic switching (i.e. cropping to grazing) in production assumed	Y	
Prices remain constant	The price of the good along the supply chain and to the end consumer do not change	Y	
Variables			
Supply chain responsiveness	The changes in intermediary actions, including value-add, in response to price and production changes	N	Supply chain nodes and responses needs to be formulated at a commodity and regional level
Demand responsiveness	Changes in supply and consumer sentiment changes demand	N	Demand elasticity parameters need to be formulated
Producer management	Financial constraints and changes in production practices to accommodate impacts	N	Consultation with industry to detail financial constraints, management approaches and plausible outcomes
Trade and global competition	Key export markets trading with other nations instead of Australia	N	Export demand parameters, exchange rate movements and competitor profiles need to be formulated
Impact of inputs	Electricity, gas, fuel, water, and land availability and cost	N	Need consumption and cost data for the inputs
Substitutions	How substitutable goods feed back into the price, production and supply of the agricultural good	N	Identify substitutes and quantify relationship
Adaptation initiatives	The extent to which productivity losses are offset by adaptation measures	N	Need to quantify the impact of adaptation measures
Emission off-set actions	Off-set activities such as land regeneration, moderated grazing patterns, methane collection, etc	N	Emission off-set curves quantifying magnitude need to be formulated
Emissions contribution	The volume of emissions output allowable for the industry (i.e. carbon budget) and how it relates to other liable industries	N	A baseline or current year of emissions output, the trajectory of annual emissions over time, how emissions generation can be managed so as to fall within allowable volumes and relationship with emissions output from other industries in meeting national and/or jurisdictional objectives
Production and emissions	The relationship between emissions output and production (other than the simple relationship of lowered production leads to lower emissions)	N	Augment the economic output function to quantify relationships between production practices and associated emissions volumes

Assumption	Description	Included	If not included, what is needed
	Model paradigm		
Existence of an equilibrium	A state or condition exists in which there is equilibrium of supply, demand, price and emissions output and this is considered an objective	N	An agreement on whether an equilibrium could and should exist and what it would look like
Iteration capability	Refers to the capability to simulate the production and consumption flow of agricultural goods and what 'shocks' occur (in addition to climate change shocks) and the impact they have	N	A database of the production and consumption flow and the types of and magnitudes of the 'shocks'

Note: Non-exhaustive list

SOURCE: ACIL ALLEN CONSULTING

5.1 Economic impact due to changes in productivity

As discussed in Chapter 4, the impact of climate change will result in changes in yields and production output for a range of agricultural activities. The conclusions from Chapter 4 are used as the basis for the production declines in the economic impact illustrations in this chapter. For the six key commodities (where productivity is impacted by 2030), the impact on the value of the sector has been analysed, based on the overarching assumptions detailed in **Table 5.1**.

The following economic impact portrays a simple relationship between the agricultural producer, the production process and value derived. It illustrates a scenario in which relationships to price, demand and intermediaries are inflexible, and actionable alternatives are limited. Simply put, a reduction in production corresponds to a proportionate reduction in value. In reality, this provides a strong incentive to adjust production processes and manage relationships with intermediaries and end consumers so as to maintain and extract as much value as possible.

The focus on yield and productivity obscures other critical effects, such as impacts on quality, marketability and price; seasonal shifts in production, which potentially affecting market windows, competitive advantages and price; changing consumer preferences; and changed distributions of pests and diseases, which will bring increased costs of management and challenges for export market access. Equally important, it also excludes the effects of drought and storms and other extreme weather events/shocks, which are increasingly important in terms of their economic impact on agriculture. These issues and their economic impact will be explored further as part of Stream 2 work in analysing opportunities and risks.

For the three sectors where it was concluded that there would be a fall in production (cattle, milk and wheat), a base case has been assessed, along with three sensitivities: scenario 1 - a lower decrease in production; and scenarios 2 and 3, looking at more significant negative changes, to test the robustness of the assumptions. The analysis has look at both the nominal outcome, as well as the economic impact in real terms (i.e. with the real figures adjusted for inflation of 2.5 per cent per year, based on the Reserve Bank of Australia's target inflation rate).

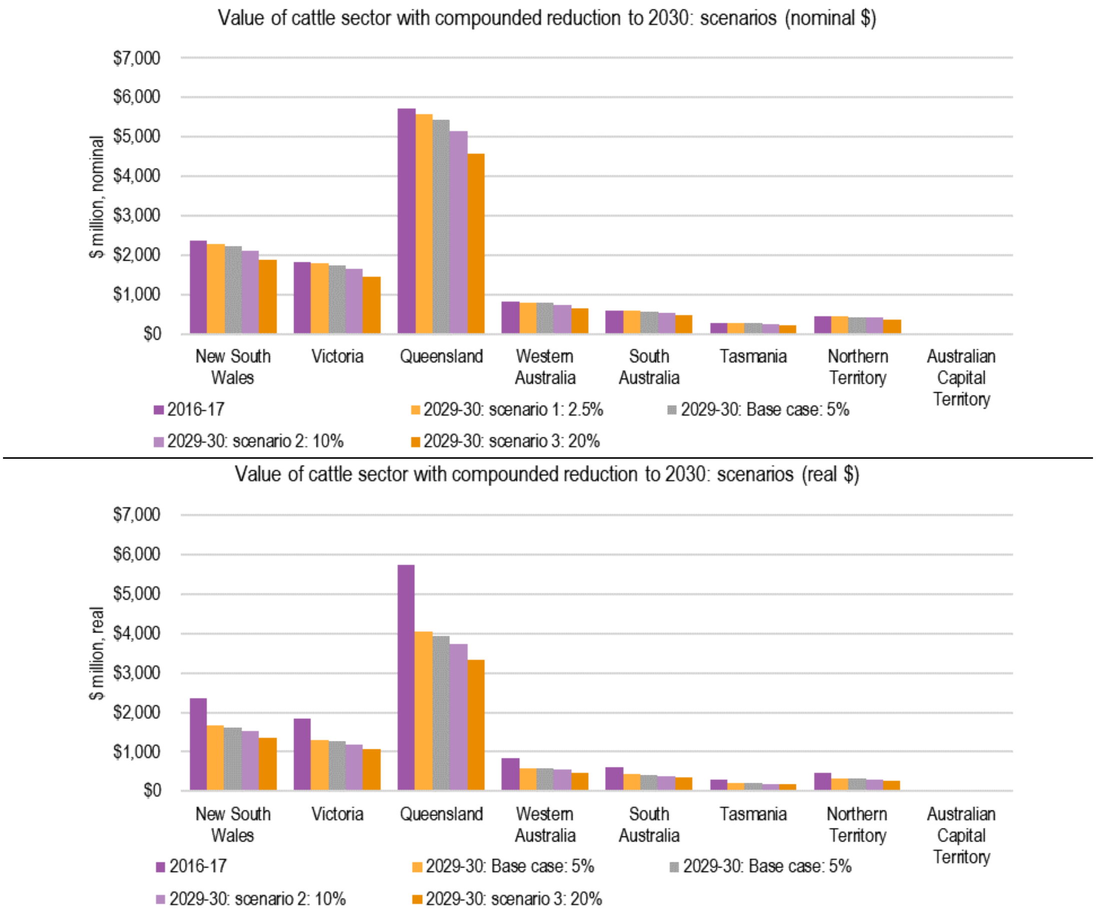
5.1.1 Cattle sector

As detailed in Section 4.3, and summarised in Section 4.3.8, production in the cattle sector is assumed to gradually drop over the period to 2030. By then productivity is assumed to have declined by five per cent. There is less certainty about outcomes beyond 2030, given the variability in climate change scenarios and the likelihood producers will have implemented adaptive responses.

Figure 5.1 shows the losses in value under the base case and each scenario, as follows:

— Base case: the baseline assumption is a *five per cent reduction* in production between 2016-17 volumes and 2029-30.
  – **Result:** the sector is valued at around $11.53 billion in 2029-30 in nominal terms and $8.36 billion in real terms. In 2016-17, the sector was valued at $12.14 billion.
— Scenario 1: assumption of a *2.5 per cent reduction in production over the period*.
  – **Result**: the sector is valued at around $11.83 billion in 2029-30 in nominal terms and $8.58 billion in real terms.
— Scenario 2: assumption of a *10 per cent reduction* in production over the period.
  – **Result:** the sector is valued at around $10.89 billion in 2029-30 in nominal terms and $7.90 billion in real terms
— Scenario 3: assumption of a *20 per cent reduction* in production over the period.
  – **Result**: the sector is valued at around $9.70 billion in 2029-30 in nominal terms and $7.04 billion in real terms.

FIGURE 5.1 REDUCTION IN VALUE: CATTLE



Note: 2016-17 figures reported by ABS. The real figures are adjusted for inflation of 2.5% per year; based on the Reserve Bank of Australia's target.
SOURCE: ACIL ALLEN CONSULTING AND AUSTRALIAN BUREAU OF STATISTICS AND ABARES

Whilst the fall in production has been assumed across all jurisdictions, the jurisdictions that will likely be hardest hit will be Queensland and the Northern Territory, given the cattle sector provides a significantly greater share of the total value of agriculture for these jurisdictions.

5.1.2 Milk

For the milk sector, the decline in productivity, assumed in section 4.4, is relatively low at 0.1 per cent per year.

Figure 5.2 shows the losses in value under the base case and each scenario, as follows:

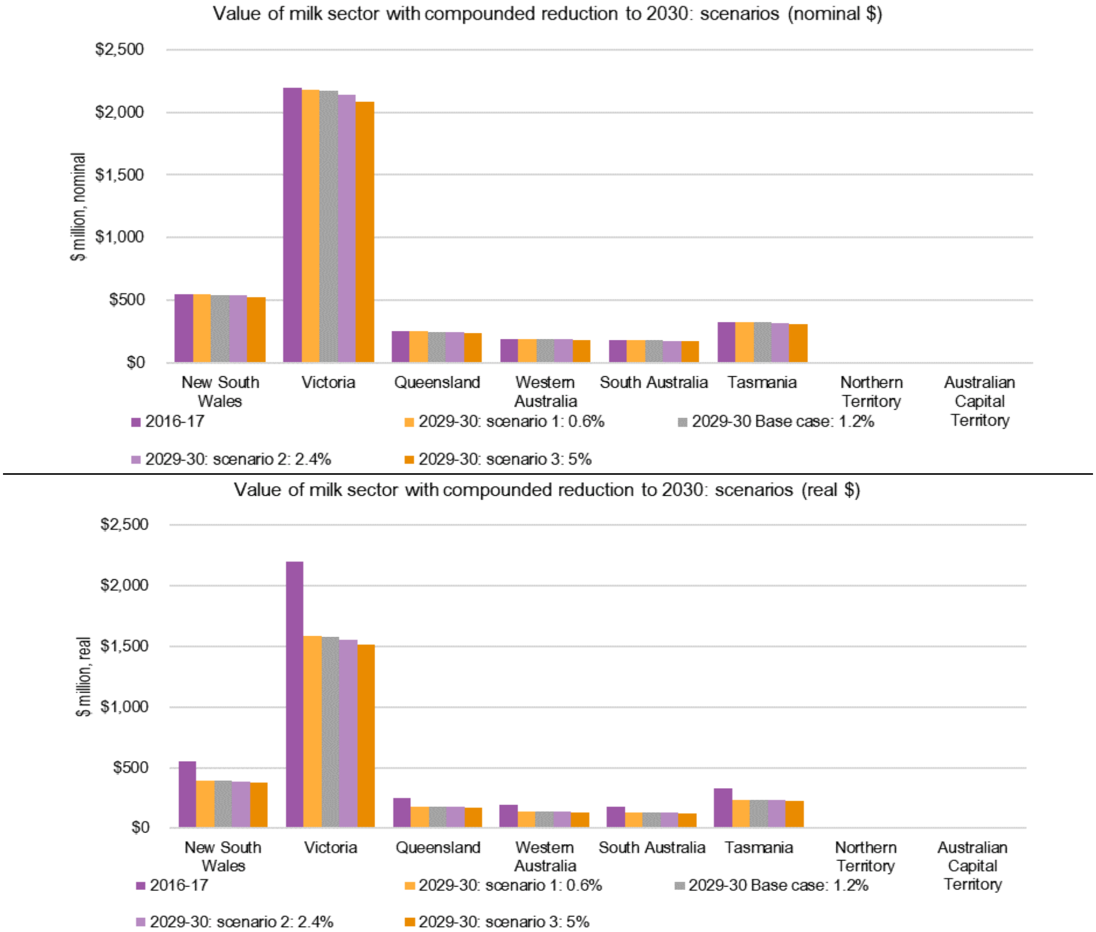
— Base case: the baseline assumption of a *1.2 per cent reduction (0.1 per cent per year)* in production between 2016-17 volumes and 2029-30.
  - **Result:** the sector is valued at around $3.65 billion in 2029-30 in nominal terms and $2.65 billion in real terms. In 2016-17, the sector was valued at $3.69 billion.

— Scenario 1: assumption of a *0.6 per cent reduction in production over the period*.
  - **Result**: sector is valued at around $3.67 billion in 2029-30 in nominal terms and $2.66 billion in real terms.

— Scenario 2: assumption of a *2.4 per cent reduction* in production over the period.
  - **Result:** the sector is valued at around $3.61 billion in 2029-30 in nominal terms and $2.62 billion in real terms.

— Scenario 3: assumption of a *3.5 per cent reduction* in production over the period.
  - **Result**: sector is valued at around $3.51 billion in 2029-30 in nominal terms and $2.56 billion in real terms.

FIGURE 5.2 REDUCTION IN VALUE: MILK



Note: 2016-17 figures reported by ABS. The real figures are adjusted for inflation of 2.5% per year; based on the Reserve Bank of Australia's target

SOURCE: ACIL ALLEN CONSULTING AND AUSTRALIAN BUREUA OF STATISTICS AND ABARES

Whilst the fall in production has been assumed across all jurisdictions, the jurisdictions that will be most affected are Victoria and Tasmania as the milk sector provides a significantly greater share of the total value of agriculture for these jurisdictions.

5.1.3 Wheat

As detailed in section 4.5, it is concluded that climate change may reduce potential wheat yield in Australia by around 0.1 per cent in 2020, and that it will decrease by 0.1 per cent a year out to 2030.

Figure 5.3 shows the losses in value under the base case and each scenario, as follows:

— Base case 1: the baseline assumption is for a 0.1 per cent fall by 2020, then *0.1 per cent per year* to 2029-30, equal to a *1.1 per cent reduction* between 2016-17 and 2029-30.

— **Result:** the sector is valued at around $7.28 billion in 2029-30 in nominal terms and $5.28 billion in real terms. In 2016-17, the sector was valued at $7.37 billion.

— Scenario 1: assumption of a *0.6 per cent reduction in production over the period*.

  – **Result**: sector is valued at around $7.32 billion in 2029-30 in nominal terms and $5.31 billion in real terms.

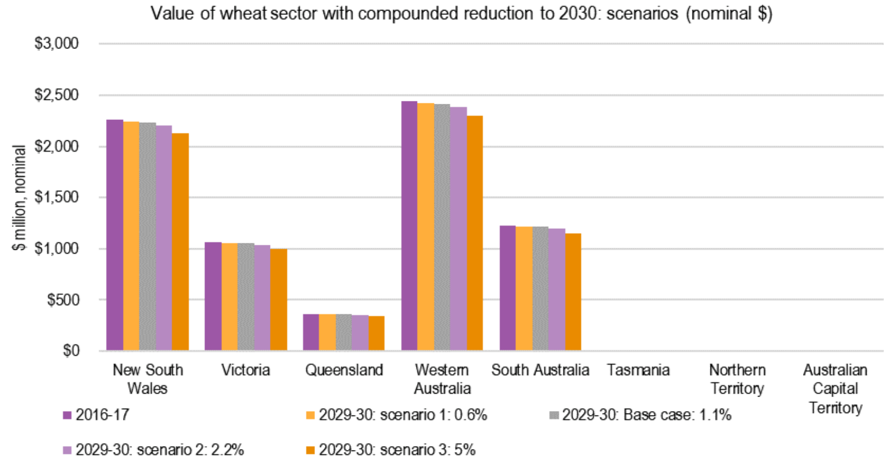
— Scenario 2: assumption of a *2.2 per cent reduction* in production over the period.

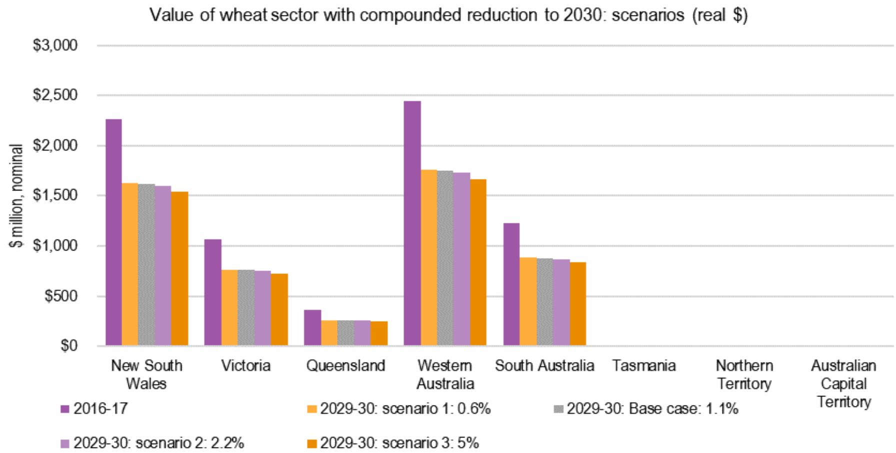
  – **Result:** the sector is valued at around $7.18 billion in 2029-30 in nominal terms and $5.21 billion in real terms.

— Scenario 3: assumption of a *3.5 per cent reduction* in production over the period.

  – **Result**: sector is valued at around $6.94 billion in 2029-30 in nominal terms and $5.03 billion in real terms.

FIGURE 5.3 REDUCTION IN VALUE: WHEAT





Note: 2016-17 figures reported by ABS. The real figures are adjusted for inflation of 2.5% per year; based on the Reserve Bank of Australia's target.

SOURCE: ACIL ALLEN CONSULTING AND AUSTRALIAN BUREUA OF STATISTICS AND ABARES

Whilst the fall in production has been assumed to occur across all jurisdictions, the jurisdictions that derive the largest shares of value from wheat are Western Australia, South Australia and New South Wales, and therefore these jurisdictions will be the most impacted.

5.1.4 Cotton

Section 4.6 concluded that the projected production of cotton is likely to initially increase due to CO_2 fertilisation (out to 2030), but then decline due to lower rainfall. For the purposes of the analysis it is assumed that cotton yield in 2030 will be the same as it is now.

5.1.5 Sugar

Section 4.7 concluded that the projected production changes of sugar will be variable, and location specific. While increased solar radiation is likely to drive increasing yields, lower rainfall may decrease production. Extreme weather may have a significant impact in production year-to-year. For the purposes of the analysis it is assumed that sugar yield in 2030 will be the same as it is now.

5.1.6 Horticulture

The change in production for horticulture is discussed in section 4.8. Australia's horticultural producers already deal with a highly variable environment. For the purposes of the analysis it is assumed that horticulture yield in 2030 will remain constant. This reflects a decrease compared to the current upward growth trajectory. Between 2014-15 and 2016-17, production in the sector grew an average of three per cent, delivering about 3,700 kt of fruit and vegetables (does not include nuts).[176] Value grew by an average of four per cent, to reach an aggregate value of around $6.83 billion in 2016-17.[177] Assuming that this trend was to continue, production in the sector will grow by four to five per cent in 2029-30 (from 2016-17 volumes), and the aggregate economic value would be similar to current levels, in real terms.

Conclusion

As discussed in Chapter 4, the impact of climate change will lead to changes in yields and production output. Concurrently, emissions management policies may constrain a producer's ability to increase yields using methods that generate emissions. This may, in turn, result in a structural reduction in production. The sector where negative production impacts are projected to be prominent is in Australia's highest value sector, cattle. Wheat and dairy (milk) are projected to experience a relatively small decline, whilst the cotton, sugar and horticultural industries are projected to have a similar economic value, compared to now.

5.1.7 Short term climate variability impacts

As well as the medium to long-term impacts of climate change, short-term impacts were also discussed in Chapter 4. A summary of the anticipated magnitude of loss and vulnerability by agricultural sectors, resulting from short-term variability and extreme events, is shown in **Figure 5.4**.

The magnitude of loss describes the potential loss of productivity, and thus value, from a particular climate related event (at either the farm level or for the entire commodity, depending upon the nature of the event). In reality, it is possible the loss could be 100 per cent. This worst-case scenario is not illustrated in the chart, which focuses on a 'mid-range' potential result, based on historical occurrences.

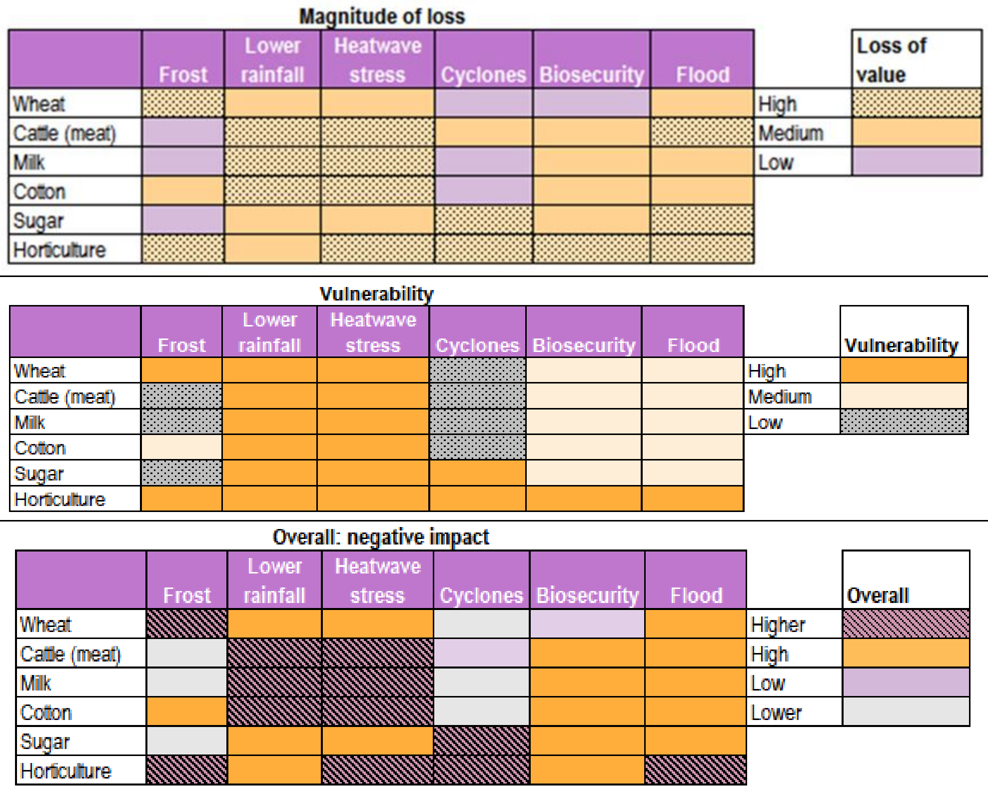
A similar approach is adopted in relation to the meaning of 'vulnerability'. Notably, vulnerability could vary considerably depending on the geographic location of the sector. **Figure 5.4** reflects the history of impact on those locations where a particular commodity is currently most abundant, rather than taking into account impacts on outlier areas. The figure does not capture sector vulnerability, region by region. The magnitude of loss and vulnerability are illustrated on a relative scale, rather than absolute figures, to provide a comparison across the six selected commodities.

176 ABARES, 2018, Agricultural commodity statistics 2018.
177 Australian Bureau of Statistics, 2016-17, *Value of Agricultural Commodities*

The rankings are a relative comparison for each impact across the commodities. For example, wheat has exhibited greater losses from the impact of frost, compared to sugar, so is labelled as 'High'.

Lower rainfall and heatwave stress are significant short-term climate events that strongly impact all the selected commodities. Frost, cyclones, biosecurity and flood are likely to impact some activities more than others.

FIGURE 5.4 SHORT TERM CLIMATE VARIABILITY IMPACTS: RISK AND MAGNITUDE OF LOSS OF VALUE



Note: The rankings are a relative comparison for each impact across the commodities. For example, Wheat has exhibited greater losses from the impact of frost, compared to Sugar, so is labelled as 'High'. The magnitude of loss describes the potential loss of productivity and thus value from a particular climate related event (at either the farm level, or for the entire commodity, depending upon the nature of the event). Vulnerability considers locations where a particular commodity is currently most abundant.

SOURCE: ACIL ALLEN CONSULTING

5.1.8 Commodity snapshots- economic implications

Box 5.1 and **Box 5.2** highlight the main themes in this chapter for each of the selected commodities. They are grouped on the basis of expected declines in production and value with **Box 5.1** containing those commodities with the largest losses in value (in the absence of adaptation).

BOX 5.1 ECONOMIC IMPLICATIONS BRIEF: CATTLE (MEAT), MILK AND WHEAT

Cattle (meat)

The highest value commodity nationally, but also the most emissions intensive agricultural sector in aggregate in 2016 (on a per animal basis, dairy cattle is more emission intensive). There are over 43,000 businesses with an average $150,000pa cash income per farm in 2016-17. Farms running beef cattle manage more than 75 per cent of the total area of agricultural land in Australia. The projected decline in production due to climate change is estimated to be 5 per cent by 2030.

Economic implications:

– The total value of sector is projected to fall to around $11.52 billion in 2029-30 in nominal terms. In 2016-17, the sector was valued at $12.14 billion. New South Wales and Queensland contribute 19 per cent and 47 per cent respectively of total national value of the sector. In the Northern Territory cattle comprise 76 per cent of the total value of the Territory's agricultural industry. These three jurisdictions will be most impacted.

Milk production

There were over 6,700 milk production businesses, with an average $89,000pa cash income per farm, in 2016-17. Production is projected to decline by 0.1 per cent per annum due to climate change. Dairy cattle are the most emissions intensive element of the cattle sector, thus the sector will be sensitive to emissions policy decisions.

Economic implications:

– The total value of sector is projected to exhibit a relatively gradual decline, falling to around $3.65 billion in value in 2029-30 in nominal terms. In 2016-17, the sector was valued at $3.69 billion. Victoria and New South Wales make up 59 per cent and 15 per cent of total national value, respectively. In Tasmania, 22 per cent of the total value of the agricultural industry is provided by the milk sector. These three jurisdictions will be most impacted.

Wheat

There are over 19,800 wheat-based businesses, with an average $420,000pa cash income per farm (in 2016-17). Three per cent of total agricultural land was used for wheat production in Australia in 2016-17. The projected decline in production due to climate change is estimated to be 0.1 per cent per annum. To counteract climate change, it is likely there will be an increasing use of synthetic fertilisers, liming and urea (which will increase emissions).

Economic implications:

– The total value of the sector is projected to fall to $7.28 billion in value in 2029-30 in nominal terms. In 2016-17, the sector was valued at $7.37 billion. New South Wales and Western Australia generated 31 per cent and 33 per cent of total national value of the sector, respectively. These two jurisdictions will be most impacted.

SOURCE: ACIL ALLEN CONSULTING, ABS, ABARES: BEEF FARMS

BOX 5.2 ECONOMIC IMPLICATIONS BRIEF: COTTON, SUGAR AND HORTICULTURE

Cotton

There were over 1,000 cotton growing businesses in Australia in 2016-17. Less than one per cent of total agricultural land is used for cotton production in Australia in 2016-17. Projected yield in 2030 is assumed to be similar to now. Increasing use of synthetic fertilisers, liming and urea will result in increased emissions output.

Economic implications:

– On the basis that cotton production may not be significantly affected by climate change (with CO_2 fertilisation effects offsetting lower rainfall), the main driving forces of the production of cotton will be those in the market - that is, demand changes, product substitution, competitive pressures and opportunities and price movements. However, access to water will be a critical consideration, given that cotton is not planted in seasons where irrigation water is unavailable.

Sugar

AgriFutures Australia estimated there were around 4,000 cane farming enterprises in Australia in 2017. Analysis by Valle & Martin estimated average cash income per farm in 2013-14 to be $89,700.[178] Less than one per cent of total agricultural land was used for sugar production in Australia in 2016-17. The projected yield in 2030 is assumed to be similar to now. Increasing use of synthetic fertilisers, liming and urea will create additional emissions, which may need to be reduced, should plans for emissions reduction (in Queensland, particularly), take effect.

Economic implications:

– Assuming yield levels are not too negatively affected by climate change, the main driving forces of the production of sugar will be the market and energy inputs. That is, demand changes, product substitution, competitive pressures and opportunities and price movements.

Horticulture

There are over 8,700 horticulture businesses. Less than one per cent of total agricultural land was used for horticultural production in Australia in 2016-17. The projected yield in 2030 is assumed to be similar to current production, which reflects a decrease compared to the current growth trajectory. The sector will require increasing use of synthetic fertilisers, liming and urea to maintain productivity which may create additional emissions.

[178] Valle and Martin; 2015; *Australian sugarcane farm businesses: financial performance, 2013–14*, ABARES research report prepared for Sugar Research Australia and the Queensland Government Department of Agriculture and Fisheries, Canberra, December 2015

Economic implications:

- Between 2014-15 and 2016-17, production in the sector grew an average of three per cent, delivering about 3,700 kt of fruit and vegetables.[179] The value of horticulture grew by an average of eight per cent, to reach an aggregate value of around $6.83 billion in 2016-17.[180] It is unlikely this growth can be maintained, given the impacts of climate change.
- Assuming yield levels remain relatively unchanged, the main driving force of the production of horticulture will be those in the market. That is, demand changes, product substitution, competitive pressures and opportunities and price movements. Horticulture has the potential to displace land used for other crops as a high-value product, in controlled environment greenhouses, that are less exposed to climate variability.

SOURCE: ACIL ALLEN CONSULTING, ABARES, ABS; AGRIFUTURES AUSTRALIA, VALLE & MARTIN (2015)

5.2 Economic impact of rising production costs

Given climate change impacts summarised in this report, it is highly likely that both water and arable land will become scarcer, and the price (and the value) of these resources will rise in response to supply and demand. Higher temperatures also suggest that the demand for water (and fertiliser) will also be greater to counter increased evaporative demand and production drop-off, pushing up the cost of these inputs (see Section 4.3.4). In effect, more, and higher cost, inputs will be required to produce the same level of output, unless other risk mitigation strategies are adopted.

Alternative methods of sourcing energy and water inputs have already been successfully developed and used in Australia. The Sundrop Farms tomato greenhouse in South Australia has a solar power thermal plant, coupled with a desalination plant, to provide energy and water. The cost of constructing the facility was estimated to be around $300 million in 2016.[181] This development was successful, in part due to significant external investment and a favourable ten-year commercial agreement with a major supermarket.

There are over 88,000 agricultural businesses in Australia. In 2016-17, farms in Australia had an annual average income of around $205,000 (see Section 2.2.2).[182] If it is assumed that three per cent of businesses invested 10 per cent of the cost of the Sundrop facility, then this would suggest an aggregate spend of $79 billion. This simple estimate of the value of adaptation investment is in excess of the current total value of the agricultural industry of $60 billion-dollars.

This figure is obviously only an indicative estimate, as it ignores the different needs for each of the agricultural businesses and declines in technology costs. It is noted that Sundrop Farms is an early adopter of technology, and that such ‘first mover’ firms often bear higher costs than subsequent adopters of the similar technology. However, the above analysis illustrates the potential scale of investment that might be required to address changing cost and availability of key inputs under a changing climate.

Furthermore, the increased severity of extreme weather events, such as drought, may challenge the viability dryland cropping (for example on the fringe of eastern wheat belt of Western Australia and the western wheat belt of New South Wales and Queensland). Rising input costs, coupled with weather extremes, will require producers to adapt and/or increase their resilience to climate change. There are a range of measures open to them including:

- an expansion of the area they manage to increase economies of scale to counteract rising input costs
- the adoption of modern farm machinery that generates further efficiency gains
- adjustment to the farm enterprise mix to return cropping land to less input intense and lower risk enterprises, such as livestock coupled with opportunistic cropping (with greater use of non-traditional, climate adapted, pasture species to improve resilience through drought periods)
- employing carbon farming to diversify income streams and build economic resilience, while encouraging land management practices known to boost productivity

179 ABARES, 2018, Agricultural commodity statistics 2018.
180 Australian Bureau of Statistics, 2016-17, *Value of Agricultural Commodities*
181 Viewed January 2019, https://www.abc.net.au/news/2016-10-01/sundrop-farms-opens-solar-greenhouse-using-no-fresh-water/7892866
182 Australian Bureau of Statistics, 71210DO001_201617 Agricultural Commodities, Australia- 2016-17

— relocation to a region with a more suitable climatic environment, and a lower risk profile.[183]

These response options, along with their implications for rural community viability and the provision of services that support the sector, will be explored in the next phase of work (Stream 2).

Conclusion

The change in the scarcity of inputs, and their subsequent costs, as a result of climate change will differ significantly between commodities and across jurisdictions. Businesses that continue to target efficiency gains to off-set these rises and make strategic asset, infrastructure and farming systems decisions, taking account of the impact of climate change, will improve their resilience and financial viability. A key consideration for subsequent work will be consideration of the implications for farms which cannot make the necessary technical adaptations, given the pace and extent of climate changes, exacerbated by short term droughts, and their impact on cash flow.

5.3 Economic impact associated with emissions management

Jurisdictions and individual agricultural commodities will fare differently if there is pressure to reduce emissions from agriculture.

The following economic impact analysis portrays a simple relationship between the agricultural producer, the production process and emissions output. It illustrates a scenario in which relationships to price, demand and intermediaries are inflexible, and actionable alternatives are limited. Simply put, a reduction in production and corresponding value implies a reduction in emissions to the extent considered necessary.

This simple relationship assumes that any emissions reduction will be met by reducing production, and that this will have no impact on prices or result in leakage. It does not consider the capacity to intensify production; to modify management to reduce emissions intensity per unit of production; either domestic or international leakage; enterprise switching to lower net emissions etc. – options which would be available to most producers. Furthermore, it assumes that new, proactive measures to manage emissions are not deployed.

This illustration is both limiting and useful in terms of its starkness of cause and effect. It provides the opportunity to garner the complexity of the economic process involved in a sector impacted by climate change, whether this be through potential policy decisions, tangible environmental changes, and demand feedback. Some of these points of discussion are described in **Table 5.1**.

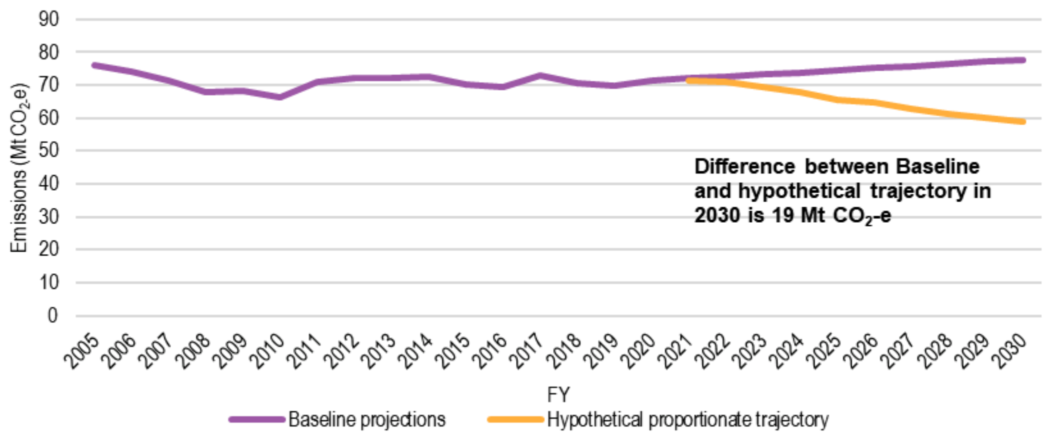
As shown in **Figure 1.1**, agricultural emissions are projected to increase out to 2030. Given the Australian Government has only adopted an economy wide target, the actions the agricultural industry would need to undertake (as a hypothetical, proxy measure), to make a proportionate contribution[184] towards meeting the Paris Agreement target by 2030, have been considered. **Figure 5.5** provides an illustrative example in which a hypothetical emissions trajectory is assumed to reach the pro-rata abatement objective. However, it is acknowledged that there are numerous other possible trajectory options. Under the baseline, a slight increase year on year is assumed. Of course, the actual outcome across all sectors may be significantly different. By 2030, the gap between the hypothetical trajectory and baseline has widened to about 24 per cent.

However, it is increasingly clear that the impacts of climate change will be felt irrespective of what is done globally to reduce emissions. All sectors of the economy (including agriculture) will need to adapt to these impacts. There is already considerable work underway that is designed to help the agricultural sector adapt to existing and future changes to climate (e.g. developing crops that tolerate higher temperatures and/or lower rainfall).

[183] For example, the mainland wine industry has been purchasing land in Tasmania where the climate outlook is for more prospective for growing wine grapes.

[184] The proportionate contribution is purely a mathematical construct that does not take into consideration the relative challenges of the agricultural sector, such as the complicated nature of reducing biogenic methane emissions

FIGURE 5.5 PROJECTED AND HYPOTHETICAL EMISSIONS TRAJECTORIES



Note: Assuming the pro-rata of emissions abatement for the agricultural sector is 13.2%. The gradient of the trajectory is less important than emitting within the allowable budget.

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, 2018, AUSTRALIA'S EMISSIONS PROJECTIONS, 2018

The most emission intensive sectors in agriculture are cattle and milk (due to emissions from dairy cattle). The emission factors for these sources is shown in **Figure 2.34**.

There are many factors at play which will affect the economic impact of any required actions to reduce emissions (see **Table 5.1**). These include, amongst others:

— the extent to which agriculture might contribute to the overall national target

— the relative splits across the agricultural sector itself (it cannot be assumed that each commodity would reduce its emissions by the same amount)

— the extent to which emissions reduction can occur, simultaneously with maintained or increased productivity

— other factors such as water availability, trade demands and the financial constraints of individual operators to meet abatement expectations.

Most importantly, the analysis in relation to emissions reduction is in effect 'ring fenced' from the earlier analysis relating to productivity losses. In reality the two are fully intertwined, with one offsetting the other. These considerations will be explored further as part of the opportunities and gaps analysis in Stream 2.

Figure 5.6 illustrates the reduction in value under an emissions-constrained future, in which agriculture needed to meet a hypothetical emissions trajectory, as set out in **Figure 5.5**. The following assumptions have been applied to simplify the analysis:

— Emissions reduction, production and value reduction are directly proportional. That is, a 24 per cent reduction in production equals a 24 per cent reduction in emissions which also corresponds to a 24 per cent drop in value. This is notwithstanding the fact that emissions management may take many forms. For instance, in relation to cattle, a reduction in the herd size is but one option. Changes in stock food composition; herd management etc. may reduce emissions, while increasing productivity (e.g. to turn cattle off sooner and reduce the numbers of unnecessary breeders by increasing reproductive rate).

— The percentage reduction per year between 2020-21 and 2029-30 is not constant; it ramps up over time.

— The cattle sector is assumed to contribute 50 per cent of the required emissions reduction and the milk/dairy sector, 13 per cent. The other agricultural commodities make up the remainder. These proportions are based on official emissions volumes reported by the DoEE.[185] In other words, in

[185] Department of the Environment and Energy, 2018, Australia's emissions projections, 2018

2029-30, the 24 per cent reduction comprises of a 12 per cent reduction in the cattle sector, a three per cent reduction in the milk sector and the remainder from other sectors.

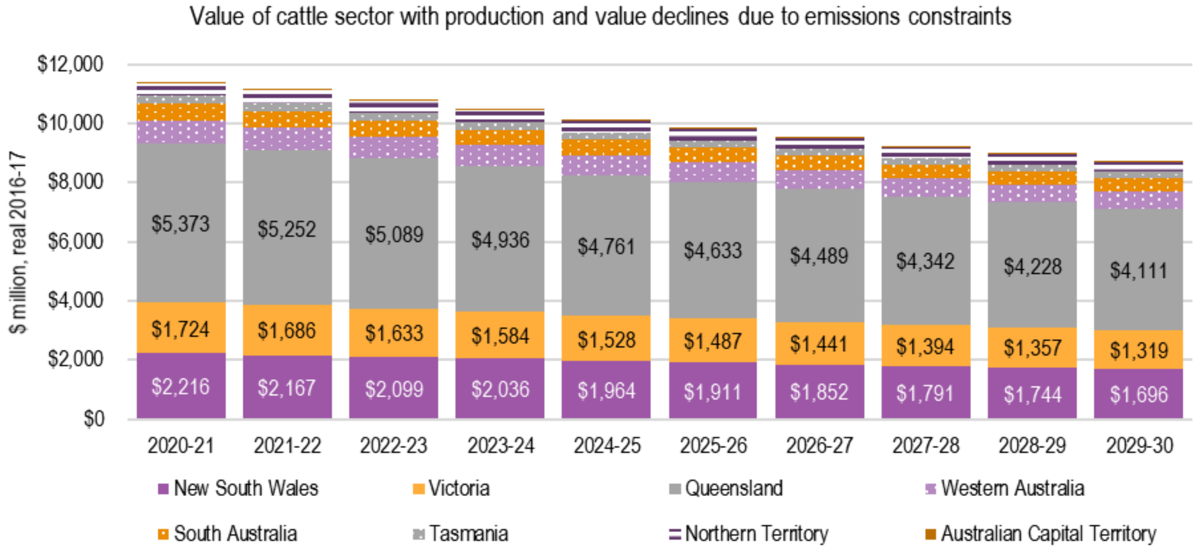
— The share of the cattle and milk sector within each jurisdiction remains the same as it was in 2016-17 (no opportunistic switching from livestock to cropping).

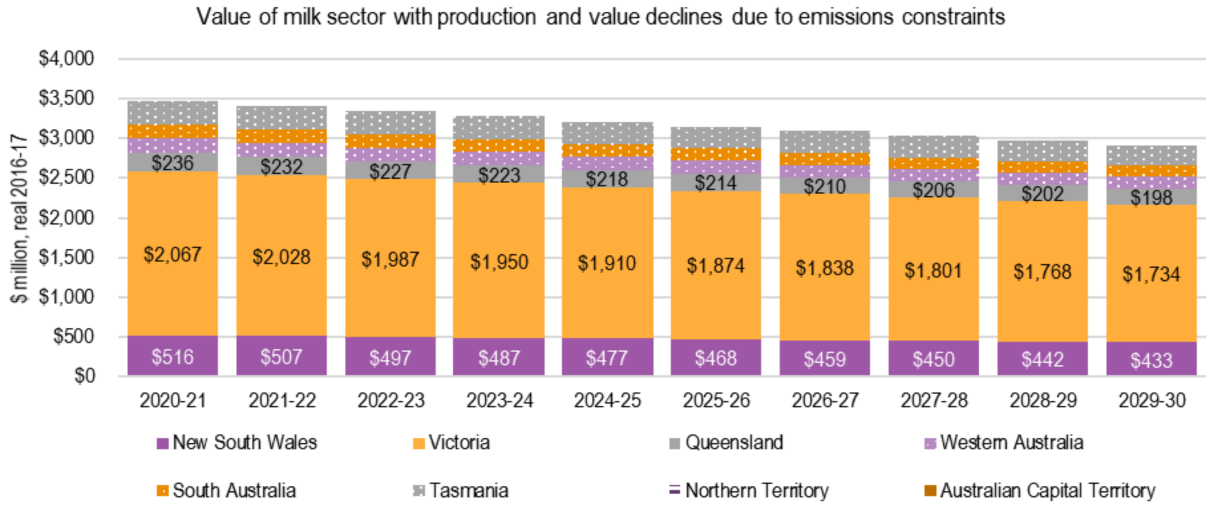
— Prices remain constant.

The analysis shows a steady decline over the period, where the baseline (no emissions reduction) and target trajectory track each other closely until around 2023-24, when the paths begin to diverge. This is because it is assumed that reduction efforts will ramp up and become more sophisticated after 2024. The baseline value of the industry is declining because, in real 2016-17 terms, the value is lower due to inflation (in nominal terms the baseline is increasing). By 2029-30, the value of the cattle sector will be around 25 per cent lower than it was at the beginning of the decade, which is about 30 to 35 per cent lower than the current value, in real terms.

Similarly, for the milk sector, the value of the sector in 2029-30 is about 20 per cent lower than 2020-21, or around 25 per cent lower than the current value, in real terms.

FIGURE 5.6 UPPER BOUND REDUCTION IN VALUE OF CATTLE AND MILK SECTORS DUE TO POTENTIAL EMISSIONS CONSTRAINTS





Note: Assumes cattle contributes 50 per cent of emissions abatement via reduced production and milk (dairy cattle) contributes 13 per cent of emissions abatement. The other sectors make up the remainder.

SOURCE: ACIL ALLEN CONSULTING, DEPARTMENT OF THE ENVIRONMENT AND ENERGY, AUSTRALIA BUREAU OF STATISTICS

The prospect of this significant loss in value emphasises the importance of addressing both emissions mitigation and adaptation methods in tandem. The impact on the cattle and milk sector is highlighted here because these sectors contribute a significant proportion of the agricultural emissions, but other commodities, which contribute to a lesser degree, will still face challenges in mitigation and adaptation.

5.4 Other impacts

There are a range of other outcomes with economic implications which will flow from the impacts of climate change. These issues will be explored with stakeholders in more detail through Stream 2.

Building resilience

Increased climatic extremes, in particular drought and flood events, will increase the risk profile of all agricultural industries. The viability of the agricultural sector is dependent on individual businesses' ability to manage the increased climatic variability through medium to long-term preparedness planning and risk assessment.

The development of assets to mitigate the risk may require additional capital investment. For instance, in terms of improving resilience to the impacts of drought, farmers might invest in improved water utilisation technologies for water intense sectors such as horticulture, cotton and grains; feed grain or hay storage facilities; redevelopment of pastures that are more resilient in longer dry periods; or the introduction of better adapted cattle breeds such as Brahman's or Droughtmaster.

Climate change will also result in increased/changed exposure to other risks such as biosecurity incursions. Producers will need to manage such risks over a longer time horizon than individual seasons, or years. This may require a new approach to how farm business enterprise plans are developed, how infrastructure is funded, and greater utilisation of financial risk instruments.

Placing a value on carbon

Given the commitment to reduce overall emissions by all jurisdictions, there will be a continuing focus on the total amount of emissions generated by agriculture, and further measures which might be taken to abate those emissions. Abatement will, in effect, result in an implicit price on carbon, even in the absence of a more formalised market mechanism.

There is a wealth of anecdotal evidence that many businesses are now factoring a 'carbon price' into their triple bottom line decisions, along with its economic implications for valuations, capital assets etc. Leading-edge farm business already adopt this approach, and there will be continuing pressure from key service providers, particularly the banking and insurance sector, to require the integration of 'carbon pricing', as part of ongoing agricultural business practice.

Carbon price signals, such as those generated by Australian Carbon Credit Units issued by the Clean Energy Regulator for each tCO_2-e stored or avoided by a project, are likely to become important market signals for agricultural operations. They may also generate more interest in carbon farming approaches which can be incorporated within an agricultural business or be an agribusiness in its own right. However, increased interest could result in land use competition in certain instances, and the potential conversion of productive agricultural land.

Carbon farming may provide the opportunity to diversify income streams, for example by undertaking an ERF project. It can also build economic resilience while delivering productivity benefits to the primary agricultural practice (for example, improved pasture and crop productivity; manure management can reduce costs; tree belts can enhance productivity of livestock and crops). The resilience building activities encouraged by ERF methods, including vegetation, will be explored further in Stream 2.

Rural adjustment

Since the deregulation of most agricultural commodities, and exposure to export markets, the average size of an economically sustainable business continues to grow. Smaller and less viable businesses have exited the industry or been absorbed into a larger business. In the short to medium-term this trend is likely to continue, in part driven by climate change impacts. There are also a range of broader social costs which might be exacerbated by climate change impacts. However, there is surprisingly little large-scale quantitative analysis of the social impacts of drought (and climate change impacts more broadly).[186] Such social impacts include:

— community development and sustainability - community social cohesion, participation in community organisations and the availability of key services
— residential mobility - household members' rates of mobility out of an area, including mobility between rural areas
— financial wellbeing - household incomes, levels of financial hardship and changes in financial position
— employment
— economic impact on farmers
— family relationships - relationship separation, the quality of couple relationships, family functioning and family conflict
— mental and physical health.

Valuation

Agricultural producers have a strong understanding of the impacts of seasonality, soil replenishment (or fallowing), and other practices on the value of their assets and their capacity to produce. There is also a growing awareness and acceptance that both planning and investment are required in the medium-term to prepare for drought, flood and cyclones. These assets form part of the farm capital value.

Climate change impacts will bring greater focus to the value of these assets, and other adaptation initiatives. In particular. the scarcity of water will become an important factor in valuation. For instance, a property with secure water resources and suitable land will increase in worth relative to those lacking such assets.

[186] Australian Institute of Family Studies, *Social and economic impacts of drought on-farm families and rural communities*; Submission to the Productivity Commission's Inquiry into Government Drought Support; Prepared by Ben Edwards, Matthew Gray and Boyd Hunter https://www.pc.gov.au/inquiries/completed/drought/submissions/sub092.pdf

6 LEGISLATION, STRATEGIES, PLANS AND PROGRAMS

This chapter presents a stocktake of Commonwealth, State and Territory legislation, policies, strategies and programs covering adaptation to climate change and the management of emissions in the agricultural sector. It draws upon information publicly available from both jurisdictions and agricultural peak bodies, and details activity across jurisdictions and different agricultural activities.

The focus of the review is on contemporary legislation, policy, plans and programs across jurisdictions. The scope of consideration is generally limited to information and materials that are no more than five to seven years old. However, judgment has been exercised and some older initiatives have been included where they still are of relevance and add to contemporary considerations. New initiatives that are relevant but represent works in-train have also been added, for example the Northern Territory released a discussion in 2018 on climate change mitigation and adaptation opportunities, but this is yet to be translated into policy/program outcomes.

A key discussion point for this chapter is that of cross-jurisdiction engagement and collaboration with jurisdictions, defined as either Commonwealth, State or Territories.

This chapter is structured as follows:

— Section 6.1: - outlines the international context for future climate change impacts and agreements on how the global community will respond by setting emission reduction targets at various time intervals.

— Section 6.2: - sets the context for the Australian climate change policy response and presents, in tabulated form, the contemporary legislation, policy framework, strategies and adaptation plans, and emission reduction and climate change adaptation programs delivered by each jurisdiction.

— Sections 6.3 and 6.4: - describe the primary and secondary legislation guiding climate change emission reduction and adaptation specifically impacting agriculture.

— Section 6.5: - describes the contemporary climate change policy framework and the strategic and adaptation planning architecture for each jurisdiction. Cross-sectoral plans and approaches are also documented.

— Section 6.7: - provides a stocktake of contemporary emission reduction and climate change adaptation programs for agriculture, delivered by governments.

— Section 6.8: - assesses the current status of each jurisdiction's emission reduction and climate change adaptation legislation, policies, strategies and plans, and program architecture.

6.1 International context

The potential economic, social and environmental impacts of global climate change are well understood from a scientific perspective at a global level. The recent assessments of the Intergovernmental Panel on Climate Change (IPCC) were discussed in some detail in chapter 2 above.

International collective action on climate change is embedded in the UNFCCC (to which Australia is a party). In 1997, the Kyoto Protocol to the UNFCCC placed legally binding emissions reductions targets on developed countries. The target of 5 per cent emissions reduction below 1990 levels will not achieve sufficient emission reductions to meet the 2.0°C target.

The UNFCCC held the 21st Conference of the Parties (COP21) in Paris, December 2015. The key objective of COP21 was the development of a protocol, or another legal instrument/outcome with legal force, to give effect to the target.

Following the COP21, 195 countries agreed to seek to keep a global temperature rise this century below 2.0°C and to pursue efforts to limit the temperature increase even further to 1.5°C above pre-industrial levels. The extent to which countries honour these commitments in the face of political and economic pressures, is yet to be fully tested. The main elements of the agreement included:

- mitigation – reducing emissions fast enough to achieve the temperature goal
- a transparency system and global stock-take – accounting for climate action
- adaptation – strengthening countries ability to deal with climate impacts
- loss and damage – strengthening ability to recover from climate impacts
- support – including finance, for nations to build clean, resilient futures.

6.2 National context

The Australian Government has made an international commitment to reduce GHG emissions by 26 to 28 per cent below 2005 levels by 2030.[187] To meet existing targets, Australia's emissions reduction rate will need to almost double from its historical annual average of 2.6 per cent to 4.4 per cent.

Ratification of the Paris Agreement by Australia has generated a significant shift in domestic climate change policy and regulation. Australia's international commitment is expected to be delivered in cooperation with all states and territories, with many of the commitments for reduction within the responsibilities of State and Territory Governments.

Action by the Australian Government has primarily focused on emissions management more broadly, (incorporating agricultural sectoral considerations) and program actions to support adaptation. There are a number of national-scale climate change related policies, including the ERF, the Safeguard mechanism, the Renewable Energy Target, the Clean Energy Finance Corporation, and the Australian Renewable Energy Agency (ARENA). This range of policies and programs reflects the diversity of the challenges posed by climate change. States and territories have also acted independently and formulated climate change agendas over the last ten years, in response to international commitments.

Table 6.1 summarises legislation, policy, strategy and plans and programs relevant to emission reduction and climate change adaptation at a Commonwealth, State and Territory levels. It covers actions which are both specific to the agricultural sector and those which are economy wide (but which have relevance to, and application for, the agricultural sector).

[187] Wilder, M. Skarbek, A. Lyster, R. (2015) *Independent Review of the Climate Change Act 2010*, Victoria Government.

TABLE 6.1 CLIMATE CHANGE LEGISLATION, POLICIES, STRATEGIES AND PROGRAMS MAPPED BY JURISDICTION

Jurisdiction	Organisation	Legislation (Primary)	Legislation (Secondary)	Policies, Strategies and Plans	Programs
Australian Government	Department of the Environment and Energy	*Carbon Credits (Carbon Farming Initiative) Act 2011*	– *Environment Protection and Biodiversity Conservation Act 1999* – *Renewable Energy (Electricity) Amendment Act 2010*	– National Climate Resilience and Adaptation Strategy 2015 – Reef 2050 Long-Term Sustainability Plan (delivered in partnership with Queensland State Government)	– Emissions Reduction Fund – Clean Energy Finance Corporation – Renewable Energy Target – Regional Natural Resource Management Planning for Climate Change Fund – Climate Change in Australia Resources Management Project – National Landcare Program – 20 million trees – National Environmental Science Program (NESP) Earth Systems and Climate Change Hub
	Department of Agriculture and Water Resources (DAWR)			– National Drought Agreement (December 2018)	– Managing Climate Variability Research and Development (R&D) Program – Carbon Farming Futures (2012-17) – Funding for Rural RDCs for R&D including on climate change issues – Funding under the National Drought Agreement
	AgriFutures (coordinates)			Climate Research Strategy for Primary Industries (2017-20) (April 2017)	

Jurisdiction	Organisation	Legislation (Primary)	Legislation (Secondary)	Policies, Strategies and Plans	Programs
New South Wales	Department of Primary Industries	No climate change reduction or mitigation law	– *Protection of the Environment Operations Act 1997* – *Biodiversity Conservation Act 2016* – *Local Land Services Act 2013*	– NSW Climate Change Policy Framework (2016) – NSW Primary Industries Climate Change Research Strategy (2018) – Primary Industries Emissions and Adaptation Plans (being developed 2017 onwards)	Current – Project 1: Clean energy solutions – Project 2: Energy efficiency solutions – Project 3: Biomass for Bioenergy – Project 4: Emissions reductions pathways – Project 5: Accessing carbon markets – Project 6: Vulnerability assessment – Project 7: Climate-Smart pilots Other programs – National Livestock Methane Program – the Soil Carbon Research Program (SCaRP) National Agricultural Nitrous Oxide Research Program (NANORP)
Victoria	Department of Environment, Land, Water and Planning	*Climate Change Act 2017*	– *Environmental Protection Act 2018* – *Catchment and Land Protection Act 1994*	– Victoria's Climate Change Framework – Victoria's Climate Change Adaptation Plan (2017-2020) – Victoria's Native Vegetation Management - A Framework for Action	– Victorian Adaptation and Sustainability Partnership Grant Program
	Department of Jobs, Precincts and Regions.				– Drought Response Package – The National Centre for Farmer Health – The Agriculture Infrastructure and Jobs Fund – Agriculture Victoria Research program focused on increasing productivity, adapting to climate change and improving resource use efficiency – The Break, The Fast Break and Climate Dogs

Jurisdiction	Organisation	Legislation (Primary)	Legislation (Secondary)	Policies, Strategies and Plans	Programs
Queensland	Department of Environment and Science	No climate change reduction or mitigation law	– *Vegetation Management Act 1999* – *Environmental Protection Act 1994* – *Water Act 2000* – *Sustainable Planning Act 2009*	– Queensland Climate Transition Strategy (2017) – Pathways to a climate resilient Queensland: Queensland Climate Adaptation Strategy 2017-2030 (2017) – Queensland Climate Change Adaptation Strategy: Agriculture Sector Adaptation Plan (2017) – A Zero Net Emissions by 2050 'Green Paper' will set out the Queensland Government's post 2020 climate transition policy (in development) – Agri-food Strategy that will have regard for changes in our climate and emissions reduction (in development) – State Planning Policy – Reef 2050 Long-Term Sustainability Plan (delivered in partnership with Australian Government)	– Land Restoration Fund – Future Climate Dashboard – Climate Risk Management Matrix – AussieGrass (pasture cover) – The Drought and Climate Adaptation Program (2017-22) – Queensland Climate Science Program – Queensland Future Climate site
South Australia	Government of South Australia, South Australian Research and Development Institute (SARDI), South Australia Grain Industry Trust Fund (SAGIT)	*Climate Change and Greenhouse Emissions Reduction Act 2007*	– *Environment Protection Act 1993* – *Native Vegetation Act 1991*	– Prospering in a Changing Climate: A Climate Change Adaptation Framework for South Australia (August 2012) – Towards a Resilient State: The South Australian Governments Climate Change Adaptation Action Plan (2017) – A Guide to Climate Change and Adaptation in Agriculture in South Australia (February 2007)	– SARDI Climate Applications Science Program – SAGIT

Jurisdiction	Organisation	Legislation (Primary)	Legislation (Secondary)	Policies, Strategies and Plans	Programs
Western Australia	Department of Primary Industries and Regional Development	No climate change reduction or mitigation law	– *Environment Protection Act 1986*	– Western Australian Government: Adapting to Our Changing Climate (2012) – Planning a new climate policy (under consideration)	– Climate change information – Carbon Farming information – Improved use of seasonal forecasting to improve farmer profitability – Australian Biomass for Bioenergy Assessment – Closing the research gap - carbon farming science – Northern Australian Climate Program - Project 3 Extension Project
Tasmania	Tasmanian Government Department of Premier and Cabinet	*Climate Change (State Action) Act 2008*	– *Environmental Management and Pollution Control Act 1994* – *Forest Practices Act 1985*	– Climate Action 21: Tasmania's Climate Change Action Plan 2017-21 – Climate Action 21: Implementation Plan	– Making Cent$ of Carbon Emissions on-farm (2014) – Fert$mart program (2014-16) – Enterprise Suitability Toolkit – Water for Profit Program – On-farm Energy Audit and Capital Grant Program
Australian Capital Territory	ACT Government Environment and Planning	*Climate Change and Greenhouse Gas Reduction Act 2010*	*Environment Protection Act 1997*	ACT Climate Change Adaptation Strategy: living with a warming climate (July 2016)	– Resilient Farms: Supporting Adaptation to Climate and Market Variability – ACT NRM Sustainable Agriculture Program
Northern Territory	NT Government	No climate change reduction or mitigation law		Climate change mitigation and adaptation opportunities in the Northern Territory: Discussion paper (2018)	

SOURCE: ACIL ALLEN CONSULTING

6.3 Australian Government climate change legislation

Recognition of climate change in Australian legislation is a relatively new phenomenon. Consideration of agriculture's role in emissions reduction is primarily related to provision of carbon-offset credits for eligible activities through the *Carbon Credits (Carbon Farming Initiative) Act 2011.* **Box 6.1** provides an overview of the objectives of the Act.

BOX 6.1 *CARBON CREDITS (CARBON FARMING INITIATIVE) ACT 2011*

Carbon Credits (Carbon Farming Initiative) Act 2011

The *Carbon Credits (Carbon Farming Initiative) Act 2011* (CFI Act) enables the crediting of greenhouse gas abatement from emissions reduction activities across Australia. GHG abatement is achieved either by reducing or avoiding emissions, or by removing carbon from the atmosphere and storing it.[188]

In 2014, the Australian Government amended the CFI Act with the *Carbon Farming Initiative Amendment Act 2014*. The Act established the ERF by expanding the crediting of emissions reductions under the Carbon Farming Initiative to the non-land-based sectors of the economy. The primary objective is to assist Australia to meet its emissions reduction targets target of five per cent below 2000 levels by 2020, which is consistent with its international obligations under the UNFCCC and the Kyoto Protocol.

The ERF will purchase approved and verified emissions reductions from registered projects. The Clean Energy Regulator is empowered under the *CFI Amendment Act 2014* to conduct processes to purchase emissions reductions and enter into contracts for this purpose. ERF eligible emissions reduction activities include:[189]

Agriculture

— beef cattle herd management
— destruction of methane from piggeries using engineered biodigesters
— destruction of methane generated from dairy manure in covered anaerobic ponds
— destruction of methane generated from manure in piggeries
— estimating sequestration of carbon in soil using default values
— fertiliser use efficiency in irrigated cotton
— measurement of soil carbon sequestration in agricultural systems
— reducing GHG emissions in beef cattle through feeding nitrate containing supplements
— reducing GHG emissions in milking cows through feeding dietary additives sequestering carbon in soils in grazing systems.

Vegetation

— avoided clearing of native growth
— avoided deforestation
— designated Verified Carbon Standard projects
— human-induced regeneration of a permanent even-aged native forest
— measurement based methods for new farm forestry plantations
— native forest from managed regrowth
— plantation forestry
— reforestation and afforestation
— reforestation by mallee plantings
— Savanna fire managements (emissions avoidance and sequestration).

Impact on agriculture

There are currently 441 ERF projects contracted, 21 of which relate directly to agriculture, with a further 253 focused on vegetation management. This accounts for 143.8 Mt CO_2-e contracted emissions reductions, which is 75 per cent of all contracted projects. Vegetation projects account for 65 per cent of all ERF contracted emissions reduction.[190]

SOURCE: AUSTRALIAN GOVERNMENT (2015) DRAFT EXPLANATORY STATEMENT: ISSUED BY THE AUTHORITY OF THE MINISTER FOR THE ENVIRONMENT, CARBON CREDITS (CARBON FARMING INITIATIVE) ACT 2011. ACCESSED 7 JANUARY 2019, HTTP://WWW.ENVIRONMENT.GOV.AU/SYSTEM/FILES/CONSULTATIONS/D3AF82F4-B4D7-4BEB-A09D-15611969D52B/FILES/DRAFT-EXPLANATORY-STATEMENT-CARBON-CREDITS-RULE-2015.PDF

189 Australian Government, Department of the Environment and Energy (2015) *Emissions Reduction Fund: eligible activities.* Accessed 7 January 2019 (http://www.environment.gov.au/climate-change/government/emissions-reduction-fund/methods)

190 Department of the Environment and Energy (2018) *Emissions Reduction Fund: Opportunities for Australian business and farmers/.* Accessed 19 February 2019, (http://www.environment.gov.au/system/files/resources/a8ea4730-e2ed-4e66-b7e1-026b6e029a98/files/erf-factsheet-opportunities-businesses-and-farmers.pdf)

Table 6.2 outlines other Commonwealth legislation such as the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) which may be relevant to climate change. For example, the *EPBC Act* is focused on the protection of matters of national environmental significance, which may mean that some agricultural activities (amongst others) require approval under the Act. There is no specific reference to climate change issues in the *EPBC Act*.

TABLE 6.2 SECONDARY CLIMATE CHANGE LEGISLAITON - COMMONWEALTH

Legislation	Purpose / objectives	Climate change and agriculture reference
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)	Australia's primary environmental legislation. The Act provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places.[191]	Climate change not specifically mentioned. Agricultural developments, likely to have an impact on a 'matter of national environmental significance', may trigger the Act.
Offshore Petroleum and Greenhouse Gas Storage Act 2006	Regulates the development of petroleum resources and offshore carbon capture and storage (CCS).	CCS unlikely to be used for agricultural emissions reduction/storage.

SOURCE: ACIL ALLEN CONSULTING

6.4 State climate change legislation

6.4.1 New South Wales

New South Wales does not have primary climate change legislation. However, the *Biodiversity Conservation Act 2016*[192] and the *Local Land Services Act 2013*[193] regulate land clearing on agricultural land, which is a key contributor to emissions. Emissions generated or reduced from change in land use, through clearing or farming practices is accounted for as 'land-use changes and forestry' rather than in the agriculture category - see details at **Table 6.3**.[194] Additionally, the *Local Land Services Act 2013*, enables each Local Land Services zone to facilitate climate change adaptation programs and activities.

TABLE 6.3 SECONDARY CLIMATE CHANGE LEGISLATION – NEW SOUTH WALES

Legislation	Purpose	Climate change and agriculture reference
Protection of the Environment Operations Act 1997	To protect, restore and enhance the quality of the NSW environment.	No specific climate change reference.
Biodiversity and Conservation Act 2016	To maintain a healthy, productive and resilient environment for the community through application of ecologically sustainable development principles.	Acknowledges changing climate as a driver for conservation of biodiverse environments. Land use change, especially land clearing for agriculture, is regulated under the Act.
Local Land Services Act 2013	To work with land managers and the community to improve primary production and natural resource management.	Provides a framework for clearing native vegetation without development consent. Facilitates on-farm NRM projects, through grant programs and the provision of technical staff/expertise.

SOURCE: ACIL ALLEN CONSULTING

191 *Environment Protection and Biodiversity Conservation Act 1999*
192 Biodiversity Conservation Act 2016
193 Local Land Services Act 2013
194 Commonwealth of Australia (2018) Australia's Emissions Projections 2018

6.4.2 Victoria

The Victorian *Climate Change Act 2017* was introduced to replace the *Climate Change Act 2010*. The Act:

— establishes a long-term emissions reduction target of net zero by 2050
— requires five yearly interim targets, to keep Victoria on track to meet this long-term target
— introduces a new set of policy objectives and an updated set of guiding principles to embed climate change in government decision making
— requires the government to develop a Climate Change Strategy every five years, which will set out how Victoria will meet its targets and adapt to the impacts of climate change (from 2020)
— requires Adaptation Action Plans for key systems that are either vulnerable to the impacts of climate change or essential to ensure Victoria is prepared (from 2021)
— establishes a pledging model to reduce emissions from the government's own operations and across the economy (from 2020)
— establishes a system of periodic reporting to provide transparency, accountability and ensure the community remains informed.[195]

The 2010 Act was reviewed in late 2011, triggered by the introduction of the *Clean Energy Act 2011* by the Australian Government.[196] In 2015, the Act was independently reviewed for a second time, in accordance with *section 18* of the Act. This review focused on the effectiveness of emissions reduction - the recommendations made by the Review are shown in **Box 6.2**. [197] The *Climate Change Act 2017* was passed by the Victorian parliament to give effect to the recommendations.[198]

BOX 6.2 INDEPENDENT REVIEW OF *CLIMATE CHANGE ACT 2010* - RECOMMENDATIONS

— Recommended inclusion of **long-term emissions reduction targets** that are based on best available science and that can be adjusted in consideration of new information. This target would be focused on pursuing efforts to limit temperature increase to 1.5 degrees, as aligned with the Paris Agreement in 2015.
— A current weakness in government is the lack of consideration for climate change in government decision making. There is no requirement in the Act to make decisions which consider the climate change principles in the Act. There are no guidelines which explain how climate change should be considered in decision making. **Development of a Climate Change Charter** is recommended. The Victorian Climate Change Strategy needs to be consistent with the charter.
— All decision making needs to consider climate change principles identified in the new Climate Change Charter. When making decisions, there must be consideration for **how a decision will impact the achievement of the emissions reduction target.**
— Further risk assessment to consider decisions that may influence climate change mitigation, adaptation and disaster risk reduction outcomes.
— Replace the Climate Change Adaptation Plan with a **five-yearly Victorian Climate Change Strategy** that addresses climate change mitigation and adaptation and disaster risk reduction.
— Government should **estimate cost of government actions**, decisions, procurement, and investments that result in GHG emissions. This could include shadow carbon pricing or costing climate mitigation measures that could be required with new infrastructure to protect it from floods, bushfires and sea level rises.

SOURCE: WILDER, M. SKARBEK, A. LYSTER, R. (2015) INDEPENDENT REVIEW OF THE CLIMATE CHANGE ACT 2010, VICTORIA GOVERNMENT.

Table 6.4 shows the secondary legislation covering climate change emissions reduction and adaptation issues relevant to agriculture. The *Catchment and Land Protection Act 1994*[199] enables catchment management authorities to develop regionally specific strategies for climate change mitigation and adaptation programs for land holders.[200]

195 Climate Change Act 2010 (Victoria)
196 Clean Energy Act 2011
197 Wilder, M. Skarbek, A. Lyster, R. (2015) *Independent Review of the Climate Change Act 2010*, Victoria Government. p.13
198 Climate Change Act 2017 (Victoria)
199 Catchment and Land Protection Act 1994
200 North East Catchment Management Authority (2016), North East Climate Ready Strategy. Accessed 7 January 2019, https://www.necma.vic.gov.au/Projects/Past-projects/NRM-Planning-for-Climate-Change

TABLE 6.4 SECONDARY CLIMATE CHANGE LEGISLATION - VICTORIA

Legislation	Purpose	Climate change and agriculture reference
Environmental Protection Act 2018	Prevention of harm to human and environmental health through application of a general duty of care.	No specific climate change reference.
Catchment and Land Protection Act 1994	Integrated management of catchments across Victoria. 10 catchment management authorities established.	No reference to climate change in the Act. However, the Catchment Management Authorities have developed climate change adaptation plans/strategies.

SOURCE: ACIL ALLEN CONSULTING

6.4.3 Queensland

Queensland has no primary climate change legislation. **Table 6.5** shows the secondary legislation covering climate change emissions reduction and adaptation issues relevant to agriculture. The *Vegetation Management Act 1999*[201] regulates land clearing and specifies conservation of land for the purpose of GHG emissions reduction. Similar to other states, the *Environmental Protection Act 1994* is focused on ecologically sustainable development, which may be triggered by some large-scale agricultural developments.[202]The *Water Act 2000* and *Sustainable Planning Act 2009* provide examples of how climate considerations are being incorporated into other legislative instruments and delivering actions under the Queensland Climate Adaptation Strategy (see Section 6.5.4), despite the lack of dedicated climate change legislation.

TABLE 6.5 SECONDARY CLIMATE CHANGE LEGISLATION - QUEENSLAND

Legislation	Purpose	Climate change and agriculture reference
Vegetation Management Act 1999	Regulates land clearing to conserve vegetation for specific purposes including to conserve: – remnant vegetation – vegetation in declared areas – prevent loss of biodiversity etc.	Conservation of land for the purpose of reducing GHG emissions.
Environmental Protection Act 1994	Protects Queensland's environment while allowing for ecologically sustainable development.	No specific climate change reference/trigger.
Water Act 2000	Provision of sustainable management of water and the management of impacts on underground water, and for other purposes.	Requires consideration of water-related effects of climate change on water availability, water use practices and risks to water resources when developing a water use plan.
Sustainable Planning Act 2009	A framework to integrate planning and development and its effects are managed in an ecologically sustainable manner.	Ensures decision-making processes consider the effects of the proposed development on climate change.
Nature Conservation Act 1992	The conservation of nature is achieved by an integrated and comprehensive conservation strategy.	The definition of threatening processes under the Act captures climate change.

SOURCE: ACIL ALLEN CONSULTING

201 Vegetation Management Act 1999
202 Environmental Protection Act 1994

6.4.4 South Australia

The *Climate Change and Greenhouse Emissions Reduction Act 2007* was the first state legislation to specifically target greenhouse emission reduction.[203] The legislation sets three targets:

1. reduce GHG emissions within the State by at least 60 per cent to an amount that is equal to, or less than, 40 per cent of 1990 levels by 31 December 2050 as part of a national and international response to climate change
2. increase the proportion of renewable electricity generated so it comprises at least 20 per cent of electricity generated in the State by 31 December 2014
3. increase the proportion of renewable electricity consumed so that it comprises at least 20 per cent of electricity consumed in the State by 31 December 2014.

The Act is primarily focused on the reduction of emissions from energy production and increasing the consumption of electricity from renewable sources.

Table 6.6 shows the secondary legislation covering climate change emissions reduction and adaptation issues relevant to agriculture.

TABLE 6.6 SECONDARY CLIMATE CHANGE LEGISLATION – SOUTH AUSTRALIA

Legislation	Purpose	Climate change and agriculture reference
Native Vegetation Act 1991	Protection of native vegetation and sets out process for applying to the clearance of vegetation.	No specific reference to climate change. Covers pastoral leases and encourages landholders to conserve vegetation.
Environment Protection Act 1993	Protection of the environment and use of ecologically sustainable development.	No specific reference to climate change or agriculture.

SOURCE: ACIL ALLEN CONSULTING

6.4.5 Western Australia

There is no primary climate change legislation in Western Australia. **Table 6.7** shows the secondary legislation covering climate change emissions reduction and adaptation issues relevant to agriculture.

TABLE 6.7 SECONDARY CLIMATE CHANGE LEGISLATION – WESTERN AUSTRALIA

Legislation	Purpose	Climate change and agriculture reference
Environmental Protection Act 1986	Protection of the environment and sustainable development.	No climate change reference. Regulation of vegetation clearing on agricultural land.

SOURCE: ACIL ALLEN CONSULTING

6.4.6 Tasmania

The *Climate Change (State Action) Act 2008* is the primary climate change legislation for Tasmania.[204]

The objective of the Act is to address issues related to climate change through setting a target for the reduction of GHG emissions in the State as a component of the national and international response to climate change. Other objectives include to:

— set interim emissions reduction targets

— identify opportunities for new social, economic and environmental opportunities that climate change will present

— promote energy efficiency and conservation

203 Climate Change and Greenhouse Emissions Reduction Act 2007
204 Climate Change (State Action) Act 2008

— promote research and development in the development of technologies focused on emissions reduction and adaptation.

The Act does not have explicit provisions for agriculture specific emissions reduction or adaptation targets or activities.

Table 6.8 shows the secondary legislation covering climate change emissions reduction and adaptation issues relevant to agriculture.

TABLE 6.8 SECONDARY CLIMATE CHANGE LEGISLATION – TASMANIA

Legislation	Purpose	Climate change and agriculture reference
Environmental Management and Pollution Control Act 1994	Protection of the environment and sustainable development.	No reference to climate change or agriculture.
Forest Practices Act 1985	Achieve sustainable management of private and public forests with consideration for the environment, taking into account social, economic, and environmental outcomes.	No reference to climate change, but does consider regulation of land clearing for agricultural uses.

SOURCE: ACIL ALLEN CONSULTING

6.4.7 Australian Capital Territory

The Australian Capital Territory's primary climate change legislation is the *Climate Change and Greenhouse Gas Reduction Act 2010.* The objectives of the Act are to.[205]

— set targets to reduce GHG emissions, and increase renewable energy use and generation in ACT

— provide for monitoring of and reporting on progress made in the ACT to meet the targets

— facilitate the government's development of policies and programs to meet the targets and to address and adapt to climate change

— encourage private entities to act to address climate change and recognise the entities that take action.

Table 6.9 shows the secondary legislation covering climate change emissions reduction and adaptation issues relevant to agriculture.

TABLE 6.9 SECONDARY CLIMATE CHANGE LEGISLATION – AUSTRALIAN CAPITAL TERRITORY

Legislation	Purpose / objectives	Climate change and agriculture reference
Environment Protection Act 1997	Protect and enhance the quality of the environment. Facilitate the implementation of national environment protection measures under national laws. Coordinate activities needed to protect, restore or improve the ACT environment.	Climate change not mentioned.

SOURCE: ACIL ALLEN CONSULTING

6.4.8 Northern Territory

Northern Territory does not have a primary climate change legislation. **Table 6.10** shows the secondary legislation covering climate change emissions reduction and adaptation issues relevant to agriculture.

[205] Climate Change and Greenhouse Gas Reduction Act 2010

TABLE 6.10 SECONDARY CLIMATE CHANGE LEGISLATION – NORTHERN TERRITORY

Legislation	Purpose	Climate change and agriculture reference
Environmental Assessment Act 2013	Provides for the assessment of environmental impacts of development proposals and for the protection of the environment.	No reference to climate change or agriculture.

SOURCE: ACIL ALLEN CONSULTING

6.5 Strategies, policies and plans

This section provides a brief snapshot of some of the key strategies, policies and plans adopted in each jurisdiction to address climate change adaptation and emissions management. It includes both economy-wide approaches, as well as those specifically focused on the agricultural sector.

6.5.1 Australian Government

National Climate Resilience and Adaptation Strategy 2015

The Strategy articulates the Australian Government's approach to adaptation to climate change through a set of guiding principles and identifies priority areas to focus future government consultation and action.

Development of the Strategy drew upon the National Climate Change Adaptation Framework 2007 which addressed cooperation between the Australian and State governments on regions and priority sectors such as water resources; coastal regions; biodiversity; agriculture, fisheries and forestry; human health; tourism; settlements; infrastructure and planning; and natural disaster management.

The future risks to agriculture and the approach government is taking to improve the resilience of the agricultural sector are identified. For example, the Strategy provides support to the Tasmanian Government for its Enterprise Suitability Mapping Project, which assess the suitability of priority crops (poppies, wheat, potatoes, wine grapes and barley) in simulated 2050 climate scenarios.[206]

The guiding principles for building national climate resilience and adaptation are:

— shared responsibility
— factoring climate risks into decision making
— an evidence-based, risk management approach
— helping the vulnerable
— supporting collaborative, values-based choices
— revisiting decisions and outcomes over time.

Priorities for national engagement include:

1. Priority one: understand and communicate
2. Priority two: plan and act
3. Priority three: check and reassess
4. Priority four: collaborate and learn.

The Strategy highlights the principle of shared responsibility, which considers governments at all levels, businesses, communities and individual responsibilities for managing climate risks. Community consultation and continued coordination between the states and territories is a priority to achieve adaptation objectives.

[206] Commonwealth of Australia (2015) *National Climate Resilience and Adaptation Strategy*. Accessed 8 January 2019, http://www.environment.gov.au/system/files/resources/3b44e21e-2a78-4809-87c7-a1386e350c29/files/national-climate-resilience-and-adaptation-strategy.pdf

Reef 2050 Long-Term Sustainability Plan

In 2015, The Reef Long-Term Sustainability Plan 2050 was released. The Plan outlines the Australian and Queensland Governments' shared approach to protect the Great Barrier Reef through building resilience to a changing climate, by:

- support of emissions reduction activities funded through the Emissions Reduction Fund
- support of best practice community stewardship activities
- improvement to Queensland's coastal planning laws to consider predicted effects of climate change
- improvement of water quality through implementing the Reef Water Quality Protection Plan, which sets targets for reduction of sediment, nitrogen and pesticide load run-off
- managing coastal land use - ports and dredging
- shipping safely through Reef waters
- ecologically sustainable fishing.[207]

The updated Plan alters the water quality targets so that they align with the Reef 2050 Water Quality Improvement Plan 2017-22.[208] [209] This reflects the renewed urgency of improving water quality on the Reef through reduced run-off of fertiliser and pesticides, of which agriculture in the primary contributor. The Plan specifies the roles and responsibilities of stakeholders in different sectors, industries and jurisdictions which contribute to issues facing the reef, and the practice changes required to meet future targets.

The strength of the Plan is the specificity of actions required to reduce climate change impacts on the Reef and the thorough definition of the stakeholder responsibilities. Furthermore, the update of objective targets for water quality indicators, in response to the new evidence following coral bleaching events in 2016 and 2017, demonstrates the Plan's flexibility and robustness.

National Drought Agreement (December 2018)

Recognising that droughts are part of Australia's landscape and that managing drought is a feature of Australian agriculture, jurisdictions have agreed to cooperate and collaborate on drought-related issues. The Agreement outlines responsibilities when supporting farming businesses, farming families and farming communities and continues to build on drought policy reform over the past decade. It focuses on assisting Australian farming businesses and farming communities to continue to adopt increasingly sophisticated and effective strategies to deal with drought and respond to climate change and variability.

It prioritises objectives and outcomes that enhance long-term preparedness; sustainability; resilience; and risk management for farming businesses and farming communities in Australia. The Agreement provides a framework to enable consistency of drought policy and reform objectives and complementarity of drought preparedness, response and recovery programs.

The Agreement also complements other measures taken by jurisdictions to promote adaptation to climate change.

6.5.2 New South Wales

New South Wales Climate Change Policy Framework (2016)

The New South Wales Climate Change Policy Framework is designed in response to the NSW Government's endorsement of the Paris Agreement. The State's aspirational goal is to achieve net-zero emissions by 2050. The policy framework defines the New South Wales Government's role in carbon emission reduction and climate change adaptation measures and sets policy directions to

[207] Commonwealth of Australia (2018) *Reef 2050 Long-Term Sustainability Plan.* Accessed 8 January 2019, http://www.environment.gov.au/system/files/resources/35e55187-b76e-4aaf-a2fa-376a65c89810/files/reef-2050-long-term-sustainability-plan-2018.pdf

[208] Commonwealth of Australia (2018) *Reef 20150 Water Quality Improvement Plan 2017-22*. Accessed 20 February 2019, https://www.reefplan.qld.gov.au/about/assets/reef-2050-water-quality-improvement-plan-2017-22.pdf.

[209] It is noted that reference to land-use impacts on the Great Barrier Reef Heritage Area should be sourced from the 2017 Scientific Consensus Statement: Land use impacts on Great Barrier Reef Water Quality and Ecosystem Condition

guide implementation of the framework.[210] Delivery of the framework is broken down into the following steps:

— develop a Climate Change Fund Strategic Plan
— develop value for emissions savings
— embed climate change considerations into government decision making
— develop action plans and strategies
  – in 2017, it was announced that three action plans would be developed, including a plan for advanced energy, energy efficiency and climate change adaptation plans, of which, management of impacts on natural resources and ecosystems and communities would be a focus (the plan is still under preparation)
— opportunities and risks for primary industries emissions and adaptation to be explored by NSW DPI.

The policy framework provides limited detail on the engagement or coordination approach for the policies and adaptation strategy development. Adaptation plans are mentioned as actions being investigated by agencies, but at this time, any adaptation or agriculture specific strategy is still to be released.

New South Wales Primary Industries Climate Change Research Strategy (2018)

The Primary Industries Climate Change Research Strategy sets out strategic priority areas for new and existing research programs that will support primary industries adapt to climate change. The primary drivers for the strategy are the understanding that, in New South Wales, agriculture contributes 13 per cent of the State's GHG emissions. The primary sources of emissions are:

— CH_4 (methane) released from cow and sheep digestion
— manure
— rice cultivation
— NO_x emissions from agricultural soils
— use of diesel fuel for tractors and machinery
— irrigated agricultural practices.

Investment is focused on the following three key areas:

1. Energy - clean energy solutions, information on new technologies/practices to address rising energy costs, and alternate electricity generation options
2. Carbon opportunities - preparation of primary industries for net zero emissions by identifying emission reduction and sequestration opportunities and helping farmers to access carbon markets
3. Climate resilience - develop knowledge of the vulnerability of primary industries to climate change and test new technologies and adaptation options to respond to climate change.

Table 6.11 lists the program areas and projects under the Strategy.

TABLE 6.11 RESEARCH PROGRAM INVESTMENT AREAS

Area	Project	Description
Energy	Project 1: Clean energy solutions	Fund innovative energy projects to support clean energy and local energy for primary producers.
	Project 2: Energy efficiency solutions	Help energy-intensive farms identify options to improve their energy efficiency and reduce costs.
	Project 3: Biomass for Bioenergy	Investigate electricity generation using organic matter (biomass).
Carbon opportunities	Project 4: Emissions reduction pathways	Investigate the feasibility of emissions reduction and carbon sequestration options to support primary industries plan to reduce emissions.

[210] NSW Government, Office of Environment and Heritage (2016) *NSW Climate Change Policy Framework.* Accessed 8 January 2019, https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Climate-change/nsw-climate-change-policy-framework-160618.pdf

Area	Project	Description
	Project 5: Accessing carbon markets	Develop new tools for farmers to generate income from access to carbon markets.
Climate resilience	Project 6: Vulnerability assessment	Deliver research to understand the vulnerability and adaptability of primary industries to climate change.
	Project 7: Climate-Smart pilots	Support farmers' pilot projects that build resilience in rural communities and primary industry.

SOURCE: NSW DEPARTMENT OF PRIMARY INDUSTRIES (2018) CLIMATE CHANGE RESEARCH STRATEGY

The Strategy does not specify engagement or coordination of programs across jurisdictions. However, research programs focused on modellings and forecasting, for example, Project 6: Vulnerability Assessment, engages BoM and CSIRO.

6.5.3 Victoria

Victoria has a number of initiatives aimed at improved planning practices taking account of climate change, perhaps best exemplified by the North East Climate Ready NRM strategy outlined in **Box 6.3**.

BOX 6.3 THE NORTH EAST CLIMATE READY NRM STRATEGY - VICTORIA

The North East Regional Catchment Strategy is the primary integrated planning framework for land, water, and biodiversity management in North East Victoria, of which the North East Climate Ready NRM strategy is a sub-strategy. The project is supported by the North East Catchment Management Authority (CMA), through funding from the Australian Government. The strategy outlines the following:

— climate change implications for natural resources in North East Victoria
— approaches to adaptation planning including R&D
— mitigation options in the North East
— implementation planning.

Objectives of the Strategy include identifying:

— priority landscapes for climate change adaptation and mitigation
— management actions to increase the resilience of these landscapes to climate change
— risks and opportunities of market driven carbon sequestration activities.

Adaptation planning

R&D priorities are identified, such as a review of the performance of groundwater system modelling under future climate scenarios and progress implications of the review. Such projects involve collaboration other agencies – The Department of Environment, Land, water and Planning, Victoria (DELWP) for implementation and Goulburn Murray Water for support.

Mitigation options in the North East

The Strategy refers to the ERF for options for emissions reduction (see Section 6.3 for ERF details).

SOURCE: NORTH EAST CATCHMENT MANAGEMENT AUTHORITY (2016) NORTH EAST CATCHMENT STRATEGY. ACCESSED 7 JANUARY 2019, HTTPS://WWW.NECMA.VIC.GOV.AU/ABOUT-US/PUBLICATIONS/STRATEGIES/REGIONAL-CATCHMENT-STRATEGY

6.5.4 Queensland

Queensland Climate Transition Strategy (2017)

In response to Australia's ratification of the Paris Agreement, the Queensland Government has made the following three climate change policy commitments:

1. 50 per cent renewable energy by 2030
2. achieving zero net emissions by 2050
3. an interim emissions reductions target of at least 30 per cent below 2005 levels by 2030.[211]

211 Department of Environment and Heritage Protection (2017) *Queensland Climate Transition Strategy*. Accessed 8 January 2019, https://www.qld.gov.au/__data/assets/pdf_file/0026/67283/qld-climate-transition-strategy.pdf

The Queensland Climate Transition Strategy outlines how the State will meet its 2030 targets. The strategy acknowledges the following State strengths and competitive advantages:

- a skilled workforce
- solar, wind and natural resources
- capacity for carbon sinks
- a strong innovation and research sector.

A two-stage approach to transition is outlined in the Strategy. This includes engaging in the national policy debate to secure outcomes for Queensland, as well as focusing on de-carbonising the energy sector. Economic trend analysis will be used to underpin Queensland's policy framework beyond 2019.

The Transition Strategy's focus areas relevant to agriculture are primarily centred on expansion of carbon farming in Queensland, through off-set programs that incentivise farmers to revegetate land, including to diversify land use for carbon farming, organic, solar and wind farms.

The Queensland Climate Advisory Council (consisting of business, industry and research leaders) provides advice to the Queensland Government on opportunities and directions to meet the transition to a zero net emissions State economy. While this governance function enables engagement across Queensland, it is unclear as to how engagement across jurisdictions might be undertaken. However, Queensland University of Technology and Griffith University have formed international partnerships through the Global Business Challenge and there are clearly opportunities for collaboration across regions and sectors with shared responsibilities for climate change issues.

Pathways to a climate resilient Queensland: Queensland Climate Adaptation Strategy (Q-CAS) 2017-2030 (released 2017)

Q-CAS prepares Queensland to both mitigate the risks and harness the opportunities arising from climate change. The Queensland Climate Adaptation Strategy Partners Group was formed to inform and support development of Q-CAS, and includes representatives from industry, community and research sectors. Agricultural sector interests are represented by the peak industry bodies, AgForce, the Queensland Farmers' Federation and Growcom with research provided by CSIRO. Other sectors with peak body representation include tourism, resources and property.[212]

QCAS's primary objectives are to:

- recognise - ensure the community understands the risks and opportunities that climate change presents
- equip - provide the community with access to the best available science and risk analysis tools to support adaptation decisions
- integrate – ensure climate adaptation is integrated into policies and processes
- collaborate - form partnerships across communities, education institutions, government and industries.

The pathways for enabling adaptation to climate change include:

- people and knowledge - empower best practice climate science, education and engagement to support climate risk management within Queensland's communities
- State Government - embed the consideration of climate change into decision making, policies, regulations and procedures, and risk assessment in relation to assets and services
- local government and regions - form partnerships between governments and regional organisations to develop adaptation solutions and embed climate change risk planning and development into decision making
- sectors and systems - enable industry and sectors to collaborate and engage with government and stakeholders to identify adaptation needs and to prioritise adaptation activities.

Implementation plans have been developed for each adaptation pathway:

[212] Department of Environment and Heritage Protection (2017) *Pathways to a climate resilient Queensland: Queensland Climate Adaptation Strategy 2017-2030*. Accessed 8 January 2019, https://www.qld.gov.au/__data/assets/pdf_file/0017/67301/qld-climate-adaptation-strategy.pdf

- a Community Engagement Plan and Science Program; a Government Adaptation Action Plan; and Sector Adaptation Plans
- Queensland Climate Resilient Councils.

These Plans were developed in partnership with key stakeholders to facilitate sectoral collaboration and identify and address common climate change issues. Local governments and NRM groups are considered important stakeholders in addressing cross-sectoral issues at a regional level. Although other jurisdictions are not directly engaged in the Q-CAS, the partners that contributed to its development have cross-jurisdictional responsibilities, particularly research providers such as CSIRO, the National Climate Change Adaptation Research Facility (NCCARF) and the Rural RDCs.

Sector adaptation plans addressing agriculture (described below) and the built environment and infrastructure sectors were the first to be developed, followed by tourism; human health and wellbeing; biodiversity and ecosystems; emergency management; small and medium enterprises; and industry and resources. Finally, the State Planning Policy links with Queensland policies through consideration of the projected climate change impacts on State interests, including agriculture.

Queensland Climate Adaptation Strategy: Agriculture Sector Adaptation Plan (2017)

The Queensland Climate Adaptation Strategy: Agriculture Sector Adaptation Plan outlines the international and national climate change science and policy context with implications for Queensland's agricultural sectors. The focus of the Plan is on-farm adaptation and it does not include post farm-gate supply chain issues. However, supply chain level adaptation strategies that support on-farm adaptation are covered. The Plan provides an overview of:

- agricultural industries - aquaculture, cotton, extensive livestock, forestry, grains, horticulture and viticulture, intensive livestock industries, sugarcane
- the current state of climate adaptation in Queensland
  - understanding the adaptive capacity
  - research arrangements underpinning knowledge of climate adaptation
  - current responses and progress towards climate adaptation
- existing primary adaptation programs including
  - The Long Paddock (a web-based Queensland Government initiative providing seasonal climate and pasture condition information to the grazing community)
  - Queensland Government Drought and Climate Adaptation Program (DCAP).

The Plan assesses the gaps and potential barriers within the current adaptation approaches and programs and uses this analysis to form recommendations for priority areas for government and industry to focus their actions on to enhance climate change adaptation measures.[213] These actions seek to:

- optimise access to climate hazard information and projections at scales that can inform industry and farm-level risk assessments
- continue to develop and refine tools and resources that support farm, regional, supply chain and industry-level management decision-making
- support the delivery of facilitation and engagement programs
- improve access to necessary finance and agricultural insurance
- explore mechanisms to enable climate risk management and climate adaptation to be addressed across agricultural supply chains
- enhance investment in programs and initiatives that support and catalyse innovation and resilience, with a particular focus on the 'next generation' in the agricultural sector.

The Plan engages all commodity sectors through peak industry bodies, agricultural service sectors and local groups. A strength of the Plan is that it sets out cross-sectoral (non-agriculture) priorities that are fundamental for agricultural sector adaptation, including:

213 Department of Environment and Heritage Protection (2017) *Queensland Climate Adaptation Strategy: Agriculture Sector Adaptation Plan*. Accessed 7 January 2019, https://www.qld.gov.au/__data/assets/pdf_file/0027/67626/agricultural-sector-adaption-plan.pdf

- a robust transport infrastructure which is essential for agriculture, specifically the resilience of the road and bridge network during future extreme weather events
- affordable and reliable energy supply
- the reliance and symbiotic relationship between agricultural industries and the tourism sector as a source of casual and skilled farm labour.

The Plan has potential for greater cross-jurisdiction collaboration at an individual sector level. For example, stakeholders with responsible for adaptation within sectors, such as for cotton (Cotton Australia, irrigation groups and the Cotton RDC, as well as private consultants) have indicated support to work on adaptation at a cross-jurisdiction level, rather than traditional state or local government boundaries. Actions under the Plan are also feeding into the cross-jurisdictional collaboration facilitated by the Adaptation Working Group (under the Meeting of Environment Ministers) and related activities, such as Victoria's Sector Adaptation Workshop in May 2018.

Implementation of recommended actions is underway (one project led by Queensland Farmers Federation (QFF)) with more to follow under a sector adaptation co-investment program. Other recommendations from multiple Sector Adaptation Plan are also already being implemented through other programs under the Q-CAS (such as the Future Climate Dashboard arising from the climate science program).

A Zero Net Emissions by 2050 'Green Paper'

A Zero Net Emissions by 2050 'Green Paper' is currently being developed. It will set out the Queensland Government's post 2020 climate transition policy. Queensland has also announced the development of an Agribusiness Strategy Green Paper (the Paper is in the in early stages of development). A timeline for delivery is yet to be set.

Agri-food Strategy (in development)

Queensland is developing a new agri-food strategy that will have regard to changes in climate and emissions reduction.

6.5.5 South Australia

Prospering in a Changing Climate: A Climate Change Adaptation Framework for South Australia August 2012

The Climate Change Adaptation Framework for South Australia is designed to guide action by business, the community, non-government organisations, the research sector and local and state government agencies, engaged in the development of adaptation response plans.[214]

The Framework's objectives include:

- leadership and strategic direction for building a more resilient State
- policy responses founded on the best scientific knowledge
- resilient, well-functioning natural systems and sustainable, productive landscapes
- resilient, healthy and prosperous communities.

The Framework is organised around five sections, namely:

1. Section one - describes the reasons for needing to adapt to climate change; articulates the roles and responsibilities of all parties; and outlines South Australia's early adaptation responses and opportunities
2. Section two - provides overall guidance for climate change adaptation activity in South Australia by outlining objectives and guiding principles
3. Section three - outlines the regional approach to climate adaptation and defines the mechanisms for how it will be undertaken
4. Section four - outlines the impacts and challenges arising from the need to adapt to climate change, organised into 12 regional themes

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214 Government of South Australia, Department of Environment, Water and Natural Resources (2012) Prospering in a Changing Climate: A Climate Change Adaptation Framework for South Australia August 2012

5. Section five - describes the implementation process for the Framework.

Central to the adaptation Framework is the development of regional adaptation plans, with twelve plans developed by 2016.[215]

These adaptation plans (described below) are developed in conjunction with business, industry and communities. The approach is different to other states, in that regional jurisdictions develop action plans through a 'bottom-up' approach, rather than at a commodity or whole-of-agriculture level. The action plans draw on earlier work (A guide to Climate Change and Adaptation in Agriculture in South Australia) released in 2007.

Towards a Resilient State: The South Australian Government's Climate Change Adaptation Action Plan (2017)

The Action Plan outlines 15 priority adaptation action areas which are considered essential to South Australia's future prosperity. It identifies primary industries as a priority. The priorities for the agricultural sector are to develop climate resilient farming systems and improve climate risk management in key South Australian primary industry sectors.

The Department of Environment, Water and Natural Resources and Department of Primary Industries and Regions, South Australia (PIRSA) lead the work programs specified in the Action Plan. The action areas and supporting adaptation plans are developed through a 'bottom up' approach, enabling NRM boards, Regional Development Australia, local government associations, business and communities to contribute to developing the plans, with support from the South Australian and Australian Governments.[216]

This approach encourages tailored approaches to adaptation by regional areas, which recognises the different impacts climate change will have regionally. While this may potentially cause duplication in the adaptation response process, the localised development of plans encourages ownership at an individual, community and business level, which may be more effective.

Box 6.4 provides an example of a regionally developed climate adaptation action plan.

215 Government of South Australia, Department of Environment, Water and Natural Resources (2016) *Regional Adaptation Plans*. Accessed 9 January 2019, https://www.environment.sa.gov.au/topics/climate-change/programs-and-initiatives/adapting-to-climate-change/regional-adaptation-plans

216 Government of South Australia (2017) Towards a Resilient State: The South Australian Government's Climate Change Adaptation Action Plan. Accessed 9 January 2019, *https://www.environment.sa.gov.au/topics/climate-change/programs-and-initiatives/adapting-to-climate-change*

BOX 6.4 YORKE AND MID NORTH REGIONAL CLIMATE CHANGE ACTION PLAN - SUMMARY

Overview

The action plan provides a summary of climate change impacts relevant to the region and differences between industry sectors. For the Yorke and Mid North, for example, despite the expected climatic impacts, many industries in the region, like dryland agriculture, have a high level of adaptive capacity. However, industries like commercial fisheries, aquaculture and manufacturing, that rely heavily on inputs, utilities or infrastructure that are vulnerable to a change in climate and cannot transition quickly may need assistance.

Who developed the plan

The Yorke and Mid North Regional Climate Change Action Plan was prepared by the Central Region of Councils, Regional Development Australia, Yorke and Mid North and the Northern and Yorke Natural Resources Management Board (the Regional Alliance), with support from the South Australian Government.

Regional actions

Region action priorities are identified, including regional coordination and leadership, biodiversity, water resource management, industry and workforce development. An example of the types of actions that might be specified for key focus areas is provided by the 'Regional Coordination and Leadership' focus point.

Regional Coordination and Leadership

Actions specified under the 'Regional Coordination and Leadership' focus point include:

— continue leadership and coordination through the Yorke and Mid North Regional Alliance
— undertake a business case for a Regional Sustainability Centre
— identify and promote local climate change initiatives
— establish a network of regional climate change decisions makers and provided targeted information of climate change vulnerability at a local level
— regular review and update of regional climate change vulnerability assessment and adaptation priorities.

The Action Plan specifies state-wide actions, which assures alignment of cross-regional issues. Examples relevant to agriculture include:

— build state-wide expertise in carbon farming and soils
— provide support for national-level sector research to develop adaptation pathways for biodiversity management and landholders relevant to the region.

Priority projects

The priority projects for the Plan include: a Regional Sustainability Centre, Coastal Digital Elevation Modelling, and a Low Carbon Transition Prospectus. An example of a priority project for the region is provided below:

Regional Sustainability Centre

The future of the region will continue to be based on sustainable agriculture and viticulture, along with emerging growth in low carbon technologies, underpinned by sustainable living and resilient rural communities. Successful climate change adaptation in the region needs to be based on regionally relevant and accessible research and an engaged community with the information and skills to adapt. The Regional Alliance is working with a number of research, educational and industry partners to progress a regional precinct style Sustainability Centre to help coordinate research efforts, showcase innovation, and provide a knowledge and educational hub and an adaptive industry cluster for the region.

SOURCE: YORKE AND MID NORTH REGIONAL CLIMATE CHANGE ACTION PLAN – SUMMARY. ACCESSED 9 JANUARY 2019, HTTPS://WWW.ENVIRONMENT.SA.GOV.AU/TOPICS/CLIMATE-CHANGE/PROGRAMS-AND-INITIATIVES/ADAPTING-TO-CLIMATE-CHANGE/REGIONAL-ADAPTATION-PLANS

6.5.6 Western Australia

Western Australian Government: Adapting to Our Changing Climate (2012)

Adapting to Our Changing Climate, which was released in 2012, was developed in the context of a national price on carbon.[217]

The document identified four approaches to continue building foundations for a profitable agricultural sector challenged by climate change:

[217] Government of Western Australia (2018) *McGowan Government to develop new climate change policy – media statement*. Accessed 11 January 2019, https://www.mediastatements.wa.gov.au/Pages/McGowan/2018/12/McGowan-Government-to-develop-new-climate-change-policy.aspx

1. improve the provision of information to key stakeholders to enhance their understanding of future risks associated with climate change
2. assist land managers to benefit from carbon capture opportunities
3. support development and commercialisation of technology to increase the resilience of agricultural businesses to climate change
4. support research to enable adaptation to a changing climate, such as new crop varieties that can thrive in hotter and drier climates.

In December 2018 the Western Australian Government announced plans to develop a new climate change policy.

Climate-ready agriculture: a situation statement for Western Australia

The situation statement provides an assessment of how climate-ready the State's agricultural sectors are and provided guidance for investment priorities for the (then) Department of Agriculture and Food for the period 2015–2020.[218]

The situation statement built on the Western Australian Government's Adapting to our changing climate document, detailing investment opportunities for each of the four approaches, which seek to give effect to the Western Australia's goal to double the value of the agricultural sector by 2025. It recognised that it is unlikely that climate changes within the next 10 years will impede achieving this goal, but seasonal variability will pose progressively greater challenges. Long-term climate change will challenge the industry's continued productivity and profitability. DAFWA identified actions to achieve each of the investment principles. These actions form the basis of our investment priorities to assist the agricultural industry to address the impacts of climate change.

The statement concludes that in the short to medium-term, the most important climate issue is to increase enterprise resilience to climate variability. Climate change is broadly acknowledged as a long-term issue. To address these priorities, there are some commonly identified research and development themes including:

— systems-based research to continue delivering incremental adaptations for short to medium-term climate variability and change
— improved weather forecasting and making climate projections available at a local scale
— a better understanding of the potential long-term impacts of climate projections on farming systems and related industries.

6.5.7 Tasmania

Climate Action 21: Tasmania's Climate Change Action Plan 2017-21

Climate Action 21 is the Tasmanian Government's action plan aimed at curbing GHG emissions. It recognises Australia's commitment to the Paris Agreement and outlines a practical action plan to meet the global challenge. Following the release of Climate Action 21, Tasmania achieved zero net emissions in 2015-16.[219] Climate Action 21 outlines six priorities as follows:

1. understanding Tasmania's future climate
2. advancing our renewable energy capability
3. reducing our transport emissions
4. growing a climate-ready economy
5. building climate resilience
6. supporting community action.

The key principles applied for the Action Plan are:

218 Sudmeyer, R, Bennett, A & Strawbridge, M 2016, 'Climate-ready agriculture: a situation statement for Western Australia', Bulletin 4876, Department of Agriculture and Food, Western Australia, Perth. Accessed 23 February 2019

219 Tasmanian Climate Change Office, Department of Premier and Cabinet (2017) *Climate Action 21: Tasmania's Climate Change Action Plan 2017- 2021*. Accessed 11 January 2019, http://www.dpac.tas.gov.au/__data/assets/pdf_file/0015/332106/Climate_Action_21_Tasmanias_Climate_Action_Plan_20172021_June_2018.pdf

— use the best available science and information
— work with businesses, the community and all levels of government
— evaluate, monitor and report on progress
— assess and respond to key risks and opportunities
— share information to support action
— complement national and international policies and initiatives.

Support for the agricultural sector is a focus of Action Plan 21. As a part of growing a climate ready economy, the actions planned for this priority area include:

— irrigation scheme development to underpin agricultural productivity in a changing climate (adaptation)
— working with producers to improve energy efficiency, reduce GHG emissions from fertiliser usage and the development of other farming practices to adapt to climate change.

Programs and projects that have been delivered against these priorities include:

— support of Fert$mart program, in partnership with DairyTas [220]
— integrated climate change projections into enterprise suitability mapping for poppies, wheat, potatoes, wine grapes and barley
— the Water for Profit Program.

Further sector specific programs are listed in **Table 6.13** below.

The Plan specifies implementation; reporting and monitoring; and evaluation responsibilities. The legislated annual GHG emission reporting acts as an accountability function, to which priorities contribute. All levels of government, community and industry are engaged in the Plan and delivery of priority programs. The Tasmanian government seeks to align its policies and programs with Commonwealth climate change policies.

6.5.8 Australian Capital Territory

Climate Change Adaptation Strategy (2016)

The purpose of the Climate Change Adaptation Strategy – Living with a Warming Climate (the Adaptation Strategy) is to support the development of community and natural environment resilience to the impacts of climate change.[221] The Adaptation Strategy is underpinned by ACT's *Climate Change and Greenhouse Gas Reduction Act 2010*, which sets emissions reduction targets aimed at zero net carbon emissions by 2050. Government objectives for the Adaptation Strategy are:

— mainstreaming climate adaptation principles in planning and services
— building resilience
— providing leadership
— ensuring effectiveness.

The Adaptation Strategy delivers its objectives through:

— communication of climate change impacts
— embedding climate change risk considerations in government decision-making, polices, programs and practices
— encouraging households and business to increase resilience and capture emerging opportunities.

The sector priority areas include disaster and emergency management; community health and wellbeing; settlements and infrastructure; water; and natural resources and ecosystems. The Strategy does not outline specific agricultural sector activities for adaptation or emissions reduction but does consider natural resources and ecosystems as a priority area.

[220] Fert$mart, a program initiated by Dairy Australia, encompasses the dairy industry's national nutrient management guidelines, developed to improve the efficiency and profitability of fertiliser use, and to improve soil health on Australian dairy farms (and thus indirectly address GHG emissions).
[221] ACT Government (2016) *Climate Change Adaptation Strategy: Living with a Warming Climate.* Accessed 11 January 2019, https://www.environment.act.gov.au/__data/assets/pdf_file/0004/912478/ACT-Climate-Change-Adaptation-Strategy.pdf

6.5.9 Northern Territory

Climate Change Mitigation and Adaptation Opportunities in the Northern Territory: Discussion Paper (2018)

The Northern Territory does not have a clearly articulated climate change policy framework (notwithstanding that its importance is recognised by Ministers). The recently released Climate Change Mitigation and Adaptation Opportunities in the Northern Territory: Discussion Paper reflects the renewed importance of climate change policy for the Northern Territory.[222]

The Discussion Paper outlines the predicted impacts of climate change for the Northern Territory; what is currently being done; and opportunities and sector specifics, including for agriculture. The Discussion Paper makes a commitment to develop environment protection legislation and development of carbon off-set policy.

6.6 Sectoral and industry-based strategies, policies and plans

A broad range of sectoral and industry-based plans have been developed. For example, regional based plans focused on the needs of a cohesive geographic area; agricultural commodity plans focused on a region, state-wide or nationally; multi-sector plans addressing sectors with a high degree of commonality such as livestock grazing; and habitat specific plans (e.g. for rangelands). However, there are a limited number of contemporary sectoral and industry-based climate change adaptation and emissions reduction plans.

The leading example of such a plan is perhaps the recently developed whole of agriculture adaptation plan in Queensland (see Section 6.5.4). At an agricultural industry level, the primary example is the Horticulture Climate Change Action Plan, which is embedded in the *Climate Change and the Australian Horticulture Industry Research Strategy*.

There are many commodity specific and local area plans which have been developed under a variety of government and industry initiatives. The sample below provides some insights as to what is possible. However, anecdotal evidence suggests that sectoral, industry and regionally based plans do not adequately address the immediate needs of farm businesses (the decision-makers) but rather focus on the needs of industry bodies, government agencies, Rural RDC's and R&I organisations. A further issue is that adaptation actions may include changing commodities or regions, and these approaches are generally not supported under commodity based or regionally based plans (that are the norm).

Climate Research Strategy for Primary Industries (2017-20) (April 2017)

The Climate Research Strategy for Primary Industries (CRSPI) is a joint initiative between the Rural RDCs, the State and Northern Territory governments, the Commonwealth Department of Agriculture and Water Resources and CSIRO.[223]

CRSPI is a cross-sectoral strategy developed under the National Primary Industries Research, Development and Extension Framework.[224] The focus of the partners involved in CRSPI is identification, coordination and communication of key climate change research needs and priorities. The scope of the issues considered within the Strategy are related to climate change impacts, adaptation and mitigation in the short, medium and long-term.

The three focus areas for CRSPI are:

1. adaptation to a changing and variable climate
2. emissions intensity and markets
3. climate change in business and policy.

[222] Northern Territory Government (2018) *Climate Change Mitigation and Adaptation Opportunities in the Northern Territory – Discussion Paper.* Accessed 7 January 2019, https://haveyoursay.nt.gov.au/climatechange

[223] Lovett, A. and McCluskey, S. (2017) *Climate Research Strategy for Primary Industries 2017-2020 (CRSPI)*. Rural Industries Research and Development Corporation

[224] Australian Government; Department of Agriculture and Water Resources; accessed January 2019 http://www.agriculture.gov.au/ag-farm-food/innovation/national-primary-industries

The collaboration between research partners aims to add value by identifying issues and sharing ideas between government, research and industry to inform research, development and extension (RD&E) priority agendas. The high-level engagement presents opportunities to co-invest in cross-sectoral climate change adaptation and mitigation programs.

CRSPI is a well-defined strategy that engages all primary research organisations that have cross-industry and jurisdiction responsibility, as well as industry specific Rural RDC's. This enables a coordinated approach for primary industries to address climate change impacts through research into emissions reduction and adaptation, thus avoiding potential research duplication and coordination failure. The ongoing success of CRSPI is dependent on the actionable outcomes of agencies from all jurisdictions collaborating and progressing climate change research issues.

National Farmers Federation 2030 Road Map

The National Farmers Federation (NFF) 2030 Road Map, which sets a target of agricultural farm-gate value of $100 billion by 2030, was released in 2018. The Road Map is a high-level plan, developed in consultation with industry, research agencies and government, that considers priority areas that will support or hinder the sector meeting the target. The Roadmap sets out five pillars of action to attain this goal:

— Pillar 1 - customers and the value chain
— Pillar 2: - growing sustainably
— Pillar 3 - unlocking innovation
— Pillar 4 - people and communities
— Pillar 5 - capital and risk management.

Responding to climate change is identified as a priority opportunity and threat to the sector. It identifies Australia as a potential leader in low-emissions agriculture but cautions that, if the issue is not dealt with effectively, it will burden farm businesses with additional costs.

Queensland multi-sectoral adaptation plans

Queensland has developed the Queensland Climate Adaptation Strategy: Agriculture Sector Adaptation Plan (see Section 6.5.4 above). This Plan covers a select number of agricultural sectors; cotton, extensive livestock, grains, horticulture and viticulture, intensive livestock industries and the sugar industries.

The QFF, in collaboration with the State Department of Environment and Science, developed the Plan in partnership with all the relevant major industry bodies, government agencies, research agencies and Rural RDC representatives. A key feature of the Plan is its ability to distil key priorities and focus areas for coordinated government and industry work. The identified priorities concentrate on issues which are foundational across all the sectors embraced by the Plan, such as infrastructure and finance and insurance programs.

This approach fosters stronger engagement and support for the planning and the action plan process. Furthermore, many of the outcomes have wider application to the agricultural sector. Implementation of priority actions identified in the plans is underway.

Rural Research and Development Corporations

Australia's Rural RDCs are the main mechanism the Australian government and primary producers co-invest in research and development for industry and the community. While the Rural RDCs' extensive research programs address a wide range of climate change issues, the effort is somewhat fragmented (often driven by researcher interest, immediate problems and many competing demands) and developed without the guidance of an overarching framework. In general, the Rural RDCs look to CRSPI for this direction. However, a number of Rural RDCs have moved to address this shortcoming. For example, the grains and cotton industries' national RD&E strategies put forward a planning hierarchy and coordination agenda (see discussion below).

Meat and livestock

The Australian Beef Sustainability Framework is a contemporary sectoral approach that considers climate change and tracks indicators over time. The Framework was developed in collaboration with stakeholders to meet changing consumer, customer, investor and stakeholder expectations. The framework is dependent on whole sector collaboration and uses meaningful metrics to track progress over time.[225] MLA has released a report setting a goal for Australia's red meat industry to be carbon neutral by 2030.[226] This research and other material will be considered further as part of the opportunities and gap analysis work in Stream 2.

Grain

The National RD&E Strategy for the Grains Industry, 2017 highlights climate change as a key industry challenge and, to address this challenge, identifies the need for further investment in RD&E programs focused at mitigation and adaptation. Furthermore, the Strategy points to CRSPI as having responsibility for coordinating climate change mitigation and adaptation responses.[227]

> *"These are a strong Australian Government priority and all primary industry agencies, universities and RDCs are currently coordinated through the Climate Change Research Strategy for Primary Industries (CRSPI) until 2017 to achieve this."*

Cotton

The cotton sector's Cotton RD&E strategy 2011 identifies climate change as a priority and draws linkages to the Commonwealth's climate change priorities. In reference to linkages with government, it highlights that future RD&E priorities will be influenced by government climate policy and will require adaptation strategies.[228] The Cotton Innovation Network oversees implementation of the Cotton RD&E Strategy. A current priority is to improve collaboration, including greater connection with cross-sectoral climate change strategies.[229]

Horticulture

Horticulture Innovation (formerly Horticulture Australia Limited) and CRSPI have developed the Climate Change and the Australian Horticulture Industry Research Strategy. The Strategy focuses on the future impacts of climate change and priority RD&E areas for the sector to guide investment in adaptation and mitigation actions. The development of the Strategy was driven by Horticulture Innovation and took into account national RD&E priorities. In engaging CRSPI in the development process, the industry strived for greater coordination and collaboration across jurisdictions with the aim of reducing fragmentation.[230]

To address the impacts and opportunities identified in the Strategy, the Horticulture Climate Change Action Plan outlines RD&E opportunities for Horticulture Innovation to prioritise in its environment portfolio. The Action Plan has three main strategies focused on adaptation, mitigation and awareness and communication.

Dairy

The Dairy Sustainability Framework was developed in 2012. It was designed to reflect the dairy industry value chain and focused on areas where dairy farmers and manufacturers have the greatest impact and control over the outcome. This approach includes collaboration by peak industry bodies and RDC's. The framework is fluid and is updated as programs and research deliver outcomes.

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225 Sustainability Working Group (2018) *Australian Beef Sustainability Framework*. Accessed 20 February 2019, file:///C:/Users/dlord/Downloads/Australian_Beef_Sustainability_Framework_2018_Brochure.pdf

226 Dianne Mayberry, Harriet Bartlett, Jonathan Moss, Stephen Wiedemann, Mario Herrero; CSIRO: 3, April 2018, Published by Meat and *Livestock Australia Limited; Greenhouse Gas mitigation potential of the Australian red meat production and processing sectors*

227 GINRDE Strategy (2017) *Research, Development and Extension Strategy for the Grains Industry*. Accessed 17 January 2019, https://www.npirdef.org/content/75/7afad8b6/Grains-Industry-National-RD-E-Strategy-2017.pdf

228 Cotton Research and Development Corporation (2011) *Cotton Sector Research Development and Extension Final Strategy*. Accessed 17 January 2019, https://www.crdc.com.au/sites/default/files/pdf/Cotton_Sector_RDE_Strategy.pdf

229 Cotton Innovation Network (2018), Accessed 17 January 2019, https://www.crdc.com.au/cotton-innovation-network

230 CRSPI and Horticulture Innovation (2009) *Climate Change and the Australian Horticulture Industry*. Accessed 15 January 2019, http://www.crspi.net.au/sites/default/files/publications/HAL-CRSPI%20Climate%20Change%20Brochure%20-%20Final.pdf

Climate change was identified by stakeholders as a priority and has focused on carbon mitigation efforts by manufacturers and impacts on the whole value chain. Adaptation will be a priority into the future.[231] Progress against baseline and performance indicators is tracked, reported against and assessed. The framework is underpinned by industry data, and ongoing consultation with industry ensures it is both relevant and contemporary.

From a program perspective, the dairy industry has implemented a national R&D program - the Dairy Climate Toolkit - focused primarily on climate change adaptation and emissions reduction. Although not specifically an adaptation plan, the coordination of a research program, with clearly defined objectives, delivering across jurisdictions and in partnership with the Victorian and Tasmanian State Governments, is a good example of how adaptation can be approached. The Dairy Climate Toolkit forms a repository of all research and communication outputs related to climate adaptation and emission reductions specific to dairy farms.[232]

An example of an emissions reduction program delivered under the climate change suite of programs is the Profitable Dairying in a Carbon Constrained Future project. This project was supported by the Carbon Farming Futures Extension and Outreach Program.[233] The objectives of the program are to deliver knowledge, embedded in farm management decisions, of practices that profitably reduce GHG emissions arising from the dairy sector. The Dairy Business for Future Climates initiative (a sub-component of the Program) is dedicated to understanding the potential impacts of climate change, emissions reduction and adaptation strategies for the Australian dairy industry.[234]

The Initiative is a partnership between Dairy Australia, the Commonwealth Department of Agriculture and Water Resources, the University of Melbourne and Tasmanian Institute of Agriculture. The research program focuses on all states and territories with dairy producing regions. The program also links dairy farmers with the ERF, with current dairy emissions reduction methods being eligible to participate in the program.[235] These Programs are dairy specific and do not engage with other agricultural sectors.

Wimmera-Mallee

At a regional level, the Birchip Cropping Group developed a climate change adaptation plan in the context of broadacre grain cropping and livestock enterprises for the Wimmera-Mallee regions of Victoria.[236] The approach recognises the similar climatic, farming system and farm business characteristics across the two sectors and what the potential impacts of climate change mean for the region. The outcome of the plan is a set of communicable adaptation options for producers including:

— adoption of climate forecasts to reduce production risk
— shifts in cropping programs to reflect changes in temperatures and rainfall
— variety selection.

The plan was developed in close collaboration with Commonwealth agencies (CSIRO, BoM and DAWR) and MLA.

Table 6.12 examines the relative advantages and disadvantages of sectoral and industry plans in driving climate adaptation and emission management issues.

231 Australian Dairy Industry Council Inc. (2015) *Australian Dairy Industry Sustainability Framework: Progress Report 2015*. Accessed 20 February 2019,
232 Dairy Australia (2017) *Dairy Climate Toolkit.* Accessed 11 January 2019, http://www.dairyclimatetoolkit.com.au/
233 Part of the Carbon Farming Futures Project 2012-17
234 Dairy Australia (2016) *Adapting the Dairy Industry: Dairy Businesses for Future Climates*. Accessed 11 January 2019, http://www.dairyclimatetoolkit.com.au/adapting-to-climate-change/adapting-the-dairy-industry
235 Dairy Australia (2015) *Emissions Reduction Fund.* Accessed 11 January 2019, http://www.dairyclimatetoolkit.com.au/reducing-farm-emissions/emissions-reduction-fund
236 Birchip Cropping Group (2008) *Farm-Level Adaptation Options: Wimmera-Mallee*. Accessed 15 January 2019, https://www.mla.com.au/globalassets/mla-corporate/blocks/research-and-development/vic-adaptation-options.pdf

TABLE 6.12 SECTORAL AND INDUSTRY DRIVEN ADAPTATION PLAN EFFECTIVENESS

Title	Description	Cross-jurisdiction collaboration	Sectors	Advantages	Disadvantages
State-wide Plans: Queensland Agricultural Adaption Plan	Agriculture adaptation plan	Queensland only	Cotton, extensive livestock, grains, horticulture and viticulture, intensive livestock industries and sugar industries	– *formulating priority actions relevant to a range of industries*	– *issues are relevant at a wider level, not just within State* – *potential duplication of research* – *industry specifics may be lost in forming consensus positions*
Sector/commodity specific plans: Climate change and the Australian Horticulture Industry	Horticulture adaptation plan	National development facilitated by CRSPI	Horticulture	– *holistic approach to adaptation across jurisdictions for horticulture* – *cross-agency engagement in research priorities*	– *potential loss of synergies with other row crop sectors, including cotton or grains*
Commodity specific plans: Dairy Climate Toolkit	Dairy climate adaptation and emissions reduction program	Commonwealth, Victoria and Tasmania	Dairy	– *farmer friendly adaptation and emissions reduction management options* – *central location of information and linkages with Commonwealth policy and programs*	– *potential loss of synergies with beef cattle and other ruminants* – *potential industry research duplication*
Farm-Level adaptation options: Wimmera-Mallee	Regional adaptation plan	Victoria and Commonwealth	Livestock and grains	– *tailored response plan for local area* – *greater ownership of adaptation options by individuals*	– *high administration costs of local level development* – *duplication of research and responses likely* – *only considers implications for cropping and livestock*

SOURCE: ACIL ALLEN CONSULTING

6.7 Climate change emissions management and adaptation programs

Table 6.13 provides a stocktake of key agricultural emissions management and climate change adaptation programs by jurisdiction. As outlined in **Box 6.1**, the ERF is the primary GHG emission reduction program, relevant to agriculture, operating at a national level.

The common approach adopted at the state and territory government level is to fund grant programs, research and digital platform services aimed at projects designed to support emissions management/reduction and climate change adaptation. The funding levels for each program is not provided in this report. Although of significant value for comparison of effort by jurisdiction, there are challenges sourcing publicly available program values, and in potential duplication and assignment of value.

In addition, there is an extensive body of research work that has been undertaken by the Rural RDCs, industry associations and academia, with an agriculture and climate change focus. This body of work is too extensive to summarise, but a range of key documents, including those drawn upon in the analysis throughout the report, are listed in the Bibliography.

TABLE 6.13 AGRICULTURAL EMISSIONS REDUCTION AND CLIMATE CHANGE ADAPTATION PROGRAMS STOCKTAKE BY JURISDICTION

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
Australian Government	Emissions Reduction Fund	A voluntary scheme that provides farmers with the opportunity to participate in emissions reduction and carbon sequestration projects	Fund	Yes	(co-benefit)	National	http://www.environment.gov.au/climate-change/government/emissions-reduction-fund
	Clean Energy Finance Corporation	Invests in clean energy projects for the Australian Government. This includes investing in renewable energy, energy efficiency and low emissions technologies.	Fund	Yes		National	https://www.cefc.com.au/
	Renewable Energy Target	A scheme designed to reduce GHG emissions in the electricity sector and encourage additional generation of electricity from renewable sources	Scheme	Yes		National	http://www.cleanenergyregulator.gov.au/RET/About-the-Renewable-Energy-Target
	Regional NRM Planning for Climate Change Fund	Supports NRM organisations plan for the impacts of climate change through the following programs: – National Climate Change Projections: Climate Change Australia – Impacts and adaptation information for Australia's NRM regions – AdaptNRM	Grants program	Yes	Yes	National	https://www.environment.gov.au/climate-change/adaptation/planning-climate-change-nrm
	CSIRO and BoM climate research including: – Climate Change in Australia Resource Management Project (funding now completed)	– collate existing climate information – communicate climate projections – undertake new analysis of next generation climate modelling to produce updated national and regional climate projections – synthesise knowledge of plausible regional climate change to provide context to the use of the projections – provide projections data sets for use in NRM planning	Research Limited extension		Yes	National	http://environment.gov.au/science/nesp https://www.climatechangeinaustralia.gov.au/en/

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
	– National Environmental Science Program (NESP)	– collate existing climate information – limited continuation of the work of the Climate Change in Australia Resource Management Project	Research and application		Yes	National	http://www.environment.gov.au/science/nesp/about
	National Landcare Program	Provides funding for industry, communities and individuals to protect and conserve Australia's water, soil, plants, animals and ecosystems	Procurement and grants program	Yes	Yes	National	http://www.nrm.gov.au/
	20 million trees	Planting of 20 million trees by 2020, to re-establish green corridors and urban forests	Procurement and grants program	Yes	Yes	National	http://www.nrm.gov.au/national/20-million-trees
	Managing Climate Variability	Climate forecasting research and services, climate risk management tools for agriculture (CliMate app)	Research		Yes	National	http://www.climatekelpie.com.au/index.php/mcvproject/
	Carbon Farming Futures (2012-17)	Funding for 200 projects between 2012-17 that aimed at emissions reduction and climate change adaptation	Grants program	Yes	Yes	National	http://www.agriculture.gov.au/ag-farm-food/climatechange/carbonfarmingfutures
	National Climate Change Adaptation Research Facility (NCCARF)	Supports decision makers in Australia prepare for climate change. The current phase (2014-2017) is focused on adaptation in the coastal zone	Research		Yes	National	https://www.nccarf.edu.au/
New South Wales	New South Wales Climate Change Fund	Support programs that reduce GHG emissions and strengthen resilience of NSW to climate change impacts through stimulation of investment in energy saving approaches and raising public awareness about climate change	Fund	Yes	Yes	No	https://www.environment.nsw.gov.au/topics/climate-change/nsw-climate-change-fund/programs

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
	– Project 1: Clean energy solutions	Fund innovative energy projects to support clean energy and local energy for primary producers	Fund	Yes		No	NSW DPI (2018) NSW Primary Industries Climate Change Research Strategy
	– Project 2: Energy efficiency solutions	Help energy-intensive farms identify options to improve their energy efficiency and reduce costs	Grants program	Yes		No	NSW DPI (2018) NSW Primary Industries Climate Change Research Strategy
	– Project 3: Biomass for Bioenergy	Investigate electricity generation using organic matter (biomass)	Research	Yes		No	NSW DPI (2018) NSW Primary Industries Climate Change Research Strategy
	– Project 4: Emissions reductions pathways	Investigate the feasibility of emissions reduction and carbon sequestration options to support primary industries plan to reduce emissions	Research	Yes		No	NSW DPI (2018) NSW Primary Industries Climate Change Research Strategy
	– Project 5: Accessing carbon markets	Develop new tools for farmers to generate income from access to carbon markets	New tools	Yes		No	NSW DPI (2018) NSW Primary Industries Climate Change Research Strategy
	– Project 6: Vulnerability assessment	Deliver research to understand the vulnerability and adaptability of primary industries to climate change	Research		Yes	No	NSW DPI (2018) NSW Primary Industries Climate Change Research Strategy
	– Project 7: Climate-Smart pilots	Support farmers pilot projects that build resilience in rural communities and primary industry	Grants program		Yes	No	NSW DPI (2018) NSW Primary Industries Climate Change Research Strategy
	National Livestock Methane Program	Developed to provide Australian livestock producers with practical strategies and tools to help them increase productivity and profitability and at the same time lower methane emissions.	Research	Yes	Yes	Yes	https://www.mla.com.au/globalassets/mla-corporate/blocks/research-and-development/01200075-program-fact-sheet_nlmp_final.pdf
	The Soil Carbon Research Program (SCaRP)	SCaRP was a nationally coordinated program of soil carbon research. The program ran from 2009 to 2012 and coordinated 13 carbon research projects	Research	Yes	Yes	Yes	https://csiropedia.csiro.au/soil-carbon-research-program/

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
	National Agricultural Nitrous Oxide Research Program	The 2012-2015 NANORP drew together researchers from across Australia under an agreed collaborative program to develop and deliver effective and practical strategies for reducing NO_x that decreases emissions while maintaining productivity.	Research	Yes	Yes	Yes	https://researchdata.ands.org.au/national-agricultural-nitrous-nanorp-collection/617208
Victoria	Victorian Community Climate Change Adaptation (3CA) Grants Program	Funds the Rural People: Resilient Futures Project	Grants program		Yes	No	https://www.climatechange.vic.gov.au/adapting-to-climate-change-impacts/community-climate-change-adaptation-3ca-grants-program
	Drought Preparedness and Response Framework	This framework provides incentives for farm businesses to build capacity, adapt and be self-reliant, and set up a process for drought assistance	Framework		Yes	No	http://agriculture.vic.gov.au/agriculture/farm-management/drought/victorias-drought-preparedness-and-response-framework
	Drought Response Package	Provided $27 million to help drought-affected communities in 2015 and 2016.	Grants program		Yes	No	http://agriculture.vic.gov.au/agriculture/farm-management/drought/dry-seasons-support
	National Centre for Farmer Health	Helps farming families improve their health, wellbeing and safety and build farm sustainability.	Grants program		Yes	No	https://www.farmerhealth.org.au/
	Agriculture Infrastructure and Jobs Fund	Supports projects that improve resilience and efficiency, such as a Doppler radar station in the Wimmera-Mallee region which gives farmers more accurate weather tracking and forecasts; the agriculture energy investment plan which supports farmers install energy efficient equipment and support own-generation capacity; and the internet of things trial supporting farmers install digital technology on-farm.	Grants program		Yes	No	http://agriculture.vic.gov.au/agriculture/food-and-fibre-industries/agriculture-infrastructure-and-jobs-fund

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
	The Break, Fast Break, and Climate Dogs	Support the sector to better understand seasonal climatic variations and address climate risks on-farm. Communication and capacity building.	Communication		Yes	Yes	http://agriculture.vic.gov.au/agriculture/weather-and-climate/newsletters/the-fast-break-victoria
	DairyBio DairyFeedbase	Research and industry development partnerships between industry and government to address impact of climate change on pasture and dairy herds.	Research	Yes	Yes	No	https://dairybio.com.au/ http://agriculture.vic.gov.au/agriculture/dairy/dairy-science-and-research
	Future Industries Fund Food and Fibre Strategy	Strategy focused on adaptation of industries to future requirements and evolution of sectors through technologies	Strategy		Yes	No	https://www.business.vic.gov.au/__data/assets/pdf_file/0007/1275460/Food-and-Fibre-strategy-web-version-20160310.pdf
Queensland	Land Restoration Fund	$500 million program aimed at expansion of carbon farming in Queensland, supporting land-sector projects that deliver environmental and economic co-benefits	Grants program	Yes			https://www.qld.gov.au/environment/climate/climate-change/land-restoration-fund
	Queensland Future Climate	Includes a dashboard of climate modelling scenarios for Queensland. Interrogable by region and climate variables.	Platform		Yes	No	https://www.longpaddock.qld.gov.au/qld-future-climate/
	Climate Risk Management Matrix	A tool that can help address uncertainty by identifying impacts, risk and vulnerability and adaptive responses associated with climate change	Guidelines		Yes	No	https://www.longpaddock.qld.gov.au/climate-adaptation/climate-risk-matrix/
	AussieGrass (pasture cover)	A modelling tool for predicting pasture growth into the future for Australia	Digital tool		Yes	National	https://www.longpaddock.qld.gov.au/aussiegrass/
	The Drought and Climate Adaptation Program (2017-22)	Research, Development and Extension projects for grazing, cropping and horticulture industries in Queensland. Grazing – The inside edge for graziers to master Qld's drought prone climate	Research		Yes	MLA, USQ, UK Met Office, BOM, Uni Newcastle, UTAS, Uni College	https://www.longpaddock.qld.gov.au/dcap/

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
		– Drought resilience and adaptation: a program of social research and knowledge support – Northern Australia Climate Program – Delivering integrated production and economic knowledge and skills to improve drought management outcomes for grazing – GrazingFutures: Promoting a resilient grazing industry – Forewarned is forearmed: proactively managing impacts of extreme climate events – Using paleoclimate data to prepare for extreme events and floods in Queensland Cropping – Forewarned is forearmed: equipping farmers and agricultural value chains to proactively manage the impacts of extreme climate events – Enhanced Crop Insurance Systems Horticulture Use of BoM multi-week and seasonal forecasts to improve management decisions in Queensland's vegetable industry				Dublin, Willis TW, QFF, AgForce, South West NRM, Southern Gulf NRM, Desert Channels Qld, Northern Gulf NRM	
	Queensland Climate Science Program	Under the Q-CAS, the Queensland Government has supported the development of downscaled climate projection data, information products and decision support tools This work is ongoing, with additional projects to produce quantitative, probabilistic information on extreme events, risk management toolkits etc (using BoM data)	Research		Yes	No	Queensland government

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
South Australia	SARDI Climate Applications Science Program	Manage Climate Risk Program – assessment of climate risk and opportunities for almond, irrigated industries, viticulture, frost events in the grains industry Crop Ecophysiology – agronomy and breeding programs designed to study climate change effects and adaptability of crops	Research		Yes	Crop Eco (UQ, UA, UWA, CSIRO)	http://pir.sa.gov.au/research/research_specialties/sustainable_systems/climate_applications
Western Australia	Climate change information	Climate change impact, risk or vulnerability assessments and/or mapping Adaptation planning or selection of adaptation responses Communication and capacity building	Communication		Yes		https://www.agric.wa.gov.au/search?search_api_views_fulltext=climate%20change
	Carbon Farming information	Promoting or removing barriers to carbon sequestration and other land-based emissions abatement mechanisms Communication, information sharing or education to support mitigation activities	Communication	Yes			https://www.agric.wa.gov.au/climate-land-water/climate-weather/climate-change https://www.agric.wa.gov.au/sites/gateway/files/Climate%20change%20-%20impacts%20and%20adaptation%20for%20agriculture%20in%20WA%20-%20Bulletin%204870%20%28PDF%204.9MB%29.pdf
	Improved use of seasonal forecasting to improve farmer profitability	Adaptation planning or selection of adaptation responses Communication and capacity building	Communication		Yes	USQ, DPI NSW, Ag Vic, Burchip, Monash Uni, SARDI, BoM	
	Australian Biomass for Bioenergy Assessment	Promoting renewable energy (including removal of barriers) and/or promoting storage technologies for renewable energy (or removing barriers) Communication, information sharing or education to support mitigation activities	Communication	Yes			https://www.agric.wa.gov.au/carbon-farming/biomass-and-bioenergy?nopaging=1

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
	Closing the research gap - carbon farming science	Promoting or removing barriers to carbon sequestration and other land-based emissions abatement mechanisms Carbon Offsets	Research	Yes	Yes		DPIRD
	Carbon Farming information	Promoting or removing barriers to carbon sequestration and other land-based emissions abatement mechanisms Communication, information sharing or education to support mitigation activities	Communication	Yes			https://www.agric.wa.gov.au/climate-land-water/climate-weather/climate-change https://www.agric.wa.gov.au/sites/gateway/files/Climate%20change%20-%20impacts%20and%20adaptation%20for%20agriculture%20in%20WA%20-%20Bulletin%204870%20%28PDF%204.9MB%29.pdf
Tasmania	Making Cent$ of Carbon Emissions on-farm (2014)	Booklet to support agricultural producers to identify practical actions to improve their emissions performance and productivity	Research	Yes	Yes	Victoria	https://dpipwe.tas.gov.au/agriculture/climate-change-and-agriculture
	Fert$mart Program (2014-16)	Assist farmers to improve the efficiency of fertiliser use to reduce emissions and costs	Research	Yes	Yes	National	http://fertsmart.dairyingfortomorrow.com.au/
	Enterprise Suitability Toolkit	Land-use suitability maps under predicted climate change assumption	Digital tool		Yes	Tas	https://dpipwe.tas.gov.au/agriculture/investing-in-irrigation/enterprise-suitability-toolkit
	Water for Profit Program	Ensure farmers are equipped with the right skills and information to increase profits and sustainability from their investment in irrigation	Research		Yes	No	https://dpipwe.tas.gov.au/agriculture/water-for-profit-program
	On-farm Energy Audit and Capital Grant Program	Provides subsidies to assist farmers to reduce their energy costs - the program is split into Audit Grants and Capital Infrastructure Grants	Grants program	Yes		No	https://www.stategrowth.tas.gov.au/business/sectors/food_and_agriculture/on-farm_program

Jurisdiction	Program	Description	Program type	Emission reduction	Adaptation	Cross jurisdiction engagement	Source
Australian Capital Territory	Resilient Farms: Supporting Adaptation to Climate and Market Variability	Support for extension programs, such as NSW DPI's Farmer's Guide to Managing Climate Risk workshops	Extension services		Yes	South East LLS and NSW DPI.	ACT provided (project proposal 1 – Resilient Farms.docx)
	ACT NRM Sustainable Agriculture Program	National Landcare funded NRM projects for farmers	Grants program		Yes	NSW LLS	Meridian Agriculture (2018) Evaluation of the ACT NRM Sustainable Agriculture Program
Northern Territory		(No climate change adaptation or emission reduction programs accessible)					

Notes: All programs listed are identified as being led by the jurisdiction. However, many programs delivered at a state level source funding at a national level, including through Rural RDC's.

SOURCE: ACIL ALLEN CONSULTING BASED ON VARIOUS SOURCES

6.8 Conclusions

Commonwealth legislation and policy context

At the Commonwealth level, the primary policy approach for emissions reduction in agriculture is through the *Carbon Credits (Carbon Farming Initiative) Act 2011,* which established the ERF in 2015. The ERF provides funding for eligible projects, with carbon credits being able to be purchased by business to off-set GHG emissions. At a policy level, the National Climate Resilience and Adaptation Strategy specifies guiding principles for the Australian Government's approach to climate change adaptation, primarily the shared responsibilities between governments and priority sectors, including agricultural sectors.

The Great Barrier Reef is a focal point for Australian and Queensland Government attention in the national and international climate change debate. The 2017 Scientific Consensus Statement concluded:

> *"Key Great Barrier Reef ecosystems continue to be in poor condition. This is largely due to the collective impact of land run-off associated with past and ongoing catchment development, coastal development activities, extreme weather events and climate change impacts such as the 2016 and 2017 coral bleaching events."*[237]

The Review and update of the Reef 2050 Long-Term Sustainability Plan, in particular the water quality indicators, has placed increased pressure on agricultural industries to change farm practices to reduce run-off to the Reef.[238] Although not climate change related per se, the damage to the Reef arising from reduced water quality, demonstrates the types of pressure agricultural industries will face to change farm practices to reduce their impact on the environment, and to contribute to actions to address climate change more broadly.

The Australian Government supports a significant component of the climate adaptation research agenda through funding of the 15 Rural RDCs, which coordinate emissions reduction and climate adaptation research priority efforts through CRSPI. CRSPI's purpose is to implement a coordinated approach to climate research and to reduce fragmentation and duplication of the research effort. However, some stakeholders believe it has stagnated and that it is no longer delivering against its objectives. Conversely, other stakeholders consider the recent adoption of the third phase of the strategy could generate momentum to deliver on CRSPI's purpose. The role of coordinated research efforts will be explored as part of the opportunities and gaps analysis.

State legislation, plans and policies

During the last decade, many state and territory governments have taken independent action (i.e. aside from the Australian Government) by enacting climate change legislation to drive the policy agenda (given the Australian Government has not enacted legislative national emissions reductions targets). Governments in South Australia, Tasmania, Victoria and the Australian Capital Territory have all established legislative frameworks. The primary focus of the legislation has been setting emissions reduction targets and renewable energy targets in line with the Paris Agreement. This approach is supported by climate change policy frameworks, that centre around climate change adaptation planning and cooperation within state and territory boundaries. However, the planning hierarchies demonstrate limited cross-jurisdictional cooperation or engagement when developing adaptation plans and action response agendas.

There is also a lack of consistency between states in relation to how they have addressed agricultural issues within adaptation policies/plans that have been developed. For instance, in:

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237 State of Queensland 2017, 2017 Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition. Accessed 21 February 2019, https://www.reefplan.qld.gov.au/about/assets/2017-scientific-consensus-statement-summary.pdf

238 Commonwealth of Australia (2018) *Reef 2050 Long-Term Sustainability Plan.* Accessed 8 January 2019, http://www.environment.gov.au/system/files/resources/35e55187-b76e-4aaf-a2fa-376a65c89810/files/reef-2050-long-term-sustainability-plan-2018.pdf

— South Australia, adaptation planning is prepared at a regional level, to engender collaboration and ownership at an individual and community level
— Queensland, (which does not have climate change specific legislation) the Pathways to a climate resilient Queensland: Queensland Climate Adaptation Strategy outlines the overall policy framework; The Queensland Climate Transition Strategy primarily focuses on how to transition different sectors to a lower carbon economy; and the Queensland Climate Adaptation Strategy: Agriculture Sector Adaptation Plan is designed to identify cross-industry priorities which Government and the agricultural sector as a whole can focus on in the short to long-term future
— New South Wales, the Office of Environment and Heritage has developed a process that aims to provide a sound basis for enabling regional adaptation and planning by working with local government, agencies and other local stakeholders to identify and understand regional climate vulnerabilities, with plans in varying stages of development (agriculture is but one of the sectors considered)
— Victoria, which has the most contemporary climate change legislation and policy framework, introduces both 'top down' and 'bottom up' climate change adaptation planning, with consideration for agricultural sectors
— Tasmania, an already carbon-neutral State, continues to explore adaptation and emissions reduction through its alignment with national objectives and clear action prioritisation - a 2018 review found that agricultural growth can be delivered without additional land clearing, given the potential carrying capacity of existing grasslands has not been reached; expected improvements in land management practices; and given an increase in irrigated land
— Western Australia and Northern Territory are both developing climate policy frameworks and adaptation plans.

There is opportunity for greater coordination of 'top down' adaptation planning between jurisdictions. The state and territories collaborate on adaptation more generally (i.e. not agriculture specific) under the auspices of the Adaptation Working Group (under the Meeting of Environment Ministers), and also share information on adaptation programs, with a view to developing consistent approaches. However, the prevailing approach, which primarily focuses on plans ending at state and territory borders, can potentially cause duplication of research and administrative efforts. Furthermore, the similarities of geography, agricultural sectors and general management responses for agricultural industries have significant cross-over between states and territories. Nonetheless, cross-jurisdiction collaboration at a research and program response level is much greater, which is a result of each agricultural industry's national focus on research, particularly Dairy through the Dairy Climate Toolkit and associated programs.

Although few agricultural sector specific plans exist, examples from Queensland, and work by the horticulture sector, demonstrate the benefits of focusing priorities. However, evidence of the effectiveness of implementation of these plans is less clear at this stage.

Programs

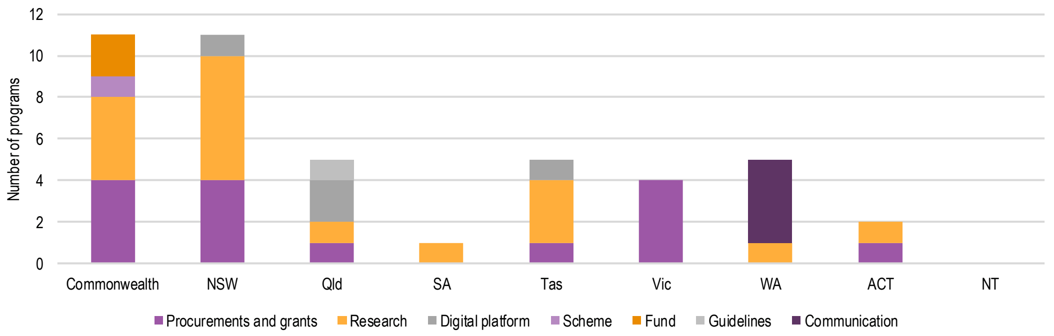
Agriculture specific climate change adaptation and emissions reduction programs are delivered across most jurisdictions. At a Commonwealth level, the ERF is the primary source of funding for emissions reduction in agriculture. A review of the ERF in 2017 found it was performing well and that, with some minor improvements, it would continue to deliver abatement in the future.[239] Along with other initiatives, including the Regional NRM Planning for Climate Change Fund and Managing Climate Variability, it provides the basis of nationally focused climate action (even though some programs have reached the end of their funding). The Commonwealth programs engage across jurisdictions and deliver outputs with regionally specific climate information for adaptation response purposes. Of the 11 Commonwealth led programs described, six have both emissions reduction and adaptation objectives, four just adaptation, and three just emissions reduction.

Figure 6.1 shows the distribution of emissions reduction and climate change adaptation programs delivered by jurisdiction and program category. The figure reflects the number of programs rather than

239 Climate Change Authority (2017) *Review of Emissions Reduction Fund*. Accessed 20 February 2019, http://climatechangeauthority.gov.au/review-emissions-reduction-fund .

their dollar value as detailed program funding figures are not readily available, and difficult to determine accurately, given multiple funding sources etc.

FIGURE 6.1 EMISSIONS REDUCTION AND ADAPTATION PROGRAMS DELIVERED BY JURISDICTION



SOURCE: ACIL ALLEN CONSULTING

State and territory governments deliver a mix of programs focused on both emissions reduction and climate change adaptation objectives for agriculture. New South Wales, for instance, is in the early stages of implementing a program mix that is focused on energy, carbon opportunities and climate resilience, designed around grant programs, research and digital platforms. Queensland, on the other hand, funds enduring research and digital platforms which are focused on long-term climate projections and implications for regional areas under the Long Paddock program and Drought and Climate Adaptation Program. However, the recently introduced $500 million Land Restoration Fund will support emissions reduction projects with environmental and economic co-benefits.

Many of Victoria's programs are grant programs, with a strong emphasis on drought support and response, which may reflect the drought conditions that have existed in recent years. There are also grant programs to improve energy efficiency and productivity. These types of programs are focused on preparedness and building resilience at a farm level, which has spillover benefits for longer term climate adaptation. There is also a focus on building the capacity of the sector to understand and manage climate risk, as well as joint investments with industry in research particularly in the dairy and grains industries.

State led programs are predominantly focused on adaptation with 60 per cent delivering adaptation projects, 27 per cent focused on emissions reduction, and 13 per cent delivering across both areas. Between States, this varies significantly, with South Australia, Victoria and ACT only funding adaptation programs. NSW, Queensland and Tasmania are the only States and Territories funding programs with emissions reduction objectives.

Western Australia and Northern Territory do not lead contemporary emissions reduction or climate adaptation programs, specific to agriculture, but run communication programs that engage farmers with the Commonwealth led initiatives. While both jurisdictions support and undertake individual R&D projects into climate change and agricultural issues, these do not appear to be delivered as a comprehensive and coordinated program. Often research and development funding for agriculture is focused on productivity and sustainability objectives, rather than climate change being the primary driver, from which adaptation and emissions reduction benefits might accrue.

7 ANALYSIS AND NEXT STEPS

This chapter summarises the key conclusions, based on the stocktake and analysis undertaken as part of the Stream 1 work. It examines the extent to which existing policies and programs reflect the likely impacts of climate change on different agricultural activities and identifies where there are overlaps or gaps in activities. It provides some initial insights into what has been successful and begins to identify potential opportunities and areas for improvement to policies and programs.

These findings provide the bridge to the Stream 2 work, which will involve a deeper investigation of the opportunities and risks that climate change poses for agriculture.

7.1 Stream 1 conclusions

The importance of agriculture

Agriculture continues to be a vital component of the social and economic structure of jurisdictions right across Australia and is the major economic driver of regional and rural communities. It is an industry underpinned by innovation and resilience, often facing significant challenges from a changing economic and natural environment. These challenges have heightened as the underlying climate signal has strengthened, and more importantly, in the recent past, as extreme weather-related events (e.g. drought, heat waves, fires, cyclones and other extreme weather events) have increased in intensity and occurrence.

Australia is a world leading producer and exporter of agricultural commodities. Australian agriculture has experienced significant growth over the past decade. This growth is, in part, due to extended market access for exports, but also reflects Australia's leading-edge production systems and its reputation for 'clean, green' products, supported by quality R&I.

In 2016-17, the agricultural sector:

- produced agricultural products valued at over $60 billion
- had exports valued at an estimated $50 billion
  - was the second and fourth largest global exporter of beef and wheat, respectively, with these commodities representing the eighth and ninth largest sources of Australian export income
- employed approximately 251,000 people in Australia.

Chapter 2 provided an overview, at both the national, and state and territory levels, of agricultural land use; agricultural activity in terms of production and value; the emissions produced by the industry; and employment in the industry. The chapter described the changes in key agricultural activities between 2012-13 and 2016-17; identified the largest economic contributors; and highlighted activities showing the highest growth and those performing less strongly.

The sector's strong performance over the past decade has been driven by significant productivity gains and major increases in the value of agricultural products, especially in export markets (which have had flow-on impacts in the domestic market). Nevertheless, climate change has already impacted agricultural productivity. The outlook for the sector is positive and, based on the current growth trajectory, the business as usual forecast is for it to be valued at $84 billion by 2030. However, challenges are foreseen, especially as productivity growth is beginning to taper off in some areas. Furthermore, climate change has already impacted Australian agriculture productivity. This is leading to a change in focus, away from continuing productivity and yield gains, to product value and opportunities for value-adding.

The NFF has laid down a vision for the industry to maintain its competitive advantage and to grow exports. The NFF recently released its 2030 Roadmap - Australian Agriculture's Plan for a $100 Billion Industry to guide industry growth.[240] The Roadmap embraces the vision of exceeding $100 billion in farm-gate output by 2030.The Roadmap clearly recognises climate change as a key issue to be addressed. The Roadmap notes that climate change can bring both opportunities and threats. It states that:

> *"Climate change will play a major role in Australian agriculture's next decade, exacerbating climate risk while creating diverse new income opportunities. Australia's policy response can position us as a global leader in low-emissions agriculture. Done poorly, our policy response could saddle farm businesses with additional costs."*

GHG emissions management is one of the key issues agriculture will have to address. While the sector only contributes 13.2 per cent of total national emissions, this proportion is likely to increase if other sectors decrease their emissions. Action will be required, especially given some importers, such as the European Union, are increasingly focused on the emissions intensity of their imports. Low emissions intensity is likely to become a key point of product differentiation and a major marketing tool.

Climate change modelling and scenarios

The IPCC's Fifth Assessment Report 2014 and 2018 Special Report provide the latest scientific evidence regarding global climate change. The scenarios used to develop the IPCC's projections are based on four RCPs. The IPCC:

— has concluded that human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels
— is highly confident that global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate
— considers that for RCP8.5 (the (the scenario with the highest emissions trajectory), the likely range of temperature change is 2.6˚C - 4.8˚C, by the end of the 21st century.

In 2015, drawing on the IPCC Reports, CSIRO and BoM developed detailed climate projections for Australia, as a whole and regionally, under three of the four RCPs scenarios (RCP2.6, RCP4.5 and RCP8.5). Projections are provided for modelled climate variables (e.g. temperature, rainfall, wind) and derived variables (e.g. indices of climatic extremes, fire weather, soil moisture).

The analysis was undertaken at a regional level, based on climatic zones and NRM regions. A simulation tool kit has been developed which provides advanced capabilities to project climate change impacts with fine granularity down to farm-scale, allowing projections to be calculated down to 5 km^2.

The modelling provides insights as to potential climatic conditions out to 2090. Beyond 2030 the RCPs diverge quite strongly, dependent on the emissions outcome that is achieved. The range of the potential outcomes becomes much wider, even though the direction of change is clear. While the long-term projections provide invaluable guidance, the lack of certainty limits their value as planning and decision-making tools, especially at the enterprise level.

240 National Farmers' Federation 2018; 2030 Roadmap - Australian Agriculture's Plan for a $100 Billion Industry; https://www.nff.org.au/read/6187/nff-releases-2030-roadmap-guide-industry.html

Improving the ability to better forecast variability/extremes and decadal projections will be important for enhancing the capacity for businesses to make better informed decisions with regard to adaptation and emissions management. Accordingly, the analysis is focused at three levels:

— on the mid-term (out to 2030) where there is a greater degree of certainty as to the assumptions underpinning the analysis
— out to 2050 where there is less certainty but a number of key research findings indicate a general deterioration in conditions
— out to 2090 where possible outcomes are stark if, in the absence of global action to reduce emissions, the RCP8.5 pathway becomes the 'business as usual' scenario, and the impacts on agriculture are likely to be severe.

Warming will not manifest itself uniformly across Australia, but more hot days and fewer cold days are expected over most land areas. Heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur. The current trajectory is effectively tracking the RCP8.5 projections - a high emissions, little action pathway. In the absence of concerted global action to curb emissions, climate change is likely to have significant implications for agriculture.

CSIRO and BoM's projections were developed for the whole of Australia and for NRM regions. Jurisdiction level projections were not presented. They are reflective of natural systems, and as such the approach does not readily align with agricultural production regions or reflect local-scale climate conditions that drive on-farm/regional production systems. A number of states have undertaken projections to fill these gaps but there is a lack of commonality in approaches and assumptions, making it difficult to compare like with like. There could be value in improving the ability to better forecast variability/extremes and decadal projections.

There would be clear advantages in better coordination of projection models and data delivery systems to increase efficiency. Consistent projections at the jurisdictional level could be undertaken (by CSIRO/BoM) with the future projections tool, provided there is a willingness to commission and pay for the work. Moreover, there is no ongoing funding to undertake the next round of projections.

A critical gap in relation to the projections is the lack of a coordinated program (across all jurisdictions) to translate the projections into effective local-level adaptation tools, with direct on-farm application, and in the setting of enabling policies and investment strategies. A limited start has been made on this work by CSIRO and some NRM groups (drawing on NESP funding).

Given the long-term climate signals (gradual rise in temperatures and an overall, but not consistent, drying effect) only manifest slowly, extreme weather events and short-term indictors (e.g. time spent in drought) are also examined. These extremes are particularly important as they can provide early indictors as to the need to implement adaptation measures (e.g. heat wave stresses on horticultural crops and diary production). However, gradual changes such as less autumn-winter rainfall across southern Australia and uncertain rainfall effects in north west Australia are becoming more evident.

Australia's projected emissions, as published by DoEE in the late 2018 annual update, provide a good insight of emissions and their sources. Emissions produced by agricultural activity have fallen since 2005, with approximately 69 Mt CO_2-e emitted. While Australia has adopted an overall emissions target to meet its Paris Agreement commitments, sector by sector targets have not been set. The emissions target is economy-wide to account for the opportunities and difficulties of reducing emissions in different sectors.

Impact of climate change on agriculture

In assessing the impacts of climate change projections on Australian agricultural production, a range of factors have been considered, including the:

— range of agricultural commodities produced and the main commodities in terms of total value
— mix of agricultural commodities in each jurisdiction and their relative importance to that economy
— drivers of production, productivity and profitability and the range of risks, including climate change
— diversity of the climatic regions, changes that have already occurred, and the extent of adaptation
— CSIRO/BoM projections at the NRM cluster level.

Nine commodities were examined in detail. These were the top commodities by value of production nationally, plus some commodities which make a major contribution to one or more jurisdictions. The selected commodities are cattle, milk (dairy), wheat, sugar cane, cotton, viticulture, potatoes, mangoes and melons. Some of these have a strong affinity to similar commodities (i.e. wheat to coarse grains) or have a particular susceptibility to climate change impacts given their specific growing requirements (i.e. cotton, given high water use, viticulture, given high sensitivity to changes in temperature and heatwave stress). Some examples of significant importance to a single jurisdiction are also examined (e.g. potatoes in Tasmania and mangoes in the Northern Territory).

While this approach is not comprehensive in its coverage, the outcomes of the analysis provide valuable insights as to the scale of potential climate change impacts on the sector out to 2030, as well as an indication of the longer-term outcomes.

The outlook is agricultural commodity dependent. However, a general decline in productivity and yields seems highly likely across most commodities. To date, any impacts from climate change have been largely offset by the increases in production/yield that have been achieved through the research programs delivered by the Rural RDCs and others. Australian agriculture has remained internationally competitive by achieving relatively high rates of agricultural productivity growth in the past.

Work by ABARES and others indicates that the sector has been able to maintain productivity and yields over the last 25 years. However, ‘business as usual’ R&D efforts are just managing to maintain existing levels of productivity, rather than enabling productivity growth. Just maintaining productivity, rather than achieving productivity growth, should be a concern for both industry and government if this is the ‘new normal’. There are also growing concerns that future productivity gains from R&I will not keep pace with the negative impacts of climate change.

Looking forward to 2030, the impact on most sectors is significant but should be able to be addressed through farm management and adaptation. There are exceptions i.e. beef which show productivity declines of up to five per cent by 2030, implying more drastic adaptation action will be required to maintain production. Beyond 2030 the impacts, in the absence of concerted global action, are likely to be more severe, with an acceleration in productivity losses being the norm for most commodities.

Although there is considerable analytical work and research examining the impact of climate change on production, it tends to be fragmented, with many quite specific, and regionally focused, in-depth studies. While it may be possible to extrapolate some of these results at a commodity-wide level, given regional differences and the lack of detailed climate projections at the local/regional level, results need to be treated with caution.

There are also challenges in ensuring that research outcomes, in terms of both climate modelling and the impacts of climate change on productivity, are made available in a way that allows them to be applied in decision making at the farm level (with the possible exception of the R&D by Rural RDCs). Furthermore, anecdotal evidence suggests that sectoral, industry and regionally based plans (including R&D plans) do not address the immediate needs of farm businesses, but rather focus on the needs of industry bodies, government agencies, Rural RDC’s and R&D organisations.

A number of issues are emerging as important to sustain productivity levels and agricultural enterprises going forward, including:

— **Biosecurity/pests and diseases -** climate change is introducing new threats to areas - farm practices must adapt
— **Plant breeding/gene technology (R&D) -** to enable the introduction of plants and animals that can tolerate the changing conditions
— **Enhancing long-term preparedness, sustainability, resilience and risk management -** in line with the National Drought Agreement
— **Business and farm planning and adaptation; R&I deployment services -** the impacts of climate change must be understood and be able to be integrated into business planning at the farm level
— **Social considerations -** rural and regional community support services, mental health support
— **Land use competition -** changing land-use patterns and increasing pressure on land from alternate, higher value uses (including carbon farming) and competition between agricultural sectors
— **Input costs/availability –** particularly water and energy.

Economic impacts

The economic implications for each jurisdiction have been analysed for the commodities examined in Chapter 5. The key assumption underlying the analysis is that changes in productivity and yield will directly and proportionately flow through to value. It is accepted that this approach oversimplifies and possibly overstates the impact. The analysis is essentially an extrapolation of biophysical impacts rather than economic modelling per se.

However, this conservative and simplified approach provides some insights as to possible economic impacts and potential consequences of climate change for key commodities. The key assumption underlying the analysis is that the potential changes in productivity and yield indicated by the research, will directly and proportionately flow through to value. The assumption of direct causal relationships oversimplifies the assessment.

The focus on yield and productivity obscures other critical effects, such as impacts on quality, marketability and price; seasonal shifts in production, which potentially affecting market windows, competitive advantages and price; and changed distributions of pests and diseases, which will bring increased costs of management and challenges for export market access. Equally important, it also excludes the effects of drought and storms and other extreme weather events/shocks, which are increasingly important in terms of their economic impact on agriculture.

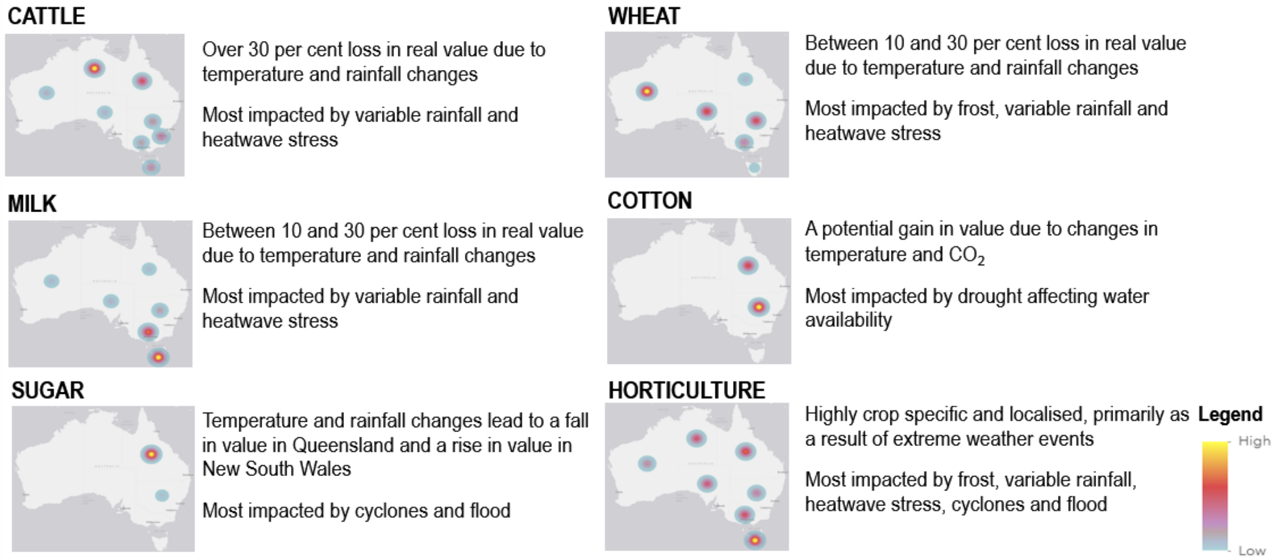
The analysis does not consider demand side effects, such as changing consumer preferences; nor does it address changes in global markets which may have a significant impact on value (both positive and negative) as future import/export opportunities play out. Furthermore, it does not take into account new and emerging technologies and practices that will support adaptation and emissions management in agriculture and offset the overall economic impacts.

Analysis of these factors is an issue for the opportunities and gaps analysis to be undertaken as part of the Stream 2 work.

Figure 7.1 shows the economic impacts on the six commodities analysed out to 2030, as well as the key drivers of that change. In relation to cattle, dairy and wheat, where the effect is most pronounced, the primary impact is from the underlying climate signal (that is rising temperatures coupled with less rainfall). For the remaining commodities extreme weather is likely to be far more significant, with impacts occurring at a local/regional level and effecting individual crops in different ways.

Across all commodities, the economic outcomes are quite different, even though all show some decline in value. In some cases the declines only become significant after 2030. The combination of potential production and yield declines coupled with rising production costs (as inputs such as water become scarce and more expensive) results in ‘winners and losers’ in terms of both commodities and jurisdictions. Economic impacts are likely to become more marked beyond 2030.

FIGURE 7.1 ECONOMIC IMPACTS ASSOCIATED WITH THE SIX COMMODITIES ANALYSED



Note: The heat map conveys the importance of the agricultural activity to the jurisdiction; that is, how much value that activity contributes to the jurisdiction compared to the total value of all agricultural activity in that jurisdiction.

SOURCE: ACIL ALLEN CONSULTING

Table 7.1 sets out the major value impacts for key commodities where the analysis shows a loss of value as a result of climate change impacts.

TABLE 7.1 ECONOMIC IMPACT ON CATTLE, MILK AND WHEAT SECTORS

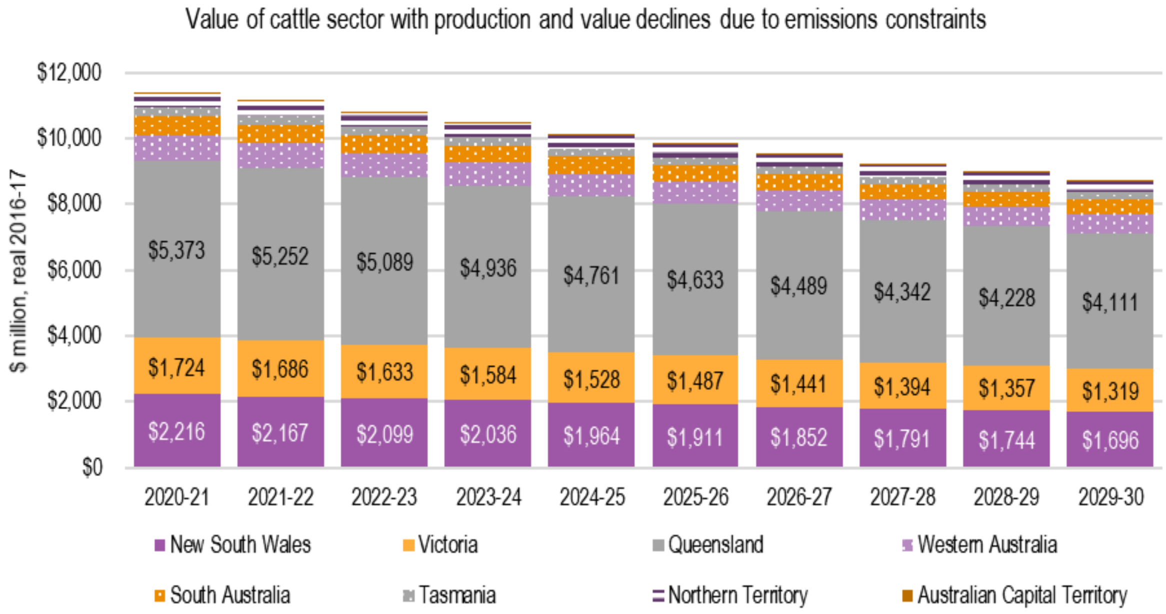
Agricultural commodity	2016/17 value	2029/30 value (nominal)	2029/30 value (real)
Cattle	$12.14 billion	$11.53 billion	$8.36 billion
Milk	$3.69 billion	$3.65 billion	$2.65 billion
Wheat	$7.37 billion	$7.28 billion	$5.28 billion

Note: Values are in both nominal and real terms; the real figures are adjusted for inflation of 2.5% per year; based on the Reserve Bank of Australia's target; table only reflects yield declines (rather than changes in production costs or land use)

SOURCE: ACIL ALLEN CONSULTING

The cost of addressing emissions from agriculture has further economic implications. **Figure 7.2** sets out the potential reduction in value of the cattle sector under an emissions constrained future. The analysis assumes that agricultural emissions are limited, to meet a hypothetical emissions trajectory, and that the cattle sector is responsible for 50 per cent of the reduction (given it currently comprises 50 per cent of agricultural emissions). The analysis is based on a simplified set of assumptions and is likely to overestimate the impact, given it makes no allowance for the adaptation and herd management/abatement initiatives which farmers would logically take to reduce emissions (rather than reducing cattle numbers). Nevertheless, as the largest single source of agricultural emissions, the impact is likely to be greatest for the cattle sector. While there will be marked differences between commodities and jurisdictions, it points to the challenge ahead.

FIGURE 7.2 UPPERBOUND REDUCTION IN VALUE OF CATTLE SECTOR DUE TO POTENTIAL EMISSIONS CONSTRAINTS



SOURCE: ACIL ALLEN CONSULTING, DEPARTMENT OF THE ENVIRONMENT AND ENERGY, AUSTRALIA BUREAU OF STATISTICS

There are a range of other outcomes with economic implications flowing from the impacts of climate change which add further to the complexity of the assessment. These include building resilience to address increased climatic extremes, in particular drought and flood; the implicit or explicit pricing of carbon and carbon price signals; rural adjustment, in part driven by climate change impacts; and broader asset valuation issues. These considerations will be addressed in detail in the Stream 2 work.

Government actions

Considerable action has been taken by governments to address the impact of climate change on agriculture, with most jurisdictions taking proactive steps.

At the national level, the key instruments are the ERF and national adaptation programs that support emissions reduction and climate adaptation responses (but many are reaching their funding limits). Moreover, ease of engagement from a farmer's perspective is a challenge - delivery could be more targeted, guided by a clear policy framework and unambiguous program requirements.

Jurisdictions have responded to international agreements for action on climate change, such as the Paris Agreement, and developed legislative and policy responses through setting emission reduction targets and the development of adaptation strategies and plans. There is significant variation in the approach to adaptation planning across jurisdictions, which include agricultural sector, state-wide and regionally specific action plans.

South Australia, Tasmania and Victoria have all made strong commitments to climate adaptation which is reflected in their legislative and policy frameworks, strategies, plans, and programs. Queensland's recent policy and planning responses at a state and agricultural sector level are also significant. The linkage drawn between agriculture and impacts on the Great Barrier Reef make Queensland a national and international focus for climate change response in Australia. Western Australia and the Northern Territory have indicated intentions to refresh climate change policy agendas in the short to medium-term.

New South Wales has focused efforts on the development of high-resolution climate change projections through NARCliM and as a major provider of rural R&D (e.g. the $29.2 million Primary Industries Climate Change Research initiative). It is also a major participant in Commonwealth funded climate related R&D programs such as the National Livestock Methane Program, SCaRP, and NANORP.

There is a gap in terms of cross-jurisdictional coordination or engagement on adaptation planning and development that is specifically focused on the agricultural sector. This presents opportunities for each jurisdiction to enhance the effectiveness of commonalities across borders, reduce duplication of research and administration effort and develop long-term priorities for co-investment or collaboration.

A consistent theme across a number of programs is the lack of coordination, particularly in terms of applied R&D to address climate change impacts on agriculture, and most importantly, the promulgation of outcomes and lessons at an on-farm level. Policy settings are critical to support this. While there are a wide range of tools and climate projections available, applying these at the local level to assist with day-to-day farm management has been limited in the majority of cases to date.

There are a number of models, for example, the 2018 National Drought Agreement, which could be readily adopted to enhance cross-jurisdictional collaboration and harmonise action. These will be considered through the Stream 2 and 3 work.

7.2 Work program for Stream 2

Climate change presents both opportunities and risks to the agricultural sector. The anticipated productivity and yield losses for a number of agricultural commodities in the short to medium-term will focus attention on adaptation measures to maintain value and profitability and build resilience. Government policy, consumer preferences and supply chain demands are also placing increasing pressure on the agricultural sector to address its emissions. There are many other factors that influence decision-making by agricultural industries including global commodity prices, technology and changes in farming practices.

While the Stream 1 has served to identify the underlying issues that agriculture will face, Stream 2 will explore, in detail, the that climate change presents to the sector. The opportunities and risks will be considered within the broader context of the many factors influencing decision making by both government and industry.

Consultation will be undertaken, including workshops in each jurisdiction, to facilitate engagement with stakeholders. Their views are critical in identifying and analysing the opportunities and risks. The consultation objectives are shown in **Box 7.1**.

BOX 7.1 CONSULTATION STRATEGY OBJECTIVES

The stakeholder engagement and communication strategy has three objectives:

1. to build ownership of and support for the project and to inform senior officials' deliberations regarding the development of advice for consideration by Ministers
2. to source the necessary information and views from stakeholders required to complete the project
3. to review and test the findings of the analysis with jurisdictions to ensure that the outcomes are valid and supported.

The intergovernmental nature of the task poses both opportunities and challenges which are central to driving the approach to stakeholder engagement. It will be essential that stakeholders are onboard and willing to take ownership of the outcomes from the work. The development of an inter-governmental consensus, alongside broad support from stakeholders, will be important in laying the foundations for the successful development and implementation of actions to address adaptation to climate change and emissions management.

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The Stream 2 work will pave the way for the Stream 3 which will identify options for consideration by officials in preparing advice for AGMIN on actions and a work program that could inform the development of a national strategy for adaptation to climate change, and emissions management in agriculture.

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A AGRICULTURAL EMISSIONS RELATING TO INDIRECT INPUTS

A.1 Emission factors – indirect agricultural inputs

Agriculture relies on a number of energy inputs - both on-farm and beyond the farm gate (i.e. liquid fuels for farm operations and also for the transportation of product to market). The emissions factors related to these energy sources are important in considering overall agricultural emissions and in examining options and actions focused on managing emissions.

The emission factors for electricity by state and territory are calculated from the emission factors of the generators located in that state or territory. Import and export flows across boundaries via the interconnectors are not accounted for. Therefore, the generation fleet located within the state and territory is the key determinant of the emission factor. Tasmania has the lowest emission factor because the generation fleet consists primarily of hydroelectric plants. Victoria is the beneficiary of several recent wind farm developments under the Large Scale Renewable Energy Target, but also hosts two of the most polluting brown coal power stations in the nation.

TABLE A.1 details the key emission factors by source.

TABLE A.1 ELECTRICITY, GAS AND TRANSPORT FUELS EMISSION FACTORS: 2018

Emission source	Units	Implied EF
Electricity consumption		
Victoria	kg CO_2-e/ kWh	1.07
NSW	kg CO_2-e/ kWh	0.82
ACT	kg CO_2-e/ kWh	0.82
QLD	kg CO_2-e/ kWh	0.8
WA: SWIS	kg CO_2-e/ kWh	0.7
NT	kg CO_2-e/ kWh	0.64
WA: NWIS	kg CO_2-e/ kWh	0.6
NT: DKIS	kg CO_2-e/ kWh	0.56
SA	kg CO_2-e/ kWh	0.51
Tasmania	kg CO_2-e/ kWh	0.19
Natural gas consumption		
Town gas	kg CO_2-e/ GJ	60.2
Ethane	kg CO_2-e/ GJ	56.5

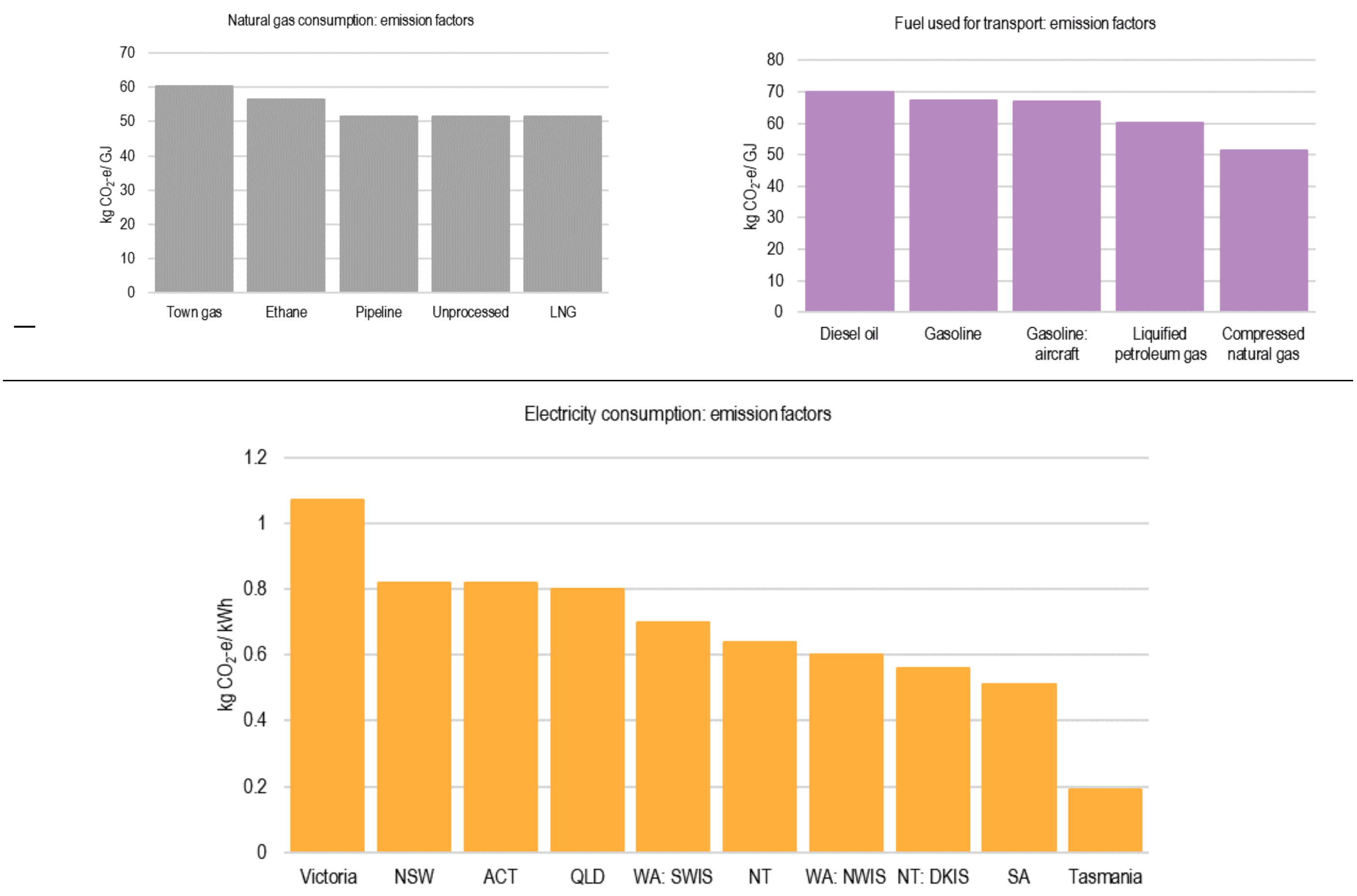
Emission source	Units	Implied EF
Pipeline	kg CO_2-e/ GJ	51.4
Unprocessed	kg CO_2-e/ GJ	51.4
LNG	kg CO_2-e/ GJ	51.4
Fuel used for transport		
Diesel oil	kg CO_2-e/ GJ	69.9
Gasoline	kg CO_2-e/ GJ	67.4
Gasoline: aircraft	kg CO_2-e/ GJ	67
Liquified petroleum gas	kg CO_2-e/ GJ	60.2
Compressed natural gas	kg CO_2-e/ GJ	51.4

Note: WA: SWIS: South West Interconnected System. WA: NWIS: North West Interconnected System. NT: DKIS: Darwin Katherine Interconnected System.

SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, NATIONAL GREENHOUSE ACCOUNTS FACTORS JULY 2018

Figure A.1 depicts the emission factors for each of the main energy inputs for agriculture.

FIGURE A.1 ELECTRICITY, GAS AND TRANSPORT FUELS EMISSION FACTORS: 2018



SOURCE: DEPARTMENT OF THE ENVIRONMENT AND ENERGY, NATIONAL GREENHOUSE ACCOUNTS FACTORS JULY 2018

B

CLIMATE PROJECTIONS: NRM CLUSTERS

B.1 Regional climate projections: NRM clusters

CSIRO and BoM have jointly produced a comprehensive set of climate change projections for Australia. The projections are presented for eight distinct regions, each of which will be affected differently by climate change (see **Figure B.1**).

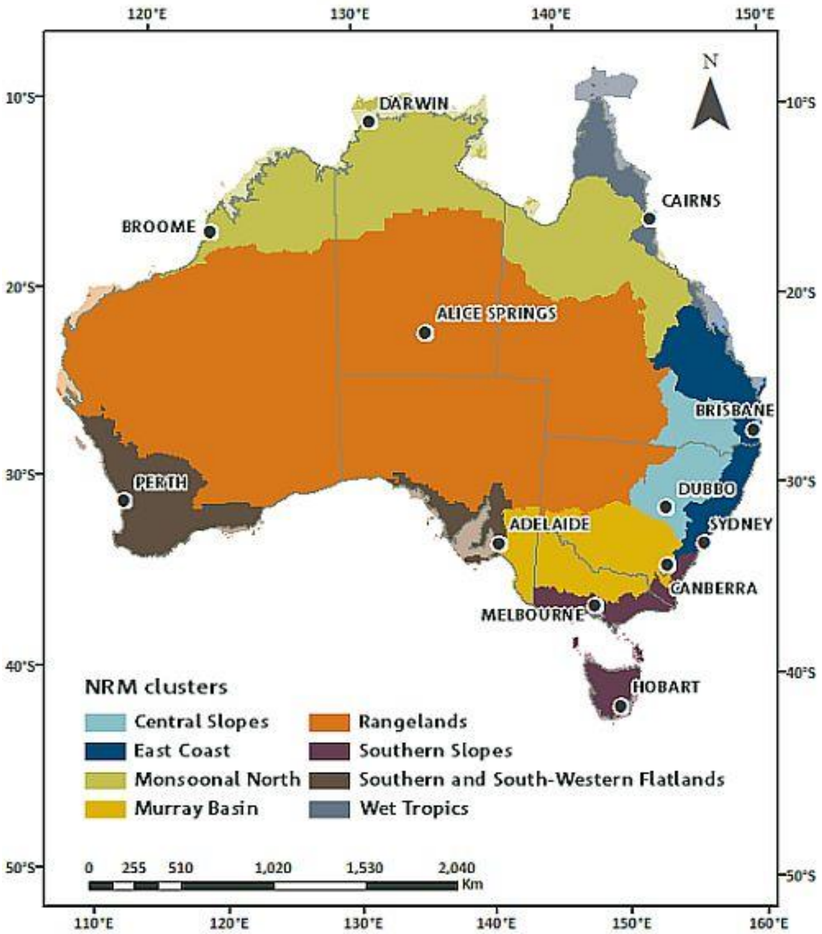
The projections are based on up to 40 global climate models that were driven by four GHG and aerosol emissions scenarios. Results have been prepared for 21 climate variables (both on the land and in the ocean) and for four 20-year time periods (centred on 2030, 2050, 2070 and 2090).

Confidence ratings for the projections are based on five lines of evidence:

— model reliability at simulating relevant aspects of the current climate
— consistency between models regarding the projected magnitude and direction of change
— results from relevant downscaled projections
— evidence for plausible processes driving the simulated changes
— the level of consistency with emerging trends in the observations.

The projections draw on the full breadth of available data and peer-reviewed literature to provide a robust assessment of the potential future climate. Details of the projections for each of the eight clusters are set out below.

FIGURE B.1 NRM CLUSTERS MAP



SOURCE: CSIRO AND BOM 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BOM, AUSTRALIA

B.1.1 Central Slopes cluster

The Central Slopes cluster comprises regions to the west of the Great Dividing Range from the Darling Downs in Queensland (Qld) to the central west of New South Wales (NSW). The area features several important headwater catchments for the Murray-Darling Basin, and is extensively developed for dryland and irrigated agriculture, grazing and forestry. The cluster area has a range of climates, from sub-tropical in the north, through to temperate in the south, with a typically drier winter and wetter summer.

Temperature

Temperatures have increased over the past century, with the rate of warming higher since 1960. Mean temperature increased between 1910 and 2013 by around 0.8°C and daily minimum temperatures have warmed more than the maximum. Across all RCP Scenarios there will be continued substantial increases in projected mean, maximum and minimum temperatures above the baseline. There is little difference between scenarios at 2030 but by 2090 RCP8.5's median temperature increase is up to three times greater at 4.2°C.

Table B.1 shows the projected median temperature change. The 10th to 90th percentile results are shown in the brackets.

TABLE B.1 PROJECTED TEMPERATURE CHANGE °C (CENTRAL SLOPES),

Year	RCP2.6	RCP4.5	RCP8.5
2030	0.9 (0.6 to 1.2)	1.0 (0.6 to 1.3)	1.1 (0.7 to 1.5)
2090	1.1 (0.6 to 1.8)	2.1 (1.4 to 2.7)	1.1 (3.0 to 5.4)

NOTE: MEDIAN PROJECTIONS SHOWN WITH 10TH TO 90TH PERCENTILE RESULTS IN BRACKETS

SOURCE: CSIRO AND BOM 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall

Table B.2 shows the projected rainfall differences as a percentage change from baseline. In 2030 all RCPs are similar so only RCP4.5 values are shown. Natural variability is projected to predominate in the near term (2030) with decreasing winter rainfall late in the century. Decreases in rainfall are also projected in spring but the direction of change in summer and autumn cannot be confidently projected due to the complexity of rain producing systems in this region.

TABLE B.2 PROJECTED RAINFALL DIFFERENCES (CENTRAL SLOPES)

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
Annual	-11 to +7	-18 to +8	-16 to +6	-23 to +18
Summer	-9 to +16	-23 to +13	-14 to +17	-14 to +29
Autumn	-22 to +19	-26 to +17	-28 to +23	-35 to +27
Winter	-20 to +11	-24 to +11	-24 to +9	-39 to +15
Spring	-18 to +12	-25 to +12	-28 to +12	-40 to +11

NOTE: PERCENTAGE CHANGE FROM BASELINE FOR 2030 FOR ALL RCPS ARE SIMILAR SO ONLY RCP 4.5 VALUES ARE SHOWN

SOURCE: CSIRO AND BOM 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme Temperature

Extreme temperatures are projected to increase at a similar rate to mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells. Frost risk days (minimum temperatures under 2 °C) are expected to decrease across the region. Some parts of the region could experience around twice the average number of days above 35°C under an intermediate and high emission scenario by late in the century.

Table B.3 shows the average number of days above 35 and 40°C for the 30-year period centred on 1995 and projections centred on 2030 and 2090.

TABLE B.3 AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (CENTRAL SLOPES)

	Dubbo (NSW)				St George (Qld)			
	1995	2030 RCP4.5	2090 RCP4.3	2090 RCP8.5	1995	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
Over 35°C	22	31 (26 to 37)	44 (36 to 54)	65 (49 to 85)	40	54 (48 to 62)	70 (59 to 87)	101 (79 to 127)
Over 40°C	2.5	3.9 (3.2 to 5.6)	7.8 (5.1 to 12)	17 (9.9 to 26)	5.1	8.2 (6.3 to 11)	15 (11 to 23)	31 (20 to 49)
Below 2°C	39	30 (34 to 27)	21 (26 to 13)	6.0 (10 to 2.4)	17	12 (15 to 11)	8.3 (11 to 5.5)	1.5 (3.5 to 0.5)

NOTE: TABLE DISPLAYS AVERAGE NUMBER OF DAYS ABOVE 35 AND 40°C (CENTRAL SLOPES) FOR 30-YEAR PERIOD CENTRED ON 1995 AND PROJECTIONS CENTRED ON 2030 AND 2090

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme Rainfall, drought and fire weather

A future increase in the intensity of extreme rainfall events is projected, although the magnitude of the increases cannot be confidently projected. Time spent in drought is projected to increase over the course of the century. A harsher fire-weather climate is also projected over the same time frame.

B.1.2 East Coast cluster

The East Coast cluster comprises NRM regions in the central part of the eastern seaboard of Australia. The area encompasses important headwater catchments for a high proportion of Australia's population. The area has a predominantly sub-tropical climate, with regional variations such as some tropical influences in the north and some temperate influences in the south.

Temperature

Mean temperature increased between 1910 and 2013 by around 1.0°C in the north of the region and 0.8°C in the south. Across all RCP scenarios there will be continued substantial increases in projected mean, maximum and minimum temperatures above the baseline. There is little difference between scenarios at 2030 but by 2090 RCP8.5's projected median warming is four times greater at 3.7°C.

Table B.4 shows the projected median temperature change. The 10th to 90th percentile results are shown in the brackets.

TABLE B.4 PROJECTED TEMPERATURE CHANGE °C (EAST COAST CLUSTER)

	RCP2.6 Low emissions	RCP4.5 Intermediate emissions	RCP8.5 High emissions
2030	0.8 (0.4 to 1.1)	0.9 (0.6 to 1.2)	1.0 (0.6 to 1.3)
2090	0.9 (0.5 to 1.5)	1.9 (1.3 to 2.5)	3.7 (2.7 to 4.7)

NOTE: MEDIAN PROJECTIONS SHOWN WITH 10TH TO 90TH PERCENTILE RESULTS IN BRACKETS

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall

Natural climate variability will dominate rainfall changes in the next few decades. Decreases in winter rainfall are projected for the south-east coast. Elsewhere, there will be little change or decreases will be more common, particularly in winter and spring.

Rainfall differences are shown in **Table B.5**. The figures are percentage changes from the baseline. In 2030 the projections for all RCPs are similar so only RCP4.5 values are shown.

TABLE B.5 PROJECTED RAINFALL DIFFERENCES (EAST COAST CLUSTER)

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
Annual	-14 to +3	-20 to +6	-18 to +9	-25 to +14
Summer	-14 to +12	-19 to +15	-16 to +13	-21 to +26
Autumn	-21 to +15	-27 to +15	-24 to +17	-32 to +27
Winter	-23 to +8	-22 to +6	-29 to +5	-44 to +6
Spring	-20 to +12	-25 to +13	-31 to +5	-44 to +7

NOTE: PERCENTAGE CHANGE FROM BASELINE FOR 2030 FOR ALL RCPS ARE SIMILAR SO ONLY RCP4.5 VALUES ARE SHOWN

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme temperature

Extreme temperatures are projected to increase at a similar rate as mean temperatures. The modelling projects a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells. Some parts of the region could experience two to three times the average number of days above 35°C under an intermediate and high emission scenario by late in the century. The number of frost risk days (minimum temperatures under 2.0°C) are expected to decrease across the region.

Table B.6 shows the average number of days above 35°C and 40°C for the 30-year period centred on 1995 and projections centred on 2030 and 2090.

TABLE B.6 AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (EAST COAST CLUSTER)

Threshold	Amberley (EC North)				Sydney (EC South)			
	1995	2030 RCPA4.5	2090 RCP4.5	2090 RCP8.5	1995	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
Over 35°C	12	18 (15 to 22)	27 (21 to 42)	55 (37 to 80)	3.1	4.3 (4.0 to 5.0)	6.0 (4.9 to 8.2)	11 (8.2 to 15)
Over 40°C	0.8	1.2 (1.1 to 1.6)	2.1 (1.5 to 3.9)	6.0 (2.9 to 11)	0.3	0.5 (0.5 to 0.8)	0.9 (0.8 to 1.3)	2.0 (1.3 to 3.3)
Below 2°C	22	16 (18 to 24)	11 (14 to 7.4)	3.1 (6.8 to 0.7)	0.0	0.0	0.0	0.0

NOTE: TABLE DISPLAYS AVERAGE NUMBER OF DAYS ABOVE 35 AND 40°C (EAST COAST CLUSTER) FOR 30-YEAR PERIOD CENTRED ON 1995 AND PROJECTIONS CENTRED ON 2030 AND 2090

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme rainfall, drought and fire weather

A future increase in the intensity of extreme rainfall events is projected, although the magnitude of the increases cannot be confidently projected. Time spent in drought is projected to increase over the course of the century and there is projected to be a harsher fire-weather climate.

Marine and coastal

By 2030 the projected range of sea-level rise for the east coast cluster coastline is 0.08m to 0.19m above the baseline for all emission scenarios. By 2090 the intermediate emissions case RCP4.5 is associated with a rise of 0.30m to 0.65m and the high emissions case RCP8.5 a rise of 0.44m to 0.88m. Late in the century warming of the East Coast coastal waters poses a significant threat to the marine environment through biological changes in marine species, including local abundance, community structure, and enhanced coral bleaching risk. Sea surface temperature is projected to increase in the range of 2.1°C to 5.7°C by 2090 under the RCP8.5 pathway. The sea will also become more acidic, with acidification proportional to emissions growth.

B.1.3 Monsoonal North cluster

The Monsoonal North comprises NRM regions in Western Australia, Northern Territory and Queensland, commonly known as the tropical 'top end'. This region experiences a pronounced wet and dry season, with differences in the timing between eastern and western parts. The Monsoonal North-West covers tropical rainforests, wetlands and arid rangelands of the Northern Territory, and the steep mountain ranges of the Ord and Fitzroy River catchments of the Kimberley. The Monsoonal North-East covers relatively intact savannah woodland and important rainforest areas as well as the Mitchell, Gilbert, Norman, Burdekin and Staaten River catchments, all of which flow into the Gulf of Carpentaria (except for the Burdekin River).

Temperature

Mean temperature has increased between 1910 and 2013 by around 0.9°C. For the near future, 2030, warming across all emission scenarios is projected to be around 0.5°C to 1.3°C above the baseline. By late in the century for the RCP8.5 pathway. the projected median warming is around four times greater at 3.8°C.

Table B.7 shows the projected median temperature change for the Monsoonal North. The 10^{th} to 90^{th} percentile projection results are shown in brackets.

TABLE B.7 PROJECTED TEMPERATURE CHANGE °C (NORTHERN MONSOONAL)

	RCP2.6 Low emissions	RCP4.5 Intermediate emissions	RCP8.5 High emissions
2030	0.8 (0.5 to 1.2)	0.9 (0.6 to 1.3)	1.0 (0.7 to 1.3)
2090	0.9 (0.5 to 1.6)	1.8 (1.3 to 2.7)	3.8 (2.8 to 5.1)

NOTE: MEDIAN PROJECTIONS SHOWN WITH 10TH TO 90TH PERCENTILE RESULTS IN BRACKETS

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall

There is considerable uncertainty in providing rainfall projections for the Monsoonal North as global climate models offer diverse results. Natural climate variability is projected to remain the major driver of rainfall changes in the next few decades. Rainfall projections for late in the century have low confidence. Potential summer rainfall changes are approximately -15 to +10 per cent under RCP4.5 and approximately -25 to +20 per cent under RCP8.5. Hence, any impact assessment in this region should consider the risk of both a drier and wetter climate.

Projected percentage changes in rainfall from baseline are shown in **Table B.8**. Changes for 2030 are similar under all pathways so only RCP4.5 values are shown.

TABLE B.8 PROJECTED RAINFALL DIFFERENCES (NORTHERN MONSOONAL)

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
Annual	-10 to +5	-14 to +4	-15 to +7	-24 to +24
Summer	-7 to +9	-14 to +4	-17 to +9	-24 to +20
Autumn	-19 to +9	-20 to +13	-19 to +1	-31 to +32
Winter	-31 to +19	-45 to +19	-39 to +19	-53 to +44
Spring	-26 to +18	-31 to +14	-30 to +29	-46 to +30

NOTE: PERCENTAGE CHANGE FROM BASELINE FOR 2030 FOR ALL RCPS ARE SIMILAR SO ONLY RCP 4.5 VALUES ARE SHOWN

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme temperature

Extreme temperatures are projected to increase at a similar rate as mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells. For Darwin and Broome, for example, days with temperatures over 35°C could be experienced for around a third of the year under the RCP4.5 pathway and for two thirds of the year under RCP8.5 by 2090.

Table B.9 shows the average number of days above 35°C and 40°C for the 30-year period centred on 1995 and projections centred on 2030 and 2090.

TABLE B.9 AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (NORTHERN MONSOONAL)

Threshold	Darwin (NT)				Broome (WA)			
	1995	2030 RCPA4.5	2090 RCP4.5	2090 RCP8.5	1995	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
Over 35°C	11	43 (25 to 74)	111 (54 to 211)	265 (180 to 322)	56	87 (72 to 111)	133 (94 to 204)	231 (173 to 282)
Over 40°C	0	0.0 (0.0 to 0.0)	0.0 (0.0 to 0.2)	1.3 (0.2 to 11)	4	7.2 (6.0 to 9.3)	11 (7.7 to 22)	30 (17 to 61)

NOTE: TABLE DISPLAYS AVERAGE NUMBER OF DAYS ABOVE 35 AND 40°C (NORTHERN MONSOONAL) FOR 30-YEAR PERIOD CENTRED ON 1995 AND PROJECTIONS CENTRED ON 2030 AND 2090

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme rainfall, drought and fire weather

Despite uncertainty in future projections of total rainfall for the Monsoonal North, the projections indicate a future increase in the intensity of extreme rainfall events. However, the magnitude of the increases cannot be confidently projected. Drought will continue to be a feature of the regional climate variability, but projected changes are uncertain.

The primary determinant of bushfires in the Monsoonal North is fuel availability, which varies mainly with rainfall. In regions where abundant rain falls (Top End and the Kimberley), climate change is not expected to change the frequency of fire. In more southerly locations, changes to future rainfall will be the determining factor of change to fire frequency. When fire does occur, fire behaviour will be more extreme.

Marine and coastal

There is very high confidence in projections of future sea-level rise. By 2030 the projected range of sea-level rise is 0.06m to 0.17m above the baseline, with only minor differences between emission scenarios. By 2090, the intermediate emissions case RCP4.5 is associated with a rise of 0.28m to 0.65m and the high case (RCP8.5) a rise of 0.38m to 0.85m. Under certain circumstances, sea-level rises higher than these may occur.

B.1.4 Murray Basin cluster

The Murray Basin cluster comprises NRM regions across New South Wales, Victoria and South Australia. The cluster extends from the flatlands of inland New South Wales to the Great Dividing Range along the southern and eastern boundaries and includes Australia's highest mountain; Mt Kosciusko, at 2228m. The cluster is relatively dry and temperate, with a warm and dry grassland climate in the north-west ranging to temperate with hot summers further east.

Temperature

Mean temperature increased between 1910 and 2013 by around 0.8°C. Daily minimum temperatures have increased more than daily maximum temperatures. Out to 2030, the warming across all emission scenarios is projected to be around 0.6°C to 1.3°C above the baseline. By late in the century for the high emission scenario RCP8.5. the projected median warming is around four times greater at 3.8°C.

Table B.10 shows the projected median temperature change for the Murray Basin. The 10th to 90th percentile projection results are shown in brackets.

TABLE B.10 PROJECTED TEMPERATURE CHANGE °C (MURRAY BASIN)

	RCP2.6 Low emissions	RCP4.5 Intermediate emissions	RCP8.5 High emissions
2030	0.8 (0.6 to 1)	0.8 (0.6 to 1.1)	0.9 (0.7 to 1.3)
2090	1.0 (0.6 to 1.5)	1.8 (1.3 to 2.4)	3.8 (2.7 to 4.5)

NOTE: MEDIAN PROJECTIONS SHOWN WITH 10TH TO 90TH PERCENTILE RESULTS IN BRACKETS

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall

Out to 2030, natural variability is projected to predominate rainfall. By 2090, cool season (April to October) rainfall is projected to decline under both the intermediate RCP4.5 and highRCP8.5) emission scenarios. In the warm season (November to March), projected changes in rainfall are less certain. The magnitude of projected changes by 2090, span approximately -40 to +5 per cent in winter and -15 to +25 per cent in summer for the high emissions case RCP8.5.

Snowfall varies significantly from year to year. Trends of snowfall decline over the past 60 years relate to the regional warming trend rather than the rainfall decline. Snowfall is projected to further decline over time with the magnitude of change dependent on the emissions scenarios and the altitude.

Projected percentage changes in rainfall from baseline are shown in **Table B.11**. Changes for 2030 are similar under all pathways so only RCP4.5 values are shown.

TABLE B.11 PROJECTED RAINFALL DIFFERENCES (MURRAY BASIN)

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
Annual	-9 to +5	-19 to +3	-16 to +4	-27 to +9
Summer	-15 to +13	-27 to +6	-17 to +10	-13 to +27
Autumn	-24 to +12	-25 to +16	-23 to +18	-29 to +26
Winter	-15 to +8	-13 to +6	-21 to +7	-38 to +4
Spring	-16 to +12	-31 to +10	-28 to +5	-48 to +6

NOTE: PERCENTAGE CHANGE FROM BASELINE FOR 2030 FOR ALL RCPS ARE SIMILAR SO ONLY RCP 4.5 VALUES ARE SHOWN

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015. CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE

Extreme temperature

Extreme temperatures are projected to increase at a similar rate to mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells. The number of frost risk days (minimum temperatures under 2°C) are projected to decrease across the region and could halve by late in the century.

The average number of days above 35°C and 40°C for the 30-year period centred on 1995 and projections centred on 2030 and 2090 are shown in **Table B.12**.

TABLE B.12 AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (MURRAY BASIN)

Threshold	Canberra (ACT)			
	1995	2030 RCPA4.5	2090 RCP4.5	2090 RCP8.5
Over 35°C	7.1	12 (9.4 to 14)	17 (13 to 23)	29 (22 to 39)
Over 40°C	0.3	0.6 (0.4 to 0.8)	1.4 (0.8 to 2.8)	4.8 (2.3 to 7.5)
Below 2°C	91	81 (87 to 76)	68 (75 to 61)	43 (52 to 35)

NOTE: TABLE DISPLAYS AVERAGE NUMBER OF DAYS ABOVE 35 AND 40°C (MURRAY BASIN) FOR 30-YEAR PERIOD CENTRED ON 1995 AND PROJECTIONS CENTRED ON 2030 AND 2090

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme rainfall, drought and fire weather

An increase in the intensity of extreme rainfall events is projected for the future, although the magnitude of the changes cannot be confidently projected. Time spent in drought is projected, to increase over the course of the century. A harsher fire-weather climate in the future is projected. However, the magnitude of the change to fire weather depends on the rainfall projection and its seasonal variation. Enhanced summer rainfall projected in some scenarios could moderate the number of severe fire weather days.

Coastal and marine

By 2030 the projected range of sea-level rise for the cluster coastline is 0.07m to 0.18m above the baseline level, with only minor differences between emission scenarios. By 2090, the intermediate emissions case, RCP4.5, is associated with a rise of 0.28m to 0.64m and the high case, RCP8.5, a rise of 0.39m to 0.84m. Under certain circumstances, sea-level rises higher than these may occur.

Late in the century warming of the Murray Basin coastal waters poses a significant threat to the marine environment through biological changes in marine species, including local abundance, community structure, and enhanced coral bleaching risk. Sea surface temperature is projected to increase in the range of 1.5°C to 3.4°C by 2090 under high emissions RCP8.5. The sea will also become more acidic, with acidification proportional to emissions growth.

B.1.5 Rangelands cluster

The Rangelands comprises NRM regions in four States and the Northern Territory. This vast region contains many varied landscapes, including the Flinders Ranges, the ranges of the Pilbara and 'The Centre (the Outback). Many Indigenous Australians live in this region. Cattle and sheep grazing are important agricultural activities. Rainfall systems vary from seasonally reliable monsoonal influences in the far north through to very low and variable rainfall patterns in much of the centre and south.

Temperature

Temperatures have increased over the past century, with the rate of warming higher since 1960. Mean temperature increased between 1910 and 2013 by around 0.9°C in the north and 1.0°C in the south. By 2030, warming across all emission scenarios is projected to be around 0.6 to 1.4°C above the baseline. By 2090, for the high emission scenario RCP8.5 the projected median warming is around four times greater at 4.3°C.

Table B.13 shows the projected median temperature change for the Rangelands. The 10th to 90th percentile projection results are shown in brackets.

TABLE B.13 PROJECTED TEMPERATURE CHANGE °C (RANGELANDS)

	RCP2.6 Low emissions	RCP4.5 Intermediate emissions	RCP8.5 High emissions
2030	0.9 (0.6 to 1.3)	1.0 (0.6 to 1.4)	1.0 (0.8 to 1.4)
2090	1.1 (0.6 to 1.8)	2.1 (1.5 to 2.9)	4.3 (2.9 to 5.3)

NOTE: MEDIAN PROJECTIONS SHOWN WITH 10TH TO 90TH PERCENTILE RESULTS IN BRACKETS

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall

Out to 2030, natural variability is projected to predominate rainfall. Winter rainfall in the south is projected to decline over the century under both intermediate RCP4.5 and high RCP8.5 emission scenarios. Changes to annual and summer rainfall for late in the century are possible, but the direction of change cannot be confidently projected. Impact assessment in this region should consider the risk of both a drier and wetter climate.

Projected percentage changes in rainfall from baseline are shown in **Table B.14**. Changes for 2030 are similar under all pathways so only RCP4.5 values are shown.

TABLE B.14 PROJECTED RAINFALL DIFFERENCES (RANGELANDS)

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
Annual	-11 to +6	-21 to +3	-15 to +7	-32 to +18
Summer	-16 to +7	-22 to +8	-16 to +10	-22 to +25
Autumn	-23 to +20	-26 to +18	-23 to +27	-42 to +32
Winter	-20 to +14	-31 to +12	-34 to +7	-50 to +18
Spring	-21 to +19	-32 to +15	-26 to +11	-50 to +23

NOTE: PERCENTAGE CHANGE FROM BASELINE FOR 2030 FOR ALL RCPS ARE SIMILAR SO ONLY RCP 4.5 VALUES ARE SHOWN

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme temperature

Extreme temperatures are projected to increase at a similar rate to mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells. For example, in Alice Springs, days with temperatures over 35°C could occur for more than a third of the year under the RCP4.5 pathway by late in the century. Where frosts (minimum temperatures under 2.0°C) occur in the region, these are projected to decrease.

The average number of days above 35°C and 40°C for the 30-year period centred on 1995 and projections centred on 2030 and 2090 are shown in **Table B.15**.

TABLE B.15 AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (RANGELANDS)

Threshold	Alice Springs (Rangelands North)			
	1995	**2030 RCPA4.5**	**2090 RCP4.5**	**2090 RCP8.5**
Over 35°C	94	113 (104 to 122)	133 155 to 152)	168 (145 to 193)
Over 40°C	17	31 (24 to 40)	49 (33 to 70)	83 (58 to 114)
Below 2°C	33	24 (28 to 19)	13 (20 to 8.4)	2.1 (6.0 to 0.8)

NOTE; TABLE DISPLAYS AVERAGE NUMBER OF DAYS ABOVE 35 AND 40°C (RANGELANDS) FOR 30-YEAR PERIOD CENTRED ON 1995 AND PROJECTIONS CENTRED ON 2030 AND 2090

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme rainfall, drought and fire weather

The projections indicate a future increase in the intensity of extreme rainfall events, although the magnitude of the increases cannot be confidently projected. Time spent in drought is projected to increase over the course of the century.

Bushfire in the Rangelands depends highly on fuel availability, which mainly depends on rainfall. A tendency toward increased fire weather risk is expected in future, due to higher temperature and lower rainfall, but the magnitude of fire weather projections is uncertain.

Marine and coastal

By 2030 the projected range of sea-level rise at Port Hedland is 0.07m to 0.17m above the baseline level, with only minor differences between emission scenarios. By 2090, the intermediate emissions case RCP4.5 is associated with a rise of 0.28m to 0.65m and the high case RCP8.5 a rise of 0.40m to 0.85m. Under certain circumstances, sea-level rises higher than these may occur.

B.1.6 Southern Slopes cluster

The Southern Slopes comprises nine NRM regions in Tasmania, southern Victoria and south-east New South Wales. This region has an extensive coastal zone and a diversity of local climates across its relatively small area. The dominant rain-bearing weather systems are cold fronts and troughs coming from the west.

Temperatures

Temperatures have increased over the past century, with the rate of warming higher since 1960. Mean temperature increased between 1910 and 2013 by 0.8°C to 1.0°C across the region. For the near future 2030, the warming across all emission scenarios is projected to be around 0.4°C to 1.1°C above the baseline. By late in the century 2090, for the high emission scenario RCP8.5the projected median warming is 3.1°C, nearly a fourfold increase.

Table B.16 shows the projected median temperature change for the Southern Slopes. The 10th to 90th percentile projection results are shown in brackets.

TABLE B.16 PROJECTED TEMPERATURE CHANGE °C (SOUTHERN SLOPES)

	RCP2.6 Low emissions	RCP4.5 Intermediate emissions	RCP8.5 High emissions
2030	0.7 (0.4 to 0.9)	0.6 (0.5 to 0.9)	0.8 (0.5 to 1.1)
2090	0.8 (0.4 to 1.3)	1.5 (1.1 to 2.0)	3.1 (2.5 to 4.0)

NOTE: MEDIAN PROJECTIONS SHOWN WITH 10TH TO 90TH PERCENTILE RESULTS IN BRACKETS

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall

Out to 2030, natural variability is projected to predominate. Out to 2090 rainfall decreases are projected for winter and spring, except for Tasmania in winter, where increases are projected. The winter decreases over Victoria are up to 30 per cent in 2090 under the RCP8.5 pathway. By the middle of the century, and under the high emissions scenario, winter changes are projected to be evident against natural variability. Changes to summer and autumn rainfall are possible but not clear, although there is a tendency for rainfall to decrease in Tasmania, particularly in western Tasmania during summer and decrease in western Victoria in autumn.

Projected percentage changes in rainfall from baseline are shown in **Table B.17**. Changes for 2030 are similar under all pathways so only RCP4.5 values are shown.

TABLE B.17 PROJECTED RAINFALL DIFFERENCES (SOUTHERN SLOPES)

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
Annual	-7 to +4	-8 to +2	-10 to +3	-19 to +5
Summer	-16 to +8	-18 to +5	-17 to +7	-19 to +13
Autumn	-11 to +9	-12 to +8	-11 to +8	-19 to +13
Winter (Vic West)	-10 to +7	-10 to +9	-14 to +7	-25 to +6
Winter (Vic East)	-11 to +6	-12 to +9	-16 to +6	-31 to +2
Winter (Tas West)	-5 to +10	-7 to +10	-5 to +14	-6 to +20
Winter (Tas East)	-11 to +5	-5 to +9	-6 to +13	-11 to +19
Spring	-11 to +5	-14 to +4	-17 to +1	-34 to +1

NOTE: TABLE DISDPLAYS PROJECTED RAINFALL DIFFERENCES (SOUTHERN SLOPES) PERCENTAGE CHANGE FROM BASELINE FOR 2030 FOR ALL RCPS ARE SIMILAR SO ONLY RCP 4.5 VALUES ARE SHOWN

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme temperature

Extreme temperatures are projected to increase at a similar rate as mean temperatures, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells. As the century progresses frost-risk days (minimum temperatures under 2.0°C) are expected to decrease across the region but with decadal variability and regional exceptions. Damaging frosts may still occur periodically.

Table B.18 shows the average number of days above 35°C and 40°C for the 30-year period centred on 1995 and projections centred on 2030 and 2090.

TABLE B.18 AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (SOUTHERN SLOPES)

Threshold	Hobart (Tas East)				Melbourne (Vic West)			
	1995	2030 RCPA4.5	2090 RCP4.5	2090 RCP8.5	1995	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
Over 35°C	1.6	2.0 (1.9 to 2.1)	2.6 (2.0 to 3.1)	4.2 (3.2 to 6.3)	11	13 (12 to 15)	16 (15 to 20)	24 (19 to 32)
Below 2°C	9.1	5.8 (6.9 to 3.7)	2.1 (4.1 to 1.1)	0.3 (0.6 to 0.1)	0.9	0.6 (0.8 to 0.4)	0.2 (0.3 to 0.1)	0.0 (0.0 to 0.0)

NOTE: TABLE DISPLAYS AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (SOUTHERN SLOPES) FOR 30-YEAR PERIOD CENTRED ON 1995 AND PROJECTIONS CENTRED ON 2030 AND 2090

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme rainfall, drought and fire weather

Even though annual mean rainfall is projected to decrease in the region, projections indicate a future increase in the intensity of extreme rainfall events. However, the magnitude of the increases cannot be confidently projected. Time spent in drought is projected to increase over the course of the century. A harsher fire-weather climate is also projected in the future. However, the magnitude of the change to fire weather depends on the rainfall projection and its seasonal variation. Relative changes are comparable across the whole region.

Coastal and marine

By 2030 the projected range of sea-level rise for the region's coastline is 0.07m to 0.19m above the baseline level, with only minor differences between emission scenarios. By 2090, under the RCP4.5 pathway a rise of 0.27m to 0.66m is projected. Under the RCP8.5 pathway a rise of 0.38m to 0.89m is projected. Under certain circumstances, sea-level rises higher than these may.

Late in the century, warming of the Southern Slopes coastal waters poses a significant threat to the marine environment through biological changes in marine species, including local abundance, community structure, and enhanced coral bleaching risk. Sea surface temperatures are projected to increase by between 1.6°C and 5.1°C by 2090 under the RCP8.5. The sea will also become more acidic, with acidification proportional to emissions growth.

B.1.7 Southern and Southwestern Flatlands cluster

The Southern and South-Western Flatlands (SSWF) region comprises NRM regions in southwest Western Australia and southern South Australia. Iconic features include the Western Australian wheat and sheep belt, Eyre Peninsula and Kangaroo Island. The SSWF area has a predominantly Mediterranean climate, with high winter rainfall and little summer rainfall in both the east and west of the region.

Temperature

Temperatures have increased over the past century, with the rate of warming higher since 1960. Mean temperature increased between 1910 and 2013 by around 0.7°C in the eastern sector, and 1.1°C in the western sector. Out to 2030, the warming across all emission scenarios is projected to be around 0.5°C to 1.1°C above the baseline. By 2090, for the high emission scenario the projected median warming is 3.4°C that is four times greater, with the west of the SSWF area warming slightly more than eastern parts of SSWF.

Table B.19 shows the projected median temperature change for the SSWF. The 10th to 90th percentile projection results are shown in brackets.

TABLE B.19 PROJECTED TEMPERATURE CHANGE °C (SOUTHERN AND SOUTHWESTERN FLATLANDS)

	RCP2.6 Low emissions	RCP4.5 Intermediate emissions	RCP8.5 High emissions
2030	0.70 (0.5to 0.9)	0.8 (0.5 to 0.9)	0.8 (0.5 to 1.1)
2090	0.8 (0.5 to 1.3)	1.7 (1.2 to 2.0)	3.4 (2.6 to 4.0)

NOTE: MEDIAN PROJECTIONS SHOWN WITH 10TH TO 90TH PERCENTILE RESULTS IN BRACKETS

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall

Decreases in winter and spring (and annual) rainfall are projected. Up to 2030, winter rainfall is projected to decrease by up to 15 per cent under all emission scenarios. Late in the century, the RCP4.5 pathway leads to a projected decrease in winter rainfall of up to 25 per cent, and under the RCP8.5 scenario winter rainfall is projected to decrease by up to 45 per cent. Changes in autumn and summer are less clear.

Projected percentage changes in rainfall from baseline are shown in **Table B.20**. Changes for 2030 are similar under all pathways so only RCP4.5 values are shown.

TABLE B.20 PROJECTED RAINFALL DIFFERENCES (SOUTHERN AND SOUTHWESTERN FLATLANDS)

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
Annual	-13 to 0	-20 to +2	-22 to -1	-36 to -2
Summer	-22 to +14	-25 to +14	-22 to +25	-26 to +28
Autumn	-18 to +9	-21 to +10	-22 to +10	-33 to +14
Winter	-16 to +2	-13 to +6	-26 to +3	-44 to +13
Spring	-20 to +3	-31 to -2	-33 to +3	-52 to -5

NOTE: PERCENTAGE CHANGE FROM BASELINE FOR 2030 FOR ALL RCPS ARE SIMILAR SO ONLY RCP 4.5 VALUES ARE SHOWN

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme temperature

Extreme temperatures are projected to increase at a similar rate as mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells. Frost risk days (minimum temperatures under 2.0°C) are expected to decrease across the region. By 2090 under the RCP8.5 pathway the number of hot days over 35°C are projected to double.

Table B.21 shows the average number of days above 35°C and 40°C for the 30-year period centred on 1995 and projections centred on 2030 and 2090.

TABLE B.21 AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (SOUTHERN AND SOUTHWESTERN FLATLANDS)

Threshold	Perth (SSWF West)				Adelaide (SSWF East)			
	1995	**2030 RCPA4.5**	**2090 RCP4.5**	**2090 RCP8.5**	**1995**	**2030 RCP4.5**	**2090 RCP4.5**	**2090 RCP8.5**
Over 35°C	28	36 (33 to 39)	43 (37 to 52)	63 (50 to 72)	20	26 (24 to 29)	32 (29 to 38)	47 (38 to 57)
Over 40°C	4	6.7 (5.4 to 7.5)	9.7 (6.9 to 13)	20 (12 to 25)	3.7	5.9 (4.7 to 7.2)	9.0 (6.8 to 12)	16 (12 to 22)
Below 2°C	3.4	2.1 (2.5 to 1.4)	0.9 (1.3 to 0.7)	0.1 (0.4 to 0.0)	1.1	0.5 (0.8 to 0.4)	0.2 (0.4 to 0.1)	0.0 (0.0 to 0.0)

NOTE: TABLE DISPLAYS AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (SOUTHERN AND SOUTHWESTERN FLATLANDS) FOR 30-YEAR PERIOD CENTRED ON 1995 AND PROJECTIONS CENTRED ON 2030 AND 2090

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme rainfall, drought and fire weather

A future increase in the intensity of extreme rainfall events is projected, however, the magnitude of the increases cannot be confidently projected. Strongly decreasing mean rainfall in the western sector indicates increased extreme rainfall for that region. Time spent in drought is projected to increase over the course of the century. A harsher fire-weather climate is projected in the future. However, the magnitude of the change as this is strongly dependent on the rainfall projection.

Marine and coastal

By 2030 the projected range of sea-level rise for the region's coastline is 0.07m to 0.18m above the baseline level with only minor differences between emission scenarios. By 2090, the intermediate emissions case RCP4.5 is associated with a rise of 0.28m to 0.65m and the high case RCP8.5 a rise of 0.39m to 0.85m. Under certain circumstances, sea-level rises higher than these may occur. Late in the century warming of the SSWF coastal waters poses a significant threat to the marine environment through biological changes in marine species, including local abundance, community structure, and enhanced coral bleaching risk. Sea surface temperature is projected to increase in the range of 1.5°C to 3.9°C by 2090 under high emissions RCP8.5. The sea will also become more acidic, with acidification proportional to emissions growth.

B.1.8 Wet Tropics cluster

The Wet Tropics comprises four NRM regions in northern Queensland. The region contains considerable biodiversity assets, for example within national parks and the Great Barrier Reef World Heritage area. The climate of this cluster is characterised by two seasons; the monsoonal wet season (from around December to April), which is dominated by prevailing north-westerly winds, and the dry season (May to November), when south-easterly trade winds dominate.

Temperature

Temperatures have increased over the past century, with the rate of warming higher since 1960. Mean temperature increased between 1910 and 2013 by around 1.1°C. Daily minimum temperatures increased by slightly more than daily maximum temperatures.

Out to 2030, the warming across all emission scenarios is projected to be around 0.3°C to 1.1°C above the baseline. By 2090 under the RCP8.5 scenario the projected median warming is 2.9°C, nearly a fivefold warming increase

Table B.22 shows the projected median temperature change for the SSWF. The 10th to 90th percentile projection results are shown in brackets.

TABLE B.22 PROJECTED TEMPERATURE CHANGE °C (WET TROPICS)

	RCP2.6 Low emissions	RCP4.5 Intermediate emissions	RCP8.5 High emissions
2030	0.6 (0.3to 0.9)	0.7 (0.6 to 1.0)	0.8 (0.6 to 1.1)
2090	0.7 (0.4 to 1.4)	1.4 (1.0 to 2.0)	2.9 (2.3 to 3.9)

NOTE: MEDIAN PROJECTIONS SHOWN WITH 10TH TO 90TH PERCENTILE RESULTS IN BRACKETS

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Rainfall

There is considerable uncertainty in providing rainfall projections in regard to the quantum and direction of change for the Wet Tropics as global climate models offer diverse results. Out to 2030 natural variability is projected to predominate. There is a low level of confidence in the late in the century with the projections giving a broad range rainfall outcomes. The potential summer and autumn rainfall changes are approximately -25 to +20 per cent under the RCP8.5 scenario and -15 to +10 per cent under the RCP4.5 pathway. Impact assessment in this region should consider the risk of both a drier and wetter climate.

Projected percentage changes in rainfall from the baseline are shown in **Table B.23**. Changes for 2030 are similar under all pathways so only RCP4.5 values are shown.

TABLE B.23 PROJECTED RAINFALL DIFFERENCES (WET TROPICS)

	RCP4.5 2030	RCP2.6 2090	RCP4.5 2090	RCP8.5 2090
Annual	-11 to +6	-16 to +5	-12 to -8	-26 to -21
Summer	-18 to +11	-16 to +8	-15 to +11	-20 to +22
Autumn	-10 to +5	-17 to +10	-16 to +11	-27 to +22
Winter	-26 to +22	-30 to +24	-31 to +28	-41 to +45
Spring	-34 to +25	-33 to -24	-35 to +50	-50 to -+104

NOTE: PERCENTAGE CHANGE FROM BASELINE FOR 2030 FOR ALL RCPS ARE SIMILAR SO ONLY RCP 4.5 VALUES ARE SHOWN

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme temperatures

Extreme temperatures are projected to increase at a similar rate as mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells. For Cairns, for example, days with temperatures over 35°C could increase around three-fold from 1995 levels under the RCP4.5 pathway by 2090.

The average number of days above 35°C and 40°C for the 30-year period centred on 1995 and projections centred on 2030 and 2090 are shown in **Table B.24**.

TABLE B.24 AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (WET TROPICS)

Threshold	Cairns (Qld)			
	1995	**2030 RCPA4.5**	**2090 RCP4.5**	**2090 RCP8.5**
Over 35°C	3	5.5 (4.4 to 7.9)	11 (7.4 to 22)	48 (24 to 105)
Over 40°C	0	0.1 (0.1 to 0.2)	0.3 (0.2 to 0.4)	0.7 (0.5 to 2.0)

NOTE: TABLE DISPLAYS AVERAGE NUMBER OF DAYS ABOVE 35°C AND 40°C (WET TROPICS) FOR 30-YEAR PERIOD CENTRED ON 1995 AND PROJECTIONS CENTRED ON 2030 AND 2090

SOURCE: CSIRO AND BUREAU OF METEOROLOGY 2015, CLIMATE CHANGE IN AUSTRALIA INFORMATION FOR AUSTRALIA'S NATURAL RESOURCE MANAGEMENT REGIONS: CLUSTER BROCHURES, CSIRO AND BUREAU OF METEOROLOGY, AUSTRALIA

Extreme rainfall, drought and fire weather

A future increase in the intensity of extreme rainfall events is projected. However, the magnitude of the increases cannot be confidently projected. Tropical cyclones are projected to become less frequent, but the proportion of the most intense storms is projected to increase. Drought will continue to be a feature of the regional climate variability, but projected changes are uncertain. In the Wet Tropics where abundant rainfall (wet season) and bushfires (dry season) are common, the projected changes in rainfall are not expected to significantly change the current seasonal cycle. The projections are for little change to fire frequency. However, when and where fire does occur, the fire behaviour will be more extreme.

Coastal and marine

By 2030 the projected range of sea-level rise is 0.06m to 0.18m above the baseline level, with only minor differences between emission scenarios. By 2090, the intermediate emissions case RCP4.5 is associated with a rise of 0.27m to 0.65m and the high case RCP8.5 a rise of 0.40m to 0.87m. Under certain circumstances, sea-level rises higher than these may occur.

Late in the century warming of the Wet Tropics coastal waters poses a significant threat to the marine environment through biological changes in marine species, including local abundance, community structure, and enhanced coral bleaching risk. Sea surface temperature is projected to increase in the range of 2.2°C to 3.6°C by 2090 under the RCP8.5 pathway. The sea will also become more acidic, with acidification proportional to emissions growth.

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