University of Hamburg
Department of Earth Sciences
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# Climate Change Impacts and Risk Management:

# Improving farm resilience through adaptation in the cropping-livestock zone of the Corangamite catchment in Victoria (Australia) with a Case Study of the ´Mount Hesse´ farm

A dissertation submitted in partial fulfilment of the requirements for the degree
“Doctor of Natural Sciences” (Doctor rerum naturalium)
at the University of Hamburg, Germany

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Hamburg, January 16th 2018

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Date of oral defense: December, 20th 2017

## ABSTRACT

Australia has not only one of the most variable climates in the world, but the country is also considered highly exposed and vulnerable to the adverse impacts of climate change. The study area is the Corangamite catchment in south-west Victoria which has experienced an increase in temperature, changing seasonal pattern and a decrease in rainfall over the last decades.

So far, no other research study has focused on farmers climate related risk perception, identified local vulnerabilities and explored adaptation options for farmers in the Corangamite catchment under climate change. For this dissertation, 53 farmers were interviewed in the catchment of which 13 farmers were interviewed face-to-face and another 40 through a structured online survey to explore perceptions in local climate change, associated impacts and employed management strategies to deal with climate related risks. Additionally, further 24 sectoral experts from private, research and governmental institutions were interviewed to a) explore factors influencing farmers risk perception and triggering adaptation constraints and b) discuss risk management strategies for farmers in the catchment to lower potential vulnerabilities from climate change related impacts and to increase on-farm resilience.

This study identified a number of perceived climate related changes by farmers including changes in the timing and amount of rainfall and more and earlier extreme temperature events coming along with impacts on agricultural production and farm well-being. Farmers have already implemented several of the suggested risk management strategies by sectoral experts to deal with increasing climate variability. However, sectoral experts recommended including climate change into planning activities and the decision-making process to stay viable in the long-term as well.

According to interviewed sectoral experts, risk management strategies include the understanding and assessment of changing risks under climate change to enable the development and implementation of sustainable farm-management strategies. However, interview partners identified different factors determining farmers risk perception and understanding of changing business risks including personal experience with environmental conditions, socio-economic factors and political influence. Constraints in adaptation such as a perceived psychological distance to climate change, lack in capacities and asset or internal and external dependencies of farmers may potentially interfere to deal with the issue of climate change in the longer term and thus increase farmers vulnerability. Although most adaptation strategies are extensions or intensifications of existing climate risk strategies, a more system or transformational adaption may be required under more severe climate change. Farm enterprises who adapt to increasing climate variability will be better placed than those who don’t especially in the long-term.

In the end, the study applies the findings of this thesis to the case study Mt Hesse farm and reveals that the farm is in an advantaged situation due to different factors including its international background, the long history of family farming in its 4th generation or its pronounced interest in dealing with climate change, thus potentially supporting the resilience to adverse climate related impacts.

# Contents

## List of Figures

## List of Tables

## List of Acronyms and Abbreviations

BOM - Bureau of Meteorology

CMIP5 - Coupled Model Inter-Comparison Project 5

DEDJTR - Department of Economic Development, Jobs, Transport and Resources

DSE - Dry Sheep Equivalents

ENSO - El Niño Southern Oscillation

FAO - Food and Agriculture Organisation

GCMs - Global Climate Models

IIASA - International Institute for Applied Systems Analysis

IOD - Indian Ocean Dipole

IPCC - Intergovernmental Panel on Climate Change

ISIMIP - Inter-Sectoral Impact Model Intercomparison Project

NGO - Non-governmental Organisation

PIK - Potsdam Institute for Climate Impact Research

SAM – Southern Annual Mode

SILO - Scientific Information for Land Owners

RCPs - Representative Concentration Pathways

UN - United Nations

WMO - World Meteorological Organization

# 1. Introduction

## 1.1. Starting Point: Problem Diagnosis

Australia has one of the most variable climates in the world with a high seasonal, inter-annual and decadal variability (BOM 2017b; Climate Change Authority 2012). However, according to the Bureau of Meteorology (BOM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2016), the observations of climate modelling paint a consistent picture of the ongoing, long-term climate change interacting with underlying natural climate variability in Australia. A reconstruction of global historical temperature development puts the *recent* climate change into a long-term context. This reveals how unusual the past four decades of human-driven climate change were compared to the patterns of natural climate variability in the past 2,000 years regarding its temporal dimension, spatial distribution and different triggers for warming (PAGES 2k Consortium 2013). Although specific future outcomes of climate change remain uncertain, projections for Australia suggest changes in the frequency, intensity, spatial extension and duration of climate extremes, which lead to increased stress on human and natural systems (BOM/CSIRO 2016; IPCC 2012).

Facing one of the most risky farming environments in the world, agriculture in Australia has developed in a way that includes managing farm businesses to cope with a highly variable environment (RIRDC 2007). However, according to the Climate Change Authority (2012), climate change and associated impacts pose *new* and diverse risks for the Australian society. The agricultural sector is considered to be in the frontline of climate change related risks through impacts on natural resources which place financial, emotional and physical stress on the farmers. Thus, climate change is likely to add extra pressure on farm businesses, since they already deal with physical factors deriving from their natural environment, economic factors, policy and institutional changes as well as social factors such as changes in the consumer demands for agricultural products (RIRDC 2007; Nguyen et al. 2005). Especially a dynamic shift in the frequency and magnitude of extreme climate events alongside with new and earlier emerging risks in the season can impact both economic (e.g. supply and demand for farm input, changes in commodity prices and financial outcomes) and social (e.g. living standards) farm dimensions (RIRDC 2007). Changes in climate pattern in combination with increasingly degraded ecosystems through some agricultural intensification strategies turn the question to agricultural sustainability and how to better respond to changing conditions to increase the resilience of social, ecological and economic systems into the future (Morton and Abendroth 2017). As climate change is likely to increase Australia's already high naturally seasonal, annually and decadal climate variability and trigger changes in the extremes of natural variations such as higher peak temperatures, managing climate variability and associated risks will become more important than it has been in the past (Harle et al. 2007; CSIRO 2001). Therefore, ARC Consulting Group (2017) suggests that a sound risk management approach is a key to moving forward in the agricultural sector to deal with climate related risks. The process of risk management under climate change is a dynamic approach which can significantly lower potential risks from extreme events and longer term changes to a system to lower specific vulnerability. As risk management is an effective way to mitigate the adverse consequences of climate change it plays an important role in climate change adaptation (Yuan et al. 2017).

Handling risks is often associated with uncertainty and considered one of the most difficult aspects of farm-system planning and management (McConnell and Dillon 1997). However, better understanding the risks associated with climate change supports building adaptive capacities to take upon appropriate adaptation efforts (Keywood et al. 2017). Thus, resilience as a capacity to adjust and adapt to shifting conditions, disturbances and uncertainties without major losses is considered a key factor to improve agricultural sustainability (Park et al. 2013, Walker and Salt 2006). Adaptation is an ongoing process and part of good farm risk management which includes identifying drivers of risks, assessing likely impacts under alternative management strategies on systems and making use of potential opportunities (Howden et al. 2007).

According to Schattman et al. (2016), how farmers conceptualize and take action in addressing risks is an important area of investigation. How farmers perceive risk and assess changing business threats is not only critical in thinking through appropriate management strategies but also influences their ability to make decisions that support positive future outcomes over immediate ones (Purdue University 2017; Schattman et al. 2016). Although perceptions are not necessarily consistent with reality, they must be identified, understood and considered in order to address socio-economic challenges, adaptation constraints and potential vulnerabilities (Kusakari et al. 2014). Understanding farmers risk perceptions also enables researchers and sectoral experts to develop integrated risk management approaches to increase farmers resilience to the impacts of climate variability and change (Purdue University 2017). Studies show, that knowledge about climate change and its impacts especially on regional and local level, typically increases overall concern about the risks and at the same time increases peoples responsibility to find appropriate solutions and willingness to take action (Milfont 2012). Therefore, increasing awareness among farmers is required to change perspectives in terms of understanding the ever changing risks associated with climate change, to overcome potential constraints in adaptation and to effectively manage the shifting risk profiles under climate change (Sheppard et al. 2016).

The study area of this thesis is the Corangamite catchment which is located in south-west Victoria, Australia. Hence, with many global studies focusing on developing countries, this dissertation contributes to the discussion about climate change, vulnerability and resilience in the agricultural sector in the context of a developed country. The Case Study of this thesis is the Mt Hesse farm which is a family-operated farm and one of the largest Merino wool producers in Australia. The farm was acquired by *Südwolle Group* in 2002 which is also the donor of this dissertation (Südwolle Group 2013).

### 1.2. Objectives and Research Questions

This thesis aims to contribute to a better understanding of the impacts of climate change and possible adaptation strategies to associated adverse consequences on regional and local level. The approach of this thesis is to provide an application oriented framework that helps farmers and decision makers in assessing and managing changing farm and business risks from climate change in the study area (a PhD summary will be sent to farmers, see Annex E). Therefore, this thesis aims to explore historical and future climate developments and seeks to identify risks and impacts deriving from climate change on the agricultural sector in this study area. This study also aims to understand which challenges and risks farmers perceive in the context of a changing climate, how they respond and which factors actually determine their risk perception. Furthermore, this thesis seeks to explore appropriate and effective risk management strategies to support farmers in building adaptive capacities and therefore increase farm resilience in socio-economic and environmental terms. Also factors potentially determining adaptation constraints are researched to better understand and address them within the risk management approach. To achieve the aim of this thesis, the following four objectives were pursued:

a) to explore historical and projected trends in climate in order to identify potential climate related risks and impacts for the study area
b) to identify farmers climate related risk perception and potential factors influencing their perception and constraining adaptation
c) to provide an application-oriented risk management framework for farmers in order to minimize potential vulnerability to climate change related impacts and to increase farm resilience from short to long-term
d) to apply results to the case study Mt Hesse farm

The key research questions that guided the study can be summarised as follows:

**Primary research question**

Which trends in climate can be identified, which risks do they pose to farmers and which risk management strategies help in reducing local vulnerability and increasing resilience to climate related impacts in the study area?

**Sub-questions**

a) How did the climate change in the last century and which developments in temperature and precipitation are expected in future for the study area?
b) Which impacts, risks and opportunities of climate change have been identified for agricultural production so far by the interviewed farmers and sectoral experts?
c) Which factors influence farmers perception in terms of climate related risks and potentially constrain adaptation?
d) How can risk management help in managing changing risks under climate change in order to support environmental, economic and social farm resilience?
e) What do the study results mean for the case study Mt Hesse farm?

### 1.3. Structure of Work

This **Introduction** part provides a brief overview of climate change as threat to the agricultural sector, highlights the demand for a sound risk management approach to support sustainable adaptation/farm resilience and presents the objectives and research questions of this dissertation.

The **second chapter** gives an overview of the Corangamite catchment in terms of its geography and climatic setting, socio-economic aspects of the basin and furthermore provides a historical overview of Australia's agricultural sector. This chapter also presents the Case study Mt Hesse; its history, geographic and climatic setting as well as farm statistics.

The **third chapter** gives an overview of the current state of research reviewing relevant literature used for this study to address its research questions, which establish the theoretical framework for this study. It presents climate change in the Australian context and defines risks, vulnerability, resilience and adaptation in the context of climate change that furthermore continues to present the concept of agricultural risk management.

The **fourth chapter** discusses the methodology used in the thesis. It presents information on used climate data as well as the procedure of the conducted interviews, including a description of the interview partners and the following data analysis.

The **fifth chapter** presents the empirical results of this study, presenting climate graphs and categories of statements from interviewed farmers and sectoral experts.

The **sixth chapter** analyses and discusses the empirical results with the help of relevant literature where sections are discussed among three hypotheses that have been generated during the research process.

The **seventh and last chapter** synthesises the findings, discusses limitations of this study and provides an outlook by giving recommendations for possible future areas of research.

## 2. Description of the Study Area - The Corangamite Catchment & Mt Hesse

This chapter presents geographical and climatic settings of the Corangamite catchment, presents an overview of the socio-economic background which follows a brief historical overview of Australia's and Victoria's agricultural sector. In the end, the case study of Mt Hesse is presented in terms of its history, geography, climate and its production characteristics.

### 2.1. Geography and Climate

The Corangamite catchment covers an area of approximately 1.3 million hectare (ha) of land of which 78 % are privately owned (CMA 2013). The following map presents the catchments within the state of Victoria in south-eastern Australia and the boundary of the Corangamite catchment located in south-west Victoria.


**Figure 1: Victoria's water catchments**
(North East Catchment Management Authority 2017)

The Corangamite catchment stretches between the Otway Coast, Ballarat and Geelong in south-west central Victoria. In the south-eastern part of the catchment, steeply dissected terrain of the Otway Ranges give way to low hills and volcanic plains to the middle area of Geelong before rising again to the moderate elevations of the northern uplands around Ballarat (DEDJTR 2017b). The coastline of the Corangamite catchment is 175 km long. Beside the bay and ocean environments, the catchment includes three main national parks, four state parks, three marine protected areas and a wide range of conservation reserves that supports rare and diverse flora and fauna species and provides recreation and touristic areas. The native vegetation has undergone major changes since the beginning of the European settlement with only 25 % of the native vegetation (pre-1750) remaining mostly in the catchment on public land. Due to pest plants and animals, fires, floods, inappropriate land use management and climate change, the native vegetation is continuing to decline nowadays. However, several legislative Acts and Strategies have aimed to prevent further loss within the catchment (CMA 2013).

The following map shows the Corangamite catchment and the location of the Mt Hesse farm in the heart of the catchment, about 55 km west of Geelong which is Victoria's second largest city (City of Greater Geelong 2015; Südwolle Group 2013).


**Figure 2: Map Corangamite catchment**
(Corangamite Catchment Management Authority 2016)

The Corangamite catchment offers diverse and productive landscapes, supporting cropping, grazing, livestock enterprises, production forests, horticulture and viticulture. As the study area is characterized by expansive volcanic plains and rock formations, different soil types support a wide variety of natural resources for native vegetation and the agricultural sector. Based on common climate, geology, landform, native vegetation and species, the catchments comprises of 6 bioregions out of 89 large geographically distinct bioregions in Australia. The region offers a diverse range of rivers and waterways, underpinning water supplies to towns and cities. The major waterways in the region include the Barwon, Moorabool, Cumberland, Wye and Leigh rivers as well as Lake Corangamite (CMA 2013; DELWP 2008). The lake Corangamite is Australia's largest permanent saline lake and Victoria's largest natural lake that serves as a wetland for migratory and non-migratory birds (CMA 2015). The catchment is named after the Corangamite lake which means ´bitter´ or salt water in aboriginal words (Corangamite Shire 2016). Also, the Corangamite catchment has more than 1500 wetlands, covering 5 % of the region. Wetlands provide habitat for flora and fauna, support hydrological regimes and help to mitigate floods. They rate among the most productive ecosystems on earth (CMA 2013). Some of the main threats to these wetlands include physical land use change by draining them for cropping/grazing purposes, urban development and climatic changes of temperature and precipitation pattern. Since almost one-third of Victoria's wetlands have been lost since 1788, there are efforts in place for improved wetland management. In terms of groundwater, there is no historical long-term data on groundwater levels or the interaction between surface and groundwater available, however increased monitoring is being focused in the recent years to better understand changes in the hydrological regime. Also, groundwater supports ecosystems such as rivers and wetlands and provides domestic, rural, and industrial water supply for the agricultural sector. As groundwater is a limited resource, management plans help use the resource sustainably and raise knowledge about aquifers and groundwater use in the catchment (CMA 2013).

In terms of the climate, Australia has one of the most variable climates in the world which can greatly vary from year to year creating different temporal and spatial levels of impact. Also Victoria and the catchment are influenced by several climatic features triggering high natural climate variability. The following figure shows the different drives influencing the country's climate in which the most important ones influencing Victoria's climate are presented below (BOM 2017b).

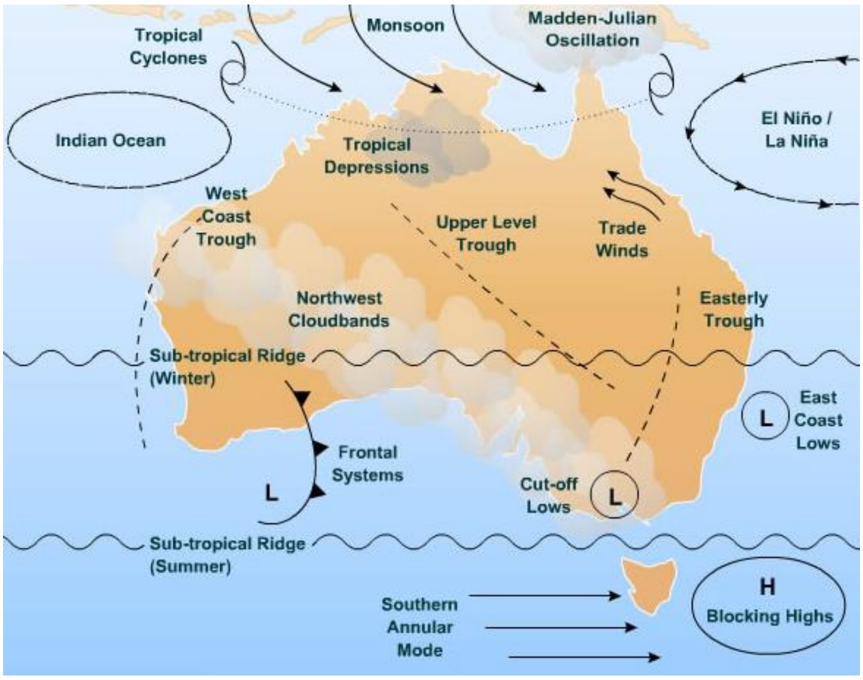



**Figure 3: Influences on Australia's climate**
(BOM 2017b)

According to BOM (2017b), blocking highs are strong high pressure systems which have developed further south than usual in the Tasman Sea and remain stationary for an extended period of time.

These high pressure systems ´block´ the flow of low pressure systems across southern Australia, can linger up to several weeks and are sometimes associated with cut-off lows which may form to the north of the blocking high. This can impact areas under influence by creating either hot or cold spells to dry or wet conditions depending on the location and strength of the blocking highs.

The Southern Annular Mode (SAM) is a mode of variability and can result in enhanced rainfall in coastal regions of southern Australia. During a ´positive´ SAM event, the westerly wind belt contracts towards the South Pole, leading to weaker than average westerly winds and higher pressure over southern Australia. During a ´negative´ SAM event, the wind belt expands northwards leading to more storm systems and lower pressure over southern Australia. According to the Australian Bureau of Statistics (2000), there is an increasing tendency to remain in a positive phase during summer and autumn with westerly winds shifting towards the South Pole.

Cut-off lows are low pressure systems which are cut-off from the main belt of low pressure to the south of Australia, bringing enhanced rainfall and strong wind to parts of southern Australia. They are common in autumn and winter and generally only last for a few days or up to a week.

East coast lows are intense low-pressure systems, bringing heavy rainfall, strong winds and high seas to parts of south-eastern Australia and are common during autumn and winter. As they often rapidly intensify overnight they can become dangerous weather systems affecting the south-eastern coast of Australia which can last for several days.

The sub-tropical ridge runs across a belt of high pressure that encircles the globe in the middle latitudes as part of the global atmospheric circulation and brings dry and stable conditions from high pressure systems to large parts of Australia depending on the position during winter and summer. The position of the ridge plays an important role for weather variability between seasons. Especially during the winter time, the sub-tropical ridge moves northward over central Australia bringing cold fronts and low pressure systems associated with colder south-westerly winds and showery conditions. During the Australian summer, the ridge is generally located to the south of the continent, bringing high pressure systems which are associated with stable and dry conditions.

El Niño Southern Oscillation (ENSO) refers to the oscillation between El Niño and La Niña conditions. El Niño refers to the extensive warming of the central and eastern tropical Pacific Ocean, triggering major shifts in weather patterns across the Pacific. It occurs every three to eight years on average and is associated with an increased risk of dry conditions across eastern and south-eastern Australia. However, also if most major Australian droughts are associated with El Niño events, they are not guaranteed with an upcoming El Niño. On the other side, La Niña occurs when the eastern Pacific Ocean is much cooler than average, bringing widespread rain and flooding to eastern and south-eastern Australia. Also temperatures tend to be below average.

Frontal systems bring rainfall to southern Australia, with cold fronts being more common than warm fronts. Cold fronts have a greater impact on the region with the greatest impact during the winter months. They usually move across southern Australia from west to east, vary in their intensity and speed and can last from a couple of days to a week.
The Indian Ocean and its sea surface temperatures (SSTs) also influence rainfall and temperature patterns over many parts of Australia. The difference of surface temperatures between the tropical western and eastern Indian Ocean is known as the Indian Ocean Dipole (IOD). The state of the IOD is one of the key drivers of Australia's climate and can have a significant impact on southern Australia’s agriculture especially during the winter crop growing season. The IOD has three phases: positive, neutral and negative. In a positive phase, the SSTs around Indonesia are cooler than average while the SSTs in the western Indian Ocean are warmer than average. If there is an increase in easterly winds across the Indian Ocean associated with the SST, the convection near Australia drops and results in suppressed rainfall over the country. In the negative phase, the SSTs are warmer than average near Indonesia and cooler than average in the western Indian Ocean. This results in stronger westerly winds across the Ocean, higher convection near Australia and enhanced rainfall over the country. According to the Australian Bureau of Statistics (2017b), the state of the IOD can be related to ENSO events. When an El Niño coincides with a positive IOD, the two phenomena trigger dry effects over Australia while La Niña in combination with a negative IOD typically increases the chance of above-average winter and spring rainfall (BOM 2017b).

Despite all listed climatic features that contribute to the high variability of Australia’s and Victoria’s climate, the Corangamite catchment itself has a fairly reliable climate environment compared to most other parts of Australia. The area has a Mediterranean climate with relatively mild seasons compared to the northern inland areas of Victoria. The annual average rainfall in the catchment is 773 mm, but can reach up to 1400 mm in the Otway ranges with most rainfall occurring during the winter and spring time between June and November. The following table shows the annual and seasonal average temperatures and precipitation in the Corangamite catchment (DELWP 2008).

**Table 1: Seasonal and annual average temperatures and rainfall in the Corangamite catchment**
(DELWP 2008)

| | Average daily temperature (°C) | Average daily maximum temperature (°C) | Average daily minimum temperature (°C) | Average rainfall (mm) |
|---|---|---|---|---|
| **Annual** | 13.4 | 18.4 | 8.4 | 773 |
| **Spring** | 12.6 | 17.7 | 7.6 | 214 |
| **Summer** | 17.8 | 24.0 | 11.6 | 134 |
| **Autumn** | 14.2 | 19.1 | 9.3 | 187 |
| **Winter** | 8.9 | 12.8 | 5.0 | 239 |

Despite quite reliable annual rainfall, variations within the four seasons are common. The following two maps show the average annual temperature and rainfall across the Corangamite region based on a 30-year period from 1961-1990 (EverGraze 2017; DELWP 2008).

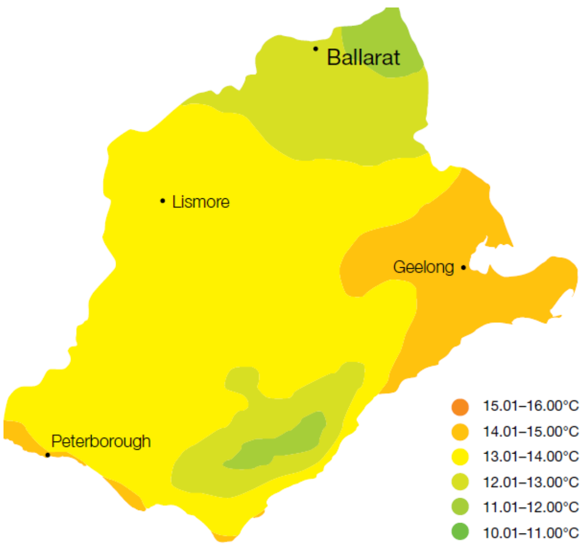



**Figure 4: Average annual temperature across the Corangamite region based on average daily temperature between 1961 to 1990**
(DELWP 2008)

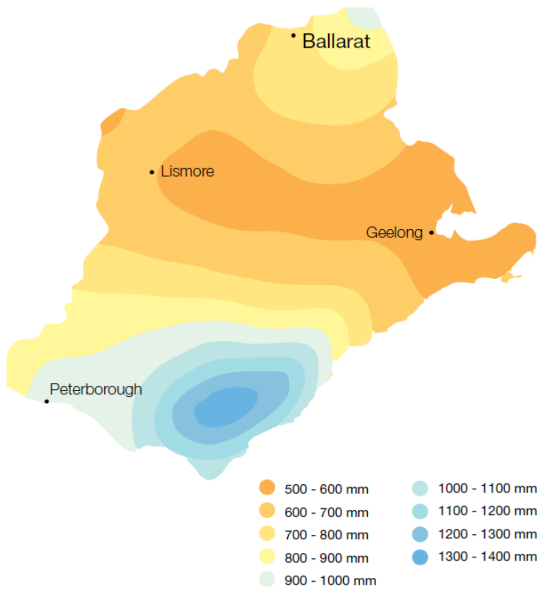



**Figure 5: Average annual rainfall across the Corangamite region based on average daily rainfall between 1961 to 1990**
(DELWP 2008)

## 2.2. Socio-economics of the Basin

The Corangamite landscape is a cultural landscape, shaped and influenced by people. The traditional owners were aboriginal people who have lived here for thousands of generations. When European settlers arrived in the 18th century, the landscape has already been inhabited, used, managed and shaped by the Aboriginal people for over 10,000 years (CMA 2013).

The catchment is home to about 370,000 people and includes all of the cities of Greater Geelong, Ballarat, Lismore and Peterborough. The population is culturally diverse and highly urbanised. About three-quarters of the people are residing in the urban centres of Greater Geelong and Ballarat. The population in the catchment is growing at one of the fastest rates in Victoria, expecting to grow at 1.5 % per annum to approximately half a million by 2026 (CMA 2013).

The economy of the Corangamite catchment is diverse and reflects a mix of agricultural and other primary industries, tourism, manufacturing and service industries. Although regional employment in agriculture and forestry sectors declined from 5 % to 3.4 % between 2001 and 2011, the sector remains an important employer for people from smaller regional communities and towns (CMA 2013). Agriculture is also the dominant land use in the region, in which dairy and wool production play a major role. About 3,450 agricultural businesses are operating across 772,436 ha land within the catchment. Enterprises include sheep and cattle grazing, dairying, cropping, forestry, viticulture and horticulture. While over 75 % of private land is used for livestock grazing, only 20 % is used for crop production including timber. The number of livestock was approximately 271,000 daily cattle, 209,000 beef cattle and 1.7 million sheep/lambs in 2006. The catchment produced about 10 % of the gross value of agricultural commodities of Victoria in 2006 (REMPLAN 2016; CMA 2013).

Manufacturing and the service sector dominate employment in larger cities including Greater Geelong and Ballarat while the tourism industry is particularly important along the coast of the catchment (CMA 2013; DELWP 2008). Tourism is an increasingly important industry and employer in the region, especially nature-based tourism destinations such as the famous Great Ocean Road with its Twelve Apostles or the Otway Ranges with its plenty of waterfalls and hiking trails. The Great Ocean Road runs along the coast of Corangamite and is one of Australia's top tourist destinations, attracting about half (163,000 thousand) of all international visitors to Victoria in 2010. Beside the Great Ocean Road, other top tourism destinations include the history and culture of Ballarat, extended beaches along the coastline, Geelong's waterfront and the Bellarine Peninsula (CMA 2013).

## 2.3. Historical Overview of Australia's and Victoria's Agricultural Industry

The agricultural industry remains an important component of the Australian economy, contributing to 2.3 % of GDP and 1 % of global agriculture production in 2015. Nowadays more than 307,000 people are directly employed in agriculture with more than 1.6 million Australian being employed in the input and output sectors, food manufacturing and processing, distribution and retail. The major commodities in 2015 were grains and oilseeds (29.8 %), meat (24.0 %), industrial crops like sugar, cotton and wine (13.5 %), wool (7.0 %), dairy (6.6 %) and horticulture (4.5 %). Asia provides the major market for over 60 % of Australian agricultural exports due to a growing population, the emerging middle class and rising incomes. China is the most important market (22.0 %), followed by Japan (9.4 %), Indonesia (7.3 %), Korea (5.8 %), Malaysia (3.0 %) and Singapore (2.8 %) (Batt 2015).

However, the agricultural sector in Australia faces many challenges. The sector continues to struggle with falling commodity prices and higher input costs putting more pressure on profit margins, declining profitability and a shortage in skilled labour. The grain exports (especially wheat/barley) have experienced a decline in demand and have to compete against subsidised production by European Union countries and the United States. Furthermore, with agricultural productivity in the country being highly influenced by seasonal variations in rainfall and temperature extremes, changes in climatic pattern affect the whole industry. Many farmers are experiencing financial pressure to restructure their farm business operations due to Australia's high exposure to international markets and a domestic environment in which farmers are expected to operate without assistance from the government. This often requires a change in the mix of activities on farms or even an expansion into new agricultural industries or areas. By adopting new technologies (e.g. satellite technology), farmers try to maintain or increase levels of profitability in the face of rising costs and environmental issues and are more aware of the need to develop sustainable farming practices than ever before (Batt 2015; Australian Bureau of Statistics 2000).

Looking back to Australia's agricultural history, the sector has experienced major changes in productivity over the last 100 years through the application of new technology and science. A hundred years ago much of the energy used to operate a farm came from manual labours, horses, bullocks or steam power. Nowadays, farms are typically operated by only a few people with the help of machinery and technology (Australian Bureau of Statistics 2000). Through the use of advanced chemicals, farmers were able to make improvement in disease and weed control while the adoption of modern technology helped to improve and increase cropping and livestock production. In the beginning of the last century, clearing scrubs in the heavily timbered areas for land reclamation was a difficult task for many small farmers. Wool sale was the reason of most pastoral wealth in Australia at that time. About 400,000 tons of mutton and lamb and 284,000 tons of beef were exported in the first decade of the century, mainly to the United Kingdom, South Africa and the Philippines. However, the extensive clearing of land turned previously vegetated land into deserts where rabbit numbers were also beginning to build up. By the time World War I began, rabbits had already a significant impact on the carrying capacity of land in Victoria and New South Wales (Australian Bureau of Statistics 2000). After the World War I, the government established new agricultural areas to provide returned soldiers with both a place to live and an occupation. Lacking agricultural expertise, some of the land broke into smaller allotments and was not suitable for small scale farming anymore. In the 1920s and 1930s, Australia's agricultural production had rapidly increased as a result of improved technology, the use of more productive grain varieties as well as advances in livestock breeding which turned the country into one of the world's major food exporters. By the end of the 1920s, Australia produced about 440,000 tons of wool, accounting for 25 % of the worlds wool supply. During the ´Great Depression´ in the 1930's, Australian agriculture experienced a severe setback with drastically falling prices for commodities. The World War II also presented a new challenge for the industry with a tremendous effect on agricultural trade as farmers became isolated from world markets. The government provided subsidy on the purchase of wheat for stock feed. After the war, the cropping areas began to increase and Australia produced about 3 % of the world's wheat which until today remains the major crop produced in the country. Large storage facilities for wheat were built to accommodate the high production but the situation changed quickly in 1957-58 when a big drought resulted in a sharp fall in wheat productions and supplies. This was the second time in Australia's history that they imported wheat out of necessity since 1902. Prosperity in the wool industry peaked again in 1950-51 which has been attributed to the demand for wool generated by the Korean War. The high prices for wool led to an increase in sheep numbers, which was around 113 million by 1950, but declined later to 21 % of the total value of production for agricultural industries in 1966-67 (Australian Bureau of Statistics 2000). Since the 1960s, wheat prices had been relatively stable but an increasing demand in the USSR and China resulted in prices almost a doubling and remained high until the early 1980s. This development resulted in an expansion in the cropping area from 9.4 million ha in 1970 to 12.9 million ha in 1984. In the 1960s and 1970s, environmental concerns arose around dryland salinity and land degradation due to poor farming practices. Several improvements in farming techniques were encouraged to reverse the damage to the farmed land in Australia. In 1995, Australian agriculture contributed only around 3 % of GDP, down from 15-20 % in the early 1950s (Australian Bureau of Statistics 2000).

As aforementioned, the Australian cropping industry has always been dominated by wheat covering 14 million ha (55 %) of the Australian cropland in 2014. The following figure shows that Australia has experienced substantial wheat yield progress over the last century with up to about 2.0 t/ha with wheat areas increasingly expanding into drier areas. Despite the high climate variability and recurring droughts, improved technology and management decisions, better adapted varieties, adjustments in fertilizer rates and improved weed and diseases management has helped to increase production (Fischer et al. 2014).

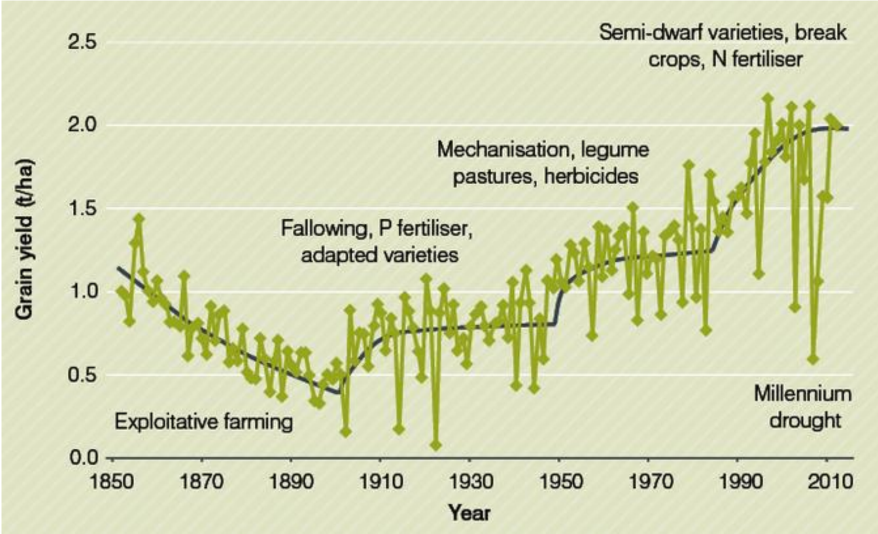



**Figure 6: Change in average farm yield of wheat in Australia from 1852 to 2011 and major drivers of change**
(Fischer et al. 2014)

Looking at Victoria, the state produced 7 million tonnes of grain on 3.6 million ha of land including 3.42 million tonnes of wheat, 1.95 million tonnes of barley, 866,000 tonnes of canola and 384,000 tonnes of pulses (lentils, chickpeas, faba beans, field peas, broad beans and lupins) in 2013. The gross value of Victoria's grain production was $2.31 billion in 2013, accounting for 16 % of the national grain exports (DEDJTR 2014a).

Also the livestock industry plays a crucial role in Australia's agricultural sector. The strong international and domestic demand for meat, beef cattle, mutton and lamb triggered increases in prices over the last two decades while the demand for wool has declined over the same period of time. Thus, expanding cropping and beef cattle activities while reducing sheep numbers were common strategies to respond to changing market conditions. However, these developments triggered inflated lamb and mutton prices relative to wool which forced farmers to restructure breeds with a focus on female dominated flocks to increase lambs production (RIRCD 2007; Australian Bureau of Statistics 2000).

Nowadays, Australia has over 30.000 woolgrowers. The country produced about 352,000 tones of greasy wool from 78.8 million shorn sheep in 2013/2014 of which 79 % were Merino sheep and 21 % other breeds. Wool production is influenced by environmental conditions such as droughts and economic factors such as consumer demand (AWEX 2014). In the end of the 1990s, Australian wool production has fallen by 35 % since 1990 (Australian Bureau of Statistics 2000). The decline in wool production and returns also reflected changes in consumer tastes and preferences, thus heavily influencing the global demand for wool (Dickson et al. 2006). The highly competitive international textiles and clothing industry especially around wool, polyester and cotton, correlated with shrinking wool production and falling prices indicated a sustained decline in the demand for wool (RIRCD

2007). Despite an overall declining demand for wool, gains in the quality of wool were reached through the adoption of new technologies and improved farm management practices over the last decades. Also due to higher prices for finer wool, the average diameter (measured in micron) of Merino wool has steadily fallen in the country especially in the high rainfall regions including the Corangamite catchment (RIRCD 2007). Australian wool shorn from Merino sheep typically ranges from 11 (very fine) to 27 micron (mean fibre diameter) and from crossbred sheep typically between 24 and 40 micron (very coarse). The type of wool is generally influenced by age, breeding, sheep husbandry practices and environmental conditions (Taylor et al. 2007).

Also in Victoria, wool production and sheep populations were declining since the early 1990s, falling from 190,600 tonnes of wool in 1990 to 70,500 tonnes in 2014 while sheep meat (lamb and mutton) production has increased by about 60 % over the same period of time. The decline in Victoria's wool production can be attributed to a decline in wool prices and relatively better returns from meat production and/or cropping over the last two decades. The sheep meat and wool industry is the third largest agricultural industry by value in Victoria with a gross value of agricultural production of around $1,497 million in 2014. In 2014, Victoria was Australia's largest lamb and mutton producing state, accounting for 44 % of Australian lamb production and 35 % of Australian mutton production. Sheep and lamb numbers fell marginally by 1.3 % to 15.7 million head in 2014 with the current sheep population being one of the smallest since the 1940s. However, despite the long-term decline in Victoria's wool production, exports from Victoria increased in value from $883 million in 2010 to $1,315 million in 2014 (DEDJTR 2014b).

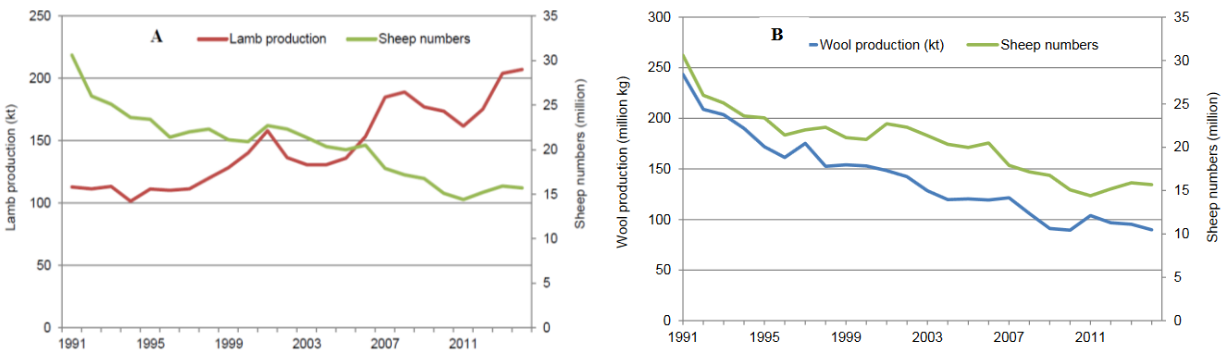



**Figure 7: Victorian lamb production (A) and shorn wool production (B) compared with sheep numbers from 1991-2014**
(DEDJTR 2014b)

Also the beef cattle and dairy industry play a major role in Australia's agricultural industry. On a global scale, Australia is a relatively small beef producer. However, due to a small population, a significant volume of beef is exported due to an increased international demand for protein. In 2011, cattle farmers run about 28 million cattle across 200 million ha of land. Producers were able to significantly increase productivity due to improved genetics, pastures and marketing (Pwc 2011). In Victoria, beef is primarily produced in the western district with more than 2 million beef cattle contributing to 14 % of the total Australian beef export value in 2016 (DEDJTR 2017b).

The dairy industry produces around 9.7 million litres of milk per year and employed over 6.000 Australian farmers and more than 100.000 Australian indirectly in related services in 2016. Also in the dairy sector, productivity continues to increase due to improved pasture, feed and herd management techniques (Dairy Australia 2017). The dairy sector is the largest agricultural industry in Victoria, accounting for more than 65 % of annual milk production in Australia. The major markets include Japan, Singapore, China, Indonesia, Philippines and Malaysia with exports valued at $1.85 billion in 2016 (DEDJTR 2017a).

With the catchment being located in the high rainfall zone of Australia, the dominant farm systems are mixed crop-livestock enterprises (Fischer et al. 2014). Rivera-Ferre et al. (2016) distinguishes agricultural systems between the grazing zone in the drier pastoral parts of Australia and mixed crop-livestock systems along the Australian wheat belt and the high rainfall zones including Corangamite.

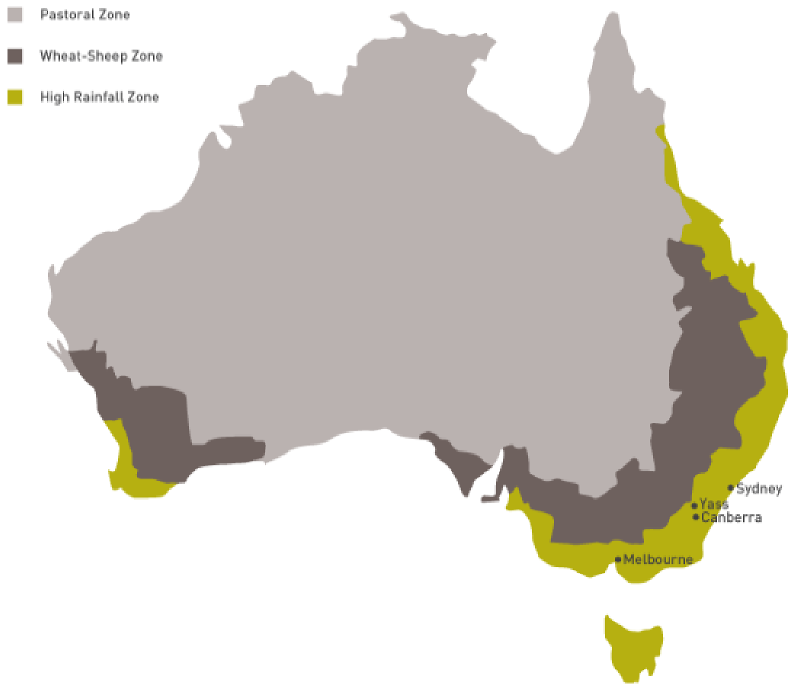



**Figure 8: Australian broad care zones & regions**
(AgScope 2013)

## 2.4. Case Study Mt Hesse Farm

Mount Hesse is a family-operated farm in its 4th generation and one of the largest Merino wool producers in Australia. The farm was acquired by the German textile company Südwolle Group in 2002 (Südwolle Group 2013).

**History**

Prior to the European settlement the Wodouros, a sub-tribe of the Witto-wu-rrong tribe roamed the tussocky plains that are now known as Mount Hesse. Relicts such as quartz chips for skinning and grinding stones have been found over the years on different sites around Mt Hesse. In 1802 the first European settlement was founded at Port Phillip Bay about 70 km east of Mt Hesse. About 35 years later, the two pioneers John Highett and William Harding took up as many acres of land as they could occupy and chose the area of Mt Hesse. Harding, who lived in England before, arrived on the property with his sister Elizabeth who married a wealthy landowner. Six years later he already ran a flock of 20,000 sheep, facing tough living conditions. Harding made many improvements on the farm such as building a stone homestead or a large woolshed. The original woolshed from that times still exists today at Mt Hesse (Südwolle Group 2013). However, unable to repay his debts, he sold the land to William Timms in 1853. The new owner was a very successful merchant in Geelong and the largest exporter of wool at that time. Under the Nicholson Act in 1861 the government auctioned the property with13 family members and friends reselling their purchased parcels to the Timms family. In the 1870's the property was split between three Timms boys. The property was auctioned again in 1882 when James L. Kininmonth, the manager and partner in the neighbouring 'Barunah Plains' property, bought Mount Hesse. This was the start of the family's ongoing association with the farm until today. James brought his overseer Sandy McCallum with him and made many improvements in terms of dams, fencing and the drainage of swamps to make the land more accessible. James died in 1896, leaving the property to be run by the trustees of his estate. Sandy was very successfully with raising around 16,000 sheep and lambs and 150 cattle on the property. He retired in 1926 leaving the management to Jim Kininmonth. After the death of his father in 1952, Peter Kininmonth took over the management with a property size of 6,500 ha. Land acquisition by the Soldier Settlement Commission resulted in a smaller property with 3,550 ha in 1956. In 1984, Peter had increased carrying capacity through the introduction of improved pastures, superphosphate and labour to 20,000 grown sheep, 452 cattle and 120 ha of crops. The current manager (2017) David Kininmonth took over the management in 1990 during a difficult situation when the reserve price scheme led to a dramatic fall in profitability of Merino sheep and with major changes in the direction of Mount Hesse. The property enterprise mix was diversified, having wool and sheep meat production still as the main focus. In 2002, the trustees of the estate of James Leonard Kininmonth decided to sell the property with the Steger family from Germany as successful purchasers. At that time the property carried 16,600 adult sheep, 470 cattle and 652 ha of crop with three permanent employees (Südwolle Group 2013).

**Geography and climate**

The Mount Hesse farm is located in the low hills of the volcanic plains in the centre of the Corangamite catchment around 70 km away from Victoria's coastline. The farm has a diverse range of soil types supporting a number of productive and interrelated enterprises. Soil types include well drained, undulating, red loam soils and dark friable lunette soils which support cropping and sheep production. Average temperature ranges between 22.4 and 25.3°C in summer and between 5.2 and 6.2°C in winter (Digital Atlas 2017). The farm is located within the high rainfall zone of Australia and had an average annual rainfall of 570 mm and 429 mm between April and October from 1883 to 2016. According to the Bureau of Meteorology (2017c) the farm is located in an area with low rainfall variability (0 - 0.5 %) meaning that rainfall tends to be relatively consistent from one year to the next. These rainfall patterns typically apply to the coastal areas of south-east Australia including south-west Victoria (BOM 2017c).

**Farm Economics**

The farm has a mixed crop-livestock system. Mt Hesse produces sheep meats (mutton and lambs) and produced on average 64.86 tonnes of wool per year between 1883 and 2016 and 86.66 tonnes of wool over the last decade from 2006 to 2016. This averages to around 17.000 sheep between 1899 to 2016 and 16.228 sheep in average over the last decade from 2006 to 2016. Sheep and wool production had increased at Mt Hesse especially from the 1960s to mid-1990s, but declined after, due to a) poor returns from sheep after the reserve price scheme was disbanded in 1991 triggering a shift from wool to meat production and b) prolonged and recurring droughts and below average seasonal conditions (DEDJTR 2014b).

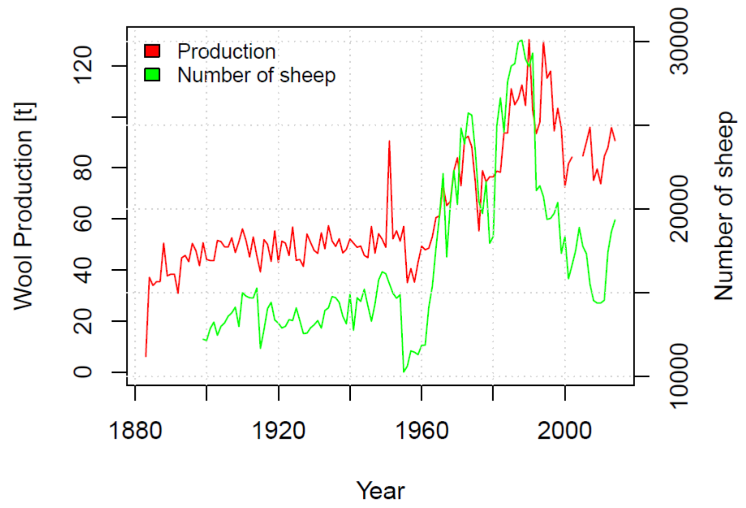



**Figure 9: Annual wool production and number of sheep at Mt Hesse (1883-2016)**

The farm was able to produce sheep with finer wool and higher percentages of clean fleece due to improved management techniques and breeding programs within the last 20 years, thus responding to changing consumer demands. According to Taylor et al. (2007), around 90 % of the value of a Merino fleece is determined by two traits a) clean fleece weight (yield in %) and b) mean fibre diameter (µm=micron). Both traits are strongly inherited, inexpensive to measure and important for profit, thus making them an ideal selection criteria for Merino breeding programs (Taylor et al. 2007). The wool produced at Mt Hesse contained on average 70.1 % yield of clean fleece weight, ranging from 48.15 % to 82.8 % and had on average a mean fibre diameter of 20.5 micron, ranging from 15.6 to 33.2 micron between 1995 and 2016.

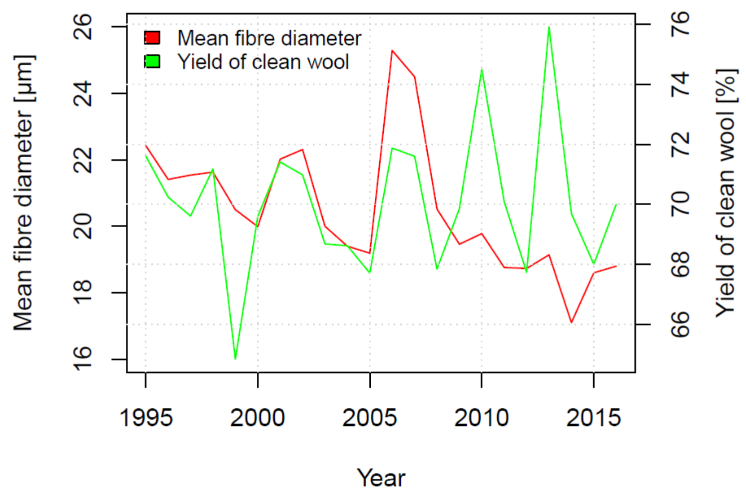



**Figure 10: Average mean fibre diameter and yield of clean wool at Mt Hesse (1995-2016)**

The farm also employs a mixed cash-crop operation on 1100 ha of the land, producing cereals, legumes and oilseeds including wheat, barley, canola and lupins. The average wheat yield at Mt

Hesse was 4.24 t/ha between 1994 and 2016 which is much higher than the average wheat yield in Victoria (1.84 t/ha) and in total Australia (1.7 t/ha) between 1990 and 2015 (CSIRO 2017). The average yield for barley was 4.1 t/ha between 1995 and 2016 and for canola 2.12 t/ha between 1998 and 2016. As wheat and barley were cut for hay, yields were not relevant as grain in 2006 and 2007.

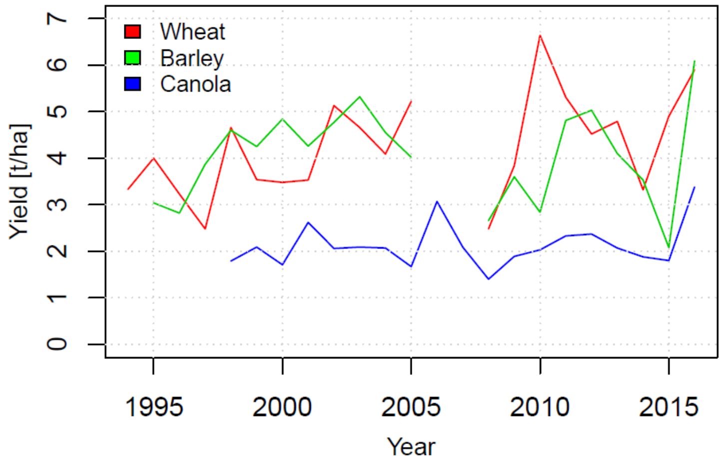



**Figure 11: Average yields in t/ha for wheat, barley and canola at Mt Hesse (1994-2016)**

# 3. Literature Review and Framework

This chapter provides a review of the current state of research regarding the theoretical framework of this dissertation. The literature review will address four main areas of research: the first section defines climate change in the Australian context. The second section presents the key terminology shaping the framework of this study including risks, vulnerability, resilience and adaptation in the context of climate change. The third section examines and discusses the frame of agricultural risk management, including risk assessment, management as well as implementation strategies and briefly summarizes main challenges and limitations for agricultural risk management and adaptation. The fourth and last section consequently describes the approach and illustrates the framework of this thesis.

## 3.1. Defining Climate Change in the Australian Context

The IPCC (2012:5) defines climate change as a „[…] change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or persistent anthropogenic changes in the composition of the atmosphere or inland use". Climate is often confused with weather. Weather is what we experience on a day-to-day basis being inherently variable and including extreme weather events such as hot days, heavy rainfall or storms. Weather variability can also occur over weeks and months. Climate however refers to the average weather over a long period of time, usually at least 30 years or longer. Analysing the variability around the average climate and from decade to decade gives information about the climatic range where societies and ecosystems live (Climate Commission 2013). Weather and climate extreme refer to the occurrence of a climate variable being above or below a threshold value of the prior observed upper or lower end of range (Seneviratne et al. 2012). However, due to simplification reasons, this thesis summarizes shorter-term weather and longer-term climate generally under the term *climate related events* to refer to these changes.

Human's activities, especially the emission of greenhouse gases in the atmosphere since the industrial revolution around 1850 has begun to influence the global climate in many significant ways. The amount of carbon dioxide in the atmosphere has increased by 40 % since the beginning of the industrial revolution thus trapping more heat within the upper and lower atmosphere at the Earth surface and within the Oceans (Climate Commission 2013, IPCC 2007). Along with general increasing temperatures, the duration and frequency of heatwaves have risen in the past decades as additional heat in the Earth surface rises (Climate Commission 2013; DELWP 2008). While the atmosphere absorbs about 3 % of the extra heat, the world´s Oceans take up about 90 % of the extra heat in the climate system. Thus, between 1955 and 2010, Australia's surrounding Oceans have warmed up by 0.18°C on average mostly occurring in the surface waters from 0 to 700 m which is associated with changes in the eastern Australian current of the South Pacific (Climate Commission 2013, IPCC 2007).

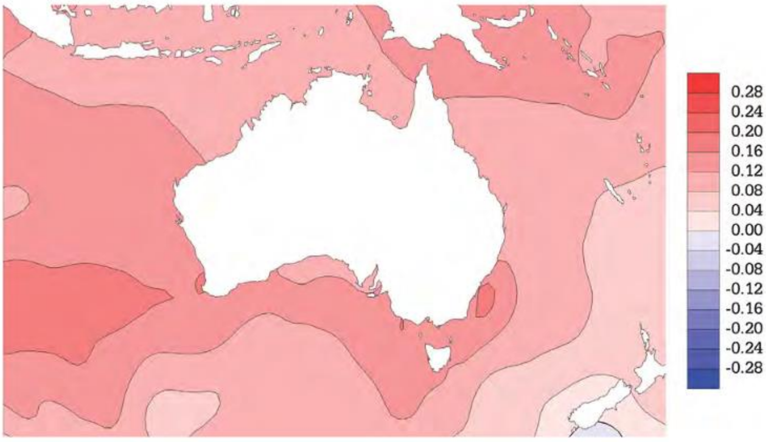



**Figure 12: Trend in annual sea surface temperature for the Australian region in °C/10yr (1950-2012)**
(BOM in Climate Commission 2013)

The global annual temperature has increased by about 0.8 °C on average since 1880. The following map shows global temperature anomaly (in °F) and carbon dioxide concentrations (ppm) from 1880-2012. This trend is consistent with the increased atmospheric carbon dioxide ($CO_2$) concentration which increased from 280 parts per million (ppm) in 1880 to almost 400 ppm in 2012 (Global Change Research Program 2016).

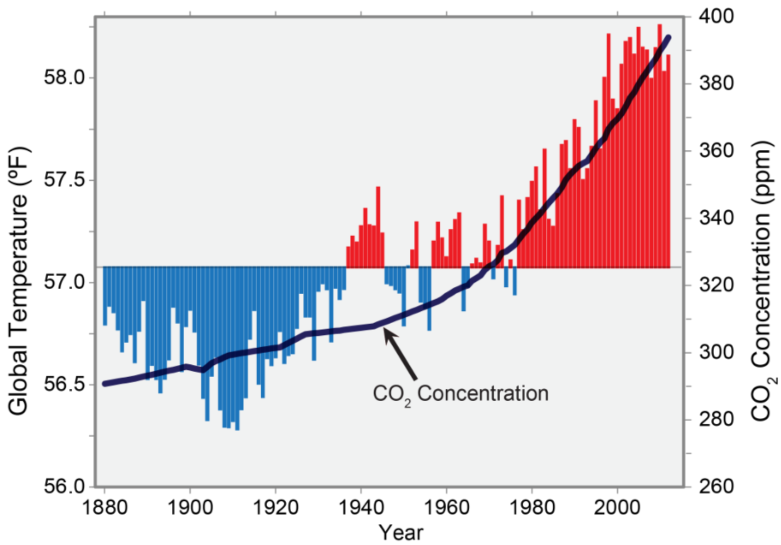



**Figure 13: Global temperature anomaly and carbon dioxide from 1880-2012 (compared to 1961-1990)**
(Global Change Research Program 2016)

Despite a high degree of climate variability from year to year and decade to decade, temperatures in Australia have increased over the last 50 years with every decade being warmer than the decade before. The average increase of air temperature in Australia of around 0.9°C since 1910 mirrors the global trend and is larger in the interior of the continent and lower along its coastlines (Climate Commission 2013).

The following map shows Australia´s annual mean temperature anomaly from 1910-2015 based on the 30-years mean climatology period from 1961-1990 (BOM 2016a). Despite a long-term increase in temperature, some years do not show a temperature increase relative to the previous years while other years show greater changes. These year to year temperature fluctuations are due to natural processes such as the effects of ENSO (Global Change Research Program 2016).

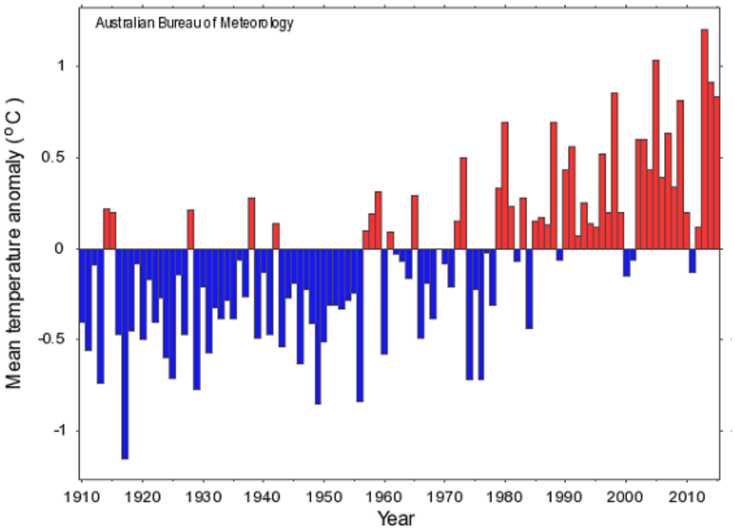



**Figure 14: Australia's annual mean temperature anomaly from 1910-2015 (compared to 1961-1990)**
(BOM 2016a)

Beside changes in temperature, also precipitation patterns are changing globally with some areas facing significant rainfall increases and others facing drying trends. However, as rainfall is highly variable in time and space, it is more difficult to determine an overall global trend compared to temperature. Regionally, drier than average conditions were widespread across much of French Polynesia, the Solomon Islands, Hawaiian Islands, north-western Canada, northwest and northeast Brazil and southern Peru while wetter regions in the world included most of Central America and India, southwestern China, east Asia, Borneo and parts of Australia (NOAA 2016b). Also for Australia, it is difficult to detect a clear long-term trend as the countries climate and precipitation pattern are highly variable in time and space (BOM 2016a).

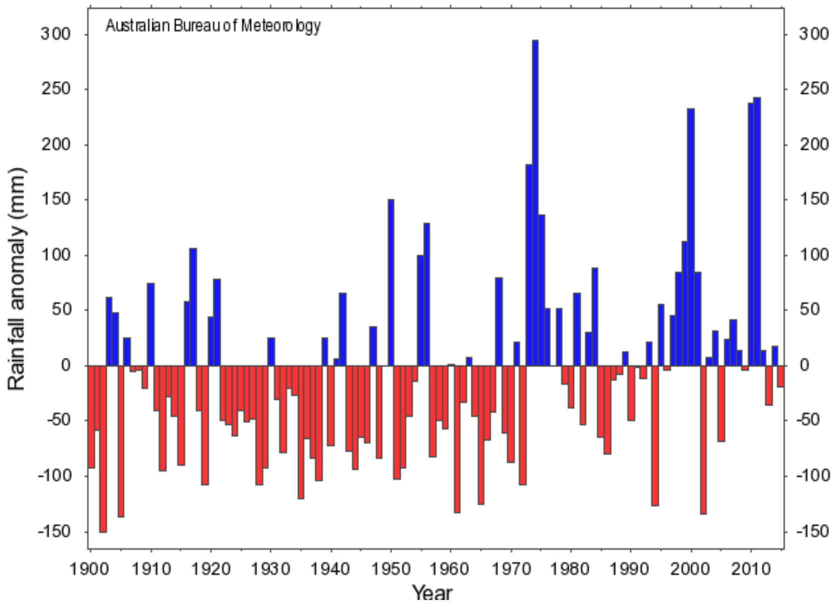



**Figure 15: Annual rainfall anomaly Australia from 1900-2012 (compared to 1961-1990)**
(BOM 2016a)

However, south-east Australia has become hotter and drier since around the 1960s. Despite wet conditions associated with La Niña in 2011 across much of Australia, the long-term regional drying trends over the south-eastern part of Australia continues (Climate Commission 2013). Especially during El Niño years the deviation is much more pronounced, as the total amount of rainfall is usually below average across much of eastern Australia with the strongest El Niño events in 1905, 1914, 1940, 1941, 1946, 1965, 1972, 1977, 1982, 1991, 1994 and 1997 (BOM 2016b).

According to Murphy and Timbal (2008) the observed warming over the last century is unlikely due to natural variability but rather due to anthropogenic greenhouse warming. Models show that observed changes in temperature and precipitation differ from inter-decadal time scales in the absence of enhanced greenhouse gas forcing. The National Oceanic and Atmospheric Administration (NOAA) considers the increase in temperature over the past several decades as one of the most obvious signals of human-induced climate change (NOAA 2016a). Also the decreasing trend in rainfall over the last two decades in south-east Australia is unlikely to be within the levels of natural variability deriving from climatic pattern such as ENSO, IOD or SAM. This is because it differs from earlier dry spells in the last century in terms of seasonal variations such as significant drier autumn months with less rainy days and lower rainfall intensity. Earlier dry periods were characterized by more homogenous below-than average precipitation during all seasons and showed a higher year to year variability (Timbal and Drosdowsky 2012; Murphy and Timbal 2008). Also if the attribution of single extreme events to anthropogenic climate change remains challenging, there is statistically significant evidence that some extremes have changed as a result of increased atmospheric greenhouse gases underlying with natural climate variability (IPCC 2007).

Several studies show (e.g. see Timbal and Drosdowsky 2012) that the subtropical ridge (STR) has intensified significantly in the vicinity of eastern Australia during the 20th century and early 21st century with climate change, influencing rainfall in south-east Australia. The intensification however was not monotonic but happened mostly during the periods from 1900 to 1940 leading to dry decades from 1935 to 1945 and from 1970 to 2010, leading to the Millennium drought. The strong declines in rainfall during the Millennium drought can be traced back to two thirds to the intensification of the ridge and is at least in part attributable to anthropogenic climate change (Timbal and Drosdowsky 2012). Reasons for shifting rainfall zones in Australia might be connected to increased sea surface temperatures of the surrounding Oceans, the strengthening of high pressures over Australia and a weakening of westerly winds from May to July since the beginning of the 2000s. These trends lead to a changes in the variability in annual rainfall such as the increase in annual rainfall variability in inland Victoria (Collis 2016).

## 3.2. Defining Key Terminology in the Context of Climate Change

Definitions and frameworks that systematize risk, vulnerability and resilience are multiple and overlapping (Oppenheimer et al. 2014). However, the next section attempts to give a comprehensive overview of the key terminology that provides the basis for assessing and managing risks to agriculture in the context of climate variability and change.

**Risks**

The IPCC (2014) defines risk as "[t]he potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values." According to Oppenheimer et al. (2014), there are two components of risk: a) the probability of adverse events occurring and b) the impact or consequences of those events. Risks depend especially on the exposure of socio-environmental systems, their sensitivity to climatic changes and their capacity to adapt, thus determining their level of vulnerability and resilience. Risks can also increase due to the indirect interactions with other risks (Xiang et al. 2016; Oppenheimer et al. 2014).

According to the Intergovernmental Panel on Climate Change (IPCC 2012), a changing climate leads to changes in the frequency, intensity as well as spatial and temporal extent of climate extremes thus posing new risk for individuals, societies and ecosystems. The following graphs show the different effects of climate change and associated risks. Changes in extremes can be linked to shifts in the mean (figure a), an increase in the variability (figure b) or a change in the symmetry or respectively the shape of probability distributions (figure c). These changes potentially trigger more extremes in hot weather and less cold weather (a), more extremes in cold and hot weather (b) or slight shifts towards more hot weather (c). Thus, extremes that would have happened due to natural climate variability become even more extreme due to the general shift in average temperature. Although many extreme events continue to be the result of natural climate variability, the effect of anthropogenic changes in the climate system is likely to increase the change in shaping future extremes (IPCC 2012).

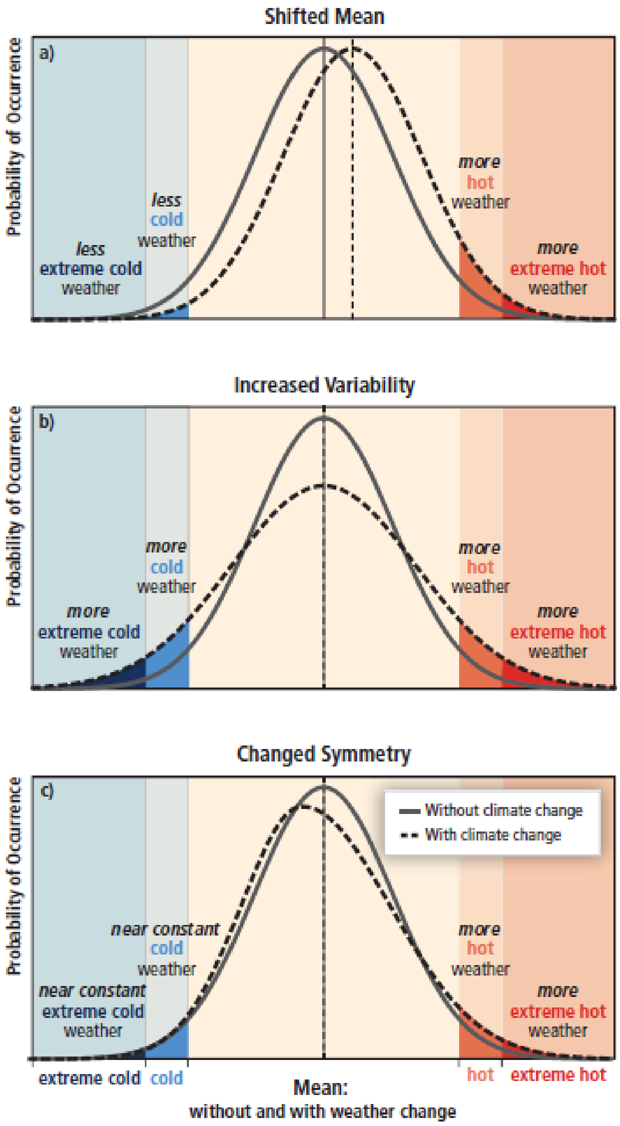



**Figure 16: The different effects of climate change and associated risks**
(IPCC 2012)

Also if slower changes in climate seem less dramatic compared to the direct impacts of extreme events, risks and impacts are more complex. Increasing water temperatures of Oceans surrounding Australia affect rainfall pattern and impact water supply and agricultural systems. Also, while some regions may become climatically more suitable than previous ones, other regions may become too dry for agricultural production (Oppenheimer et al. 2014; IPCC 2012).

Besides human activities triggering the erosion of terrestrial and marine ecosystems through deforestation, the drainage of wetlands and general land use changes, climate change also increases the risk of damaging ecosystems. As ecosystem services benefit humans in many ways (e.g. protection from extreme weather events, water purification, preservation of soils, recycling of nutrients or pollination of crops), the losses of ecosystem poses a major risk for societies and industries. Thus, risks from climate change do not only arise from external changes in the climate system to which societies respond, but are rather the result of complex interactions among societies and ecosystems (Oppenheimer et al. 2014).

If extreme weather and climate events interact with exposed and vulnerable human and natural systems, they can lead to disasters (IPCC 2012). It is believed that economic losses from climate related disasters have increased over the last few decades with large spatial and inter-annual variability. Financial consequence from extreme events might increase people's vulnerability and potentially drain the financial resources of families and businesses, thus making them more vulnerable to economic stresses and reducing their resilience (IPCC 2012).

Risks can also evolve from risk perceptions and cognitive constructs, adaptation options and the cultural context that influence adaptive capacities and therefore people´s vulnerability. There are several factors that shape people´s risk perception and influence their response to climate events which include a) their interpretations of the threat as well as their understanding of the root cause of the problem, b) their exposure and personal experience with events and especially recent consequences, c) their priorities/motivations and d) environmental and general value systems. Perception of risks is a product of the interaction between social, cultural, psychological or institutional processes which are partly subjective, rather than based on *objective* information. Individual perceptions and responses, such as farmers reaction to climate-related forecast, depend on their emotions based on past experiences (Oppenheimer et al. 2014). However, an improved understanding and knowledge of changing risks associated with climate change is considered to support effective and sustainable risk management both in the short and long term future (Climate Commission 2013; IPCC 2012).

**Vulnerability**

The IPCC (2014) defines vulnerability as "[t]he propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (Oppenheimer et al. 2014). Vulnerability is generally dynamic and context specific which refers to the degree to which humans or environmental systems are susceptible or exposed to injury, damage or harm. The following figure shows the concepts encompassed by vulnerability including sensitivity, exposure and adaptive capacity which influence each other and determine the overall vulnerability of a system (Oppenheimer et al. 2014; IPCC 2014).

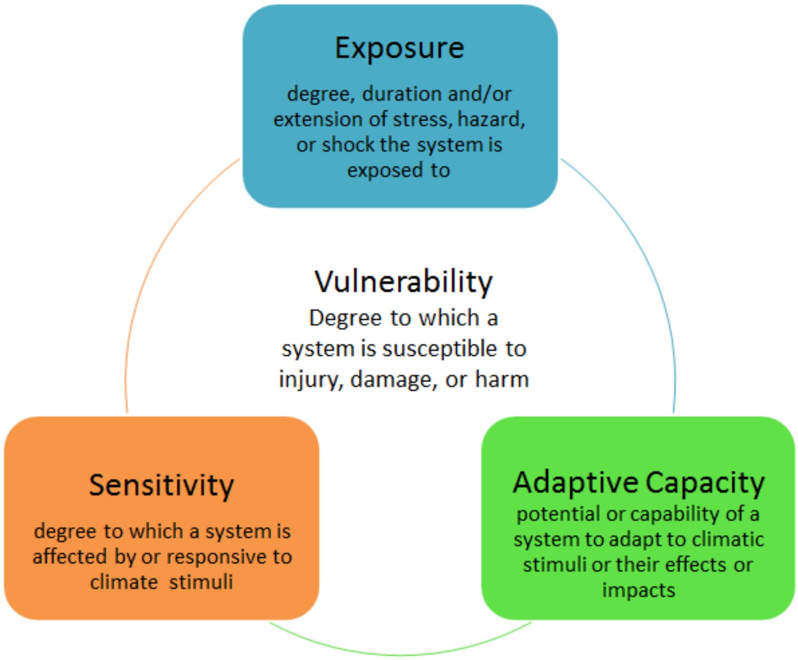



**Figure 17: Framing vulnerability to climate change**
(Oppenheimer et al. 2014; IPCC 2014)

While sensitivity refers to the physical predisposition of human and environmental systems that are affected and suffer from hazardous events, exposure refers to the presence of people, resources or economic, social or cultural assets in place that could be adversely affected (UNISDR 2017; IPCC 2012). Capacities generally refer to the combination of strength, available resources and attributes of individuals or societies that can be used to achieve certain goals which include the access to information that reduce vulnerability and the ability to deal with consequences of hazards (IPCC 2012; O'Brien et al. 2012). However, adaptive capacity comprises of the specific usage of capacities including the ability to adapt to adverse climate related impacts to reduce risks (IPCC 2014). Adaptive capacities are considered as a key significance especially in the context of uncertain environmental changes which allow individuals and societies to manage risks, take advantage of the new set of circumstances and cope and adapt to future climate variability and change (IPCC 2012; Barber 2009). The concept of adaptive capacities can be differentiated by timing or degree of planning involved. Adaptive capacities include both short-term coping as reactive response to impacts and long-term management strategies as planned adaption to a changing environment. Eventually the severity of climatic extreme events and associated impacts strongly depend on the level of sensitivity and exposure as well as adaptive capacities of systems to deal with extremes. Generally, the higher the sensitivity and exposure along with a low adaptive capacity, the higher the vulnerability of a system (IPCC 2011; 2007).

According to IPCC (2012), climate change comes along with changes in vulnerability for socio-economic and ecological systems. There are several factors influencing individual's vulnerability. These factors include social status, wealth, education, health or gender which influence the exposure and capacity to cope and adapt to climate related risk. Socially or economically disadvantaged individuals are considered to be the most sensitive to climate change, with sensitivity typically being the result of cross cutting social processes such as inequalities in the socio-economic status and exposure to risk (Keywood et al.2017; IPCC 2012). Vulnerabilities can also differ within societies as children, elderly and women are considered more vulnerable to climate related risks especially in developing countries (O'Brien et al. 2012). Ecosystems can also be vulnerable to climate change of which services and functions human societies depend on, including the agricultural sector. Especially already degraded ecosystems from previous human activities are considered more vulnerable to climate change impacts. With an increased degradation of ecosystems and inability to act as natural barrier against climate related extremes, also people's vulnerability increase (Oppenheimer et al. 2014). Thus, as human societies depend on certain environmental conditions, a changing climate can alter these conditions and cause stress to social systems and societies (Scheffran 2011). Hence, healthy and resilient ecosystems can facilitate adaptation to changing climate conditions through regulating services such as flood regulation or soil erosion avoidance which decrease vulnerabilities (Oppenheimer et al. 2014). The level of vulnerability is a major driver in determining the transitions from a hazardous situation to a disastrous event. Therefore, the assessment of the vulnerability of socio-ecological systems to hazards is a key approach in evaluating and implementing effective adaptation and risk management strategies to build resilience (IPCC 2012).

**Resilience and Adaptation**

UNISDR (2017) defines resilience as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management."

According to Rickards (2012) resilience to climate variability is of increasing importance not only because agriculture is progressively exposed to frequent and severe climate extremes under climate change, but also due to its exposure to economic conditions which may increase vulnerabilities to financial shocks. Since adaptation is part of the risk management process, both concepts promote sustainability in social, economic and environmental development and help with managing existing and projected future risks to increase resilience of individuals and societies (UNISDR 2017; Lavell et at. 2012). One of the most common used definitions of sustainable development is the following: "Sustainability refers to a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). This definition covers three pillars: to achieve economic and social development as well as environmental protection in a balanced manner (United Nations 2017).

According to FAO (2015), in order to reduce the vulnerability of socio-ecological systems from hazardous impacts, recommendations to strengthen the resilience include prevention/mitigation and coping/adaptation strategies. While prevention aims to reduce the occurrence of disasters, mitigation focuses on reducing and managing the impacts before, during and after disasters (Gunjal 2016). Coping primarily refers to capacities of a system to protect itself from adverse consequences (e.g. climate related risks) while adaptation is an on-going and dynamic process involving adjustments in the system (Oppenheimer et al. 2014). According to Kates et al. (2012), all human and environment systems adapt to climate and its natural variations. However, with human induced climate change vulnerabilities and risks may change thus requiring farm systems to adapt to climate change related impacts. Adaptation as part of good risk management is considered to adjust farm practices, processes and capital to effectively manage potential climate risks over the coming decades of climate change (Howden et al. 2007). Most adaptation efforts are extensions or intensification of already existing climate risk management or production enhancement activities (Barber 2009; Howden et al. 2007). The purpose of adaptation in effectively managing potential climate risks from climate variability and change allows farmers to adopt efforts on different levels of incremental and system response as well as more strategic transformational strategies (Lal et al. 2012; Howden et al. 2007). Incremental adaptation refers to maintaining existing activities with smaller adjustments to the system to be more reactive and proactive, while transformational change refers to more tactical strategies to deal with climate related risks such as major changes in enterprises (Brundell et al. 2011). Incremental adaptation refers mostly to short and mid-term response efforts and includes extensions of actions and behaviours to reduce losses or enhance benefits of natural variations and extreme events. This *fine tuning* to the existing system that deals with natural variations in climate and extreme events can take place during or after climate related impacts or advance the projected threats that pose serious risks to the farming systems. Incremental adaptation may be accomplished by taking local seasonal climate forecasts from daily to inter-annual time scales into account (e.g. refer to adjustments in planting times) (Kates et al. 2012). Shorter term planning typically faces less risk and uncertainty than long-term planning and thus may be easier to implement (McConnell and Dillon 1997). Also reducing costs in the short-term is a common strategy for farmers to maintain equity in periods of reduced income. Such examples include cutting back inputs, postpone equipment maintenance, delay or abandon plans for expansion, carrying debt or buying something on credit (Rickards 2012). However there are limitations under increased climate variability and extreme events, which require more systematic or even transformational changes to the farming system. While system adaptation refers to changes in the existing structure such as diversification of production systems, transformational adaptation can be adopted on a larger scale or intensity, such as transforming places or shift locations. Proposed changes in the water rights system or scenarios for drying landscapes may trigger decisions for transformational adaptation which promote decisions e.g. for transforming cropping areas to grazing land to reduce long-term vulnerability to climate change related impacts. Since transformational adaptation is a more radical spectrum of farm change, it requires explicit planning and implementation of decision-making processes which may be driven by long-term climate trends and projections. However, given the high uncertainty of long-term climate projections and associated impacts on finer spatial and temporal scales, uncertainties of long-term adaptation benefits or high costs of transformational actions might complicate associated decisions (Kates et al. 2012). Nevertheless, Thamo et al. (2017) considered a delay in the adaptive responses to climate change causing damages in farm business in the long-term.

Differences between incremental, system and transformational adaption may not always be clear-cut which make adaptation strategies often difficult to categorize. Adjusting the current system incrementally may be followed by major transformative options depending on the degree of climate change. However, incremental changes can appear to be a transformational over the long run as well (Kates et al. 2012). Short-term response actions can be linked to long-term adaptation and are beneficial in coping with potentially larger impacts later in the future (Kates et al. 2012; Howden 2007; Giordi 2005).

Effective adaptation also includes learning, reassessing and reviewing past tactics to address current vulnerabilities and to prioritize system adjustments that increase resilience to present and potential future risks. Learning is also a major factor in terms of innovation, leadership and adaptive management strategies, which can reduce adaptation constraints and offer potential pathways into a more resilient and sustainable future. However, beside those skills and capacities, also the improvement of basic structures and functions in societies may increase resilience (Lavell et at. 2012, IPCC 2012). Additionally, the integration of (historical) local knowledge, scientific/technical awareness but also capacity building programs can help with effective adaptation to climate change in increasing overall resilience (IPCC 2012; Cutter et al. 2012).

### 3.3. Agricultural Risk Management

Risks and uncertainty are present in any business environment including the agricultural sector which makes its understanding and management critical to the long-term success of farm businesses (Centrec Consulting Group 2010).

Risks in agriculture arise from a variety of sources and while some risks can be managed with traditional or low regret measures, others can be reduced through the integration of a risk management framework (Gunjal 2016). A proper risk management approach can help in organizing the elements of a decision which creates a process by identifying and analysing risks, developing appropriate strategies and applying tools in order to reduce addressed risks and deal with the consequences of climate related risks. Also if applied tools will not guarantee success in risky decision-making processes, they do improve the chance to capture all information available to make a solid decision (Bowyer et al. 2014; Centrec Consulting Group 2010).

According to the World Bank (2016), effective risk management usually requires a combination of measures.

The illustration on the left hand side presents the different steps in agricultural risk management. Starting with risk assessment it refers to the identification of risks, their understanding and evaluation. Developing strategies includes making decisions on how to address the identified risks through e.g. short-term responses or longer term adaptation measures. Strategies can be implemented through a variety of tools at farm level or also in finance or market terms (World Bank 2016).

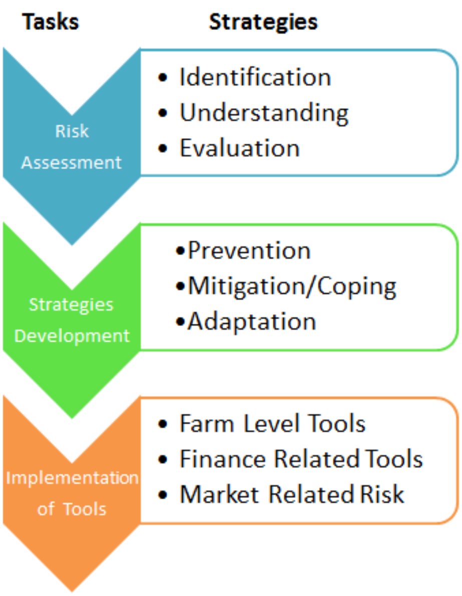



**Figure 18: Risk management strategy process**
(Own representation based on World Bank (2016); Oppenheimer et al. (2014))

#### 3.3.1. Risks from Climate Change on the Agricultural Sector

Climate change it is not a risk per se for agriculture but rather the combination of climate related risks that interact with the vulnerability and exposure of systems that determine the changing level of risk (Oppenheimer et al. 2014). As the agricultural sector inherently faces various external risks (e.g. natural environment, economic, social and policy risks) and internal sources of risks (e.g. risks internal to the farm household) both briefly presented in the following, climate change might add extra pressure on farm systems (World Bank 2016; McConnell and Dillon 1997).

Risks associated with the natural environment are of especially high importance for farming as agricultural production is directly linked to environmental depletion, short-term weather events (droughts, floods or frosts) and long-term changes in climate affecting areas of cropping, market supply and local/global prices. Economic risks are related to uncertainties of market conditions (demand and supply), prices for inputs and outputs, inflation and interest rates which are particularly relevant for long-term planning. The social environment itself is not a major source of risk although views, perceptions, beliefs, education or changes in lifestyle and consumer preferences can bear certain risks for agriculture as well. Changes in the domestic and international governmental policy may be a significant source of risks and can impact farm household's incomes, e.g. through changes in commodity prices, taxes, availability and cost of credit, environmental standards, water rights and other inputs, availability of public infrastructure, labour laws, export and import regulations, exchange rate controls or changes in the ideologies within the political environment.

Internal sources of risks in the agricultural sector relate to short-term risks including a) physical and mental health of the farm operators and b) inter-personal relations between farm-household members influenced by personality, changing values and attitudes and c) leadership style, values or knowledge of the farm operator. Long-term internal sources of risks include a) resource and ecological risk through farm management approaches (conservation or degradation of farm resources), b) financial risks through the use of credit to finance the farm's operation and development as well as c) succession risk through inter-generational transfer of the farm (Purdue University 2017; McConnell and Dillon 1997).

Also if many Australian producers are well adapted to natural climate variability, climate change triggers new risks such as changes in the pattern of extreme events coming along with reduced productivity and profitability in some locations while presenting new opportunities in others. However, most benefits in agriculture under climate change are likely to be outweighed by the impacts of a changing climate including damages of natural resources that support agriculture, changes in water availability or heat stress on animals and crops (Climate Commission 2013).

According to Rivera-Ferre et al. (2016), climate change include both short-term impacts such as extreme events like heat waves, droughts, floods and storms as well as longer term impacts referring to a more gradual change in the averages of climate variables such as local temperature, rainfall, seasonality and higher atmospheric $CO_2$ concentrations.

Impacts of climate events on agricultural production includes a) direct physical impacts on animals, crops, pastures and infrastructure from heat, cold and water stress and (b) indirect impacts on the feed base through changes in the quality and quantity of feed and water. Indirect effects from climate change also arise from longer term changes in the geographical distribution of vector-borne diseases, volatility of the price market such as rising costs of water and feeding and a general increase of uncertainty and vulnerability (Rivera-Ferre et al. 2016; Lopez-i-Gelats 2015).

Economic impacts from the changing pattern of climatic extreme events include direct and indirect economic loss. Direct losses normally occur during or after the event and are relatively easy to measure which include a reduction in exports and revenues, an increasing need to import agricultural products/commodities to meet the domestic demand or the physical destruction of crop/ livestock production. Indirect economic loss refers to a decline in economic value as a consequence of direct economic loss and impacts on humans and the environment. Revenue declines due to business interruptions (micro-economic), interruption of supply chains or price increases (meso-economic) can have negative impacts on stock market prices (macro-economic impacts) (UNISDR 2017; FAO 2015). Losses in yields also bear direct and indirect risks beyond the region which impact price volatility, losses across the food and manufacturing value chain and economic losses on food security (FAO 2015; Oppenheimer et al. 2014). Negative consequences along the food value chain include linkages with processing, distribution, markets and retailers. As the agriculture sector supplies vital resources to industry, production losses can reduce industrial/manufacturing output in sectors that depend on agriculture and raw materials. While the food processing industry is considered particularly vulnerable, also non-food agro-industries including the textile industry can be negatively affected by production losses with consequences for domestic supplies, exports, national revenues and added value from manufacturing (FAO 2015). Other direct risks from a hazardous climate may include damage to agricultural infrastructure such as livestock shelters or storage facilities, supplies, financial/business services or inaccessibility of public roads (FAO 2015).

Also slower processes associated with climate change bear risks in agriculture including uncertainties concerning the rate and magnitude of changes in the climate systems itself, changes in agricultural land fertility, animal production pattern, spatial shifts in the pest/diseases spectrum or shifts in ecological zones (Oppenheimer et al. 2014; Fischer et al. 2002).

According to Purdue University (2017), the simplest way to categorize agricultural risk include the following three broad categories: Business, Financial and Strategic. Business risks for agriculture refer to production, price/market, casualty, technology, relationships, legal/regulatory and human risks (figure 19). Financial risks can impact return on equity and refer to debt use, leverage, interest rates, capital lease commitments, working capital, liquidity, incomplete budgeting or investment analysis. The third category includes long-term strategic risks, typically more difficult to assess and include trends and variability in the business climate or other factors usually outside of the organization's control.


**Figure 19: The seven main categories of business risk in agriculture**
(Purdue University 2017)

### 3.3.2. Risk Assessment and Strategies

According to Lavell et al. (2012), risk assessment is one starting point within the broader risk management framework for adaptation to climate change. Risk assessment includes the identification, understanding and evaluation of climate related risks and potential impacts, typically depending on the general awareness of changing risks, individual perception and social interpretation. Also general beliefs, values and norms can influence the understanding of risks, although perceptions of risk typically differ among groups or individuals which is typically driven by psychological and cultural factors and general value systems (IPCC 2012). Risk assessment approaches can support identifying appropriate risk management strategies that deal with the adverse consequences of climate change (Purdue University 2017).

According to the Purdue University (2015), studies show that the vaguer the understanding of elements in a risk-management situation, the more likely decision makers base their decisions on emotion or instinct, rather than fact or analysis. Understanding and identifying risk factors deriving from a changing climate is a key challenge as it presumes an improved understanding of underlying vulnerabilities, coping and response capacities. Thus, risk assessment is a process to comprehend and determine the nature of risk level that depends on the underlying understanding of exposure and vulnerabilities (Cardona et al. 2012).

Historical records of climate or production data and information of previous management strategies to climate related risks can provide a basis for current and future risk assessment and support learning processes and interventions. An analysis of historical farm trends regarding yields, production and meteorological data such as rainfall or temperatures help to identify trends and risks.

Additionally, the inclusion of climate projections and possible impacts can help in the decision-making process despite uncertainties in estimating the likelihood and magnitude of future climate developments and associated impacts. Also if previous adaptive approaches have not always succeeded, they can provide models for long-term efforts. Also different types of global integrated assessment models allow spatial analysis of climate change impacts which can later be used as a starting point for regional case studies on vulnerability and adaptation strategies (Oppenheimer et al. 2014; IPCC 2012).

Furthermore, effective risk communication among groups and individuals helps to better assess risks which include exchanging, sharing and integrating knowledge about climate related risks (IPCC 2012). Having both appropriate information and knowledge is critical for a decision-making process within the risk management approach (Cutter et al. 2012).

### 3.3.3. Risk Management Strategies and Implementation Tools

Effective risk management is a critical element in the long-term sustainability for societies and economies (O'Brien et al. 2012). Risks, impacts and vulnerability of individuals, societies and ecosystems largely depend on a mix of risk assessment as well as mitigation and adaptation efforts (Cutter et al. 2012). As agriculture inherently operates in an uncertain and risky environment in terms of seasonal conditions or markets, each farm manager makes decisions based on assumptions about different variables (Handmer et al. 2012). The perception of risk strongly influences the behaviour of people in terms of risk mitigation and adaptation strategies to climate change and therefore their exposure and vulnerability to climatic hazards (Cutter et al. 2012).

The importance of culture and traditional knowledge over generations in shaping strategies for adaptation is widely recognized and considered as an important source in dealing with risks. People have developed local knowledge, skills and different management systems which enabled them to interact with their environment and to respond to disruptive environmental events. However, also if farmers have traditionally dealt with risks such as extreme events and uncertainties, current and future local responses will require the acknowledgement of changing risks under climate change (e.g. higher frequencies or changing magnitudes of extreme events) (Cutter et al. 2012).

With a changing climate in the study area, one important part of the decision making process is the ability to adopt risk management strategies and tools to changing circumstances. Traditional approaches might be limited to a certain extent regarding the management of uncertainty. However, most of the adaption strategies are extensions of existing climate risk management activities and do not require fundamental changes over night, but rather on-going adjustments to the farm system (Barber 2009). According to O'Brien et al. (2012) if extreme weather events increase significantly in the coming decades, climate change adaptation strategies are likely to require changes from incremental to more transformative approaches in farm systems. Adaptation strategies that better manage the impacts of climate change by using climate-resilient pathways aim to increase the resilience which is dependent upon the sensitivity and exposure to change and the capacity to adapt to change (Keywood et al. 2017). Especially the adoption of climate-smart inputs can help farmers in maintaining productivity levels and concurrently reduce GHG emission intensity (OECD 2015). Adaptation also requires a shift in views of risks which means not just seeing climate change as a threat, but also as an opportunity. Therefore, farm managers are encouraged to stay flexible and take advantage of emerging agricultural opportunities that will arise (Moser 2007).

The following figure presents key tools in the agricultural sector that are useful in managing risks (Gunjal 2016):

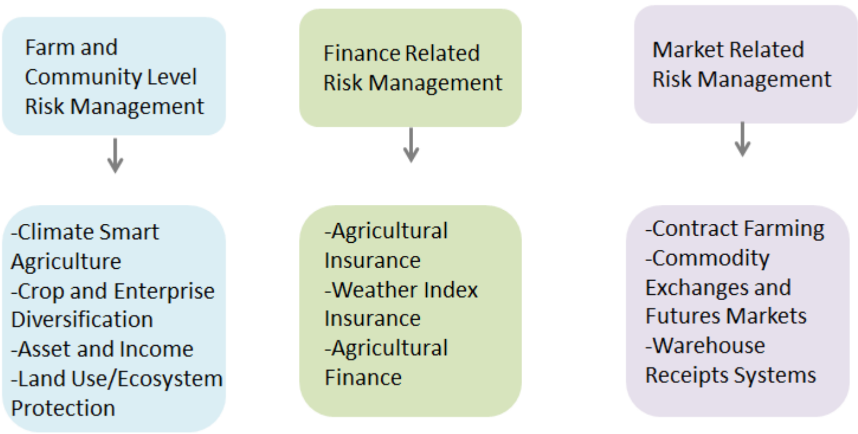



**Figure 20: Agricultural Risk Management Tools**
(Own representation based on Gunjal (2016))

**<u>Farm level risk management</u>**

There are several farm level risk management tools for farmers to cope with inherent risks in agriculture by making use of traditional and/or modern farm practices (Gunjal 2016). One main advantage of risk management and adaptation to climate extremes at local level is their independence from national interventions while using traditional knowledge that can support managing risks under climate change (Cutter et al. 2012). The following three risk management tools are considered to help farmers in managing their farm risks:

a) Climate Smart Agriculture
b) Crop and Enterprise Diversification
c) Asset and Income Based Strategies
d) Land Use and Ecosystem Protection

Climate smart agriculture

Climate Smart Agriculture (CSA) is defined by FAO as "[…] an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible" (FAO 2017; Gunjal 2016). CSA practices can result in climate change adaptation and mitigation benefits such as helping with more stable and higher yields. CSA therefore helps to reduce risks and avoid the overall negative impacts of climate change on production and incomes, e.g. through the use of improved weather forecast systems. This tool deals with both short-term risks as well as adaptation to long-term changes in climate to achieve overall resilience of agricultural production systems (Gunjal 2016). Especially climate scenarios can help to better estimate future impacts and support adaptation to more weather extremes, e.g. through investments in water infrastructure or shifts to more drought tolerant and less water consuming crops (O'Brien et al. 2012). A good starting point for addressing projected trends in climate, climate extremes, exposure and vulnerability are low-regret measures which have the potential to offer benefits nowadays while addressing projected changes. Potential low-regret measure include early warning systems, sustainable land management including land use planning, climate proofing infrastructure, water drainage systems as well as ecosystem management and restoration activities (Lal et al.2012, IPCC 2012).

Agricultural Diversification

The diversification of agricultural activities or enterprises is an important risk management tool. It refers to the re-allocation of certain farm activities into new activities to reduce risk against climate variability or agricultural price volatility. The aim of diversification is to spread farming risks while maintaining the highest possible level of income. This is accomplished by minimizing risks at farm levels associated with crop/livestock activities to increase farm resilience. The diversification of enterprises can contribute to increase productivity in a symbiotic way by offsetting potential losses in one activity with gains from others and therefore help with a more stable farm income. Diversification does not only refer to farm enterprises but also to diversification within a single enterprise such as crop diversification. For example multiple crop cultivation can reduce losses from weather, pests, diseases or unfavourable market conditions that usually affect a certain crop (Gunjal 2016).

Assets and Income Based Strategies

Farm family asset, "[…] including income, is traditionally used to cushion the family's welfare from shocks to the farming business and the livelihood derived from it" (Gunjal 2016:27). Asset diversification at farm-level can be used to reduce and mitigate risks in agriculture by maintaining a balance between productive assets such as land, livestock, machinery, food stocks or liquid assets such as saving accounts or food reserves. On the other side, income diversification is a much more active strategy with the objective to maintain a continuity of income flow through alternative farm and non-farm sources. Family farm asset can help with making investments and taking advantage of new and improved technologies which in turn helps to better manage farm risks and making the farm more productive and profitable in the long-term future (Gunjal 2016).

Land Use and Ecosystem Protection

Also sustainable land management helps in building resilience against climatic hazards which includes land use, planning, zoning, conservations, buffer zones or land acquisition. Especially protection, management and restoration activities address deteriorating environmental conditions including watershed rehabilitation, agroecology or forest landscape restoration. Reducing pressures on ecosystems and the sustainable management of natural resources can facilitate efforts to mitigate climate change and therefore help reduce vulnerabilities to extreme climate and weather events (O'Brien et al. 2012).

**Finance Related Risk Management Tool**

Another risk management tool is the "Finance Related Risk Management Tool". The following financial tools are based on the principle of transferring risk and can provide protection in the form of potential compensation for losses in exchange for pre-paid premiums (Gunjal 2016).

a) Agricultural Insurance
b) Weather Index Insurance
c) Agricultural Finance

Agricultural Insurance

Insurance as a mechanism to transfer a specific risk can help farmers to protect against climate variability. It is a measure to cope with production or revenue losses and might help to smooth farm income over years. The most common type are crop insurance schemes, protecting farmers from unfavourable shocks against low yields, production and revenue drops (Gunjal 2016). Insurances can provide a tool to reduce risks at farm levels through transferring the risks spatially or temporally and are a common risk transfer mechanism at a local level (Cutter et al. 2012). As the need for Australian farmers to adapt to increasing climate variability increases, insurance and index based products (see next sub item) are considered as suitable tools to protect against risks from extreme events such as yield losses. Especially index based products have gained popularity in recent years while traditional yield insurance products have often failed. However, Australian farmers have a low appetite for insurance products due to uncertain climatic and market conditions as costs are perceived too high and above the cost of risk. However, peril crop insurance schemes are the most widespread agricultural insurance scheme in the country, providing farmers with protection against specific perils, such as frost, hail or fire (Hatt et al. 2012).

Index-based insurance

The weather index insurance is an alternative to traditional crop insurance and especially helps with losses in the event of a drought. It consists of different types such as area-yield index insurance providing protection against drops in production, weather index insurance based on meteorological stations data, satellite images or on animal production statistics (Gunjal 2016).

Agricultural Finance

By taking a formal credit through banks or other credit institutions, farmers may be able to invest in improved seeds, fertilizer and other technologies in order to enhance farm productivity. Banking and other financial services for farming such as making use of credits are a tool to manage different types of risks in agriculture (Gunjal 2016).

**Market Related Risk Management Tools**

A third risk management tool refers to "Market Related Risk Management Tools". Nowadays the marketing of farm commodities plays an important role in the financial success and wellbeing of a farm family. Also if a farm is highly productive, it won't achieve financial success in the long-term if the farmer is not able to market the products efficiently by getting remunerative prices and mitigate market risks. The following tools outline how to get the best possible prices and a secured access to the market to minimize risks (Gunjal 2016):

a) Contract Farming
b) Commodity Exchanges and Futures Markets
c) Warehouse Receipts Systems

Contract Farming

Contract farming has grown significantly in the last decades around the world as farmers face reduced/eliminated prices and market access risks by sharing production or marketing risks with other firms under contract. The term is used to cover traditional contract farming, contract with supermarket chains, marketing contracts, organized group marketing and different types of arrangements between the primary producer and a firm. It is a possible tool for farmers to hedge against price volatility and to manage price risk (Gunjal 2016). The contracts usually stipulate the compensation that the farmer will be paid while in return the farmer is often compensated with a price premium and generally lower market risks through guaranteed market access (Gunjal 2016). According to Purdue University (2017) farmers who are operating under contract might have better opportunities for yield and price-risk avoidance, reduction and transfer than traditional independent farmers. These opportunities might be offset by increases in less traditional risks such as strategic or relationship risks (Purdue University 2017). In Australia a higher use of shared farming, land leasing and contract farming agreements could help a new generation of farmers to start building capital and allow older farmers to reduce workloads and transition to retirement. As the landowner leases his land to a contractor, he or she officially retains the ownership status of the land and is involved in decision making, while the contractor does not bear all risks in a bad year which leads to a share in risks (Duff 2016).

Commodity Exchanges and Futures Markets

Another tool to manage agricultural risks is to make use of commodity exchanges which is "[…] a platform for multiple buyers and sellers to buy and sell commodity-linked contracts on the basis of rules and procedures laid down by the exchange" (Gunjal 2016). Market tools are a good way to manage commodity price volatility and risks. Buyers and sellers place their legally binding commodity offer of a specific quantity and quality at the exchange which leads to more accurate pricing and efficient marketing of agricultural products.

Warehouse Receipts Systems

Warehouse systems are formal agreements between a licensed storage operator and a depositor who defines the quantity and quality of a specific commodity held in a secure storage environment. It is a tool to manage seasonal price risk and becomes a marketing tool when the production can be sold at the most opportune time usually much later than the harvest period (Gunjal 2016).

### 3.3.4. Challenges and Limitations of Risk Management

Individual understanding and perception of risk, exposure, vulnerability and adaptive capacities strongly determines risk management, including risk assessment and the development of strategies and implementation tools which all aim to decrease vulnerability and increase resilience to the effects of climate change (Cutter et al. 2012).

Individuals are often underestimating the risk of climate change and rather take a short-term than a long-term view also due to social norms and barriers which may hinder making appropriate decisions (Cutter at el. 2012; O'Brien et al. 2012). This is due to climate change typically being seen as a very slow and multigenerational process why individuals, businesses and government are only slowly investing into adaptation measures (O'Brien et al. 2012).

Traditionally local and farm risk management strategies focused on short-term climatic events without considering long-term projection presented by climate change which would help build long-term resilience (Cutter at el. 2012). Also a lack in cash flow and technology access can impede efficient risk reduction strategies for long-term climate change adaptation. According to Cutter et al. (2012), other obstacles to climate change adaptation include a) lack of information transfer and communication, including limitation in modelling the climate systems, b) institutional and cognitive barriers in understanding climatic information or receiving advance warning or c) the capacity and willingness of decision makers to modify traditional actions. Additionally, a general lack of synergy, willingness and/or capacities between institutional arrangements for climate change adaptation is part of the problem on regional or national levels (O'Brien et al. 2012).

### 3.4. Synthesis and Application for this Thesis

This study provides a comprehensive and spanning overview of climate change, associated risks and options for adaptation for the agricultural sector in the Corangamite catchment. However, as impacts are different across Australia and even between northern and southern Victoria, the approach of this thesis is to provide individual farm managers and decision-makers in the study area an application-oriented framework for their very specific catchment area which helps in a) raising awareness for climate change related risks to support a self-assessment of their own farm business vulnerabilities in the study area and b) provide information about adaptation options and farm risk management strategies to support farmers in building farm-level resilience. Since no long-term climate graphs were available for neither the study area nor the area of the case study, the author of this study conducted a statistical climate analysis to support historical climate analysis of the study area. An extensive literature review, the conduction of qualitative and quantitative interviews with farmers and sectoral experts from private, research and governmental institutions regarding climate change impacts and risk management strategies allowed for a broad overview of the research topic. Additionally, findings could be applied to the case study and conclusions be drawn by reference to a single farm of the catchment. As there was no comparable study been conducted for the Corangamite catchment this dissertation contributes to the importance of this region specific analysis.

This chapter provides the theoretical framework for this thesis embedding the concepts of risks, vulnerability and resilience which play a major role in assessing, developing and implementing agricultural risk management. The following graph represents the conceptual framework of this thesis. Changes in climate and extremes triggered by natural variability and the anthropogenic influence on the climate system pose diverse risks on the agriculture sector. Socio-ecological and economic risks however derive from external and internal factors and might be aggravated by the effects of climate change. However, a sound agricultural risk management aims to support an increase in farm resilience and to lower potential vulnerabilities deriving from climate related risks.

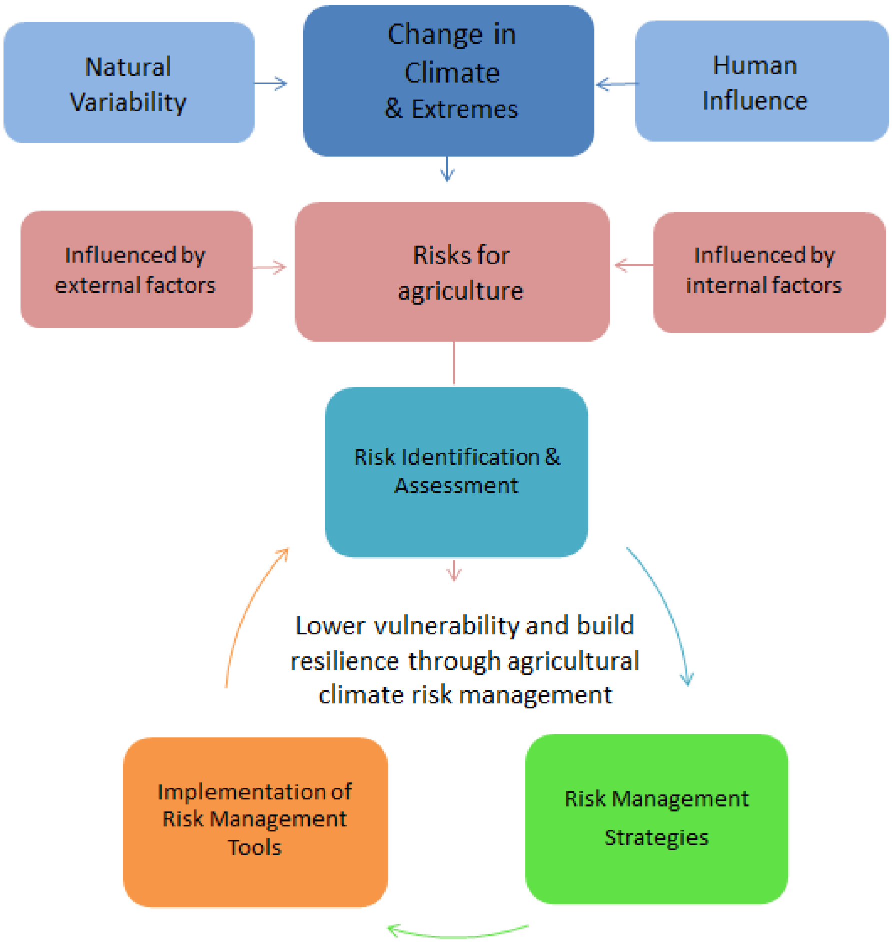



**Figure 21: Framework of this dissertation**
(Own representation)

## 4. Methodology

The aim of this chapter is to discuss the methodology used in this study to address the aforementioned objectives of this study. To answer the research questions and to achieve the aims of this dissertation, the study methodology consists of qualitative and quantitative methods. This study lasted from September 2014 to September 2017 allowing for a rough classification of the methodological procedure into three phases:

The **first phase** involved a literature review and Internet based research to obtain theoretical background information about the study area, climate change and associated risks for agriculture and potential risk management options in the agricultural sector. Sources of information included scientific papers, governmental reports, reports from international organisations such as the United Nations (UN), reports from regional and local catchment management authorities and Landcare groups as well as other relevant documents from international, national and regional organisations, institutions and non-governmental organisations (NGO). The literature review was an essential and on-going process during the whole three years of this dissertation but was of particularly importance in the first year as research questions and goals needed to be defined to plan for further research procedure. In the very beginning of this dissertation, a field trip to Australia was conducted from November 21st to 29th in 2014 which included:

a) visiting the study area, particularly the Mt Hesse farm where the author of this study was able to meet the farm management of Mt Hesse in person

b) a presentation to local farmers in order to 1) raise interest for this dissertation thus potentially increasing the willingness of farmers to support this study by giving interviews and 2) to present and discuss the ideas and research questions of this study

c) a presentation at the Australian-German College of Climate & Energy Transitions at the University of Melbourne thus allowing for a follow-up discussion and feedback for the research proposal

Furthermore the programming language R, a free software environment for statistical computing and data visualisation was acquired through the participation of a semester-long seminar and lecture in statistics offered by the Geography Department of the Humboldt University of Berlin (R Foundation 2016). This was important to enable the author of this study to analyse and visualise climate data for the study area.

The **second phase** involved an extended field to Australia from November 2015 to April 2016 which included:

a) the conduction of 13 semi-structured interviews and the online survey with farmers in the catchment as well as more insights into the daily farm business during a two-month stay at the Mt Hesse farm
b) the conduction of 24 interviews with sectoral experts from private, research and governmental institutions in Melbourne, Geelong and Sydney
c) a three month guest stay at the Climate and Energy College and a presentation and discussions regarding the methodology and results from all conducted interviews
d) a presentation of all summarized results from the climate analysis and the conducted interviews to the local farming community in Inverleigh with around 50 participating farmers

During and after the field trip, all interviews were transliterated, encoded and analysed. In the second year, two other seminars were attended at the Agricultural Department of the Humboldt University of Berlin to increase specialized knowledge about agriculture and climate science.

In the **third phase**, all results were compiled, reviewed and discussed along the research questions and goals both in oral and written form. A last field trip to Australia was conducted from January to March 2017 to discuss the methodology and study results with the local supervisor and other PhD students from the Climate and Energy College.

During the whole three years of this study, the author of this dissertation frequently gave presentations at the Institute of Climate Impact Research (PIK) and the graduate programme of the Humboldt University of Berlin *IRI THESYs*, thus allowing for presenting the research progress, reviewing and discussing the study methodology and interim findings.

### 4.1. Introduction

The mixed methods approach combines quantitative and qualitative research and is a relatively recent approach to break down barriers between the two approaches that have been seen as opposites for many decades (Grbich 2013). According to Glaser (2004), whichever methodology is chosen for scientific research, it always implies a certain type of data collection, timing and pacing for data collection and analysis. Hence, every methodological approach contains implicit and explicit problems and affects the research product to a certain extent. The main difference between quantitative and qualitative methods is their flexibility (Glaser 2004).

Qualitative research is a type of scientific research that seeks to understand a given research problem, mostly in the social contexts of particular populations and from the perspective of involved persons. As findings are not determined in advance, this approach is considered especially effective in obtaining culturally specific information about perceptions, opinions, values or behaviours. The explicit goal of qualitative data is description and the strengths of the qualitative approach is to provide complex textual descriptions of how the interviewees experience a given research issue. For example information about the ´human´ side of an issue such as opinions or emotions can be explored and represented. Qualitative approaches are generally more flexible, allowing greater spontaneity and adjustments of interactions between researchers and study participants according to the situation (Glaser 2004). However, issues with qualitative research are accuracy, truth and the objectivity of the data as the accuracy focuses on its subjectivity and its interpretive nature (Glaser 2004). Also according to Flick (2009) individual analysis and interpretation of data is a specific problem in qualitative research.

Qualitative in-depth interviews are beside participant observation and focus groups one of the most commonly used qualitative approaches. Qualitative methods such as interviews are generally believed to provide a ‘deeper’ understanding of social phenomena than would be obtained from purely quantitative methods, such as questionnaires. As qualitative interviews consist mostly of open-ended questions, participants have the opportunity to respond in their own words which tend to be more elaborated and detailed rather than forcing them to choose from fixed responses such as ´yes´ or ´no´ (Flick 2009; Glaser 2004). Open questions provide the opportunity to express personal perceptions and feelings, life experiences, views and beliefs, to discuss opinions in a face-to-face situation and produce findings that were not determined in advance. The interviewer itself has usually the privilege to be entrusted by the interview partner with a glimpse into their personal lifes, perceptions and opinions. In-depth interviews also provide an opportunity to understand how people interpret and order their environment and to address sensitive topics that participants would perhaps avoid to discuss informal group settings. During the interview, the interviewee is considered the expert while the interviewer is considered the student. The motivation of the researcher is to learn everything about what the person being interviewed can share by asking questions in a neutral manner, listening attentively to the responses and asking follow-up questions (Mack et al. 2005).

Quantitative methods are generally more inflexible as all participants are identically being asked the same questions in the same order in a questionnaire. Quantitative research is based on the assumption that there is an objective truth existing in the world that can be measured and explained scientifically. Thus, pre-defined hypothesis are sought out to be verified or falsified. The advantage of inflexible closed-ended or fixed questions is that it allows for a meaningful comparison of responses across all participants of a study which is generally less time consuming than qualitative approaches. At the same time it requires enough background information on how to ask questions and to provide an adequate range of possible responses (Mack et al. 2005). Hence, the strength of quantitative research is a relatively high objectivity for research results by providing a clear specification of dependant and independent variables for investigation. Nonetheless, the main concerns of the quantitative approach include reliable measurements, a lack of information and understanding of the studied phenomena from the researcher side, the inability to control the environment where the respondent provides the answers to the survey questions and limited outcomes due to closed-ended questions from pre-structured formats (Matveev 2002).

**Table 2: Comparison of quantitative and qualitative research approaches**
(Own representation based on Mack et al. (2005))

| | Quantitative | Qualitative |
|---|---|---|
| **General Framework** | - Seek to confirm hypotheses about phenomena<br>- Use highly structured methods such as questionnaires or statistical analysis | - Seek to study phenomena and generate hypothesis during the research process<br>- Use semi-structured methods such as in-depth interviews, focus groups and participant observation |
| **Analytical objectives** | - To quantify variation<br>- To predict causal relationships<br>- To describe characteristics of climate, a population etc. | - To understand a research problem<br>- To describe and explain relationships<br>- To describe individual experiences<br>- To describe variations |
| **Question format** | - Closed-ended | - Open-ended |
| **Data format** | - Numerical | - Textual |

However, despite qualitative social research not being common in the agriculture science allowing outcomes to be uncertain and bear certain risks (Rickards 2012), the author of this study considered a combination of quantitative and qualitative approaches as the most promising approach to answer the research questions and to achieve the goals of this dissertation. According to Flick (2009), both strategies can be applied parallel before the results from both steps are deepened and assessed in a qualitative phase, as it has been applied in this thesis.

When qualitative interviews are used along with quantitative methods, "[…] qualitative research can help to interpret and better understand the complex reality of a given situation and the implications of quantitative data" (Mack et al. 2005). For this study, a quantitative climate analysis for the Corangamite catchment and especially the case study has been conducted. This was to a) complement available literature in the interest of this dissertation since specific climate information was not specifically available for the catchment nor for the very location-specific area of Mt Hesse to identify potential climate related risks and b) to compare the analyzed climate development from farmers perception.

To explore farmers perceptions and their farm management strategies, a qualitative study with farmers was conducted in the catchment. Where possible, this study also included the attempt to quantify the semi-structured qualitative interviews as answers were analyzed along categories and their frequencies which allowed for grounded interpretations and presentation of findings (Flick 2009).

As the qualitative research allows for generating hypothesis, they can be tested with a broader farming community through surveys and other approaches thus presenting a first necessary step in a successful mixed method approach that highlights the complementary of different methodological approaches (Schattman et al. 2016; Flick 2009). Furthermore, a quantitative online survey with farmers was conducted to complement the qualitative interviews with farmers. Larger sample sizes of interviewed farmers allowed for an improved representation of the farming community in the catchment. However, both approaches were applied in their own logic (see next two sub-chapters). By linking the results of the qualitative and quantitative approaches it highly contributed to obtain profound knowledge of the research issue which is considered broader than the single research approach (Flick 2009).

## 4.2. Climate Data

The climate analysis aims to complement available climate related information including historical trends and climate scenarios for the study area. The following part summarizes which climate data has been used for the analysis of this study and briefly presents how they have been analysed.

### 4.2.1. Datasets

**SILO**

SILO (Scientific Information for Land Owners) is a database of enhanced long-term Bureau of Meteorology data provided by the Queensland Government. It is a database of historical climate records for Australia from 1889 to 2017, providing daily datasets for different climate variables in several formats suitable for a variety of applications. SILO provides national coverage climate data with no missing data in a ready-to-use format, supporting a wide range of research projects in Australia but also worldwide for crop and pasture modeling. The datasets are constructed from observational records of around 4,800 weather stations provided by the Bureau of Meteorology (BOM) and are available on latitude/longitude resolution grid cells of 0.05 x 0.05° (about 5km$^2$ at the equator) across Australia (DSITI 2017). SILO processes the raw data that may contain missing values to derive datasets which are both spatially and temporally complete. The data are available through paid licensing, but only the data within Queensland are available free of charge (DSITI 2016). Silo data was provided from the University of Melbourne for this study and analyzed for the area of the Corangamite catchment from 1889 to 2014 with the corner coordinates from longitude 142.80° to 144.70° and latitude -37.40° to -38.83°.

According to BOM (2017a), datasets were homogenised with different techniques to ensure comparability through time. Nevertheless, discontinuities in climate over time may be caused by changes in the observation networks or instrumentation practices why especially temperature data before 1910 are not included in the BOM datasets for monitoring climate change. Mostly, climate data are used from 1950 to ensure homogenised measurement techniques across the Australian continent.

**ISIMIP**

For temperature and precipitation scenarios, ISIMIP (Inter-Sectoral Impact Model Intercomparison Project) data were used. ISIMIP was initiated by the Potsdam Institute for Climate Impact Research (PIK) and the International Institute for Applied Systems Analysis (IIASA) in 2012/2013 and is nowadays used by over 100 modelling teams around the world (PIK 2017). It is a community driven modelling initiative that a) aims to contribute to a quantitative and cross-sectoral synthesis of the different impacts of climate change and its associated uncertainties and b) aims to contribute to a comprehensive understanding of the impacts of politically and scientifically-relevant climate-change scenarios (PIK 2017). According to van Vuuren et al. (2017), ISIMIP uses community-agreed sets of scenarios with standardized climate variables and socio-economic projections as input data to project future risks and associated uncertainties within and across sectors. ISIMIP is organised into simulation rounds, which are provided with a common set of climate input data and other data, guided by a focus topic to ensure cross-sectoral consistent impacts simulations. In the simulation scenarios, the participating models cover impacts of the agriculture, water, global biomes, coastal infrastructure and vector-borne diseases sectors and newer simulations also the regional forest, water, fisheries, permafrost, energy and biodiversity sectors on a global scale. In additions to these sectors, simulations also cover studies of climate-change mitigation. However, very little is known about how different impacts of global warming may potentially interact between different sectors (PIK 2017). Many of the produced paper were cited in the Fifth Assessment Report of the IPCC. The scenarios facilitate model evaluation and the representation of the impacts of extreme events and variability (PIK 2017).

The climate-input data are observational data sets covering the 20$^{th}$ century (PIK 2017). The framework provides a set of scenarios of climate projections from five Global Climate Models (GCMs) which are driven by the RCPs (Representative Concentration Pathways). The RCP´s are the latest generation of scenarios providing input for climate models and were developed by a global community of integrated assessment modelling groups forming the Integrated Assessment Modelling Consortium (Bjørnæs 2016). The four RCPs (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5[1]) are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities. This includes changes in land use and provides specific radiative forcing pathways

[1] See explanation in chapter 5.1.2

which measure the additional energy taken up by the Earths system due to the increase in climate change pollution. The gases and pollutants that are included in the RCPs include greenhouse gases such as $CO_2$, methane, nitrous oxide, several groups of fluorocarbons and sulphur hexafluoride, but also aerosols and chemically active gasses such as sulphur dioxide, soot, organic carbon, carbon monoxide, nitrogen oxides, volatile organic compounds and ammonia (Bjørnæs 2016).

**Mt Hesse data**

The management of Mt Hesse provided measured annual and growing-season precipitation data of the farm since 1883.

### 4.2.2. Climate Data Analysis

SILO climate data, including precipitation, minimum, mean and maximum air temperature were available for the years 1900-2014 covering the study area. The data was loaded and analysed using the open-source statistical software R3.42 (R Foundation 2016). A local regression loess smoothing line was applied to the climate data (with default span $\alpha = 0.75$) to fit a smooth curve between the variables temperature/precipitation and time (StatsDirect 2017). The number of days with a mean air temperature above 30°C and below 5°C was calculated for each year from 1900 to 2014, for the catchment and the Mt Hesse location. Temperature and precipitation anomalies were calculated for each season (summer: December, January, February, autumn: March, April, May, winter: June, July, August and springs: September, October, November). Temperature and precipitation anomalies were calculated as departures from a climatological mean over the World Meteorological Organization (WMO) reference period 1961 to 1990 (Murphy and Timbal 2008). To test for trends in the number of hot and cold days per year and seasonal precipitation and temperature anomalies over the years 1900 to 2014, a simple linear regression analysis was applied.

To assess potential future trends in precipitation and temperature, output of global circulation models as provided in the ISI-MIP project were analyzed. Climate data from five global climate models from the Coupled Model Inter-Comparison Project 5 (CMIP5) experiment and four RCPs (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) were used: a) GFDL-ESM2M (GFDL/US Dept. of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory/USA), b) HadGEM2-ES (HadGEM/Hadley Centre for Climate Prediction and Research/UK), c) IPSL-CM5A-LR (IPSL/Institute Pierre Simon Laplace/France), d) MIROC-ESM-CHEM (MIROC/University of Tokyo, National Institute for Environmental Studies and Frontier Research Center for Global Change/Japan), and e) NorESM1-M (NorESM/Norwegian Climate Center/Norway) (MACA 2016). They are part of the newest generation of climate models that provide researchers and decision makers from policy and different sectors with the most up-to-date view of future climatic changes. Over 40 different modelling groups around the world participated in CMIP5, but only 20 of these models produced daily outputs for variables that are interesting for the project such as minimum/maximum temperature, precipitation, wind, humidity and solar radiation (MACA 2016). GCM outputs were bias-corrected within the ISI-MIP framework (Hempel et al. 2013). In cooperation with PIK, temperature and precipitation projections were averaged per grid cell across all five models and then aggregated to catchment level. Individual model results and a 7-years smoothing filter were applied and complemented by a simple linear regression analysis to test for trends in temperature/precipitation over time.

### 4.3. Interviews

The literature review prior to the field trips to Australia revealed a long-term climate change coming along with impacts on the agricultural sector for south-east Australia, including Victoria and the study area. Despite several studies conducted in Victoria in terms of climate change, farmers perceptions and adaptation options (e.g. Rickards 2012), there exists no comparable study for the Corangamite catchment. This thesis aims to increase farmers awareness for climate change related risks and aims to provide a practical guidance for farmers in terms of adaptation options in the catchment. According to the author's conception of this thesis this can be reached, beside a region-specific climate analysis, through expert interviews with farmers in the study area and interviews with sectoral experts who provided profound agricultural expertise knowledge from different working background areas. Thus, the conducted interviews in Australia have provided important supplementing information to the available written sources.

According to Flick (2009), an expert is a person with specific capacities in a certain field of activity due to personal experiences and/or their own biography. Expert interviews can be used for exploration, for orientation in a new field in order to give the field of study a thematic structure, to generate hypotheses or also to collect context information complementing available written material (Meuser and Nagel 2002).

Due to this definition, all interview partners of this study were experts. So are farmers not only personally affected from local climate impacts affecting their production and economic farm outcome, but also tend to have exceptional knowledge of their local area in terms of their environment, climate conditions, associated risks and farm management strategies that deal with their environment (Rickards 2012). This is also reflected by the fact that the vast majority (75 % of the interviewed farmers) in the study area were involved in agriculture for at least 21 years or more, taking on the family farm business in the 2$^{nd}$, 3$^{rd}$, 4$^{th}$ or even 5$^{th}$ generation. However, the definition of an expert also applied to the interviewed participants from different private, research and governmental institutions working on regional and national level. They were typically not personally affected from climate impacts in terms of production, but had an exceptional sectoral knowledge and typically a broader overview of the whole agricultural sector. Both groups had very specific knowledge; farmers were personally affected from local climate risks and impacts with having practical experience in managing their own environment also by using knowledge from previous generations if available, while the interviewed participants in Melbourne, Sydney and Geelong had very specific scientific and or/sectoral expertise. However, to facilitate the differentiation between interviewed groups, the terms ´farmers´ and ´sectoral experts´ were used in this study.

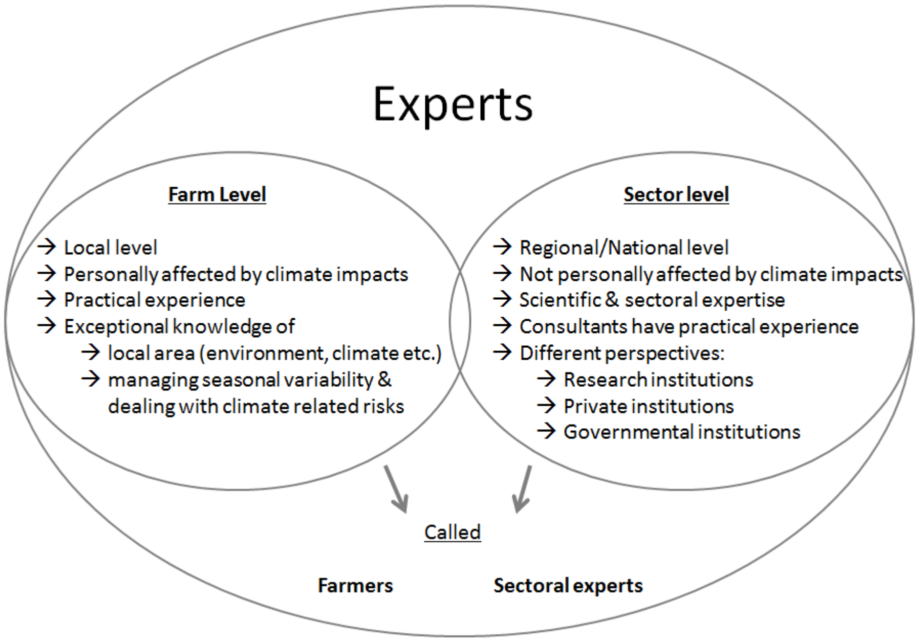



**Figure 22: Conceptualisation and differentiation between interview partners**
(Own illustration)

### 4.3.1. Procedure of Interviews

In total, 13 semi-structured **qualitative interviews** with a common outline were carried out with farmers in the Corangamite catchment. Semi-structured interviews consist of a catalogue of key questions covering the area to be explored, provide room for flexibility while open ended follow-up questions stimulate the answers of participants (Gill et al. 2008).

During the second field trip to Australia, the management of Mt Hesse provided a list of about 20 farmers with names and telephone numbers, using a social network of friends and neighbours in the catchment who might support this study. According to Mack et al. (2005), ideally the researcher works together with local people or community leaders to identify and recruit potential participants for the interview. All listed farmers were contacted by telephone and asked for an interview. The participants, who accepted an interview, were personally visited on their farm by the author of this study. Interviews lasted between 30 to 120 minutes. The catalogue of questions contained an introductory, a main and a terminal part focused on the farmers perceptions regarding temperature and precipitation development, extreme events, associated impacts on production as well as farm management strategies (Annex B). With the introductory questions being part of each interview, the main part was slightly adjusted in accordance to the business operation of each interviewee. Although most farmers had a mixed livestock-cropping enterprise, some farmers only focused on cropping operation while other focused on sheep or cattle production. The closing sections gave room to clarify questions, to ask questions in return and to allow additional remarks which were not addressed during the interview.

Beside the qualitative interviews with the farmers, a **quantitative online survey** was conducted to address more farmers in the Corangamite catchment. Structured interviews consist of a list of predetermined questions with little or no room for variation or follow-up questions, thus supporting quicker administrations and simplified comparison of given answers. However, this research approach allowed for limited participant responses and less *depth* compared to open or semi-structured qualitative interviews (Gill et al. 2008). The participants of the online survey were mainly recruited with the help of the *Upper Barwon Landcare Network*. The facilitator of this network helped to recruit farmers for the survey by sending E-mails to all participants of the Landcare network, in which this PhD project was briefly presented and farmers asked to participate in the survey. Besides sharing the survey on the electronic way, printed versions of the questionnaire were personally a) dropped into the letterboxes within the catchment and b) handed out at local events to the farmers. The catalogue of questions was subdivided into an introductory, main and closing section to arrange a hierarchical structure within the questionnaire (Annex D). The introductory session of the questionnaire included easy-to answer questions such as age or farm size. The main section of the questionnaire continued with questions addressing farmers views on perceived historical and seasonal development of rainfall and temperature, changes in extreme events and risks, associated impacts on production as well as employed farm management strategies. The last question referred to farmers assessed sustainability of farming under increasing future climate variability. Some questions allowed room for additional comments. In total, 31 questionnaires were filled in electronically and 9 questionnaires manually thus requiring them to transfer data into the online platform. In total about 300 farmers were requested to participate in the study. Hence, the number of the participants with 40 answered questionnaire counted for 13.3 %.

Additionally, **24 semi-structured qualitative interviews** with sectoral experts from research, private and governmental institutions were carried out. Interview partners were found through an extended Interned-based research and chosen according to their expertise, working fields and potential benefits in answering the research questions in the areas of agriculture and climate science. Further interview partners were recommended from other interviewees who were considered to contribute to the success of this study. As soon as potential interview partners were identified, contact was made up via E-Mail and telephone to ask for an interview, including an introduction about the research topic and a brief overview about the questions of interest. Thus, a brief guideline of the interview questions was attached to the E-Mail to enable the interviewee to prepare for the interview. The received feedback was positive as every inquired person accepted the interview request. During the interviews, mostly open-ended questions were used to allow the interview partner to answer what she or he considered to be the most important while leading questions were avoided. To ascertain that the research questions of this dissertation were addressed and to provide a reference framework, a catalogue of questions were developed for the interviews prior to the second field trip to Australia. Adjustments have been made in according to the expertise and working area of the interviewee prior to the conducted interview (Annex A). The interviews were subdivided into an introductory section which were part of all interviews and a main section being adjusted accordingly to the expertise of the interviewee. Similar to the interviews with farmers, the closing sections of the interviews gave room to clarify questions, to ask questions in return and allow additional remarks which were not addressed during the interview. 18 interviews were conducted personally by the author of this study in Melbourne, Sydney and Geelong while 6 interviews were conducted via Skype, as the time and costs for the outward journey would have been disproportionate to the time of the interview.

All qualitative interviews were audio-recorded with an IPhone 6 dictation app. In addition, notes were taken down during or immediately after the interview which included key points, striking statements, additional thoughts about the interview and the interview location. After the first two or three interviews with farmers and sectoral experts, the interview outline was reviewed. While some questions were omitted, others were revised or reworded due to new informations and experiences obtained during previous interviews.

### 4.3.2. Description of Interviewees

**Farmers from the qualitative interviews**

The interviewed farmers in the Corangamite catchment were on average 55 years old men (IP1 - IP13). Two couples were interviewed as well. All interviewed partners were the owner of the farm, and worked in the agricultural sector for at least 15 years or more.

**Farmers from the online survey**

The majority (75 %) of the 40 participants were between 55 and 74 years old, of which 80 % were male. Most farmers (77.5 %) stated to be the owner of the farm with the rest either partially owning the farm (10 %), working as employees (5 %) or as tenants (2.5 %). 75 % of the interviewees worked more than 30 years or more (30 %) on their farm while only 5 % worked less than 10 years as farmer. 15 % of the survey participants indicated that their farm has been in family hands for several generations. Most participants worked on a farm with a size between 100 ha and 1000 ha (72.50 %) and only 20 % worked on bigger farms between 1000 ha and 4000 ha.

**Sectoral experts**

The interviews partners (IP14 - IP37) were representatives from private institutions (e.g. consultants), research institutions (e.g. University of Melbourne/Sydney) as well as governmental institutions (e.g. Bureau of Meteorology) who are presented in the following.

**IP14** is working at the Bureau of Meteorology (BOM). The BOM is an executive agency of the Australian government and Australia's national weather, climate and water agency. The BOM provides one of the most fundamental and widely used services of the Australian government through regular observational, meteorological, hydrological and oceanographic services such as forecasts, warnings, monitoring and advises across the continent. IP14 has been a climate scientist at the BOM for 20 years and focuses on the development of long-term historical data sets for the assessment of climate change and current and historical analysis of extreme events (The Conservation Trust 2016a).

**IP15** is also working at BOM and focuses on the gap between seven-day weather forecast and three month seasonal outlook in cooperation with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), an Australian government corporate entity that started life as an Advisory Council of Science and Industry in 1960. The organisation is internationally recognised for its quality research and provides advice in economic, environmental and social issues (CSIRO 2016a). Ocean and atmosphere models provides multi-week rainfall and temperature forecast products, designed for Australian farmers to improve their resilience to future climate events (Hudson et al. 2015).

**IP16** is a weather bureau senior climatologist, working at the communication division at BOM. Communicating climate information to different interested stakeholders is important so that users, including farmers can understand, interpret and apply the information to their decision-management process, reduce the impacts of climate-related disasters and enhance climate related management. Therefore, BOM introduced the "Managing Climate Variability (MCV) Climate Champion program" which aims to help farmers in managing climate risk by providing several climate tools, products, practices and seasonal outlooks. The program also supports farmers in understanding how to use climate information and how to incorporate them into their farm business operation (Hewitt et al. 2015).

**IP17** is a professor for climate science at the University of Melbourne. He is an internationally recognised sectoral expert in climate change and climate variability, including greenhouse climate change, inter-annual climate variations due to El Niño-Southern Oscillation as well as stratospheric ozone depletion and provides advice to the Australian government on climate change policies (University of Melbourne 2016e).

**IP18** leads an agricultural and resource-economic group at the University of Melbourne, which assesses questions of agricultural/natural resource management/policy, agribusiness industry issues, climate change, water and food security. IP18 published several papers addressing pasture, livestock and cropping management under climate change (University of Melbourne 2016c).

**IP19** is also working at the University of Melbourne. He is an expert in grazing and dairy production systems, climate change impacts and adaptation on profit, risk and people. He published several papers addressing greenhouse gas emission from grazed pastures, crop and livestock production scenarios to future climate change, economic impacts of climate change on the Australian dairy sector and soil carbon issues (University of Melbourne 2016a).

**IP20** is an expert for agricultural, resource and farm management economics, working at the University of Melbourne. He focuses on pasture management, innovation in lamb production, food security, the impacts of environmental variability on the productivity of agricultural enterprises and adaptation to a changing climate. He published papers addressing issues such as pasture improvement and economics, feeding options adapted to decreasing water availability on dairy-farm economics or modelling of farm system changes (University of Melbourne 2016d).

**IP21** is a climate scientist at the University of Melbourne focusing on climate change, uncertainties, and emission scenarios and has been contributed to various chapters in the Fourth Assessment Report of the IPCC (University of Melbourne 2016f).

**IP22** works as a consultant for farmers in livestock management in Victoria and holds a position at the University of Melbourne, working on livestock and pasture programs (University of Melbourne 2016b). His areas of expertise include sheep farming systems, genetic improvement, animal health and management of business, pasture growth, nutrition/feed drought, reproductive and disease (CSIRO 2016b).

**IP23** is working at the RMIT University of Melbourne. She is an expert in environmental science and management and published papers about human and environmental resilience issues, reflexive climate change adaptation and barriers to effective climate change mitigation (RMIT University 2016).

**IP24** is a climate modeller with a major focus on terrestrial processes in global and regional climate models and leads a climate change research group at the University in Sydney. He explored the global and regional impacts of land cover change and has interests in climate extremes and possible pathways in the future. IP24 regularly contributes to the media on the science of climate change (CCRC 2016).

**IP25** is also a climate researcher, focusing on extreme climate events and how their occurrence changes over time. He is particularly interested in understanding the mechanisms that drive these changes and in quantifying the uncertainties related to the representation of climate extremes in observational data sets and climate simulations (Donat 2015).

**IP26** is a seasonal climate specialist and an expert in farmers education working at the Department of Economic Development, Jobs, Transport and Resources (DEDJTR). He regularly gives analytical presentations on the key factors driving Victoria's and Australia's climate and climate variability, decadal and seasonal changes in climate as well as how to deal with uncertainty in the agricultural sector (BLG 2016).

**IP27** is working as a seasonal climate risk agronomist at the Department of Economic Development, Jobs, Transport and Resources, focusing on the cropping industry in Victoria and the share of information as an editor of an online website that provides information on yield model outputs and useful web links (DEDJTR 2016).

**IP28** works as a Land Management and Livestock Extension Officer at the Department of Economic Development, Jobs, Transport and Resources. He is an expert in cropping and pasture management and tested/implemented different pasture-livestock farming systems in the high rainfall zone of southern Australia (EverGraze 2016).

**IP29** is working for the Department of Economic Development, Jobs, Transport and Resources and provides climate and agriculture services in the Australian beef and sheep industry. He is an expert in managing the sheep production systems, adaptation to the impacts of climate change and strategies for mitigation emissions (MLA 2016a).

**IP30** is working at the University of Melbourne in the area of greenhouse gas emissions from agricultural systems, grazing systems, whole farm modelling of climate change impacts, mitigation and adaptation strategies. He works as a science advisor for Australia, New Zealand and the UK and has authored over 100 publications (University of Melbourne 2016g).

**IP31** is working for the CSRIO who is involved in several research projects working with farmers that aim to increase resilience of Australia's cropping systems to climate variability and change. He assists farmers to improve on-farm climate risk management in the cropping and grazing industry and evaluates adaptation options for several case study farms across the country (The Conversation Trust 2016).

**IP32** is also working at CSIRO and a globally recognized expert in climate and sustainability (ANU 2016). He is specialized in the impacts of climate variability and change on agricultural systems, the dynamics of grazed and cropped ecosystem as well as the development of sustainable and innovative farming systems (The Conservation Trust 2016b). He published or contributed to more than 200 journals and book chapters, working on mitigation and adaptions options across a range of sectors (ANU 2016)

**IP33** works at Sheep Genetics which operates for Australian sheep producers with expertise in the areas of environmental change and its impacts on the sheep industry. The organization has facilitated genetic evaluation for wool and prime lamb producers and aims to improve the quality, scope and utilisation of cross-flock and breed genetic information for the Australian sheep industry (Sheep Genetics 2016).

**IP34** works at Crop Life, which is Australia's peak industry organisation representing the agricultural chemical and plant science biotechnology sector in Australia. He has an extensive scientific knowledge of plant science, biotechnology in the crop sector as well as environmental changes. Additionally, he has authored several journal papers, government reports and publications relevant to his areas of expertise (CropLife 2016).

**IP35** works for the Global Challenges Program at Rural Industries Research and Development Corporation (RIRDC) with expertise in the area of managing climate variability. The government-industry partnership corporation was established by the Australian Government to work with the industry to invest in research and development for a more profitable, sustainable and dynamic rural sector (RIRDC 2016).

**IP36** works at Corangamite Catchment Management Authority (CMA). The task of the CMA is to "[…] coordinate, facilitate and lead an integrated approach to the protection and enhancement of land, water and biodiversity of the Corangamite region by engaging and supporting the community and regional partners" (Corangamite CMA 2015). The functions of the authority are governed by a range of legislated requirements such as the Water Act from 1989 (Corangamite CMA 2015).

**IP37** is a veterinarian who has developed new ways of breeding fleece-coated animals for high levels of fibre quality and plain-bodies sheep with floppy ears which might help to deal with climate extremes such as droughts (SRS 2016).

**Table 3: List of Interview Partner (Sectoral Experts)**

| IP Partner | Institute | Expert in… |
|---|---|---|
| IP14 | Bureau of Meteorology | Climate science, the development of long-term historical data sets for the assessment of climate change, and the analysis of extreme events, both current and historic |
| IP15 | Bureau of Meteorology | Climate predictions for Australia and complex global processes that influence the variability of Australia's climate, improvements and representation of climate models |
| IP16 | Bureau of Meteorology | Communication with the public and farmers |
| IP17 | University of Melbourne | Climate variability and change, stratospheric ozone depletion and inter-annual climate variations due to El Niño-Southern Oscillation |
| IP18 | University of Melbourne | Agricultural technology adoption, water use and climate change |
| IP19 | University of Melbourne | Pasture production under climate change , cropping, livestock adaptation, climate prediction for 2030 |
| IP20 | University of Melbourne | Agricultural and resource economics and farm management economics |
| IP21 | University of Melbourne | Atmospheric science and climate modelling |
| IP22 | University of Melbourne | Veterinary Services, Veterinary and Agricultural Sciences |
| IP23 | RMIT University Melbourne | Sustainability and Urban Planning, Climate change and adaptation strategies |
| IP24 | Climate Change Research Center, University NSW | Terrestrial processes in global and regional climate models, global and regional impacts of land cover change |
| IP25 | Climate Change Research Center, University NSW | Climate extremes/parameter, changes on inter-annual to centennial time scales, quantifying the uncertainties related to climate extremes in climate data sets |
| IP26 | DEDJTR | Seasonal climate variability and change, Farmers education |
| IP27 | DEDJTR | Seasonal Risk Agronomist |
| IP28 | DEDJTR | Crop and pasture agronomist |
| IP29 | DEDJTR | Sheep production and adaptation to climate change |
| IP30 | DEDJTR/University of Melbourne | Greenhouse gas emissions from agricultural systems - mainly livestock, Nitrogen cycling in intensive grazing systems, whole farm systems modelling of climate change impacts, adaptation and mitigation strategies |
| IP31 | CSIRO | Adaptation and resilience of Australian cropping systems to climate variability and change |
| IP32 | CSIRO | Climate variability and change, innovation and adaptation management |
| IP33 | Sheep Genetics | Biotechnology, Sheep genetics |
| IP34 | Crop Life | Biotechnology, Crop Genetics |
| IP35 | RIRDC | Sustainability across the rural sector, advisor for skills in climate forecast |
| IP36 | Corangamite Management Authority (CMA) | Sustainability in the Corangamite catchment, ecology and climate change |
| IP37 | SRS Company | Breeding advisor, climate change adaptation |

### 4.3.3. Data Analysis

Every single interview was transcribed directly after the interview itself by the author to prepare for the coding process, to facilitate further data analysis and to help for interpretation of the data. During the transcription process, all tape-recorded mp3 files were played-back so that the author was able to listen simultaneously while writing down what the interviewee said. Non-verbal sounds such as laughter, ´äh´ or ´hmm´ were not written down, as a verbatim transcript was not considered relevant for the research questions of this thesis. Bringing oral interviews into written form is important to prepare for the following coding and analysis of the interviews. In total, 114 pages of written material were produced from the interviews with the farmers (45 pages) and the sectoral experts (69 pages). The methodological approach used for this thesis is the Grounded Theory which is an inductive research style for qualitative research that aims to understand and explore *social reality* to facilitate the generation of hypothesis and theories. According to this methodological approach, the importance of certain aspects of the study subject emerges during the research process which is not implicitly defined or postulated in advance by a commitment of a hypothesis. Thus, instead of verifying or falsifying a given theory, it rather aims to develop and generate a hypotheses which is ´grounded´ in the data and therefore undergoes constant changes and modification during the research process (Dilger 2000).

Afterwards, all written documents were imported to the computer program Maxqda, which is considered to be one of the most popular ´computer assisted qualitative data analysis´ (CAQDAS) tool for scientific qualitative research. Maxqda helped to support the organisation and structure of the text-based material, to reduce the complexity of the material and to identify a direction and trend of the saying (Kus Saillard 2011). It furthermore supported the analysis of qualitative data according to the grounded theory through coding and conceptualisation of interviews data, representation and the foundation of the grounded theory (Glaser 2004a). Thus, the written transcripts were categorised during a coding process which included the development of certain categories and sub-categories, along which the interviews were analysed. A coding process categorises data in terms of research questions and helps to understand the meaning of the text based material. It helps to organise and reduce the interviews to the most important statements, beliefs, opinions, differences or similarities of the interviewees to certain questions and topics which helps to develop an analytical structure. The coding process itself was done manually by line-to line coding which did not follow a linear path but was rather tentative and open, as new categories or subcategories were developed, initial codes extended or deleted and sub-categories merged together with others. Line by line coding forces the analyst to verify and ensure the grounding of the developed categories. Interview sections which did not address relevant issues and were considered unimportant regarding research questions were not encoded and therefore left out (selective coding) in the further analysis (Glaser 2004). Also ´memos´ were taken down during the coding process which allowed for understanding and reconstructing the formation of categories and subcategories. Memos are theoretical notes and reflective commentaries about certain aspects of the data that help for a deeper analysis and a conceptual connections between the categories (Glaser 2004). This data linking process helped to connect relevant data segments and to identify cluster or networks of information (Flick 2009). This way of categorizing, sorting, reviewing and revisions are important steps to ensure internal integration among all categories and to provide theoretical completeness (Glaser 2004). The final codes merged into certain themes (e.g. adaptations strategies) and were exported to *Excel* in the end of the coding process to facilitate further analysis. To seek meaning from the data, a manifest content analysis was done following the methodological approach proposed by Mayring (2004) which analyses the interviews mainly in relation to categories rather than to case studies (Flick 2009). Therefore, tables with 3 columns were developed to allow an overview and visualisation of the content. For reasons of confidentiality and for matter of convenience, a numbering system was established in which each interview partner of the qualitative survey was numbered from IP1 to IP37. The 'Quote' column refers to an important quote of the interview partner while the ´Generalisation´ column summarizes the most important statements for a quicker overview.

**Table 4: Table structure of qualitative interviews as found in Annex B and C**
(Own representation)

| IP | Quote | Generalisation |
| --- | --- | --- |
| IP5 | -What I can say from my life experience is that we are not getting in the last 10 to 15 years is long sustained periods of rain. Having growing up here, we got here 4 to 5 days rain when I was a child, but we very rarely get a rain event that lasts more for 12 hours nowadays. That is for me the biggest difference. | -Less sustained rain |

The online survey with farmers was conducted with SoGo survey, an online platform for quantitative research (SoGo Survey 2017). After buying a license, questions and answer options were entered online into the system allowing participants of the study to choose between different answers or in some cases to choose between multiple answers. The results of each single questionnaire were saved online while a notification about complementation was sent to the author of this study. As all answers were categorised automatically by the program, results could be viewed online with different opportunities for data editing and visualisation.

### 4.3.4. Ethical Consideration

Prior to the interviews, each interview partner was asked for permission to audio-record the interview with the numbering systems preserving certain anonymity. Additionally, following the aim of this study, an application oriented summary of this doctoral thesis will be sent after completion via E-Mail to all interview partners (Annex E).

The following chapter summarizes the results of this study.

# 5. Empirical Results

In this chapter, the results of this study are presented in a descriptive way following the methodology explained in the fourth chapter. The first part starts with the conducted climate analysis for the study area which is subdivided into two parts: a historical climate analysis for the last 114 years (1900-2014) and future climate scenarios up to 2099 for the study area. The chapter continues with the results from the conducted interviews – both the quantitative online survey as well as the qualitative face to face interviews with farmers in the catchment and is followed by the results from the sectoral expert interviews. The statements from the interview partners are presented in a number of tables grouped along the classification system and the coding process with Maxqda (chapter 4) and can be found in Annex B (for farmers) and Annex C (for sectoral experts).

## 5.1. Climate Analysis

The following two sub-chapters present the results from historical climate analysis and climate projections for the study area.

### 5.1.1. Historical Climate Analysis

The following figures shows the mean, annual mean minimum and annual mean maximum air temperature of the Corangamite catchment between 1900 and 2014 based on SILO data. Between the beginning of the century and 1950, a decrease in mean and maximum temperatures can be observed, while the minimum temperatures were relatively stable. After 1950, an increase in mean, minimum and maximum temperatures can be observed. On average, mean and annual mean maximum temperatures are higher at Mt Hesse than for the whole area of the catchment, although the annual mean minimum temperature is higher for the catchment up till the 1980s. In terms of annual mean precipitation between 1900 and 2014, there is a slight increase in precipitation since the beginning of the last century and a slight decrease since about the 1970s. The average amount of rainfall in the catchment lies above the rainfall at the Mt Hesse farm (725 mm for the catchment and 559 mm for Mt Hesse). The mean annual rainfall at Mt Hesse from the SILO dataset was 15 mm higher than the measured rainfall data at Mt Hesse (574 mm) between 1900 and 2014.

**Historical temperature and precipitation development between 1900 to 2014**

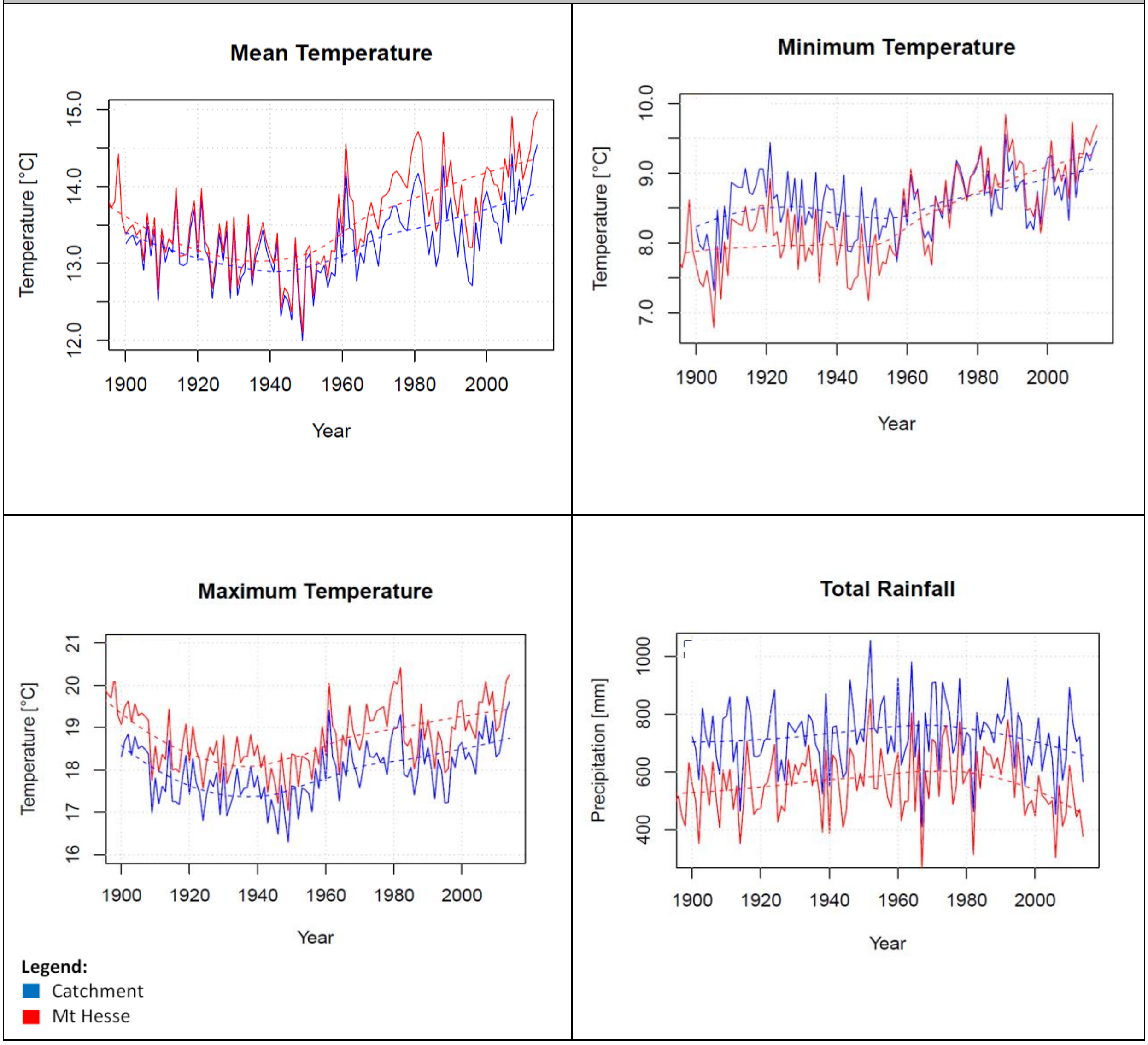



**Figure 23: Average annual mean (top left), minimum (top right), maximum temperature (bottom left), and precipitation (bottom right) between 1900-2014 with smoothing line for the catchment (blue) and Mt Hesse (red)**

Figure 24 shows the development in the number of cold days per year (below 5°C) and the number of hot days per year (above 30°C) between 1900 to 2014 for the whole area of the catchment including Mt Hesse. On average, 14.7 days per year were above 30°C (N=1692 days) and 57.5 days per year were below 5°C (N=6615 days) between 1900 to 2014.

**Development of hot and cold days between 1900-2014**

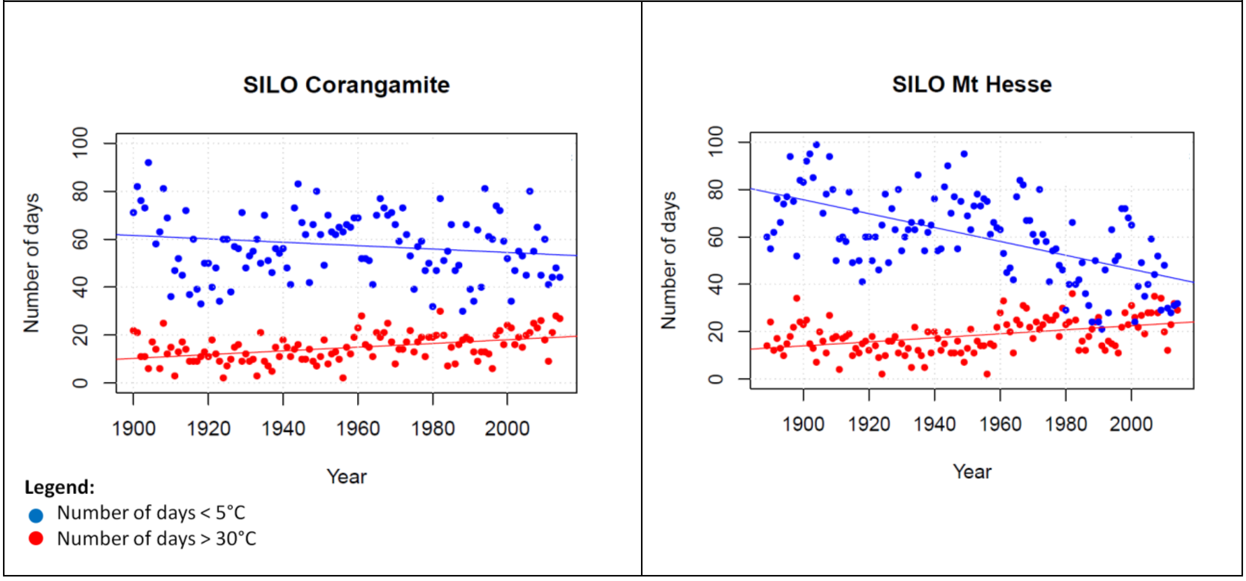



**Figure 24: Development of cold (blue) and hot (red) days for the Corangamite catchment (left) and Mt Hesse (right)**

Table 5 shows the values for the trending line slope, the confidence intervals, the p-value and the coefficient of determination ($R^2$) for the development of cold and hot days in the catchment and at Mt Hesse. The trend (slope) indicates if there is a linear relationship between the predictor and predicted variables (here the predictor x is *time*, and the predicted variable y is *number of hot/cold days*). The confidence intervals (CIs) estimate the degree of uncertainty associated with the trend line and indicates the lower (2.5 %) and upper (97. 5 %) estimate of the slope. The confidence level sets the boundaries of the confidence interval and is set at 95 %, i.e. there is only a 5 % probability that an identified time trend is observed purely by random chance (StatsDirect 2017; Lai 2010). Additionally, the presented p-value summarises the significance of the slope or time trend. The p-values test the null hypothesis that the coefficient is equal to zero. If the p-value is below the chosen significance level, the null hypothesis is rejected (here the significance level of α =5 % has been used). To indicate the strength of the evidence, the following categories are commonly used: $p > 0.05$ means there is no evidence against the null hypothesis, $p < 0.05$ means there is moderate evidence against the null hypothesis in favour of the alternative hypothesis and if $p < 0.001$ (less than one in a thousand chance of being wrong) there is strong evidence against the null hypothesis. The $R^2$ value shows the proportion of variation in the dependent variable explained by the statistical model (i.e. in this case the fraction of variation associated with the time trend) (Lai 2010).

The estimated value of the slope is positive for hot days and negative for cold days per year in the catchment that includes Mt Hesse (days/year) (Table 5). The time trend is significant for hot days at the Corangamite catchment and for cold days at Mt Hesse, however no significant trend in cold days at Corangamite were identified. The explained fraction of variance ranges between 0.03 and 0.34 which indicates that time can only explain some of the variability of trends in hot and cold days over time with fluctuations being influenced by many climate drivers (see chapter 2.1).

**Table 5: The estimated trend line slope, confidence intervals, p-value and $R^2$ using linear regression from 1900 to 2014 for cold and hot days in the catchment and for Mt Hesse (N=114)**

| | Slope | CIs | p-value | $R^2$ |
|---|---|---|---|---|
| **Corangamite** | | | | |
| **Cold days** | -0.07 | 2.5 % CI:-0.15<br>97.5 %:6.43 | 0.07 | 0.34 |
| **Hot days** | 0.08 | 2.5 % CI: 0.05<br>97.5 % CI: 0.11 | < 0.05 | 0.18 |
| **Mt Hesse** | | | | |
| **Cold days** | -0.3 | 2.5 % CI: -0.37<br>97.5 % CI: -0.22 | < 0.05 | 0.03 |
| **Hot days** | 0.09 | 2.5 % CI: 0.05<br>97.5 % CI: 0.12 | < 0.05 | 0.19 |

Figure 25 present the seasonal (autumn, spring, summer and winter) minimum and maximum temperature anomaly from 1900 to 2014 in the Corangamite catchment and for Mt Hesse, based on the reference time period from 1961 to 1990. The red bars show above temperature deviations and the blue bars below temperature deviation from the 30-years mean period.

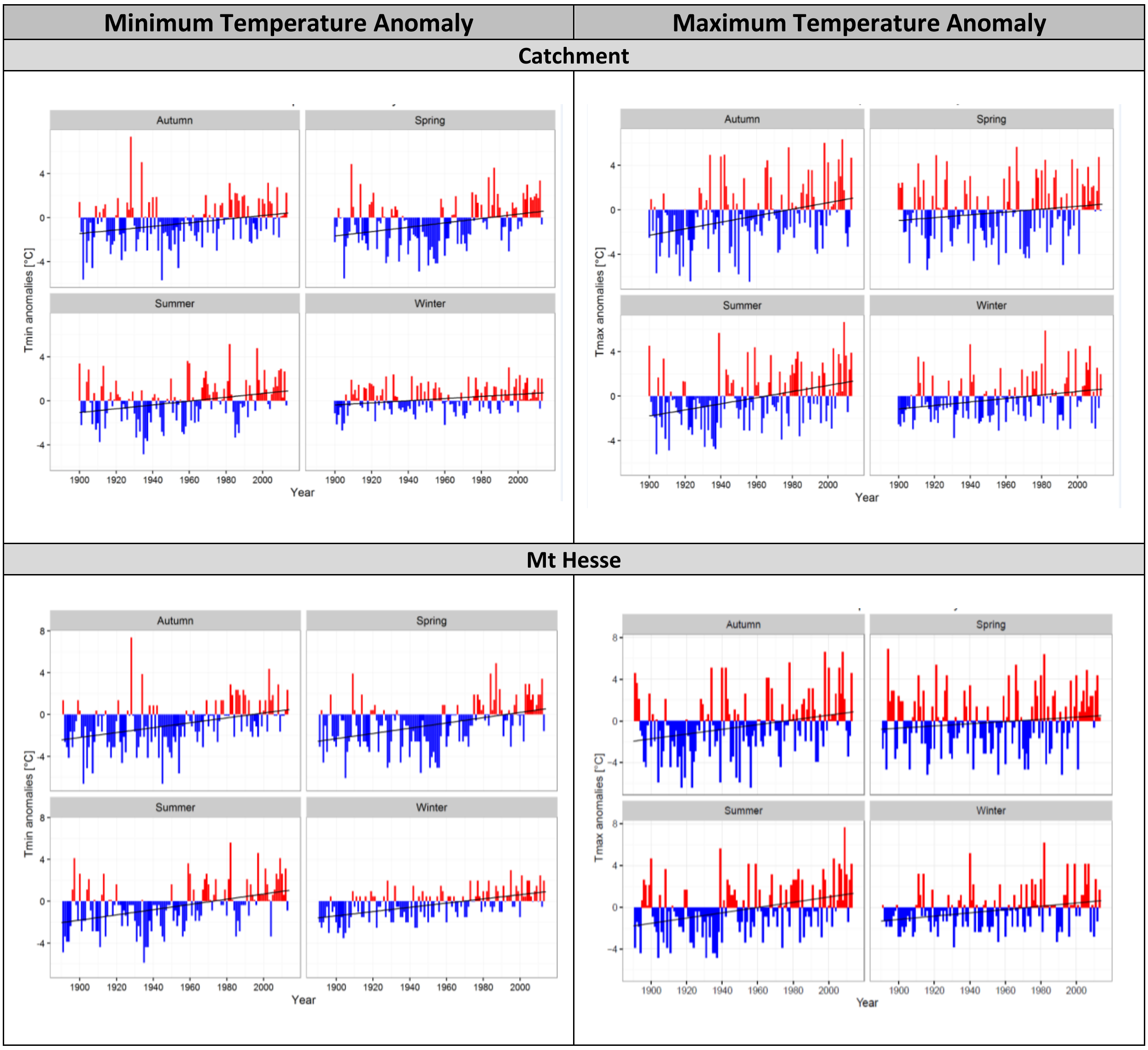



**Figure 25: Seasonal minimum (left) and maximum (right) temperature anomaly for the catchment (top) and the Mt Hesse farm (bottom) with regression line**

Table 6 indicates some differences between the catchment area and the Mt Hesse farm as well as differences between the four seasons. The estimated value of the slope is positive for all seasonal anomalies for minimum and maximum temperature in the catchment and at Mt Hesse (°C/per year). The time trend is significant for seasonal minimum and maximum temperature anomalies except for spring's maximum temperature for the catchment and at Mt Hesse. The explained fraction of variance ranges between 0.02 and 0.27, indicating that time can only explain little variability in seasonal minimum and maximum temperature anomalies over time as annual fluctuations over the last century were influenced by many climate drivers, including ENSO (see chapter 2.1).

**Table 6: The estimated trend line slope, confidence intervals, p-value and $R^2$ using linear regression from 1900 to 2014 for seasonal minimum and maximum temperature anomaly in the catchment and for Mt Hesse (N=456)**

| | Slope | CIs | p-Value | $R^2$ |
|---|---|---|---|---|
| **Catchment minimum temperature** | | | | |
| **Autumn** | 0.02 | 2.5 % CI: 0.01<br>97.5 % CI: 0.03 | < 0.05 | 0.08 |
| **Spring** | 0.02 | 2.5 % CI: 0.01<br>97.5 % CI: 0.03 | < 0.05 | 0.11 |
| **Summer** | 0.02 | 2.5 % CI: 0.01<br>97.5 % CI: 0.03 | < 0.05 | 0.09 |
| **Winter** | 0.01 | 2.5 % CI: 0.01<br>97.5 % CI: 0.02 | < 0.05 | 0.07 |
| **Catchment maximum temperature** | | | | |
| **Autumn** | 0.03 | 2.5 % CI: 0.01<br>97.5 % CI: 0.03 | < 0.05 | 0.12 |
| **Spring** | 0.01 | 2.5 % CI: -0.001<br>97.5 % CI: 0.03 | 0.08 | 0.03 |
| **Summer** | 0.03 | 2.5 % CI: 0.01<br>97.5 % CI: 0.04 | < 0.05 | 0.13 |
| **Winter** | 0.02 | 2.5 % CI: 0.01<br>97.5 % CI: 0.03 | < 0.05 | 0.07 |
| **Mt Hesse minimum temperature** | | | | |
| **Autumn** | 0.02 | 2.5 % CI: 0.01<br>97.5 % CI: 0.03 | < 0.05 | 0.15 |
| **Spring** | 0.03 | 2.5 % CI: 0.02<br>97.5 % CI: 0.04 | < 0.05 | 0.18 |
| **Summer** | 0.03 | 2.5 % CI: 0.02<br>97.5 % CI: 0.04 | < 0.05 | 0.18 |
| **Winter** | 0.02 | 2.5 % CI: 0.01<br>97.5 % CI: 0.03 | < 0.05 | 0.27 |
| **Mt Hesse maximum temperature** | | | | |
| **Autumn** | 0.02 | 2.5 % CI: 0.01<br>97.5% CI: 0.04 | < 0.05 | 0.08 |
| **Spring** | 0.01 | 2.5 % CI: -0.002<br>97.5% CI: 0.02 | 0.11 | 0.02 |
| **Summer** | 0.03 | 2.5 % CI: 0.01<br>97.5 % CI: 0.04 | < 0.05 | 0.1 |
| **Winter** | 0.02 | 2.5 % CI: 0.01<br>97.5 % CI: 0.02 | < 0.05 | 0.09 |

The following figures show the seasonal anomaly for precipitation from 1900 to 2014 for all four seasons, based on the time period from 1961 to 1990 for the Corangamite catchment and for Mt Hesse.

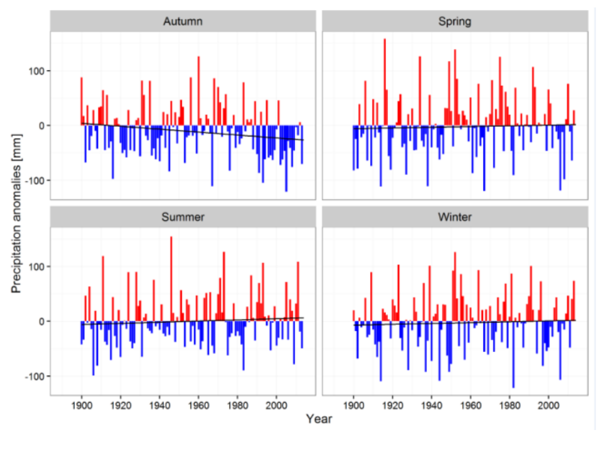
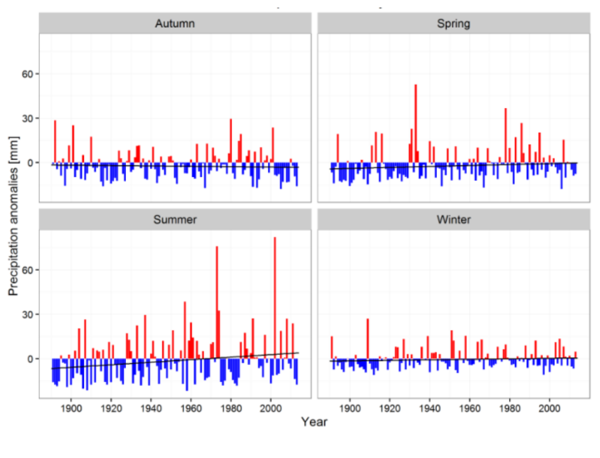
| Precipitation Anomaly | |
|---|---|
| **Catchment** | **Mt Hesse** |
|  |  |





**Figure 26: Precipitation anomaly for the catchment (left) and the Mt Hesse farm (right) with regression line**

The time trends are significant for autumn rainfall in the Corangamite catchment and summer rainfall at Mt Hesse, but not significant for seasonal precipitation anomalies in other seasons. The explained fraction of variance ranges between 0.01 and 0.04, indicating that the variability of seasonal precipitation anomalies is primarily explained by other climate drivers (see chapter 2.1).

**Table 7: The estimated trend line slope, confidence intervals, p-value and $R^2$ using linear regression from 1900 to 2014 for seasonal rainfall anomaly in the catchment and for Mt Hesse (N=456)**

| | Slope | CIs | p-Value | $R^2$ |
|---|---|---|---|---|
| | | **Catchment precipitation** | | |
| **Autumn** | -0.03 | 2.5 % CI: -0.53<br>97.5 % CI: < 0.01 | 0.04 | 0.03 |
| **Spring** | 0.06 | 2.5 % CI: -0.25<br>97.5 % CI: 0.38 | 0.69 | 0.01 |
| **Summer** | 0.12 | 2.5 % CI: -0.16<br>97.5 % CI: 0.38 | 0.44 | 0.01 |
| **Winter** | 0.08 | 2.5 % CI: -0.21<br>97.5 % CI: 0.36 | 0.6 | 0.01 |
| | | **Mt Hesse precipitation** | | |
| **Autumn** | -0.01 | 2.5 % CI: -0.06<br>97.5 % CI: 0.04 | 0.67 | 0.01 |
| **Spring** | 0.02 | 2.5 % CI: -0.03<br>97.5 % CI: 0.08 | 0.39 | 0.01 |
| **Summer** | 0.09 | 2.5 % CI: < 0.01<br>97.5 % CI: 0.17 | 0.04 | 0.04 |
| **Winter** | 0.01 | 2.5 % CI: -0.02<br>97.5 % CI: 0.05 | 0.39 | 0.01 |

### 5.1.2. Climate Projections

Scenarios are used by decision makers and planers to analyse possible developments whose outcomes are uncertain. In the climate science, emission scenarios are used to explore how much humans might contribute to future climate change, considering uncertainties such as population growth, economic development or development of new technologies. The purpose of scenarios is not to predict the future, but rather to explore both implications of different plausible futures such as possible developments of temperature or precipitation. Thus, projections provide information about the likelihood that something will happen in the future if certain influential conditions develop and represent possible ways in which the future may unfold. In order to calculate and analyse how global human activities could affect the climate system, factors such as greenhouse gas concentrations, changes in land use or pollution are inserted into climate models. These developments depend on future social and economic developments, including economic growth, innovation/technological changes, population growth or urbanization which can be estimated (Bjørnæs 2016). The four different RCPs 2.6, 4.5., 6.0 and 8.5 are consistent with certain socio-economic assumptions in the future and briefly presented in the following (Bjørnæs 2016).

The **RCP 2.6 represents the low emissions scenario**, developed by the PBL Netherlands Environmental Assessment Agency. Radiative forcing decreased by year 2100 and requires ambitious reductions in greenhouse gas emissions over time. According to Bjørnæs (2016), the future would require:

- Declining use of oil
- Low energy intensity
- A world population of 9 billion by year 2100
- Use of croplands increase due to bio-production
- More intensive animal husbandry
- Methane emissions reduced by 40 per cent
- $CO_2$ emissions stay at today's level until 2020, then decline and become negative in 2100
- $CO_2$ concentrations peak around 2050, followed by a modest decline to around 400 ppm by 2100

The **RCP 4.5 represents the intermediate emissions scenario**, developed by the Pacific North West National Laboratory in the United States. This scenario assumes that radiative forcing is stabilised shortly after year 2100, consistent with a future with relatively ambitious emissions reductions. According to Bjørnæs (2016), this future is consistent with:

- Lower energy intensity
- Strong reforestation programmes
- Decreasing use of croplands and grasslands due to yield increases and dietary changes
- Stringent climate policies
- Stable methane emissions

- $CO_2$ emissions increase only slightly before decline commences around 2040

The **RCP 6.0 represents the intermediate emissions scenario** and was developed by the National Institute for Environmental Studies in Japan. Also this scenario assumes that radiative forcing is stabilised shortly after year 2100, which is also consistent with the application of strategies and technologies for reducing greenhouse gas emissions. According to Bjørnæs (2016), this future is consistent with:

- Heavy reliance on fossil fuels
- Intermediate energy intensity
- Increasing use of croplands and declining use of grasslands
- Stable methane emissions
- $CO_2$ emissions peak in 2060 at 75 per cent above today's levels, then decline to 25 per cent above today

The **RCP 8.5 represents the high emissions scenario**, developed by the International Institute for Applied System Analysis in Austria. It is consistent with a future of no policy changes to reduce emissions and increasing greenhouse gas emissions that lead to high concentrations over time. According to Bjørnæs (2016), this future is consistent with:

- Three times today's $CO_2$ emissions by 2100
- Rapid increase in methane emissions
- Increased use of croplands and grassland which is driven by an increase in population
- A world population of 12 billion by 2100
- Lower rate of technology development
- Heavy reliance on fossil fuels
- High energy intensity
- No implementation of climate policies RCP 6

The time trends are significant for all four RCP scenarios, estimating a further increase in temperature up to the end of the century. Only RCP 2.6 simulates a slight decrease in temperature from about 2080 as this scenario assumes a reduction in methane and $CO_2$ emissions in the course of this century. The high emission scenario RCP 8.5 suggests the highest increase in temperature of about 3°C up to the end of this century. The explained fraction of variance ranges between 0.08 and 0.74, indicating that time can increasingly explain estimated developments in temperature with higher scenarios.

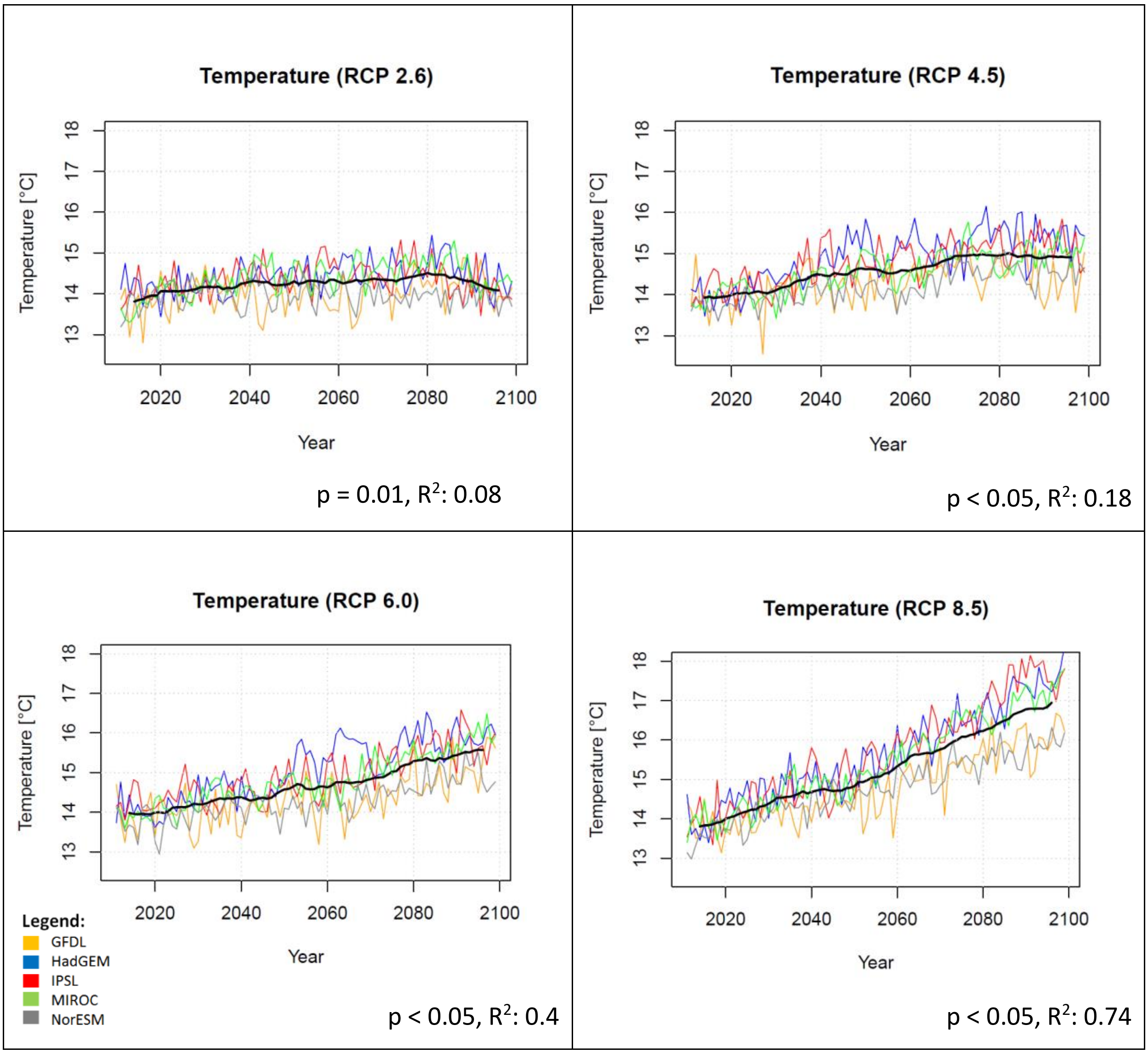



**Figure 27: Scenarios for temperature development (in °C) for the RCP 2.6/4.5/6.0/8.5 showing a 7-year smoothing average line and values for regression trend (N=84)**

The time trends are not significant for RCP 2.6 and RCP 4.5 for precipitation scenarios. However, the time trend shows moderate evidence for RCP 6.0 and RCP 8.5, suggesting an average precipitation decline by end of this century. The explained fraction of variance ranges between 0.01 and 0.04, indicating that the projected variability of precipitation may be primarily explained by other climate drivers (see chapter 2.1).

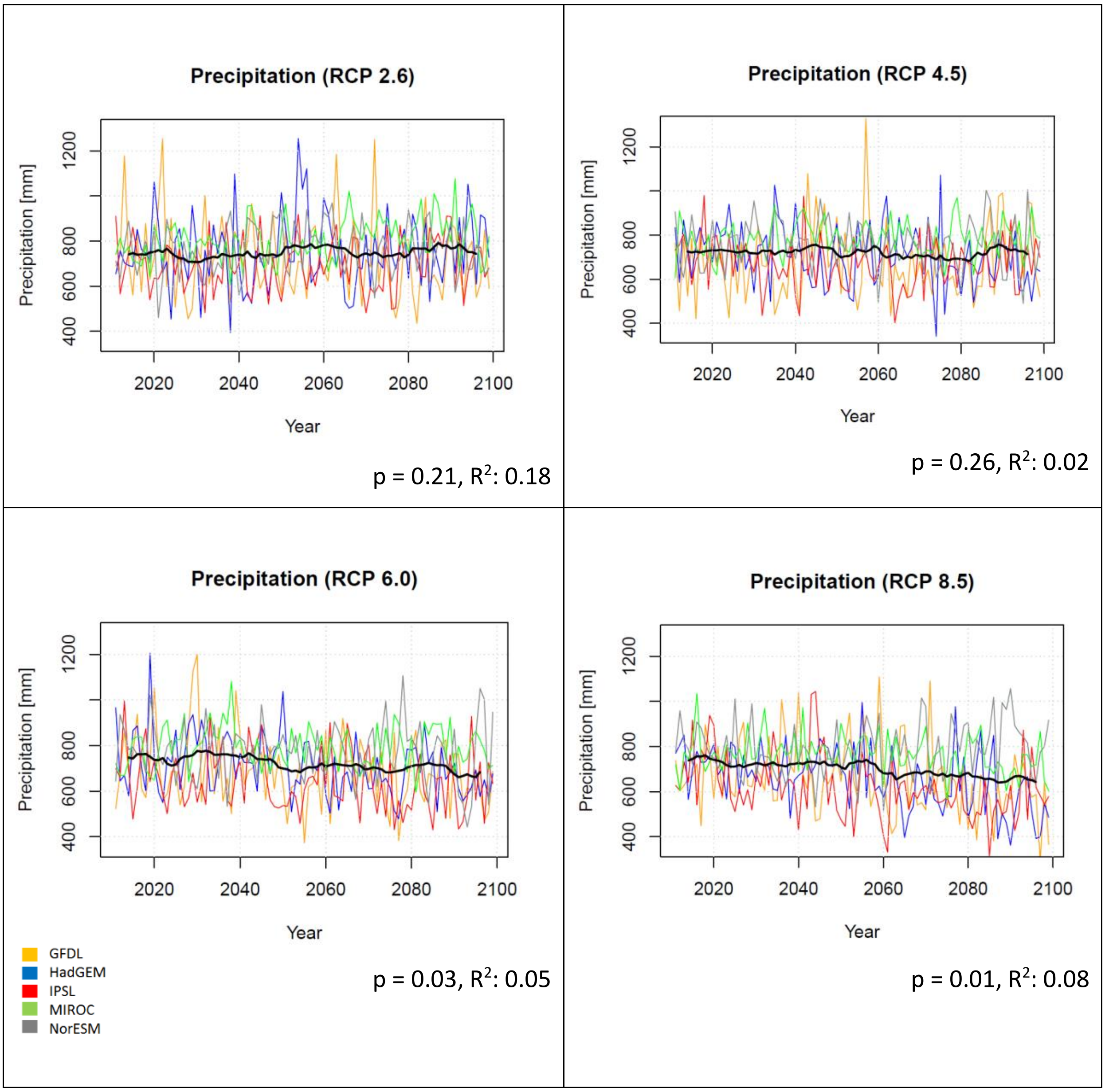



**Figure 28: Scenarios for total precipitation development (in mm) for the RCP 2.6/4.5/6.0/8.5 showing a 7-year average line and values for regression trend (N=84)**

Summarizing, ISIMIP climate projections suggest a further increase in temperature depending on the socio-economic developments and emission pathways with high fluctuating precipitation pattern, suggesting a decrease a rainfall for intermediate and high emission scenarios. However, users of climate change projections data outputs are encouraged to consider the limitations of different approaches when interpreting model outputs. Modelling climate change projection go always along with uncertainties or errors which can be propagated from the underlying climate data, GCM models, spatial downscaling (for a coarse to finer grid) or also temporal downscaling (from monthly to daily). Thus, scenarios may under- or overestimate the effect of climate change. Nevertheless they might contribute to show different possible pathways that can support decision-makers (Burgess et al. 2012).

## 5.2. Qualitative Interviews with Farmers

13 qualitative interviews with farmers were conducted to explore insights into farmers perceptions of climate related risks and associated management strategies. The interviews were encoded into several categories and statements organized along tables which can be found in Annex B. The following part presents a summary of all categories, supported by statements of the interviewed farmers including a) observed changes in climatic and growing season pattern as well as water availability, b) farmers view on climate change and c) employed farm management strategies. The last table summarizes the most important results to provide a better overview.

**Observed changes in climate**

Although most interview partners found it hard to detect longer term changes in rainfall due to its high spatial and temporal variability, the majority of farmers perceived certain changes in rainfall pattern. These included a general decrease in the amount of rainfall and a change in timing of rainfall events for the last two decades coming along with impacts on surface water, more extremes and shorter rainfall events/less rainy days and drier or failed springs in the last years coming along with negative business effects [IP1-12]. Also the cycle of droughts were perceived to become more frequent [IP1;3;4;5;9;11], autumn breaks were perceived to get more unreliable or started later and some farmers perceived slightly more summer rainfall [IP1;4;9]. However, farmers found that the general drying also offered new opportunities as cropping got more viable in south-west Victoria while less water logging improved access to land [IP2;4-11].

Consulting farmers about changes in temperature, the answers were not as clear as perceived changes for precipitation. IP4;6;7;8;11 were unsure about changes due to the general high variability of temperature or found other explanations such as differences in people´s sensations, age or similarities which made it harder to detect long-term trends. However, perceived changes in temperature included longer and earlier heat waves/extremes [IP1;2;3;5;8;9;12], a general increase in air temperature [IP1;5;9], milder winter [IP2;6;10] and fewer frozen puddles during winter time [IP3].

**Change of the growing season**

The growing season is crucial for crops during the winter period, starting with the autumn break around May/June which is the first significant rainfall event in the season (Pook et al. 2009).

According to the interview partners, changes in the growing season were numerous. Almost all farmers perceived a general shift of the growing season with flowering times starting about 3-6 weeks earlier on average in comparison to 30 years ago [IP1-10;12;13]. This means more unreliable, earlier or quicker springs at the end of the season [IP1;3;4;5;6;7;9;12] with a tendency of autumn breaks starting later [IP1;6;7;12] and thus a general shortening of the growing season [IP7;9;12] that brings along massive consequences for cropping and animals production [IP3;8;10]. IP11 did not perceive any changes in the growing season.

**Water supply**

Farmers were also interviewed about water supply and possible changes in water availability. Although water shortages are a common issue in Australia [IP1], several farmers observed a trend in decreasing surface water, including draining dams, creeks and swamps and higher evaporation rates due to higher temperatures and changing precipitation pattern [IP1;4;5;8;10]. Two farmers noticed a decrease in groundwater in their farm areas [IP3;4]. Problems were seen around unauthorised water pumping without licence, leaking water infrastructure and increasing water pollution from fertilizers [IP1;5;8;9]. Most farmers in the Corangamite catchment rely on bore water for their farm [IP1;3;9;10;12], others use town water as additional backups [IP6;8] while domestic roof water is mostly used for gardening [IP10;12].

**General view on climate change and impacts**

Farmers were also asked about their own view on climate change. The received answers were quite diverse: some farmers were deeply concerned about human induced climate change, impacts, the pace of changes and consequences for future generations [IP1;2;9;12], others contributed changes in climate to natural variability and were uncertain about human influences on the climate system [IP2;3;6;9;10]. IP9 summarized: “It is a worry. I think it is obvious that climate is changing. I am not convinced to which degree mankind is causing that”. A common argument *against* human-induced climate change was that climate has always changed in history and extremes have always been there as well [IP3;4] while another farmers found evidence against a warming atmosphere: “[…] when I went to glaciers in New Zealand it was actually growing” [IP2]. Two farmers felt that the perception of increasing extreme events can also be traced back on more reporting of the media [IP2;4]. Farmers also mentioned that climate change is a big industry, creating jobs for many people including researchers [IP4;5]. One farmer also added a lack of understanding the science of climate change which makes it harder to understand its implications [IP6]. Other farmers focused more on new opportunities from climate change such as improved cropping options and access to land while higher temperatures were considered positive for plant growth and for the study area [IP5;7;9]. Despite perceived differences regarding the reasons for observed changes in climate, main challenges were seen around changing seasonal pattern such as shorter growing seasons to finish lambs, earlier heat days, lack of water resources affecting animal, crops, pasture production and more variable financial farm outcomes [IP1;2;3;4;6;7;8;10;11;12]. Additionally, increasing costs of farm inputs in keeping the farm business running [IP2;4;8;10;13], unreliable seasonal forecast and increased planning uncertainty were seen as challenging under perceived increasing climate variability [IP2;4;8;10;13].

**Crop and Soil management**

In addressing more unreliable springs and to pick up more winter rain, many farmers were sowing earlier due to improved weed control [IP4;6;8;9,10]. Some farmers also changed crop types and varieties to changing precipitation and temperature patterns to address seasonal risks and improve production [IP5;6;13]. Sustainable soil management played an important role for most farmers in the Corangamite catchment [IP1-13]. The majority of farmers made use of soil conservations methods, which included no ploughing, minimal tillage or direct drilling to avoid wasting soil moisture and to encourage the grass roots to grow down deeper to access moisture further in the soil [IP1;3;4;6;7;12]. Farmers also indicated to stock off sheep in time and keep at least 80 % ground cover to avoid wind erosion [IP1;3;9;11]. Another strategy to avoid wind erosion was Landcare planting which also provided shelter for animals [IP2;8]. Controlled traffic was used to avoid soils compaction [IP3;4;5]. Besides, using chemical fertilizers, rotational shifts of pigs [IP5] and use of chicken manure [IP8] were mentioned to help with fertilizing the soils. Raised beds were also used by some farmers to address wet seasons [IP3;4;12].

**Livestock and Pasture management**

Many farmers changed from autumn to spring lambing in the last decades due to more unreliable springs, a drier climate, better feed usage and nutrition issues to minimize the chance of feeding animals supplementary or in order to avoid worms during winter time [IP1;3;4;5;7;10;12]. Changes in shearing times however were attributed to logistically and commercial reasons such as the best time for finding shearers rather than to climatic reasons [IP3;11]. To address seasonal changes and to ensure pasture availability for the animals, many farmers introduced more deep rooted perennials which are more drought tolerant such as phalaris and fescues [IP3;6;8;10;11;13] or changed varieties of grazing species to increase production [IP3;5;6;11;12]. Some farmers introduced summer active crops to make use of more summer rainfall such as Lucerne [IP1;6;8;13] or native pastures with higher tolerance ranges of heat [IP5;8;10], as well as making use of rotational grazing [IP3;5;7;12] or shorter season varieties [IP3]. IP4 mentioned to use mechanical weed control rather than chemical. IP5 made use of a sophisticated New Zealand system in terms of the feed growth cycle, working out carrying capacity along a feed budget plan.

**Table 8: Management strategies of farmers to deal with perceived changes in climate**
(Own representation based on interviews with farmers)

| Management Strategies of Farmers |
|---|
| **Cropping & Soils** |
| • Earlier sowing to address more unreliable springs & to pick up more winter rainfall<br>• Changes of types and varieties with higher production rates and better handling of drier times<br>• Improved weed control or using mechanical rather than chemical weed control<br>• Stock off animals in time to keep at least 80 % ground cover to avoid wind erosion<br>• Soil conservation methods: no ploughing, minimal tillage or direct drilling to avoid wasting soil moisture and to encourage the roots to better access soil moisture, controlled traffic to avoid soils compaction<br>• Rotational farm systems<br>• Raised beds to better control water run off during wetter times |
| **Livestock & Pastures** |
| • Change from autumn to spring lambing to address more unreliable springs, a drier climate, for better feed usage and nutrition issues, to minimize the chance to feed them supplementary or to avoid worms during winter time<br>• Combine farming systems with Landcare which also provides shelter for animals<br>• Change in varieties of grazing species to increase production and use species that better handle heat & use of shorter season varieties<br>• Use of deep rooted perennials which are more drought tolerant such as phalaris or fescues<br>• Introduction of summer active crops to make use of more summer rainfall such as using Lucerne or native pastures with higher heat tolerance range<br>• Improved pasture management in terms of the feed growth cycle to work out carrying capacity along a feed budget plan<br>• Rotational grazing system |

## 5.3. Quantitative Survey with Farmers

To reach more farmers in the Corangamite catchment beside the conducted qualitative face-to-face interviews, a quantitative online study was conducted. The following section shows the results from the survey (N=300, n=40). The survey contained 51 questions, based on the following themes a) demographic items and business structure, such as age, sex, farm size, type of agricultural production, b) perception of climate related changes and associated impacts c) employed adaptation strategies. The complete questionnaire can be found in Annex D.

The majority (80 %) of the respondents were male, with 75 % being between 55 and 74 years old. The majority of the respondents (77.5 %) also indicated to own the farm while only the minority partially owned it (10 %), worked as employees (5 %) or leased the farm (2.5 %). Three quarters of the population (75 %) either worked more than 30 years or more on the farm while 32 % of the respondents worked less than 30 years on the farm. The average farm size in the study area was found between 100 and 1000 ha (72.5 %) with 20 % of farmers working on larger farms between 1000 to 4000 ha.

Farmers were initially asked to rate their perceived climate change risk for their farm business on a scale from 0 (not concerned) to 9 (maximum concerned). The results show that that the perceived risk varied between 4 (medium concerned = 22.86 %) and 9 (maximum concerned = 11.43 %) with no farmers indicating 0 (not concerned = 0 %).

Participants were also asked about extreme weather events. In terms of extreme rain fall events, 47.5 % stated to have been affected in the last 15 years, while 40 % of the interviewees perceived that heavy rainfall events decreased and only 2.5 % stated that heavy rainfall events increased. In relation to droughts, 75 % of the participants have been affected from an extreme drought in the last 15 years in which more than half of the farmers perceived that the frequency (55 %) and the duration of droughts (37.5 %) increased. Nobody agreed that the frequency or duration of droughts decreased. The majority (62.5 %) did not perceive a change in frost frequency while 32.5 % did. However, a quarter of the farmers (25 %) felt a decrease in frost frequency while 7.5 % stated that frost events had increased. 75 % of the interviewees had not been affected from floods in the last 15 years while 22.5 % had. In terms of changes in winter season rainfall, the majority (85 %) perceived a change of which 45 % observed a slight decrease and 35 % a significant decrease. Only 5 % observed a slight increase, but no one perceived a significant increase in winter rainfall. The answer is even more obvious for a change in spring season rainfall where 90 % stated that they perceived a change of which 32.5 % observed a slight decrease and 52.5 % a significant decrease. Only 5 % perceived a slight increase and no one indicated a significant increase of spring season rainfall.

Almost two-thirds (60 %) of the participants perceived a change in the winter temperature of which 40 % stated a slight increase while 20 % described a slight decrease. Asking for summer temperatures, 52.5 % did not notice a change while 42.5 % did of which 30 % observed a slight increase and 12.5 % a significant increase.

Regarding the autumn break or the start of the local wet season in south-east Australia (Murphy and Timbal 2008), the interviewees were divided as half (50 %) noticed a change while 47.5 % did not. However, 25 % of the interviewees perceived that the autumn break tends to start later and comes along with less rainfall (22.5 %). In relation to changes in the growing season, the answers were quite heterogenic. 27.5 % did not perceive a change in the growing season, while 17.5 % noticed a slight decrease and 15 % perceived a slight increase. 22.5 % noted that the growing season started earlier in the season while 17.5 % stated the opposite. Only 10 % noticed new animal diseases while 27.5 % noticed new croppings/weeds in the last decade.

75 % of the respondants observed a decrease in water availability, 12.5 % did not observe any changes and only 2.5 % observed an increase in water availability. 10 % of the respondants observed a change in seasonal water supply. In terms of water quality, more than half of the respondants (55 %) could not detect a change in the water quality, although 32.5 % observed a decrease in water quality (e.g.higher salinization).

Asking for future expectations in climate development, a quarter (25 %) of the participants assumed that rain will decrease in future, with higher variability of precipitation patterns (65 %) and seasonal changes (30 %) coming along with more insecurity for planning (22.5 %). Regarding temperature, almost half (47.5 %) assumed an increase in temperature as well as seasonal shifts (45 %), more heatwaves (37.5 %) and increasing insecurity planning (35 %).

The participants of the survey were also asked to rate the statement that adaptating to climate change is important. 45 % fully agreed, 32.5 % agreed, 12.5 % were unsure and only 1.5 % partially agreed or disagreed.

70 % of the respondants indicated to stay informed about short to mid-term upcoming weather events within the next 3 months, while 22.5 % were not. The majority of farmers (75 %) took farm management decisions *before* or *during* droughts in response to the situation while 22.5 % additionaly developed and used a proper drought management plan.

In terms of on-farm management strategies, 65 % started adaptation strategies to perceived changing weather conditions. 57.5 % also gathered information to improve knowledge in terms of climate related risks, 52 % made use of improved soil and water conservation methods, 40 % used crop varieties with higher tolerance to weather extremes, 35 % managed decisions (e.g. stocking and de-stocking, time of sowing) based on climate prediction systems and 17.5 % made use of agricultural decision-support tools which helped in making climate-related decisions. The majority (75 %) also stated that sustainable pasture management played an important role on their farm. Half of the interviewees indicated the use of rotational grazing to meet animal requirements (50 %), fit stocking rates for improved pasture utilization (40 %) or increased soil fertility through fertilizer application (30 %). 42.5 % changed crop types in the last 15 years. Half of the participants (50 %) changed their lambing times within the last 30 years while 15 % did not. Common reasons to change lambing times were to maximise lamb survival (35 %), improve pasture availability (37.5 %) and ewe (female sheep) nutrition (35 %). Asking for lambing times *before* and *after* the last change, results indicate a change from lambing times mainly from April/May to June/July/August and September.

The last question aimed to explore farmers attitude regarding sustainability of farming under increasing climate variability. Only 7.5 % stated that an increase in climate variability would make farming in their region unsustainable, 45 % were unsure about this question and 42.5 % did not believe that farming would become unsustainable if climate variability increased in their region.

### 5.4. Qualitative Interviews with Sectoral Experts

Besides interviews with farmers in the catchment, 24 further qualitative interviews with sectoral experts from private, research and governmental institutions have been conducted. This was to gain more knowledge in terms of climate change related risks and impacts for the study area as well as to explore and discuss adaptation options and strategies for farmers to deal with a changing climate.

**Changes in weather patterns and longer term climate**

Sectoral experts were asked about Australia's and south-west Victoria's climate variability and change. According to IP15, Australia's climate is mostly influenced by natural variability derived from ENSO, IOD, and SAM. As the variability of rainfall is more inconstant in short distances than for temperature [IP14;17;25], it is easier to detect trends for temperature than for rainfall. However, at the same time it is much harder to say which changes in rainfall pattern can be attributed to human induced climate change in Australia [IP15;IP19;25]. The following changes in climate were mentioned by the interview partners: a general trend of increasing temperatures of about 1°C over the last century [IP17;19;21;23;25;26;27;37], especially in spring but also winter and summer [IP19;22;26] and an increase in the variation and frequency of temperature extremes (less cold extremes in winter and earlier days of high temperatures in spring) [IP14;15;23;24;25;26;27;35;37]. Furthermore, a general drying trend of south-west Victoria was identified in the last two decades [IP14;23;25]. This was due to changing rainfall patterns, more episodic/shorter intense rainfall events, longer dry periods [IP23;26;37] slight increases in summer rainfall and a decrease in spring and winter rainfall which is often ineffective for agriculture [IP21;35]. As a warmer atmosphere contains more water, the chance for heavy rainfall events can increase [IP14;17;26;37]. However, IP25 alluded to the fact, that definitions for extreme rainfall events are still rare which makes it harder to have clear evidence of increasing extreme rainfall events. Other changes that interview partners mentioned were a shift and a shortening in the growing season with longer summer and earlier/shorter springs [IP21;22;23;24;26;35]. Also an increase in the predominance of high pressure systems over winter and spring in South Australia was mentioned which was explained by the warming of the Oceans to the north of Australia. This measurable trend over the last 100 years very closely followed the average rise in temperature in the world, which triggered a decrease in rainfall for the study area [IP19;22]. Another reason for decreasing rainfall might come from the trend of shifting cold fronts southward and not eastward anymore [IP22]. Two interview partners were especially concerned about the rate of change compared to historical climate changes [IP30;32]. However, according to IP37 south-west Victoria remains a fairly stable environment compared to the rest of Australia.

Asking for potential changes in water availability, climate change was considered to aggravate existing water issues. Thus, as water stress might increase in future it might also affect water security in the study area [IP22;23;27,32]. Since south-west Victoria used to be a wet landscape in the past, interview partners assumed that more water regulations will come up to guarantee an equitable share of water when the resource becomes more constrained [IP20;22]. Some impacts mentioned were a quicker use of soil moisture due to higher temperatures [IP19], dropping catchment flow in parts of south-west Victoria [IP22], slower fill up of smaller dams and less runoff [IP22;27;35]. In some parts of Victoria, groundwater is already dropping [IP20;22] and people sometimes tap into ancient groundwater which is not a renewable source [IP20]. According to IP20&22, part of the challenge of south-west Victoria is that the water cycle is not well understood yet, especially the connectivity of groundwater within Victoria is still poorly understood. Thus, there is a push for farmers to connect to the domestic water grid, particularly for stock [IP20].

**Climate scenarios**

According to interviewed climate experts, south-west Victoria will face increasing temperatures in the future depending on the $CO_2$ levels [IP24;25;31], additional hot days over 40°C, seasonal changes with the onset of spring and summer coming earlier and a slight increase of midwinter temperatures [IP31]. Also a general decrease in spring and winter rainfall with no clear signals for summer and autumn rainfall were mentioned [IP20;21;24;25;27;31;32]. Higher temperatures might trigger dryer days and limit rainfall events while the southward shift of the ecological zones were considered as likely to continue even though impacts were considered to be more dramatic for northern Victoria than for south-west Victoria [IP20;35]. The following table summarizes what farmers (on the left hand side) and what sectoral experts (on the right hand side) indicated in terms of changes in rainfall, temperature and extreme events.

**Table 9: Farmers perceptions of changes in climate compared to statements of sectoral experts**
(Own representation based on interviews with farmers and sectoral experts)

| Farmers | Sectoral experts |
|---|---|
| **Rainfall & Water Availability** | |
| - Highly variable rainfall pattern which makes it hard to detect longer term trends<br>The following changes were perceived by farmers:<br>• Change in total amount and timing of rainfall, change in rainfall pattern: general decrease in the amount of rainfall with impacts on surface water<br>• More extremes and shorter rainfall events/less rainy days<br>• Drier or failed springs in the last years and therefore negative business effects<br>• Cycle of drier times/droughts are becoming more frequent<br>• Autumn breaks get more unreliable<br>• Slightly more summer rainfall<br>- Benefits: the general drying makes cropping more viable in south-west Victoria<br>The following changes in water supply were perceived by the farmers:<br>• Trend in decreasing surface water, including draining dams, creeks and swamps<br>• Decrease in groundwater in some areas<br>• Increase of water pollution | - Variability for rainfall much higher at short distances than for temperature which makes it harder to detect trends<br>The following changes in rainfall were indicated by the sectoral experts:<br>• A general drying trend of south-western Victoria in the last 2 decades due to changing rainfall pattern, such as more episodic, longer drier periods and short intense rainfall events which might be ineffective for agriculture<br>• Higher risk of heavy rainfall events due to warmer atmosphere, however definitions for extreme rainfall events are still rare which makes it harder to have a clear evidence in the increase of extreme rainfall<br>• Slight increase in summer rainfall and a decrease in spring and winter rainfall<br>• Climate change aggravates existing water issues, water stress likely to increase in future<br>• Water resources in south-west Victoria become more constraint, more water regulations likely to come up to guarantee an equitable share of water<br>• Drop of groundwater in some parts of Victoria, understanding water cycle in Victoria |

| | |
|---|---|
| | remains challenging |
| **Temperature** | |
| Farmers more unsure about temperature development than precipitation due to:<br>• High variability of temperature & differences in personal sensations due to an air and temperature regulating environment<br>Perceived changes in temperature included:<br>• More, longer and earlier heat waves/extremes<br>• Higher evaporation rates<br>• Milder winter<br>• Fewer frozen puddles during winter time | The following changes were indicated by the sectoral experts:<br>• Increasing temperatures of about 1°C over the last century, especially in spring but also winter and summer → trend more evident than a change in precipitation<br>• Increase in the variation and frequency of temperature extremes such as less cold extremes (in winter) and more and earlier heat days<br>• Increase of temperature can be attributed at least to 90 % to human activities<br>• Higher evaporation rates |
| **Growing season** | |
| The following changes in the growing season were perceived by the farmers:<br>• General shift of the growing season, e.g. flowering times have come forward by about 3-6 weeks in average compared to about 30 years ago<br>• More unreliable, earlier or quicker springs at the end of the season<br>• Autumn breaks tends to start later<br>• Due to later autumn breaks and earlier start of spring a general shortening of the growing season | The following changes were indicated by the sectoral experts:<br>• Shift in the growing season, flowering times have come forward by up to 6 weeks<br>• A shortening of the growing season due to more unreliable autumn breaks and earlier and shorter springs<br>• Longer summer |
| **Climate scenarios** | |
| The online survey revealed that farmers assumed the following developments in climate:<br>• Continuation of decreasing rainfall trend with higher variability of precipitation pattern and seasonal changes<br>• Further increase in temperature, seasonal shifts, more heatwaves<br>• More insecurity for planning | The sectoral experts indicated the following impacts of future climate scenarios for the study area:<br>• Increasing temperatures, depending on the $CO_2$ levels<br>• More hot days over 40°C<br>• The onset of spring and summer coming earlier<br>• Slight increase of midwinter temperatures<br>• Changing rainfall pattern such as rainfall decline in spring and winter, with no clear signal in summer and autumn, dry days in between and possibly more impulse rainfall events<br>• Southward shift of ecological zones likely to continue |

**Impacts of climate change on south-west Victoria**

When sectoral experts were asked about impacts of climate change on agricultural production for south-west Victoria which includes the Corangamite catchment, interview partners mentioned that the danger of climate change does not necessary lie in the gradual change of climate, but rather in the change of frequency and magnitude of extreme events [IP20;25:32]. Australia was considered likely to be in the frontline in terms of climate change related impacts coming along with shifts in risk profiles for agricultural production. Also higher chances of droughts were mentioned while wetter years may not be as often and as productive anymore [IP32;25]. New threats may emerge earlier in the season, such as earlier spring heatwaves with possible reductions in productivity. Thus, climate change adds extra stress on land use or particular enterprises which might come along with higher farming input costs [IP15;19;20;22;25;34]. Higher temperatures might trigger more dry days in between and change rainfall patterns thus impacting pasture production. Slightly warmer winter temperatures with stable soil moisture contents will potentially support winter pasture production increases, but less growth in late spring as it dries up about three weeks earlier in average [IP20]. Others challenges for farmers from increasing seasonal variability were seen around longer lasting summer which might increase the feed gap for livestock and therefore result in higher expenses for animal feed. Additionally, there might be possible shifts in land value which are mostly driven by markets, but with drier conditions, better accessibility to land and more viable cropping options, land values are considered to increase in south-west Victoria [IP22;23;25]. Grazing and wheat cropping areas are moving further south while cropped areas might become more suitable to grazing land in some areas in Victoria. Also a southward shift in the pest and diseases spectrum were mentioned due to a warming climate and the general southward shift of ecological zones [IP25;34;35].

In the long-term, IP21 assumed a trend of lower input systems. This includes lower stocking rates and farm systems that don't take as much advantage of good seasons but are not as exposed in poorer seasons and therefore are less risk prone by trading off some profitability. Risks might especially grow for small-scale farms with little diversification options, while larger farms as well as multinational or externally supported farms were considered less vulnerable to climate related risks. This was explained by better abilities of larger farms to buffer against climate related impacts due to enterprises and incomes diversification options while a good financial background supports the implementation of adaptation strategies to make certain investments. Also enterprises which already have trouble being profitable were considered to be more vulnerable to climate change, depending on their risk management [IP15;22;30]. Risks und vulnerabilities also emerge from the fact, of how well a farm is used and prepared for stressors such as droughts. This was observed with northern Victorian farmers who dealt more regularly with droughts and tend to have quite well adapted management strategies while farmers in the high rainfall zones of south-west Victoria might be less prepared and adaptable to changing frequencies of droughts [IP20;22]. However, impacts of climate change were considered bigger on drier (mostly northern) areas of Victoria which will be more affected by shorter growing seasons and less rainfall with profound effects on agriculture than south-western Victoria [IP17:32].

**Livestock**

In regards to specific impacts on the livestock sector, direct impacts from heat waves and higher evaporation rates were seen around more heat and water stress on animals which tend to impact production [IP23:37]. Also shorter springs means a higher risk of having to feed livestock which comes along with more pressure on farming systems and profitability [IP22]. In terms of heat events, interview partner pointed especially to cattle as single heat waves have shown a reduction in the amount of milk for the next three to four month in Victoria. Impacts of heatwaves were particularly high when the nights remained above 25°C and cows were beyond the peak of lactation, while impacts were less significant when the nights cooled down and cows were before the peak of lactation [IP16;20;19]. Sheep were considered lightly less affected by heat as cattle, but heat days over 40 degree could have direct short-term impacts on ram fertility and even increase mortality rates when shade and water is lacking. Wool quantity and quality depend more on indirect impacts from the pasture base and nutrition which however also might be affected by climate change and management strategies [IP27;37]. Other impacts mentioned were an increased risk of temporal and spatial shifts in animal diseases, such as tropical diseases coming further down with a warmer climate or seasonal changes in the occurrence of flystrikes[2] which might not only arise in late September but also later in autumn or earlier in spring [IP17]. IP35 furthermore indicated that the already compromised sheep that were brought to Australia 200 years ago are going to be more compromised in a hotter and drier environment, especially animals with wrinkly skin.

**Pastures**

The interview partners were interviewed about impacts on pasture production. According to the pasture expert IP27, around 50 % of the annual pasture production occurs in a six-week period during spring. There will be more pressure on the pasture growing season with a four to six weeks shorter growing season compared to the 1973-2000 baseline and a trend towards later autumn breaks. Models showed a big shift in the pasture production curve, with a) springs being earlier, pasture growth less productive and more variable, b) winter being slightly more productive due to temperature effects, c) a trend towards a delayed start of pasture growth in autumn and d) a change in the peak of pasture growth from mid-November to late October [IP21;22;26,27]. Warmer and drier springs shorten the time for pasture production coming along with changes in pasture availability and nutrients for animals and furthermore decreases the ability to cut large amounts of fodder, hay, silage for farmers. Thus, investments might be needed to increase storing capacities

[2] Flystrike happens when blowflies lay their eggs in wet or dirty wool typically around a sheep's bottom and the hatched maggots burrow into the flesh of the animals causing pain or even death (AWI 2017).

while expenses to hand-feed grain and hay may potentially increase with a hotter environment [IP19;22]. More pasture growth in winter and less in late spring already resulted in shifting dates to cut silage around one month earlier than 30 years ago in the study area [IP20]. Also if models for Victoria suggest areas with slight improvements in winter pasture production, the overall effects are more negative as pasture production is likely to decline without adaptation [IP21;24;27].

**Cropping**

One of the main identified problems by interviewed sectoral experts referred to earlier hot days in the season coming along with higher evaporation rates and stress on crops and animals [IP15;23;25]. Due to slightly warmer winter and springs, crops tend to grow more rapid, mature earlier while soil moisture gets utilized quicker [IP19]. As the seasons are coming forward by nearly a day per year, the crops are being harvested a month earlier than about 30 years ago [IP16]. With changing rainfall zones and higher temperatures, spatial shifts of cropping land especially for wheat and canola can already being observed in Victoria in the last two decades [IP20;22;35]. Although the number of years with failed crops have especially increased in north-west Victoria, south-west Victoria might be increasingly affected by failed seasons in the future [IP20;23]. Another challenge might come from warmer seasons thus giving more room for insects and fungal diseases such as the prevalence of more crown rott (root disease) through hotter and drier springs [IP19]. According to IP24, despite higher $CO_2$ levels models suggest a declining trend in yields and farm profit for Victoria in the mid-to long-term under climate change without adaptation.

**Benefits of Climate Change**

According to interview partners, climate change does not only come along with certain challenges for farmers in the Corangamite catchment but also with some benefits. The opportunities in coastal areas of Victoria were considered as great because of slightly warmer temperatures which might improve farmers productive ability under stable rainfall conditions, expect for heat waves and others extreme events. Especially slight increases in winter pasture production and a lack of water logging was considered as main benefit and as expense for shorter spring production [IP19;20;22;24;26;27]. As south-west Victoria used to be a wet environment, the region faces nowadays fewer issues with wet winters and waterlogging which improved access to farm land and supported easier use of tractors [IP37]. Cropping got much more viable than in the past with greater options for all sorts of crops, especially for some legumes [IP22;37]. Farmers are also increasingly enabled to change enterprises in drier seasons [IP17]. IP23 summarized that benefit come from how responsive farmers are including their willingness to adapt which would increase their success in farm business.

## Recommendations for adaptation strategies

The following part focuses on adaptation strategies recommended by the sectoral experts to deal with the increasing variable climate in the study area. The first part summarizes general comments on adaptation and risk management, following specific recommendations for livestock, pasture, cropping, soil and water management. Much of the strategies closely follow or are in line with generally suggested best-management strategies for farming.

### General comments on adaptation and risk management

According to IP14&15, reacting to climate change means that the principles of running a farm have not changed but might get tougher thus making it more important to have a proper business model by taking into account changing risk profiles under climate change. The interview partners agreed that there is a need for adaptation to changing climate conditions and that adaptation is part of maintaining a profitable farm and a healthy environment [IP14-37]. Today's best practice management strategies are the best response for the short or mid-term conditions, but longer term climate change may require larger adjustments to management systems [IP26;27]. Adaptation means less risk and the opportunity to make more money, e.g. by operating closer to the production potential of the farm [IP37]. The further inland a farm is located in Victoria the more adaptation is required {IP20;25].

A general awareness about mid to long-term future developments by including climate scenarios in decisions can be very helpful in the long-term, especially if farmers consider larger forms of investments such as buying new farmland or consider other forms of expansions or adaptation actions [IP14;16;19;20;21;32]. Changes do not need to be dramatic as there is no unexpected climate change and farmers can incrementally adapt in steps [IP21;22]. Being open, flexible and responsive to climate conditions while taking opportunities will help farmers to maintain farm profitability [IP15;21;23].

Interview partners pointed to the importance for farmers to stay profitable to be able to adapt while less profitability was considered to give less room for adaptation [IP19;22;34]. Also if farmers are able to cope with the current variability in the short to mid-term, they need to be able to deal with future extreme variability as well [IP19]. As risks from climate change mainly derive from changes in the frequency and magnitude of extremes events, building a farm system that is able to withstand *bad times* is important, e.g. by having most of the productive season over by November which is always a balance act [IP20]. Therefore, planning the future under a more variable climate is important to stay profitable [IP27]. The ability to adapt might be especially problematic for farmers who are already having trouble being profitable and for those without succession plan and lack money for investments [IP26]. However, every farmer has to find the right system that works sustainably, responding to what markets and what the climate is doing to stay profitable, such as shifting the proportion of enterprises [IP22]. The most profitable management activities in the past 15 years might also be the sort of adaptation option that gives profitability in the future [IP23;27]. A good business advice can also be important especially in terms of timing of investments, as actions of today can significantly support farmers and maintain long-term profitability in future [IP22;23]. Furthermore it was pointed out, that taking decisions *in time* offers several advantages as it gives farmers a forehead positions and a possible competitive advantage. This can be considered when buying farm land in viable areas before land prices go further up in south Victoria. IP15 pointed to a good example of adaptation referring to Victoria's wine industry that has been extremely active in the last years by buying land in Tasmania to grow warm weather wines [IP15]. IP19 referred to another example where farmers north of the Great Dividing Range in Victoria started buying land south of the Range to spread their business risk [IP19]. Also acquiring and leasing land in other districts or leasing out parts of the own farm might be an option to spread risk [IP22]. Diversifying income was generally considered as good strategy to maintain equity in the farm to be able to stay responsive to changing climatic conditions [IP22;23]. Many sectoral experts recommended a mixed crop-livestock system which can help farmers to balance out some climate risks and buffers against bad years [IP19;20;22;23]. Livestock was generally considered more resilient to drought conditions as crops and by farmers growing/raising both, they may keep their income and get the best out of two worlds [IP19;22;23].

To better understand changing business risks under climate change and increase management skills, interview partners recommended farmers to gain relevant information provided by other farmers, workshops or information portals which was seen as an important step in the adaptation process [IP15;20;22;25;31]. Also a better understanding of probabilistic forecast and long-term climate scenarios might help to incorporate relevant region-specific information into the business decision-making process and thus gives farmers a certain head up position [IP22]. Furthermore, also incorporating some science in terms of soil, cropping or livestock management might help farmers with certain decision-making processes [IP22;26;35].

Many interview partners also agreed in the fact, that most farmers are already adapting to changing climate conditions to increase their business profitability and resilience, but rather subconsciously than tracing back certain decisions on climate change [IP15;22;27]. However, with more shocks to the system such as increasing summer feed gaps, rethinking business models might get more important to lower vulnerability [IP22;30]. Thus, IP30 assumed if farmers are more proactive they can make use of a range of opportunities and improve profitability to maintain farm resilience [IP30].

**Livestock Management**

One of the main things that interview partners mentioned in dealing with increasing climate variability was a) to provide enough shade either from trees or infrastructure such as shelters to decrease heat stress for animals and increase lamb survival and b) to provide access to (cool) and reticulated water to survive the heat [IP19;20;21;27;37]. IP20 added that combining Landcare and biodiversity not only helps with providing shape, but also with dryland salinity and the resell value of farms. Planting wildlife corridors could also be connected with potential carbon plantations to generate some income [IP20].

Studies in Australia have shown that on a longer term basis, producing prime lamb in a reliable high rainfall area (southern coastal areas of Victoria, Warrnambool through to Colac) and wool in more drought prone areas gives farmers the most income [IP20]. In terms of heat events, it might get more important to have in mind the reproductive cycle and fertility of animals, to adjust joining time and give enough time for reproduction to increase the chance of gestation during hotter times [IP27;36). The use of pregnancy scanning to check on conception with a view to re-join or dispose of dry animals could also be a strategy [IP27].

According to IP14, lambing time is an important driver of profitability and the number of sheep a farm can run. Adjusting lambing times to allow lambs to finish on green feed according to market specifications or use alternative strategies for finishing lambs such as feedlot help with adaptation to increasingly variable seasons. As warmer winters tend to be less feed limiting, shifting lambing times a bit earlier was considered favourable as lambs will be bigger by summer. If the season cuts out earlier, sheep need to be in a certain weight to survive the drier period in summer. Hence, warmer conditions could enable to shift lambing times earlier in the year [IP27]. Integrated climate-agriculture models for 2030 show that the optimum lambing dates are around four weeks earlier (June/July than normal lambing times in Victoria (August/ September) to finish sheep off by the end of spring, which are projected to get more unreliable. However, earlier lambing requires earlier joining, which reduces potential reproductive rate around 5 % per year, thus making lambing times a balance act for farmers. Regarding shearing times, the best way to avoid nutrition stress and manage major breaks in wool is to shear the weaners close to the break [IP27].

Managing livestock accordingly to more variable seasons might include matching and adjusting stocking rates to pasture production, stocking off pastures and selling animals in time, adapting joining and lambing time to seasonality of grass production, using feedlots to finish animals off and planning for higher risk to supplementary feed animals [IP20;22;26;30;37]. IP20&21 recommended making the best use out of winter pasture production since in some parts of Victoria growth rates are increasing. Also investments in silos to increase storing capacity gives more flexibility in dealing with dry times [IP22]. Managing feed by cutting down the feed intake and making feed more digestible to cut down the metabolic load might be helpful in dealing with drier times and a bigger summer feed gap as well [IP37]. IP14 also suggested having proper worm control programs to address changing risks of flystrikes earlier in the season. Also changing from cropping to grazing might be an option under increasingly drier conditions [IP27].

In the longer term, breeds of animals that are able to cope with higher temperatures are getting more important [IP19;20]. Breeding programs can help to make sure having the right animals for a specific environment. Reducing the amount of fat in a livestock due to changing consumer demands is a trade-off as it's harder for animals to store enough energy and maintain conditions for variable seasons. Animals, particular the females with certain fat levels retain better breeding flocks and have a higher resilience and ability to cope with variable seasons. Good body reserves such as muscles and fat were positively related to reproductive trades and increased the ability to milk well during drier times [IP30]. However, a quicker fattening of lambs with shorter growing season might get more important in the future as lambs need to be finished off earlier [IP27]. Also certain animal characteristics such as sheep with less wrinkles and large floppy ears or cattle's with radiation reflecting fur (called *slag gene* in Black Angus breeds) might furthermore help with heat resistance or certain diseases and requires less management [IP20;33;36].

**Pasture Management**

Interview partners suggested certain recommendations regarding pasture management under climate change, which included to go more for deep rooted and drought tolerant perennial pastures rather than annuals, chose the right pasture species compositions and make sure fertilizer input are adequate [IP17;19;20;21]. As deep rooted perennials allow pastures to tap further into soil moisture during dry periods and furthermore help to keep organic carbon in the soil, they help with adaptation to climate change [IP20;24;26;27]. Once established, phalaris is one of the most productive and drought tolerant species, as it establishes slowly and competes with weeds. Perennial ryegrasses have better production rates, compete really well with weed, but are potentially not as good in the long-term persistence as they don't like heat as much. Other options would be Cocksfoot or Fescues [IP26]. Phalaris and tall fescues are harder to manage, but there are always trade-offs [IP21]. Native pastures such as Themeda triandra have the advantage to tolerate a massive temperature range [IP20]. Also having a proportion of summer active pasture species on the farm that can respond to summer rainfall like Lucerne or Chicories help to extend the growing season as they do much better in recent years than relying on annual pastures [IP17;19;21]. Waterlogged areas should be sown by more summer active types of perennials [IP26].

IP26 suggested diversifying pasture species composition on a farm to minimize production losses. An example would be having varied paddocks of ryegrass, Lucerne, Fescue, Cocksfoot or Phalaris instead of just having one or two different species. Also having a good species composition of native pastures might benefit in drier years to cope with extremes [IP20]. Pasture improvement and renovation with new and different species help to tolerate warmer conditions and sustain longer dry periods [IP17;21;26]. There is also quite a lot of research going on in terms of pasture species that handle better changing environmental conditions [IP24].

If farmers change enterprises, they need to fit the enterprise system to the pasture growth cycle [IP17]. Generally it is important to balance pasture production and consumption, by planning the annual production cycle to have most consumptions during periods of peak production which is shifting forward [IP27]. Therefore, IP20 suggested focusing more on the winter periods for grazing than on late spring. This can be achieved by putting in nitrogen fertilizer in winter and stimulate grass production earlier in the season to compensate for the three weeks that farmers lose at the end of the year. Additionally, out-of-season opportunities with feedlots were considered as good way to deal with a more variable climate and to handle tougher periods which goes hand in hand with drought management [IP17]. Also better grazing management techniques help to keep pastures healthy [IP26]. IP20 highlighted the chance for farmers in south-west Victoria to just look slightly west on the same latitude where they will find an agricultural system that is already coping with extremes. For example farmers from Colac might look at what farmers in Albany and Esperance are doing.

**Cropping and Soil Management**

Also if most farmers have good weed control programs or make use of moisture conservation methods, interview partners suggested to plan for more heat days and set up an agricultural system that can survive more extremes [IP20;22;30]. Most inland areas especially in northern Victoria have to do fairly serious adaptation because of more failed wheat crops and worse heat conditions [IP20]. Mixed crop-livestock systems buffer failed crops as dry matter can serve as food for animals [IP20]. Interview partners suggested going for varieties that are more adapted to changing seasons and higher extreme temperatures. This would include crops that are more heat tolerant with lower water requirements and to adjust sowing practices and the crop calendar with changing climate conditions [IP14;16;23;34;37]. Crops which were sown on time or earlier tend to yield better than crops that were sown late [IP19]. One management strategy could be to have a proportion (a third or half) of crops in the ground if it has not rained by the first week of May. Once there is more confidence how the season unfolds, interview partners suggested to put more nutrients into the crop in good seasons, but holding back on that expenditure and not wasting money in poor seasons [IP19;23]. Generally, south-west Victoria was considered much more flexible in sowing dates than northern Victoria [IP19]. Also rotation of crops is important to minimize weed and diseases problems, which helps to keep soil carbon stable and avoid soil depletion while chemicals and fertilizer come at greater expenses [IP19]. Proper drainage such as raised beds can furthermore help with expansion to more waterlogged prone farm areas [IP17;19].

In terms of sustainable soil management, maintaining ground cover of at least 70 % flat or 90 % at hills and having a base of pasture is important to avoid wind and water erosion especially during extreme events [IP21;26]. Better pastures and less bare ground can also mean less weeds [IP26]. Destocking in time was considered especially important before an upcoming drought, such as putting animals in stock containments. Also if feed expenses may be higher in short-term, the damage to the paddocks and the need to frequently re-sow are lower and therefore less expensive in the long-term [IP26]. Also subsoil manuring was mentioned to improve soil structure and water holding capacity and therefore helps to increase crop yields while minimum or no tilling helps with carbon sequestration and keeps nutrients/soil moisture [IP19;34]. Reassessing the farm operation, becoming more familiar with soil variability across the farm and checking whether or not the farm practice match the soil types helps in dealing with increased climate variability [IP23]. Also, fencing according to soil types and adjusting use of paddocks help keep healthy soils under changing climate conditions [IP23].

**Water Management**

Facing water shortages including dropping groundwater and less runoff from local creeks and springs in some areas, farmers were recommended to manage their systems accordingly and to make the most out of times with pasture and water availability in order to make profits [IP22]. Interview partners suggested to adapt to higher frequencies of droughts especially as less governmental support can be expected [IP22;23]. Thus, dealing with water shortages and security on farms is becoming more important, as sequences of drier years possibly might increase in future also if wet years and floods in between remain challenging as well [IP21;22]. As droughts are a major risk to a farm business, managing them accordingly was considered highly important especially from a financial point of view. Having a proper plan and funds for the worst case of a drought including feeding costs and protecting resources, such as offloading sheep in time or using feedlots can help overcoming dry times [IP17]. Interview partners suggested increasing the amount of water available, such as installing farm dams, trying to access ground water or buying licenses to ensure a reliable water supply on the farm. Also having a greater storing capacity and buffer for two or three years rather than just for one year was recommended [IP21]. Thus, bigger and deeper dams show lower evaporation rates and are much more effective than having several shallow dams on different paddocks [IP22;27]. Investments to improve infrastructure such as connected pipelines across paddocks with reticulated water shows less evaporation and leakage and might also help in dealing with water shortages [IP22;27]. Having water or not can be the difference between selling the stock or keeping them and thus making the difference to farm profit [IP22]. Town water is expensive, but can also help as backup [IP22]. Also new technology like desalination plant can help to overcome water shortages, but might possibly be too expensive for most farmers. Furthermore, integrative discussions can help to solve different pressures and interests about water resources [IP22]. The following table summarizes the results from interviews with sectoral experts.

**Table 10: Summary of comments of interviews with sectoral expert regarding impacts and suggested adaptation strategies under climate change**
(Own representation based on interviews with sectoral experts)

| Impacts | Adaptation |
|---|---|
| **General** | |
| General comments on the impacts of climate change on agricultural production for the study area included:<br>• Australia is likely to be in the frontline in terms of climate change impacts<br>• Danger lies especially in the change of frequency and magnitude of extreme events<br>• Climate change means a shift in risk profile, increasing the wide band of uncertainty<br>• It is likely to see more droughts, while wetter years may not be as often and as productive<br>• Higher vulnerability of agricultural systems due to changing seasons and new threats emerging earlier in the season (shorter springs and impacts on pasture growth, bigger summer and feed gap, earlier spring heatwaves, possible reduction of productivity)<br>• Increasing variability of seasons adds extra stress on particular enterprises<br>• Higher input costs (e.g. feeding animals etc.)<br>• Impacts are bigger on drier (mostly northern) areas of Victoria than coastal areas<br>• Land value shifts are driven by the markets but with drier conditions, better accessibility to land and more viable cropping options, land values might continue to increase in south west Victoria<br>• Southward shift of rainfall and ecological zones, grazing and wheat areas as well<br>• Possible shifts in pests and disease spectrum with a warming climate coming further south<br>• In parts, cropped areas might become more suitable to grazing land<br>• Risks grow especially for smaller farmers, while multinational or farms with external foreign support tend to be less vulnerable<br>• Enterprises which already having trouble being profitable will be exposed more to climate change, depending on risk management<br>• In the long-term, there might be a trend of | - Many recommendations closely follow or are in line with generally suggested sustainable on-farm management strategies<br>- Reacting to climate change means that the principles of running a farm have not changed but it might get tougher and it is more important to run it profitably<br>- There is a need for adaptation to changing climate conditions such as higher temperatures, more rainfall variability and changing seasons<br>- General comments on adaptation to climate change included:<br>• Adaptation is part of maintaining a profitable farm and a healthy environment; adding climate change as factor of the decision-making process helps to minimize vulnerability and increase farm and business resilience<br>• Working on equity level on a farm or restructuring the farm to improve equity is a good adaption option<br>• Farmers with a reasonable amount of equity in a property can be more responsive while less profitability gives less room for adaptation<br>• Being open, flexible and responsive to climate conditions and for changes in the frequency of events while taking opportunities will help to maintain profitability<br>• Changes don't need to be dramatic as there is no unexpected climate change<br>• Adaptation means less risk and the opportunity to make more money, e.g. by operating closer to the production potential<br>• Today's best practice management strategies are the best response for the short or mid-term conditions, longer term climate change requires adjustments to management systems<br>• The further inland a farm is located the more adaptation is required<br>• Plan for more heat days & set up an agricultural farm system that can survive more extremes<br>• Have a proper business model and take into |

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lower input systems which don’t take as much advantage in good years but are not as exposed in poorer season and therefore less risk prone by trading off some profitability
<ul>
<li>Risks und vulnerabilities also emerge from the fact, how well a farm is used and prepared to shocks, farmers in high rainfall zones in south-west might be less prepared for droughts than northern Victorian farmers and adaptable in comparison</li>
<li>The bigger the shock to a system a farmer is not used to, the more vulnerable the system</li>
</ul>
<u>Identified benefits of climate change:</u><br>
Opportunities mentioned were:
<ul>
<li>Great opportunities especially in coastal areas of Victoria because of slightly warmer temperatures with still enough rainfall which will improve farmers productive ability, expect for heat waves and others extreme events</li>
<li>Less issues with wet winters and waterlogging</li>
<li>Improved access to farm land and easier use of tractors</li>
<li>Cropping is much more viable than in the past, greater options for all sorts of crops, especially some of the legumes</li>
<li>Winter production is the main benefit for pasture and cropping due to a lack of water logging while higher temperatures improve winter grass production for livestock (which will be the expense for shorter spring production)</li>
<li>Benefit comes from how responsive farmers are, if they are willing to adapt they can be very successful</li>
</ul>
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account changing risks associated with climate
<ul>
<li>Diversify income and spread risk, maintain good equity in the farm to be able to respond</li>
<li>A mixed crop-livestock system balances out climate risks and buffers against bad years</li>
<li>Plan for the future under a more variable climate to stay profitable: Include climate projection into decision making, e.g. if considering to buy new land & making investments during good times for the future</li>
<li>Take decisions in time and not when you are forced to, e.g. adapting enterprises in time or buying farm land in viable areas before land prices go further up in south-west Victoria</li>
<li>Taking decisions in time gives farmers a forehead positions and a possible a competitive advantage</li>
<li>Acquiring and leasing land in other districts or leasing out parts of the own farm might also be an option to spread risk</li>
<li>Rethinking single activities on farm is important or using information on risk management, provided by other farmers, workshops, information portals e.g. the climate resilience community project might be an option to stay informed as well</li>
<li>Need in skills to better understand the science of climate change, changing business risks and seasonal forecast</li>
<li>Combining Landcare and biodiversity not only helps with providing shape and helps with dryland salinity but also increases the resell value of farms</li>
<li>Most farmers are already adapting to changing climate conditions</li>
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<td colspan="2">Cropping & Soils</td>
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The following risks on cropping and soils under climate change were mentioned:
<ul>
<li>Seasons coming forward by nearly a day per year, harvest about a month earlier than 30 years ago</li>
<li>Spatial shifts in grazing and cropping areas coming further south</li>
<li>Earlier threats in the season for the crops due to hot days hitting earlier in the season and higher evaporation rates put stress on crops</li>
<li>Much of that extra heat is in winter and particularly in spring: Quicker growing rates in winter and spring, earlier maturing</li>
<li>Increase of failed crops, especially further inland with worse heat conditions, not so much in south-west Victoria</li>
<li>More summer rain could trigger more weeds growing that give more room for insects and fungal diseases over summer, higher prevalence of the root disease crown rott</li>
<li>Models suggest a declining trend in yields and farm profit for Victoria in the mid-to long-term</li>
</ul>
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The following adaptation for cropping and soils were mentioned:
<ul>
<li>Choose varieties that are more adapted to changing seasons, higher temperatures and have lower water requirements</li>
<li>Adjust sowing practices and the crop calendar to changing climate conditions</li>
<li>Crops which are sown on time or earlier, always yield better than crops that are sown late</li>
<li>Rotation of crops, e.g. wheat fields with longer perennial systems to minimize weed and diseases problems (chemicals and fertilizer come at greater expenses) and to keep soil carbon stable</li>
<li>Use proper drainage at soils types which are prone to waterlogging</li>
<li>More perennial rather than annual help with better organic carbon which has benefits for fertilization</li>
<li>Reassess farm operation, become more familiar with soil variability across the farm match and farm practice to soil types</li>
<li>Maintain ground cover at least 70 % flat or 90 %</li>
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| | |
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| under climate change without adaptation, despite higher $CO_2$ levels<br>• Quicker use of soil moisture from higher temperatures and possible changes in the rate of organic matter decomposition by soil microorganisms | hill, keep base of pasture to avoid wind and water erosion<br>• Destock in time before an upcoming drought, use stock containments to preserve resources<br>• Subsoil manuring helps remarkably to increase yields of crops in drier springs<br>• Minimum or no tilling helps with carbon sequestration, to keep nutrients and soil moisture<br>• Monitor soil moisture and base some decision around that |
| **Livestock** | |
| The following impacts on the livestock sector were mentioned:<br>• Heat waves and higher evaporation rates puts stress on animals which tends to impact production<br>• Indirect impacts refer to changes in the pasture base through changing seasons<br>• Especially cows are suffering from heat events, a single heat wave can cause drop in milk reduction for the next 3 to 4 month, especially when night temperature remain above 25°C and if they are beyond the peak of lactation<br>• Sheep are not as affected by heat as cattle, but heat events might have short-term impacts on ram fertility and increase mortality<br>• Wool quantity and quality might change if pasture availability and nutrients decrease but also depend on management strategies, e.g. such as having feedlots<br>• Shorter springs mean a higher risk of having to feed livestock which comes along with more pressure on farming systems and their profitability<br>• Animals with wrinkly skin will suffer more from heat than plain body animals, especially in north Victoria<br>• Tropical diseases might come further down in a warmer climate in future<br>• Increase of risk for flystrikes, not only in late September but also later in autumn and a bit earlier in spring | The following adaptation for the livestock sector were mentioned:<br>• Provide enough shade (trees, wildlife corridors, shelter cloths) and access to (cool) reticulated water to avoid stress from wind and heat<br>• Plan for shorter springs, bigger summer and feed gaps & higher risk to feed sheep<br>• Manage variability: match and adjust stocking rates to pasture production, stock off pastures earlier, make use of feed lots & sell stock in time to deal with dry times<br>• Make the best use out of winter growth production, perennial pastures provide a good feed supply<br>• Investments in silos to increase storing capacity gives more flexibility<br>• Have in mind reproductive cycle of the animals; adjust joining time during or after heat events, provide enough time for reproduction, make use of pregnancy scanning to check on conception, with view to re-join or dispose of dry animals<br>• The amount of body fat is positively related to reproductive trades & ability to milk well during drier times, good body reserves help with better resilience and ability to cope with variable seasons<br>• Quicker fattening of lambs with shorter growing season becomes more important in future, needing to be finished off earlier<br>• Climate change with warmer conditions could enable to shift lambing times earlier in the<br>• Prefer animal breeds that cope better with heat and diseases<br>• Long-term studies show: produce prime lamb in reliable high rainfall area (south-west Victoria) and wool in more drought prone areas gives farmers the most income over time<br>• Worm control programs help to address changing risks of flystrikes earlier in the season |
| **Pastures** | |
| The following impacts on pastures sector were mentioned:<br>• Change in seasonal distribution of pasture growth and persistence in, opportunities with more winter growth rates but more variable | The following adaptation for pastures were mentioned:<br>• Go for deep rooted and more drought tolerant perennial pastures, such as Phalaris, perennial ryegrasses → there are always trade-offs |

| | |
|---|---|
| growth in spring<br>• Dealing with the increasing variability of autumn breaks is quite challenging, possibly farmers have to hand feed grain and hay at great expenses to their stock<br>• About 50 % of the annual pasture production occurs in a 6-week period during spring. With a 4-6 weeks shorter growing season compared to 1973-2000 baseline and a trend towards a later autumn break, there will be more pressure on the pasture growing season<br>• Model shows a big shift in the pasture production curve with a change in peak of pasture growth from mid-November to late October, spring being earlier and less productive, winter being slightly more productive due to temperature effect, a trend towards a delayed start of pasture growth in autumn<br>• Generally, more grass growth in winter and less in late spring result in shifting dates to cut silage of about one month earlier than 30 years ago, maybe impacts on the amount of fodder to be cut and to save that for later in the year<br>• With increasing temperatures and decreasing rainfall pattern, pasture production is likely to decline in future, also if models for Victoria suggest areas with slight improvements in winter pasture production, the overall effects are more negative | • Chose the right pasture species compositions and make sure fertilizer input are adequate<br>• Generally: Pasture improvement and renovation with new and different species help to tolerate warmer conditions and sustain longer dry periods<br>• Have a proportion of the farm that can take advantage of summer rainfall such as Lucerne or Chicories → way to extend growing season<br>• Diversify pasture species composition on farm to minimize risk, e.g. by having one paddock with ryegrass, another with Lucerne, Fescue, Cocksfoot, Phalaris etc.<br>• Change emphasis and focus more on winter period for grazing than on late spring, e.g. put some nitrogen fertilizer in winter and stimulate grass production earlier in the<br>• Better grazing management techniques helps to keep pastures healthy<br>• Fit the enterprise system to pasture growth cycle (especially with enterprise change), balance pasture production and consumption by planning the annual production cycle to have most consumptions during period of peak production (which is coming forward)<br>• Look at opportunities out of season with feedlots<br>• Native pastures tolerate a massive temperature range, having a good species composition of native pastures is of benefit in drier years to cope with extremes |
| **Water and Droughts** | |
| The following impacts on water were mentioned:<br>• Climate change aggravates existing water stress and affects water security<br>• More water regulations in future assumed with water resources becoming more constraint<br>• Quicker use of soil moisture due to higher temperatures, slower fill up of dams<br>• Increasing risks of droughts as major risk to a farm business<br>• South-west Victoria is increasingly running out of water, key challenge for some farmers<br>• Wet year (with floods) in between remain<br>• Sequences of drier years without runoff might increase in future<br>• Trend in dropping groundwater in parts of Victoria affects catchment flow and some local creeks and springs, but also stable groundwater in some areas<br>• Still lack of understanding the water cycle in south west Victoria, especially the connectivity with the groundwater in terms of where it comes from<br>• People tap into ancient groundwater in some areas of Victoria which is not a renewable resource | The following adaptation for water and droughts were mentioned:<br>• Adapt to higher frequencies of droughts, e.g. have funds for droughts (e.g. feeding costs) & protect resources and save costs (e.g. offloading sheep in time by using feedlots instead of chewing down paddocks)<br>• Water security becoming more important: manage systems accordingly and make the most out of the time with pasture and water availability to make profit<br>• Increase the amount of water available, e.g. put in farm dams, try to access ground water or buy licenses<br>• Improve infrastructure to deal with water shortages; e.g. connected pipelines across paddocks with less leaking and evaporation<br>• Ensure reliable supply and efficient use of water, have greater storing capacity and a buffer for 2 or 3 years rather than just for one year → bigger and deeper dams to access ground water<br>• Town water is expensive but also help as backup<br>• Broader use of technologies to harvest, use and transport water where rainfall decreases<br>• Use proper drainage at soils types which are prone to waterlogging |

**Factors triggering farmers perception and constraining adaptation**

IP14 pointed to the fact that memories of humans are very subjective, especially in the long-term which explains differences in people's perceptions regarding historical climate developments. Additionally, the strong climate variability makes it even harder to keep objective memories as farmers and geographic areas are differently affected from extreme events [IP22]. Compared to people in urban areas, farmers are much more aware of small climatic shifts which also influence their perceptions. IP26 mentioned that farmers perceptions are not always in line with reality and that some farmers underestimate the impact of increasing temperatures in terms of flowering, ripening or grass growth cycles but rather only perceive changes in rainfall as critically important.

Also social differences were mentioned to influence perceptions as younger people and woman were generally considered to be more open to the issue of climate change than older people and men [IP18;20]. Beside demographic and gender issues, also farmers cognitive protection against pessimistic messages was identified to potentially constrain debates about climate change impacts and adaptation [IP19;22]. Another issue mentioned were family structures, as a farm usually needs to be in a very strong financial position to have a succession between generations. Due to a lack of succession between generations or even passed debts, the window of opportunities of succession closes, which is furthermore triggered by a massive social change [IP18;30]. Younger people increasingly want to start a career and not come back to farms or begin with big debts [IP18]. Another issue might be barriers in terms of social acceptance and norms that limit farmers to step out and do new things which might be seen as *weird* by fellow farmers [IP37].

The public opinion was also mentioned to be influenced by voting preferences and the media, which is partly controlled by the Australia government who, according to some interview partners, has a clear agenda of not wanting the public to worry about man-made climate change. This is due to a large part of Australia's wealth still being based on the coal mining industry [IP14;25;37]. The issue of climate change was also considered to became very political in the last years as accepting climate change or not mostly refers to a political identity in Australia. Most interview partners mentioned to frame their presentation to farmers around climate variability rather than climate change because talking about climate change will make people jump into two different camps [IP14;15;16;20;22;24;29;30;31;33]. IP32 stated that the debate around climate change is still lacking behind other parts of the world. Also a long history of bad farming-government relationship was mentioned as farmers have been subjected to many various information campaigns and incentives in the past. This includes clearing trees for modern efficient farming while nowadays farmers receive subsidies for Landcare and planting trees again. Thus, farmers became more ´relaxed´ about messages including the whole issue of climate change or carbon markets [IP18;20].

Many farmers also lack the scientifical understanding of climate change which may hinder taking appropriate adaptation decisions in the long-term, also driven by mitigation policies such as discussed carbon taxes that would trigger business threats for farmers [IP17;22;37]. However, IP20 assumed that it is not a serious constraint when farmers do not accept climate change, but in the mid to long-term future they might be disadvantaged if they deny to deal with changing business risks through climate change. According to interviewed experts, although most farmers perceive certain changes in climate and already adapt management strategies, many farmers remain sceptical about a human induced climate change but rather attribute perceived changes in climate to natural variability [IP15;19;22;23;24;30;34;37]. Thus, "[i]ronically you get a situation where farmers are already responding to climate change but they are not attributing it to climate change, they attribute it to variability" [IP23]. Also a lack in farm equity may aggravate adaptation actions to stay responsive, while working on equity levels, such as restructuring farms may help to increase investments options and maintain farm resilience [IP23]. Generally, farmers were considered to struggle in adapting new systems or changing to new technologies as long as they don't face impacts like restrictions in water allocations during droughts [IP20]. In the short to mid-term, uncertainties in understanding the literacy of probabilistic forecast and sometimes a poor ability of complex analysis was mentioned to trigger *wrong* decisions [IP16;22;28;29]. Also a lack of good weather forecast itself was mentioned, which still comes from a lack in computer power despite big improvements in climate models and resolution issues in the last years [IP22;23;25;28]. This leads to a misconception in the system and distrust in weather and seasonal forecast [IP29]. In the mid to long-term, a market failure with adaptation was identified by several interviewed experts as private companies trigger a system where farmers get locked into a cycle where they have to buy regularly new seeds with a lack of incentive to sell long lasting perennial pastures [IP17;20;26]. Farmers were therefore considered to be reliant on a business sector that might not be motivated by selling a deeper rooted pasture species that can service that extra three weeks in November or selling a pasture species that handles the heat better for summer survival and does not need to be replaced. About 10 % of all higher production dairy farmers replaced about 10 % of their farm area every year just because they are locked into this cycle [IP20;26]. However, due to a massive range of opportunities it is also becoming harder for farmers to distinguish between *good and bad* information [IP17].

Also small capacities of researcher to work with farmers themselves and a mismatch between what kind of information or maps scientists provide and what farmers actually need was considered as potential constraint in adaptation [IP23;37]. Also Australia's strong seasonal variability might trigger a focus on more short and seasonal conditions rather than focusing on long-term strategic farm adaptations [IP14]. Allocating resources when conditions feel risky and uncertain in the long-term was considered difficult as climate change is perceived more on a long-term horizon and therefore beyond the planning horizon of many farmers [IP18;20]. Another constraint in the long-term future might come from the fact that a lot of farmers sit on committee that approve funding for research and if they do not believe in the subject matter, they won't approve funding for research in climate change [IP20]. This might come along with a lack of research in areas that were considered important to farmers such as research in long lasting pasture species [IP26]. As several farmers remain sceptical about the science of climate change, growing awareness might support certain adaptation strategies and support farmers in taking decisions in time to lower potential vulnerabilities to climate related impacts [IP23;27;36].

The following chapter will discuss the results of this study.

## 6. Discussion and Recommendations

In this chapter, the findings of the study are discussed and supported by relevant literature. The first section discusses factors determining farmers risk perception and potential constraints in farmers adaptation. The subsequent section discusses recommendations for climate change adaptation to lower potential farm vulnerabilities and to increase farm resilience. Finally, the findings and discussion are applied to the case study of this thesis Mt Hesse.

The following graph summarizes the results of this study which are discussed and presented in this chapter. This study reveals that several internal and external factors influence farmers risk perception and capacities to adapt. Farmers in the study area perceived certain changes in temperature, precipitation pattern and seasonal changes coming along with vulnerabilities in terms of production outcomes and overall farm well-being. However, interviewed sectoral experts suggested several adaptation strategies to deal with the adverse consequences of climate change and thus, to increase farm resilience of which several strategies were already employed by farmers in the catchment.

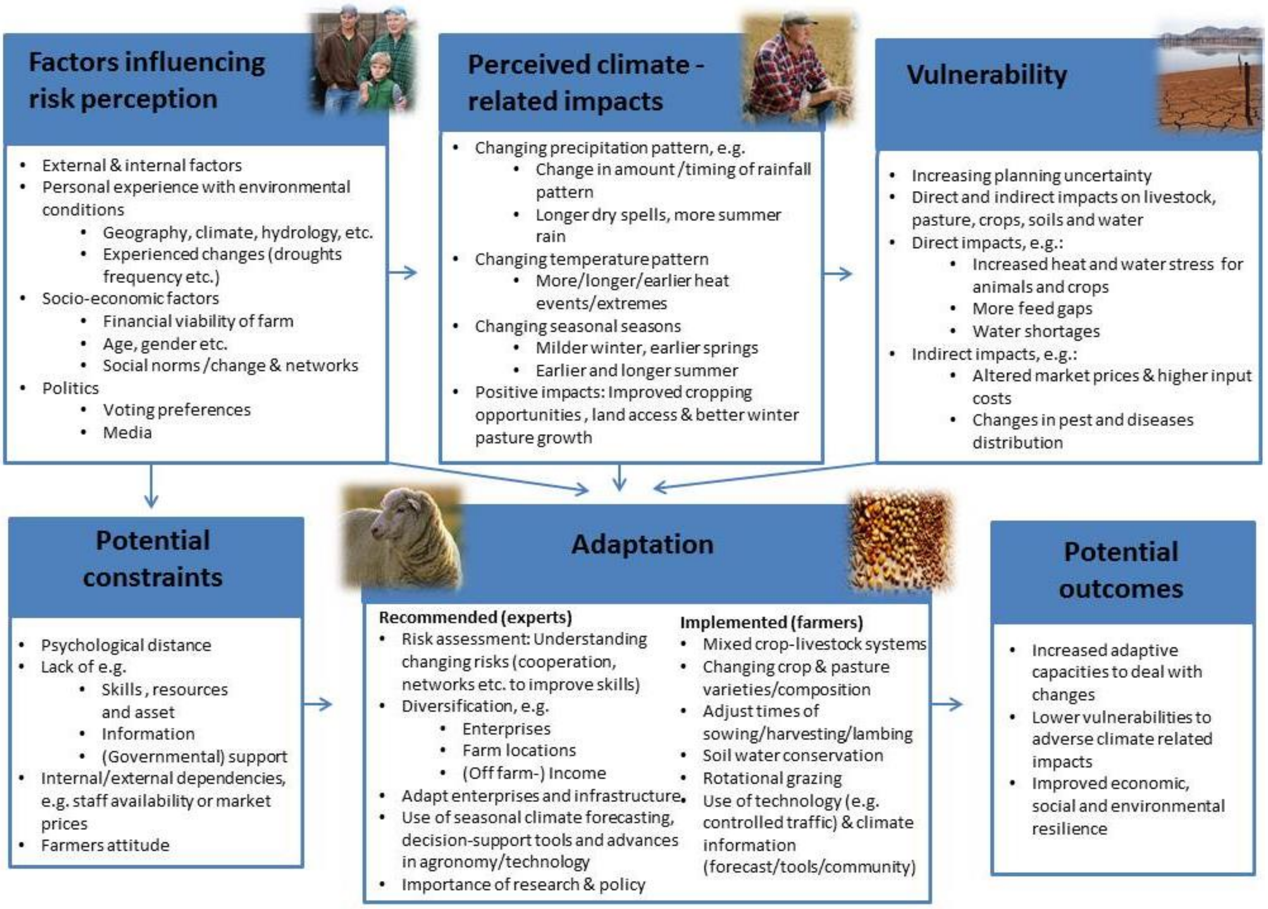


**Figure 29: Schematic overview of findings and discussion**

## 6.1. Key Factors determining Farmers Risk Perception and constraining Adaptation

This section examines internal and external factors influencing farmers risk perception suggested by sectoral experts and literature. Identifying factors and drivers influencing farmers perception can help to provide adequate advisory services to farmers to enrich climate change understanding and to support appropriate farm-level climate change adaptations within the Victorian agricultural sector (Keywood et al. 2017; Graymore et al. 2016). The following graph illustrates potential factors and drivers influencing farmers risk perception including personal experiences with environmental conditions, socio-economic and political factors.

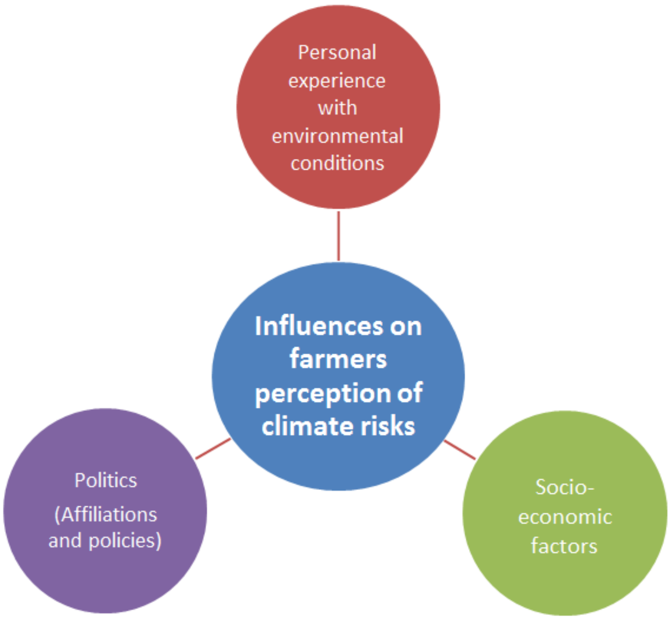


**Figure 30: Influences on farmers risk perception based on sectoral expert interviews and literature review**
(Own representation based on interviews with sectoral experts)

**Personal experience with climatic conditions**

Despite the introduction of new technology and different on-farm approaches, production systems such as crop yields still track growing season's rainfall which make experiences with local climate conditions to one of the most powerful influences on farmers risk perception. According to Rickards (2012:79), "[w]e make sense of climate by relating it to our past experience". Farmers generally tend to use a longer historical reference range than members of the general public, not only because they take much more notice of climate conditions and weather events, but also because farmers usually include experiences from earlier farming generations if available as part of their own. This furthermore tends to broaden the degree of variability that farmers perceive as *normal* (Rickards

2012). However several studies found out that there is often a mismatch between perceived and actual risk (see e.g. Arbuckle et al. 2015; Botterill and Mazur 2004), a mismatch between intentions to change and the actual behaviour change (Niles et al. 2016).

Therefore, based upon conducted interviews and literature review the following hypothesis is discussed in the following:

- Farmers climate perceptions are not consistent with historical climate records of the study area

According to Smith (2004), little trend in rainfall exists over the whole last century from 1900 while trends in rainfall can only be identified since about 1950. Since then, the total amount of rainfall in Australia increased mainly due to wetter summer conditions compared to the first half of the century especially in north, central and Western Australia (Smith 2004). However, south-west Australia is facing decreasing amounts of rainfall since the middle of the last century with the most critical rainfall declines and associated water shortages during the Millennium drought from about 1995 to 2010/11, which is considered the most severe drought since instrumental records began in the 1900s (Cai et al. 2014). The drop in annual rainfall during the Millennium drought can especially be traced back to autumn rainfall declines and a general failure of *usual* autumn breaks (Murphy and Timbal 2008). According to BOM/CSIRO (2016), south Victoria faced a general decline in growing season rainfall (April - October) of around 11 % since the mid-1990s with the largest statistically significant rainfall decrease from April to May. Also seasonal rainfall anomalies (figure 26, chapter 5) show a decreasing trend of autumn rainfall during the last century.

Changes in rainfall for Australia were mapped by the Grains Research and Development Corporation of the Australian government. Figure 31 shows the rainfall zones based on rainfall data from 1900 to 1999 and figure 32 shows the shifts of rainfall zones based on rainfall data from 2000 to 2015. For these maps, data of more than 8000 stations of the Bureau of Meteorology around the country were analysed (Collis 2016). The maps indicate that regions in south-east and south-west Australia with winter-dominant (Mediterranean climate) rainfall zones are contracting in a south-westerly direction while the summer dominant rainfall zones in north and central Australia are expanding in a south-westerly direction in western Australia, southwards in South Australia and in a south-easterly direction in eastern Australia. The southern boundary of the transition zone in which rainfall is quite evenly distributed throughout the year has already shifted from southern/central New South Wales down into central Victoria and the Mallee region of south-east Australia. In south-west Australia, the zone already reached the eastern edge of the wheat belt which places pressure on the

Mediterranean climate zone. The winter rainfall zone only expanded in south-west Tasmania, leading to more reliable winter rainfall (Collis 2016).

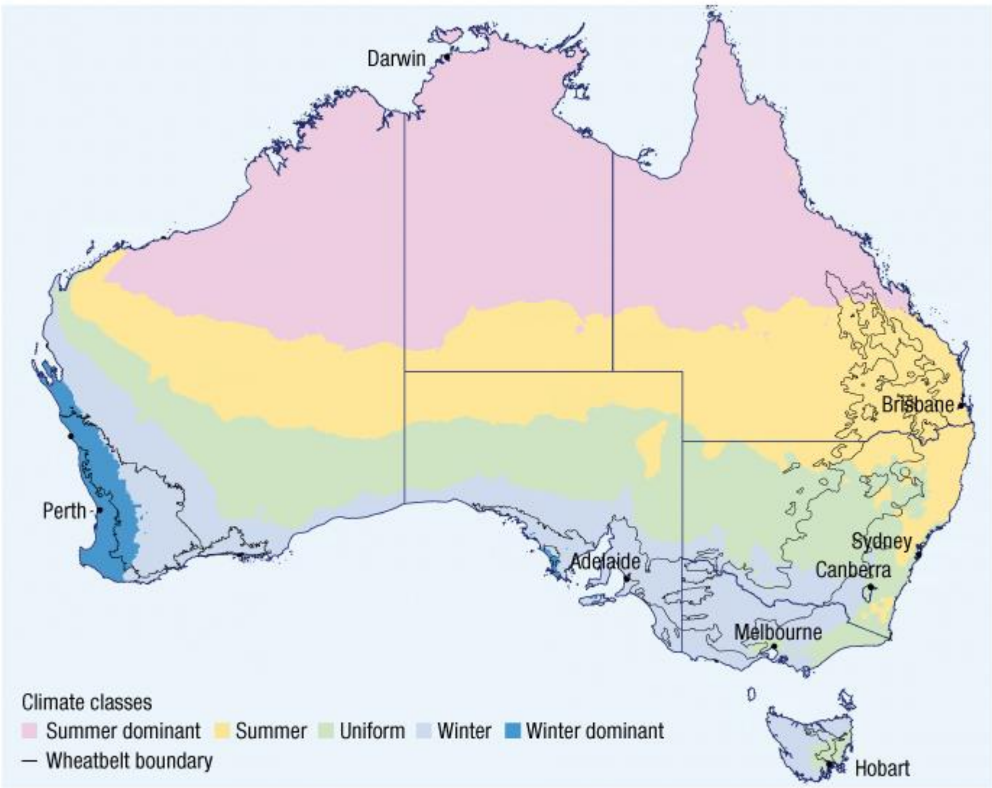


**Figure 31: Australia's seasonal rainfall zones from 1900-1999**

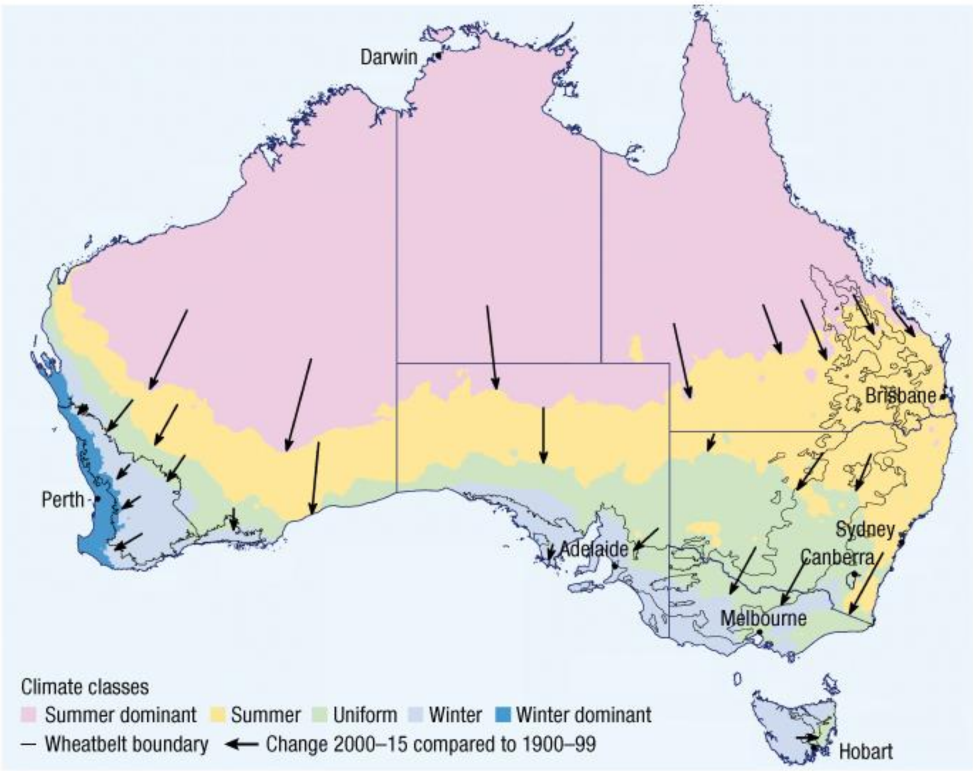


**Figure 32: Australia's new seasonal rainfall zones from 2000-2015**

(AEGIC 2017)

The rainfall zones boundaries have shifted between 100 to 400 km in Australia. Beside the shifts in rainfall zones itself, a general increase in summer rainfall up to 40 %  and a corresponding decrease in winter rainfall by 10 to 30 % has been observed across south Australia (Collis 2016). As the study area receives most of its precipitation in the winter half of the year, farmers perception of slightly more summer rainfall might indicate this shift in rainfall zones. However, Schattman et al. (2016) suggests that the southward shift of rainfall and ecozones will have a much greater impact on the north-eastern region of Victoria compared to south Victoria.

Interviews with farmers in the catchment revealed that all farmers perceived a general decrease in rainfall over the last two decades with some farmers remembering the exact years of droughts. The average age of interviewed farmers in the Corangamite catchment was 55 years old, and the following graph shows the experienced annual rainfall variability in a lifetime of a farmer in the catchment. The four major drops in average annual precipitation (red arrows) during this lifetime happened in the years 1967, 1982, 2006 and 2014 with a general decrease in precipitation over the last two decades.

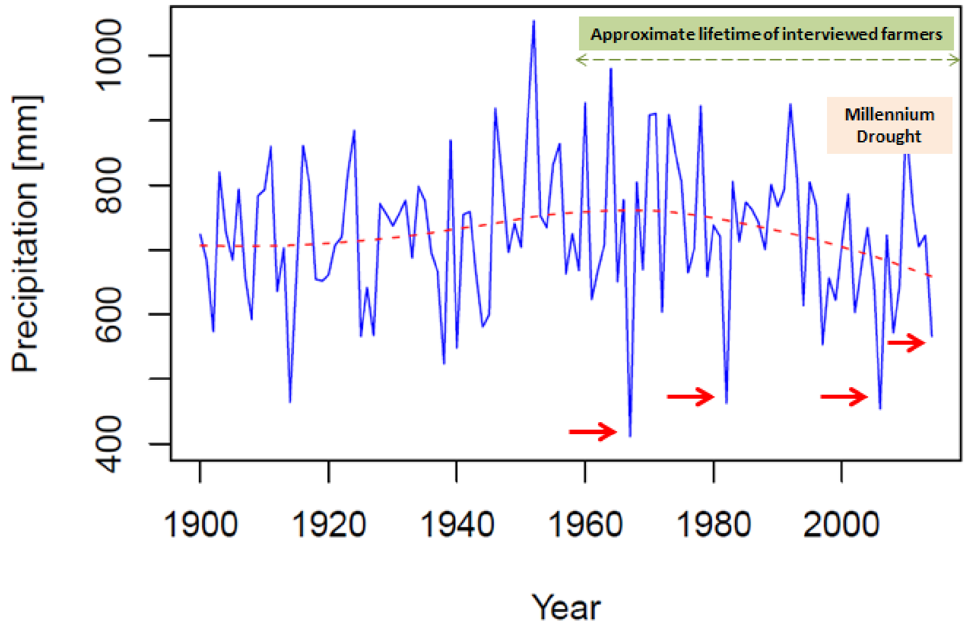


**Figure 33: Rainfall at Corangamite (with smoothing spline), approximate lifetime and experienced dry times in history of interviewed farmers**
(Own representation based on climate data and interviews)

However, the majority of farmers pointed particularly to a decrease in spring and winter season rainfall rather than to the observed decrease in autumn rainfall (BOM/CSIRO 2016). Perceived seasonal changes also included a slight increase in summer rainfall.

Thus, farmers pronounced notice of changes in spring season rainfalls might be explained by the *higher importance of springs* for farmers in terms of agricultural production such as fattening lambs or cutting hay. IP4 summarized:

> "It is generally very variable but we had two dry springs in a row which is most unusual. That has probably the most effect, we are most used to bad autumns or late autumns".

And IP8 stated:

> "The main problem are the failed springs […], springs are a key issues, that's where you get your yields, your grass to fatten the cattle or to grow your wool".

Beside seasonal changes and spatial shifts in rainfall zones, also rainfall events have become more extreme especially in autumn (Murphy and Timbal 2008). However, according to interviewed sectoral experts, definitions for extreme rainfall events are still rare thus making it much harder to have clear evidence for the increase of extreme rainfall events. This is also reflected by different perceptions of farmers when asking if they had been affected from extreme rainfall events in the last 15 years with 47.5 % stating ´yes´ and 40 % stating ´no´. Perceptions of extreme events and associated risks may also differ among farmers due to different personal experience with characteristics of farm sites, such as mountainside farm locations being more affected from heavy rainfall events than flat areas (Schattman et al. 2016).

Asking for temperature, farmers were unsure about trends compared to perceived changes in rainfall. More than half of the farmers from the online survey perceived no change in summer temperatures, although 42.5 % did of which a third felt a slight increase in summer temperatures. In terms of winter temperature, more than half of the farmers perceived a slight increase. Qualitative interviews revealed that farmers also perceived longer and earlier heat events, milder winter and a general increase in hot days in the study area which is presented in the following graph.

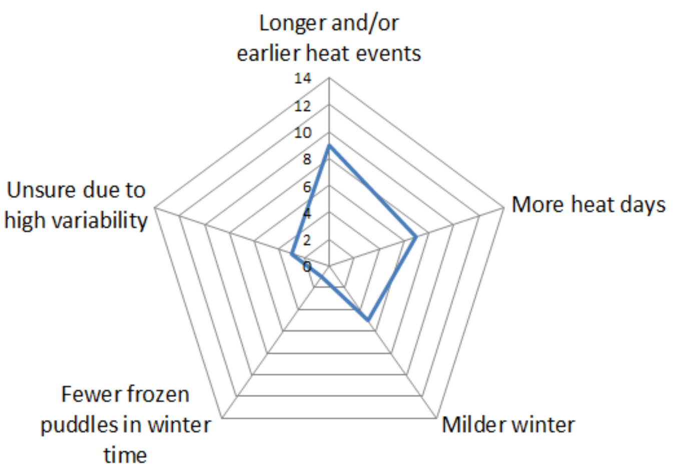


**Figure 34: Perceived changes in temperature**
(Own representation based on qualitative interviews)

Associated with higher temperatures, farmers also noted changes in flowering times starting about 4-6 weeks earlier in the season compared to 30 years ago and a shortening of the growing season. However, perceived trends in temperature and changes in extremes varied among the interviewed farmers. IP8 assumed that people felt temperatures differently depending on their age:

> "[m]aybe it has something to do with the fact that I am 54 and just feeling the cold a lot more than if you are 24",

while IP 11 assumed that

> "[…] we work so much in air-conditioning and when you get out of a cooled car or house, you think it is very hot. When I was a child there was no air-conditioning and you just learnt to live with the heat. […] I think we are getting softer because we regulate the way we live".

According to the Australian government, the average air and surrounding sea surface temperature in Australia has increased by about 1°C since 1910 with an increasing trend in temperature especially since the 1950s for all seasons with weaker trends in autumn and winter in south-east Australia (BOM/CSIRO 2016; Murphy and Timbal 2008). However, humans are not able to feel a century-long increase in temperature of about 1°C, but rather changes in seasons and the frequency and magnitude of extreme events. As presented in figure 16 (chapter 3), an increase in average temperatures can have large effects on the frequency and extent of extreme hot weather events which is also becoming more apparent in Australia (BOM/CSIRO 2016). Seven of Australia's ten warmest years on record have occurred in the 13 years from 2002 onwards with only one cooler-than-average year in 2011 and 2014 being the warmest year on record with maximum temperatures of 1.16 °C above average (BOM 2015). In 2009, record high temperatures occurred twice as often as record lows with 2012-13 being Australia's hottest summer since records began, including the hottest day on record. Heatwaves in general have increased in duration and frequency since the 1970s (BOM/CSIRO 2016; Climate Change Authority 2012). The development of hot and cold days over the last century can also be seen in figure 24 with the number of hot days (over 30 °C) per year significantly increasing and the number of cold days per year decreasing in the catchment (BOM/CSIRO 2016). This development of more hot and less cold days of the Corangamite catchment follows the general global trend (IPCC 2013) with climate projections suggesting further increases in the intensity, temporal and spatial extensions of heat waves and warm spells (Oppenheimer et al. 2014).

Along with a decrease in rainfall and increasing temperatures over the last two decades, the majority of the interviewed farmers also perceived a decrease in surface water availability while some farmers perceived a decrease of groundwater availability in some areas of the catchment. However, with dry times presenting major challenges for production, farmers nevertheless agreed that the general drying of the study area was benefitting for cropping production although wet years in between were mentioned as negative counterpart as well. Three quarters of the farmers also stated to have been affected from extreme droughts in the past 15 years with more than half stating, that the frequency of droughts have increased while none of the interviewed farmers agreed that the frequency or duration of droughts have decreased in the past 15 years.

According to Murphy and Timbal (2008), temperatures have not only increased but warming has accelerating in the recent decades thus increasing evaporation rates and affecting the severity of droughts. Due to temperature and precipitation correlations, the combination of higher maximum temperatures with lower rainfall leads to more severe droughts (Nicholls 2004). Also the higher frequency in hot and dry events is strongly linked to drought risk whereby long-term trends are generally more influenced by temperature than rainfall, consistent with the global warming (Kirono et al. 2017). Although there have always been periods of low rainfall in the past, in combination with higher temperatures water resources are increasingly put under more stress compared to previous historical dry spells (Murphy and Timbal 2008).

Summarizing, perceptions of farmers revealed both differences and compliance with historical climate records. Certain changes such as failed springs were noticed more strongly by farmers than the general long-term decrease of autumn rainfall over the last couple decades. Additionally changes in spring rainfall were associated with stronger impacts for agricultural production systems than changes in autumn rainfall. However, differences between farmers perceptions and meteorological evidence might also be explained through *confusions* between perceived changes in rainfall, temperature and seasons with changes in the sensitivity of farming systems and different impacts for agricultural production systems on farms in Corangamite. Thus, as geographic areas and agricultural production systems have varied vulnerabilities to climate related risks and are affected differently by climate related impacts, farmers perceived changes in climate differently (Schattman et al. 2016). Therefore, direct personal experiences of farmers, such as through losses in crops or water shortages, did not only influence the degree of self-awareness of exposure and sensitivity to local climate risks but also influenced farmers general risk perception (Menapace et al. 2015; Rickards 2012). However, interviewed sectoral experts and literature furthermore suggests other factors beyond local shifts in climate influencing farmers risk perceptions including socio-economic differences or political influences which are presented in the following.

**Socio-economic factors**

According to interviewed sectoral experts, differences in economic farm household conditions including incomes, social environments and the willingness of farmers to gain climate change related information influence farmers risks perception and their understanding of changing business risks under climate change.

Also Emtage et al. (2006) suggests that farmers vary considerably in their socio-economic characteristics, values and capacities. A study in Australia (see Hogan et al. 2011) revealed that farmers perceive and assess their situation and their risks associated with climate change according to the material and social circumstances in which they found themselves and the extension to which they saw themselves as being affected (Hogan et al. 2011; Latour 2004). Brumby et al. (2011) argues that the interplay of climate and socio-economic factors can exacerbate already existing vulnerabilities of farmers. So is the financial viability of farms in Australia greatly affected by climate variability and associated impacts on production as well as changes of price markets or input costs (Berry et al. 2011a). Younger farmers often face other economic challenges compared with that of earlier generations as terms of trade continue to diminish while other vulnerabilities of farm households and risks deriving from climate change increase. This is further exacerbated when the financial viability of farms are already affected. Thus, if a farm household already faces economic instability, climate extremes can intensify financial stress thus impacting risk perceptions of younger farming generations (Schattman et al. 2016; Rickards 2012; Hogan et al. 2011). However, the vulnerabilities and opportunities of a farm household varies over time at different stages of life and business growth cycles according to their own capacities, needs and goals (Inwood and Sharp 2011). People who are socially or economically disadvantaged tend to be more sensitive to climate change related impacts and thus typically perceive risks differently than people in a stronger economic position (Keywood et al. 2017). Sensitivity is usually the result of social processes, inequalities in socio-economic status, income and the exposure to risk. However, Richards (2012) argues that risk perception is highly subjective as her study revealed that farmers in north-west Victoria who reported to be in a relatively strong financial position admitted to feel highly stressed under climate change.

According to Cutter el al. (2012), social norms, social capital and networks shape people's perception of climate related risks and associated vulnerabilities to climate change as they influence behaviours and actions before, during, and after extreme events. Social norms refer to rules of behaviour, driven by neighbourhood, cultural and familial groups that can structure actions to climate change while social capital refers to social engagements within communities that bonds people and generates a positive collective value. Social capital and resources can facilitate the share of information, expertise and resources regarding climate change and associated risks among stakeholders, determine behaviours regarding coping and adaptation strategies to local climate conditions and therefore influence local resilience to climate change related risks. Social networks and relationships do not only shape farmers perceptions of risks, but communities with strong social networks are also considered to be better prepared for managing climate extreme events due to better access to information and social support. However, when social networks lack open-mindedness, innovation, diversity or the inflow of expertise they might impede climate change adaptation (Cutter et al. 2012; Crabbe and Robin 2006; Brenkert and Malone 2005, Buckland and Rahman 1999).

IP13 also summarized how social networks can influence and impede discussions about climate change related risks:

> "Adaptation to climate change is a conversation killer, around farmers and rural community. If I start talking about climate change, they door starts swinging in the pub and everybody stops and the piano also stops playing. I know that people who give a presentation title their presentation differently and not climate change. There is something psychological going on there".

Besides social networks and norms, also a social change within the agricultural sector in Australia including demographic variables, level of education/information and gender issues forms farmers risk perceptions. The majority of farms in Australia are owned by family-operated businesses although the number of farming families declined by 22 % over the last 15 years. There are several reasons why families, but especially younger people are leaving agriculture such as personal (e.g. retirement pension), economic (e.g. low commodity prices) or environmental (e.g. more dry spells) factors. An increasing trend towards ageing farmers is consistent with the overall trend among Millennials (young people born between 1982 and 2000) who tend to delay marriage, parenting or return to the farm after going to the university (ABS 2003). Also the influence of mass media and use of technology plays a role in influencing farmers risk perceptions. Younger, tertiary educated, left of centre and urban-based Australian people tend to be more concerned about green issues as older and rural people (Pakulski and Tranter 2004; ABS 2003) and tend to mostly agree that climate change is real and that human actions to mitigate further emissions is urgently needed (Tranter 2011). Millennials also tend to have different views on education, work and family pattern than these from previous generations, which is framed by political, economic and cultural processes coming along with a transition and change in the agricultural sector as well (Wyn and Woodman 2007). Furthermore, differences in age and intergenerational family issues influences farmers perceptions/worldviews, farming goals and management practices due to different time horizons of younger and older generations and different thinking, views and goals. Also disagreements in terms of timing of succession between generations can be a source of challenge for families, making intergenerational family issues as one factor which influences capacities to adapt farms to changing climate conditions (Schattman et al. 2016; Hogan et al. 2011; Rickards 2012). Also education but especially people's willingness to gather information about climate change plays a role in farmers perceptions, structuring attitudes and behavioural intentions. Typical sources of information for environmental issues and climate change are natural resource communities such as Landcare networks or catchment management communities through newsletters, presentation or other forms of information sharing (Sulemana and James 2014).

According to Rickards (2012), climate risk perceptions are also influenced by gender issues. Women are more likely to favour environmental protection over economic growth and tend to take climate change more serious than man (Tranter 2011). However, strong cultural norms within rural communities often pretend what is viewed as *appropriate* to discuss and how to express to others which can affect discussions about climate change and lower capacities to freely express certain worldviews and take actions upon (Rickards 2012).

However, despite differences in farmers perception, concerns around environmental issues and degradation are increasing in the last decades within the Australian agricultural community (Sulemana and James 2014). The following graph summarizes socio-economic factors influencing farmers risk perception.

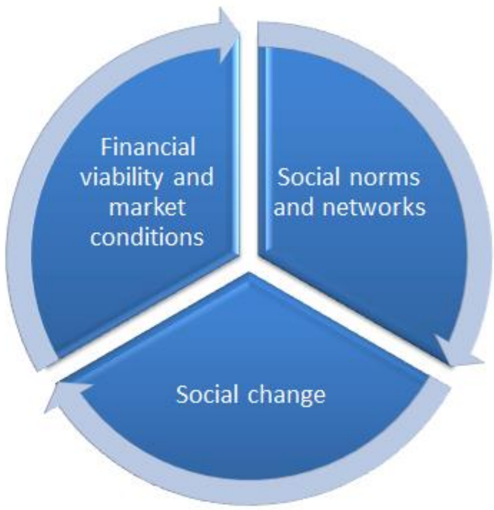


**Figure 35: Socio-economic factors determining farmers risk perception**
(Own representation based on interviews with sectoral experts and literature)

**Political influence**

According to several interviewed sectoral experts, farmers are traditionally conservative with a tendency to vote for the right wing. Several interview partners pointed to the fact that Australia's energy sector and wealth is strongly based on coal mining thus explaining the low interest especially among the right wing supporters on national level to discuss climate change issues and mitigation polices in reducing emissions. Thus, interview partners raised concerns about Australia's *unwillingness* to discuss climate changes issues which not only influences farmers perceptions and view on climate change, but also influences behaviours and adaptation efforts.

According to Niles and Mueller (2016), how individuals perceive climate related risks including climate change is linked to whether individuals support climate policies. Also Australian political leaders influence public opinions and concerns including climate change and other environmental issues (Tranter 2011). However, policies and political leaders do not only influence perceptions and opinions, but furthermore people's willingness to address environmental issues, typically influenced by partisanship. The support base of environmental concerns is generally much stronger among Labour and Green supporters, mostly from the left political spectrum than those on the right (Tranter 2011; Tranter 1996).

Beside political influences based on party affiliations, the long history of bad government-farming relationship in Australia was identified by the interviewed sectoral experts to influence farmers risk perceptions. Farmers have been subjected to many different changes in policy, information campaigns and incentives in the past why interviews partners assumed that farmers are becoming more *relaxed* or even cynical about messages of climate change and associated perceived risks such as carbon taxes. One example mentioned was Australia's incentives for clearing trees for modern efficient farming some decades ago while farmers nowadays receive subsidies for Landcare and planting trees again. Several sectoral experts are also raised concerns about the massive policy shift away from drought support and associated subsidies for farmers which may also influence changes in risk perceptions of farmers. While droughts have been historically treated as disasters in Australia, the Australian Commonwealth Government removed droughts from the Natural Disaster Relief Arrangement in 1989 and established a Task Force to investigate alternative arrangements for drought assistance (RIRDC 2007; Gow 1996). This policy changes was implemented due to two main reasons: first, there was no objective basis for deciding between a *normal* and an *exceptional* drought. While droughts are seen as freak of nature, a failure of historical rainfall patterns and a disastrous run of seasonal conditions in the traditional agricultural viewpoint, the scientific view rather attempts to quantify droughts in terms of negative deviations from the parameter mean like rainfall, production, soil moisture, vegetative cover or income. Second, treating droughts as a disaster was often criticised as it might discourage farmers from restructuring their production processes to better suit drier conditions and thus to reduce farmers incentive to improve drought adaptation management practices. Therefore, the policy aimed to treat droughts as a manageable risk element of farmers decision making processes (RIRDC 2007; Gow 1996).

Additionally, sectoral experts as well as farmers themselves suggested the influence of media on their risk perception. While interviewed sectoral experts raised concerns about the governmental control of the media in parts and clear agendas of not wanting the public to accept the fact of global warming, interviewed farmers focused more on a change in news coverage. Some farmers assumed that disasters (from climate change) around the globe hadn't changed but rather the global-wide network, which created a new degree of awareness. IP4 summarized this in the following passage:

> "[W]e hear a lot more bad things we wouldn't have heard about in the past".

A study (see Bacon 2011) conducted in 2011 from the University of Technology in Sydney analysed 3971 articles dealing with climate change policy in Australia. The study revealed that due to Australia's high dependency on fossil fuels and its ranking among the highest per capita greenhouse emissions in the world, climate change is a hot topic in the Australian media. This is not so much because climate change poses a threat for the planet but more because of its tense political struggle in terms of response strategies in the Australian government. Media coverage remains still a main tool for the government to retail politics. More than half (54 %) of the analysed articles were political sources and only 2 % from non-government organisations typically who play a prominent role in campaigning for climate change adaptation. According to the study, only 18 % of the articles were *positive* in terms of mitigation policies and actions to reduce greenhouse gas emissions (Bacon 2011).

**Potential key factors determining constraints in adaptation**

According to Richards (2012) potential vulnerabilities can not only arise from farmers risk perceptions, but also from several other features creating barriers to their capacity to adapt which generally vary across individual farmers, farm systems and regions. Thus, identifying factors constraining adaptation can help in addressing them within a broader risk management framework (Rickards 2012).

Interviewed sectoral experts identified several factors potentially determining constraints in adaptive capacities on farm-level. This included *internal and external factors* such as a psychological distance and uncertainty regarding climate change related risks/impacts, a lack of capacities and asset, dependencies or farmers attitude, which are presented in the following graph.

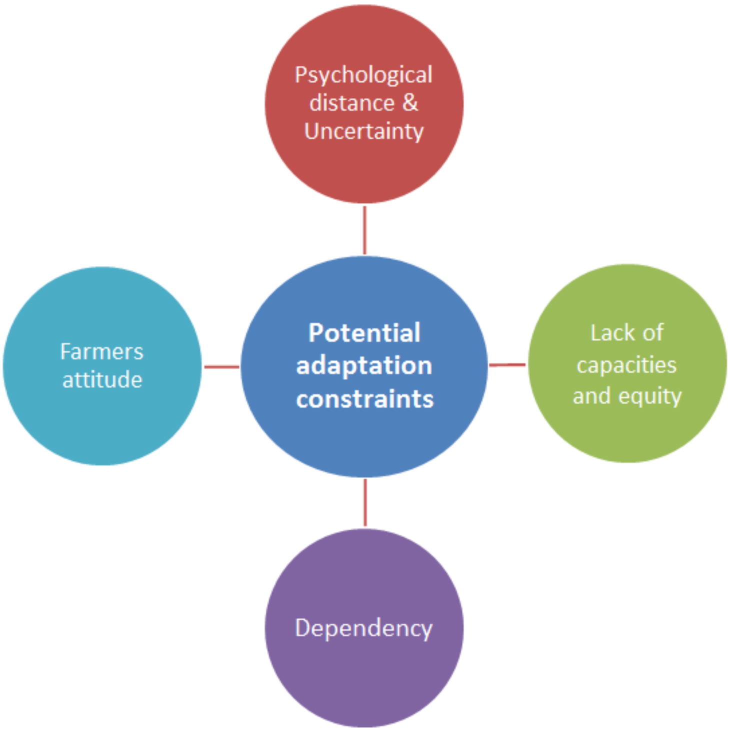


**Figure 36: Potential constraints in adaptation to climate change**
(Own representation based on interviews with sectoral experts and literature)

**Psychological Distance & Uncertainty**

According to interviewed sectoral experts, uncertainties about future climate scenarios and developments make it harder for farmers to take decision nowadays to prepare for the future. Due to the strong natural seasonal, yearly and multi-decadal variability of Australis climate, the focus is more on short to mid-term response strategies while planning for the long-term future is behind the planning horizon of most farmers. However, interview partners suggested that including climate scenarios into the decision-making process would help farmers to minimize potential risks and increase business resilience in the long-term, especially if larger investments are planned such as buying new farm land.

Climate change is psychologically often perceived as distant while the less distant the issue is perceived the higher is generally the level of concern. This in turn usually leads to a rethinking of farming activities and increases the wish to find adequate adaptation strategies to climate change (Spence et al. 2012). However, long-term planning might be impeded due to a high level of uncertainty about future climate change including a wide range of financial outcomes for farmers and relatively small benefits from adaptation when changes in climate are less substantial than expected (Thamo et al. 2017). Schattman et al. (2016) suggests that the conceptual abstractions of future climate change gives greater weight towards concrete and immediate response activities in the near future than long-term adaptation planning and especially mitigation focused activities. Personal long-term goals related to climate change also tend to be less specific as future impacts cannot be experienced directly such as salient issues in daily life (Pahl et al. 2014; Cary et al. 2001). Also future events that impact societies at large are commonly perceived as more abstract while the near future as well as personal events are more concrete (Trope and Liberman 2010). According to Pahl et al. (2014), "[f]rom an evolutionary point of view it is not surprising that individuals and societies have difficulty understanding and dealing with the climate change challenge [as] [t]he human brain developed in a time when humans were largely concerned with their direct environment (e.g. foraging for food) and immediate dangers (e.g. from predators)".

Also the time lines which are commonly used by climate scientists and other researchers to describe future changes in climate, such as scenarios for 2050 or 2100, are too far removed from personal experience of farmers and not conceptually accessible to most people (Pahl et al. 2014). People on average can conceptualize the future for about 15 years with limited abilities to imagine the future beyond (see study Tonn et al. 2006), thus making the standard timelines of scientists not meaningful to the general public. The impacts already happening compared to the temporal dimension and far-reaching impacts of future climate change create a temporal distance and a time lag between present and projected future impacts. Furthermore, researchers are often perceived as theoretically oriented and therefore disconnected from reality (Otto-Banaszak et al. 2011). Beside the limited utility in long-term climate projections for farmers, also the high uncertainty of models at a finer spatial and temporal scale in terms of regional climate change projections bears many uncertainties which limit decision making among farmers (IPCC 2007; Giorgi 2005). However, according to Pitman and Perkins (2008) also if reliable projections on the global, continental and regional scale remains a major scientific challenge, climate projections can help in assessing possible pathways and impacts on biophysical, human or economic systems and support decision-making under future climate change.

Human response mechanisms furthermore have their own temporal dynamics and constraints such as election cycles, community planning and cost-benefit analysis (Pahl et al. 2014). Also the way of access to climate change information plays a role as information on general climate change impacts are generally perceived as more abstract and distant compared to locally specific information which creates a sense of concreteness. However, despite the perceived distance to climate change and uncertainties regarding climate projections at local and regional scale, avoiding the issue of climate change is one of the most urgent social risks today especially in terms of mitigation (Schattman et al. 2016; Spence et al. 2012).

**Lack of information, capacities and equity**

According to several interview partners, a lack of information and capacities of farmers to understand and deal with climate change as well as a lack in farm equity potentially lowers farm resilience. Especially, uncertainties in the understanding of probabilistic forecast were mentioned several times by sectoral experts, thus triggering decisions which may not suit later seasonal climate conditions. Furthermore, a lack of farm equity was considered by sectoral experts to give less room for adaptation. According to interview partners, farm family equity also depends on family structures and succession plans between generations which may be affected by a massive social change shown by the Millennials.

Also according to Richards (2012), limitation for successful adaptation includes inability to understand the nature of climate change, including sources of certainty and uncertainty. Studies from Victoria show some large differences between the understanding of climate drivers, the awareness of climate information sources and the literacy of forecasting (Graymore et al. 2016). Also a lack of adequate knowledge and information about system characteristics (e.g. risks of different adaptation approaches and their interaction) as well as a lack in time and energy required for strategic planning and constant adaptive management present limiting factors for adaptation (Rickards 2012).

Furthermore, the implementation of specific adaptation strategies can be constrained by access to financial capital and a lack in farm equity or debts that impede farmers ability to take on some financial strains for adaptation strategies (Klein et al. 2014; Rickards 2012). Also if many Australian farm businesses have high equity, both in aggregate and percentage terms due to diversification with portfolios, on-farm enterprises, off-farm investments or spatially diversification, a lack in financial resources and access to services are generally considered as major constraint for adaptation (Hogan et al. 2011; Martin et al. 2005). Also if contract debt is a normalised business strategy to improve the long-term viability of a farm, it bears certain risks for the farm business. According to Rickards (2012), "[a]s a fixed and often growing cost, debt greatly increases the vulnerability of a business and associated family to any unfavourable climatic or economic conditions". Also the study of John et al. (2005) suggested that climate change is projected to reduce the financial capacity for adaptation responses due to reductions in financial liquidly. Thus, making larger capital investments (e.g. cropping gear or additional farmland) may get more difficult to undertake especially when increasingly unfavourable seasons inhibit capital replacements and thus affect farmers abilities to take certain decisions (John et al. 2005).

**Dependencies**

Several interviewed sectoral experts raised concerns about the reliance of farmers on certain business sectors such as private seed companies which were associated as a market failure for farmers. According to sectoral experts this is especially concerning when seed companies only focus on the promotion of higher production rates but at the same time hide information such as the life time and replacement cycles of pastures. This means higher frequencies in pasture renovation processes to avoid running into feed gaps and thus, might trigger locked-in systems in which farmers regularly have to buy new seeds in the long-term.

According to the International Network for Seed Based Restoration (2017), the appropriate choice of seeds play a major role to survive unfavourable climate conditions. However, the privatization of seed companies, poor adaptation of new varieties in parts and the large number of varieties offered on the market can make it more difficult for farmers to choose the right variety which are better adapted to extreme conditions (International Network for Seed Based Restoration 2017).

Besides the reliance on certain business sectors, the study from Rickards (2012) revealed that vulnerabilities perceived by farmers in Victoria also arise from the reliance on others' people skills, good will and integrity. With the increased use of contract labour in Australia, farmers rely on labours availability, timely turn up and prices which can impede short-term responses especially during climatic extreme events. If contracted shearers refuse to touch flyblown sheep (in which maggots infest and decompose the sheep's flesh) at a time when sheep especially needed shearing or a harvester is not available during a dry window of opportunity, the farmers might find himself behind the timetable and therefore in a vulnerable position especially under increasing frequencies of extreme events (Rickards 2012).

Another major vulnerability in many farm households is their dependency and exposure to volatile global price markets, both in selling their goods and purchasing inputs. Australian farmers have experienced a long period of declining terms-of-trade with high input prices commonly perceived as enduring concern among farmers which can especially be worsened by poor climatic conditions and other factors (Rickards 2012). Also dependencies on governmental regulation can lower adaptive capacities of farmers and increase vulnerabilities such as Australia's shift away from drought support (Oppenheimer et al. 2014; RIRDC 2007).

**Farmers attitude**

Interviews with sectoral experts revealed that farmers attitude and individual's value systems do not only influence climate related risk perceptions, but may also hinder adaptation to climate change. These *cultural kinds of resistance* and cognitive protection against pessimistic messages of farmers were considered as factors which may potentially hinder consideration and discussions about climate change impacts and adaptation. According to interviewed experts, a barrier against negative messages might come from a subconscious concern in terms of business risks (e.g. mitigation policies such as carbon taxes) or unattractive climate projections (e.g. increasing extreme heat events) which would increase the need to act or to rethink current farm activities and strategies to better plan of the future. This might be especially challenging for farm businesses with low equity, passed debts or uncertain farm succession. The interviewed sectoral experts furthermore pointed to the general attitude of farmers of being more pragmatic than problem oriented while their desired optimism for farming keep farmers sceptical about climate change messages. This optimism is also reflected in the quote of this farmer:

> "But we are optimistic; you have to be optimistic when you are a farmer, so we are always looking at the bright side" [IP5].

This optimism for farming is also represented in the online survey, as 42.5 % of the interviewed farmers stated to not think that farming would become unsustainable with increasing climate variability while 42.5 % of the interviewees were unsure about it. However, almost 80 % of the interviewed farmers either fully agreed or agreed that adaptation to climate change is important as risks are increasing with almost half of the farmer planning further adaptation strategies in future.

Despite assessing farmers optimism as generally understandable in the face of Australia's high climate variability, the interviewed sectoral experts nevertheless remained worried about farmers who deny dealing with climate change related risks especially in the long-term future.

However, Rickards (2012) points to the importance of optimism as it is considered an important source of motivation and provides a mental advantage especially during tougher times such as droughts (Rickards 2012). Nevertheless, more optimistic people are generally less concerned about the environment, especially among climate sceptics as more optimism is associated with less guilt, less perceived responsibility and lower behavioural intention. Thus, despite optimism being a powerful motivator to deal with threats it may change response to preparedness demands and therefore be negatively associated with an active response to environmental changes (Pahl et al. 2014).

## 6.2. Managing Climate Related Risks

This section discusses suggested risk management strategies based upon interviews with sectoral experts and literature for the study area.

Climate scenarios for Australia and for the study area project a further increase in temperature depending on emission pathways (see figure 27, chapter 5) especially along the southern coast of Australia, due to a coupling of the temperature response with reduced rainfall (Pitman and Perkins

2008). Low emission scenarios for south-east Australia suggest a further temperature increase between 0.3 to 1.5°C while high emission scenarios suggest a temperature increase up to 4°C by end of the century compared to the 1980-1999 average (Griggs et al. 2012). Furthermore, models suggest more frequent, intense and spatial expansions of dry spells and droughts under higher temperatures, a further increase in hot days and a decrease in cold days (BOM/CSIRO 2016; Climate Change Authority 2012; Pitman and Perkins 2008).
However, the range of uncertainty for projected rainfall and the magnitude of change remains large (see figure 28, chapter 5) (Griggs et al. 2012). Literature furthermore suggests a reduction in rainfall for south-east Australia, dependant on emission scenarios by up to 10 % to the end of this century and an increase in rainfall intensity due to a warmer atmosphere (BOM/CSIRO 2016; Climate Change Authority 2012; Griggs et al. 2012; Pitman and Perkins 2008).
Also if the precise extent, timing and location of climate change impacts cannot be known with certainty due to the high complexity of the climate systems itself, impacts and risks will depend on a) how much and how rapidly the climate warms and b) on human-ecological exposure and vulnerability. However, higher temperatures and declines in rainfall will have large effects for the agricultural sector in the study area and trigger risks for farmers such as a reduction in the productivity of land, crops and livestock (Climate Change Authority 2012).

Interviews with sectoral experts revealed that the danger of climate change for farmers lies more in the increase of extreme events rather than the gradual change of climate. Farmers exposure to increasing climate related risks includes a shift in the risk profile coming along with a higher vulnerability of agricultural systems which requires appropriate risk management strategies. Many adaptation strategies closely follow general principles of good management strategies for farming such as adaptation contributes to maintain a profitable farm and a healthy environment by reducing risks and making use of opportunities. Therefore, sectoral experts suggested adding climate change as a factor within the decision-making process by planning for a more variable climate in the future and setting up an agricultural system that can a) survive more extremes, b) help minimize farm vulnerability and c) increase farm/business resilience. Interviewed sectoral experts suggested several strategies for farmers in managing the risks of changing climate conditions. This included a) farmers interest and motivation to deal with climate change related risks, such as acquiring relevant location-specific information to enable risk assessment and therefore increase adaptive capacities and b) to develop and implement risk management strategies such as improving agronomic practices as well as diversification strategies of on- and off farm activities to spread business risks under increasing climate variability. These recommendations given by interviewed sectoral experts are discussed more in detail in the following sub-chapter.

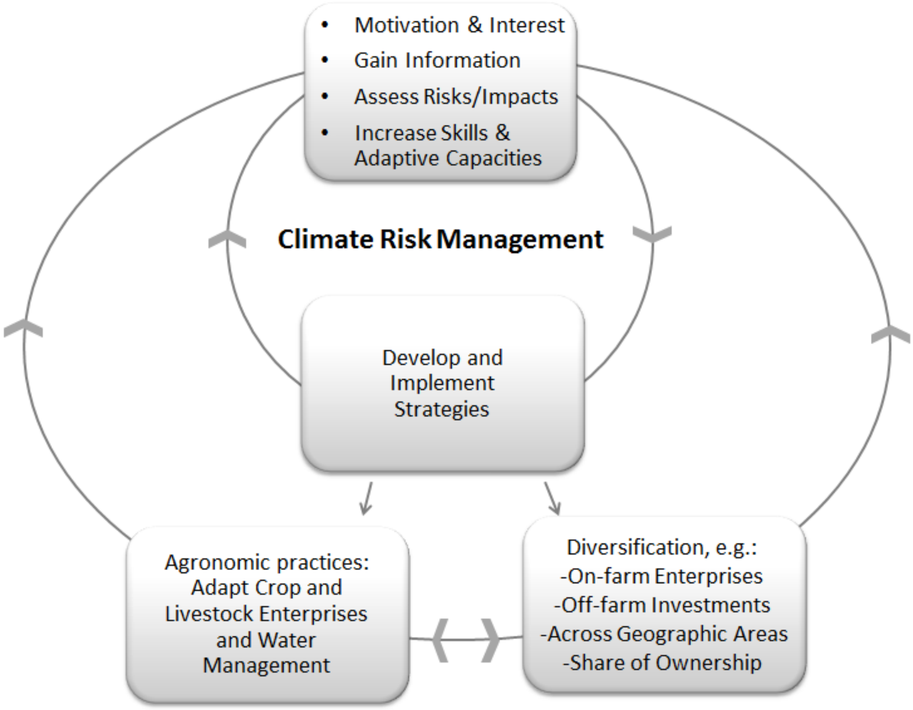


**Figure 37: Recommended climate risk management options to deal with climate change**
(Own representation based on interviews with sectoral expert and literature)

### 6.2.1. Risk Assessment and Adaptive Capacities

Most interviewed sectoral experts of this study pointed to the importance for farmers to gather climate change related information to better understand and assess changing business risks, incorporate information into the decision-making process and to improve skills. Especially improving skills in understanding probabilistic forecast was considered highly important by interview partners to facilitate adequate decision-making. Sectoral experts suggested sharing knowledge with other farmers, participating at workshops or using online information portals to increase management skill. The online survey revealed, that almost two-thirds of the farmers in the catchment already gather climate change related risk information in better understanding the fluctuating business risks and facilitate on-farm decision making processes.

The success in managing climate related risks depend on the adaptive capacity of the individual or enterprise which typically depends on socio-economic and environmental factors. Adaptive capacities, based on the capacity to cope with change, the ability to take on new challenges, use information and solve problems help enhancing farmers ability to deal and manage climate related risks to reduce vulnerabilities (Hogan et al. 2011; Berry et al. 2011b). Raising awareness and building capacities can support to overcome potential constraints in adaptation to climate related impacts (Moser and Ekstrom 2010). However, adaptation typically occurs when the farmer perceives the innovation in question as enhancement and relative advantage to prior practices in achieving economic, social and environmental goals (Pannell et al. 2006). According to Hogan (2011) and Barber (2009) incentives for farm owners and managers to adopt successful climate risk management strategies depend on different factors including the motivation and interest to change and work towards sustainable practices based on farmers risk and opportunity perception associated with change but also on farmers health and ability to plan, learn and reorganize. Other factors include access to capital, enterprise mix and projected enterprise profitability, farm location, accessibility/acceptance of new technology, attitude to risk, expectations of government intervention, off-farm opportunities or the level of management skills (Gunaskera et al. 2008).

Therefore, Crimp et al. (2016) suggests that understanding the changing nature of climate risk is a first major step for farmers in assessing risks and dealing with climate change. So does e.g. a proper understanding and use of variable temporal/spatial climate information forecast support improved decision-making, increase preparedness, resolve some uncertainties and support better social, economic and environmental outcomes (Barber 2009; Meinke and Stone 2005). Hence, understanding probabilistic forecast can help farmers in better assessing fertilizer input, timing of planting dates, choice of appropriate varieties, estimate the number of stock days of feed available, adjusting stocking rate or prepare on-farm infrastructure for dry spells (Ash et al. 2007).

Effective communication is typically considered as critical element in promoting climate risk assessment to support adaptive capacities (Harvey et al. 2012). Communication of local and regional risks and impacts of a changing climate does not only help in reducing the psychological distance to climate change but also helps in reconsidering varying risks and eventually promote sustainable farm strategies (Spence et al. 2012). Nowadays climate change information is increasingly being communicated, discussed and shared across different stakeholder groups thus helping to raise awareness, identify problems and assist in decision-making (Harvey et al. 2012; Johnson 2011). Additionally, *social learning* through the share of knowledge in a participative form increases adaptive capacities and improves management skills which has received increasing attention in the last couple years (Otto-Banaszak et al. 2011; Collins and Ison 2009). Also the shared dialogue across farmers supports pooling personal experiences, encourages the learning process through reflection/awareness building (e.g. share of response strategies to extreme events) and therefore helps to increase adaptive capacities to overcome potential barriers constraining the implementation of adaptation (Keywood et al. 2017).

Farmers have different options in gathering information on climate related risks which supports risk assessment and help to increase adaptive capacities. An example of this is participating at local community groups, programs, professional networks and conferences to share experiences/ responses which help in creating new partnerships in a localised context (Harvey et al. 2012). Also private agronomists can provide farmers with skills, knowledge and options to continue adapting their farm practices to climate variability and change (Graymore et al. 2016). Furthermore, there are several online platforms and decision-support tools/programs available in Australia aiming to help farmers in managing climate risk. This provides them with the best up to date climate tools, products, practices and seasonal outlooks to help farmers understanding and integrating that information in their farm business operation. For example, the *Climate Champion Program* from the Australian Bureau of Meteorology (BOM) aims to enable Australian farmers to manage risks and exploit opportunities from a variable change in climate. It also gives climate researchers a chance to interact with farmers and to get feedback about what is needed from research (Grains Research & Development Corporation 2017; Hewitt et al. 2015). Also the integration of local knowledge and skills of farmers with external scientific and technical knowledge is considered as an important dimension of climate risk assessment and adaptation, especially through participatory methods of all different stakeholders (Cutter et al. 2012). Furthermore, social networks and relationships with neighbours and friends are often referred as an important source of support, knowledge and skills as experiences from other farmers can provide a useful lesson in learning and to question own decision-making processes (Rickards 2012).

### 6.2.2. Impacts on Enterprises and Ecosystems and recommended Adaptation to Climate Related Risks

This section presents impacts of a changing climate on livestock, pasture, crops, soils and water and discusses recommended adaptation strategies by interviewed sectoral experts and literature review.

**Livestock and pastures**

The interviewed sectoral experts suggested a higher vulnerability of agricultural systems due to changing seasons and new threats emerging earlier in the season thus affecting production and financial outcomes for farmers in the Corangamite catchment.

According to Rivera-Ferre et al. (2016), livestock production is not only an important source of greenhouse gas emissions (playing a major key role in the climate change debate), but at the same time production is highly vulnerable to changing climate conditions. The most direct impacts of climate change on livestock systems are linked to extreme temperatures triggering heat, water and feed stress on animals. Indirect impacts mostly refer to seasonal changes of the feed bases including higher variability and/or reductions in the availability and quality of pastures and crops. Heat stress reduces productivity (e.g. meat and less milk with lower quality), reproduction rates and animal health in the beef, sheep and wool sectors which can lead to mortality in extreme circumstances (McKeon et al. 2009).

Not only short-term climatic events have impacts on livestock and pasture production, but also slower processes from creeping shifts of Australia's climate zones (figure 31/32) can have clear impacts for farming systems and management requirements (Collis 2016). Although the effect of elevated temperatures on pastoral systems is expected to be positive by up to 2°C in temperate regions, increasing seasonal rainfall variability and especially declines in rainfall and soil water availability impacts pasture and livestock production (Easterling el al. 2007). Additionally any reduction in pasture growth and production results in less grazable biomass and a potential reduction in livestock profitability and numbers (Thamo et al. 2017). Animals may also experience growth constraints due to limited grazing resources (Johannesen et al. 2013). Although impacts on net primary livestock productivity vary between different integrated agricultural-climate models, projections suggest an average productivity decline of 9 % for 2030 and 7 % in 2050 for southern Australia. However, declines in profit are mostly expected at drier locations, with larger differences across locations rather than between livestock enterprises (Moore and Ghahramani 2013). Also spatial shifts in the distribution of pests and diseases due to a warmer environment (flystrikes or cattle ticks) are causing injury to animals (IPCC 2007). The following table summarizes direct and indirect impacts of climate change on livestock systems both from mean changes in climate as well as from extreme events.

**Table 11: Some direct and indirect impacts of climate change on livestock system**
(Based on interviews with sectoral experts and Rivera-Ferre et al. 2016)

| Direct Impact | | Indirect Impact | |
|---|---|---|---|
| **Mean climate changes** | **Extreme Events** | **Mean climate changes** | **Extreme Events** |
| • Chronic temperature stress<br>• Water stress<br>• Reduced feed intakes<br>• Decreased production and reproduction of livestock | • Temperature stress events<br>• Lowered productivity and reproduction of livestock<br>• Impacts on animal health<br>• Livestock mortality and distress sales | • Variation of the quality, quantity, seasonality and distribution of pastures<br>• Variation of the quality and quantity of fodder (stover, pastures)<br>• Increased incidence of livestock pests and disease<br>• Decreased productivity of livestock<br>• Increased cost of feed and water<br>• Changing enterprise viability due to extra costs<br>• Move to lower productivity but higher heat stress resistance breeds<br>• In dry margins, grazing may increase over cropping | • Pasture and fodder shortage<br>• Damage to standing feed<br>• Negative impacts on livestock numbers<br>• Increased volatility of feed supplies and their price<br>• Increased cost of feed and water<br>• Increased variability in ground-cover<br>• Soil erosion and vegetation damage<br>• Destruction of infrastructure<br>• Increased costs through insurance |

Although wet years in between remain challenging for farmers in the study area, interviewed sectoral experts suggested that an increase in the thermal heat load including more frequent and earlier heatwaves and changing precipitation pattern requires farmers to plan for more variable seasons. Providing enough shade and water for animals, planning for higher risk of feed gaps, adjusting lambing and joining times and maintaining good body reserves of animals were considered ideal with a changing climate. In terms of pasture management, adjusting and diversifying pastures varieties/compositions that suit better drier conditions, making use of rotational grazing and introducing summer active crops were frequently mentioned as well. By increasing on-farm storing capacities farmers can furthermore be better prepared for drier times and reduce their risk to be exposed to high prices of feed supply during times with high demands. However, IP21 assumed that "[i]n the longer term we will probably see a trend of lower input systems which means for example lower stocking rates to feed your animal, systems which don't take as much advantage in good years but are not as exposed in poorer season and thus are less risk prone by trading off some profitability".

According to Easterling et al. (2007), changing management practices at farm level is a key component in adapting agriculture to climate change. Improved on-farm infrastructure such as shelters as cooling systems and water pipe systems are needed to ensure adequate water supplies and mitigate increasing risks of heat-stress related reductions in productivity, fertility and increased mortality (Howden et al. 2007). Technological options may include breeding strategies (e.g. adoption of high-yield breeds or selection of breeds with improved feed-conversion efficiency and higher heat- and disease-tolerance) and information and communication technology to gain greater understanding of climate and livestock interactions. Similarly to statements of interviewed experts, the study of Rivera-Ferre et al. (2016) pointed to certain trade-offs that farmers need to take to cope with difficult climate conditions such as changes toward breeds that tolerate higher temperatures which may show lower productivity potentials. This may require changes in the skills and knowledge base as well as practical changes (Rivera-Ferre et al. 2016).

According to Howden et al. (2007) adaptation to climate change also includes adjustments in management including to continuously match stocking rates with pasture production. Especially destocking *in time* to leave enough feed in the paddocks to avoid soil erosion can help farmers in better managing climate risks. An example of making decisions in time means selling stock before a farmer is forced to either buy feed/sell stock in a market during times when everyone else is in the same situation and prices are high for fodder and low for animals (Hewitt et al. 2015). Reductions in stocking rates lead to reductions in the amount of extra feed to sustain livestock and helps in keeping certain levels of groundcover that guards against soil erosion under climate change (Thamo et al. 2017). As climate change will affect the natural resource base of livestock production including the productivity of feed crops and rangeland, feeding strategies, modification of grazing/reproduction times or using adapted forage crops can help dealing with climate related risks (Weindl et al. 2015; Howden et al. 2007). Common strategies in pasture production include adjustments in pasture types, varieties/composition, fertiliser rates, allocation of land according to soil types or rotational sequences. A dryer and warmer climate in the study area will require changing to pastures that are better adapted to higher temperatures, water constraints and also changes in soil fertility. Providing additional nitrogen is also important. As seed dormancy/germination and pasture growth are especially sensitive to reductions in rainfall, breeding may result in pasture systems to suit for future conditions. Not only do new pasture species help to suit better environmental conditions, but the grazing management itself needs to be adjusted in assisting the pasture establishment (Barber 2009). While some adaptation strategies derive from local traditional knowledge developed over decades of co-evolution in changing environments, other strategies require more exogenous knowledge and inputs that need to be implemented. This includes research in understanding climate and livestock interactions or access to technologically-advanced breeding strategies (Rivera-Ferre et al. 2016). There are several freely available sophisticated models that aim to help farmers in their decision-making based on potential future pasture productivity and stocking rates. These models provide a range of possible outcomes and offer indications for the lower to upper bound expectations of pasture availability under the most likely climate scenario (Barber 2009). The following graphs summarises suggested risk management strategies for livestock for different timescales and levels of adaptation.

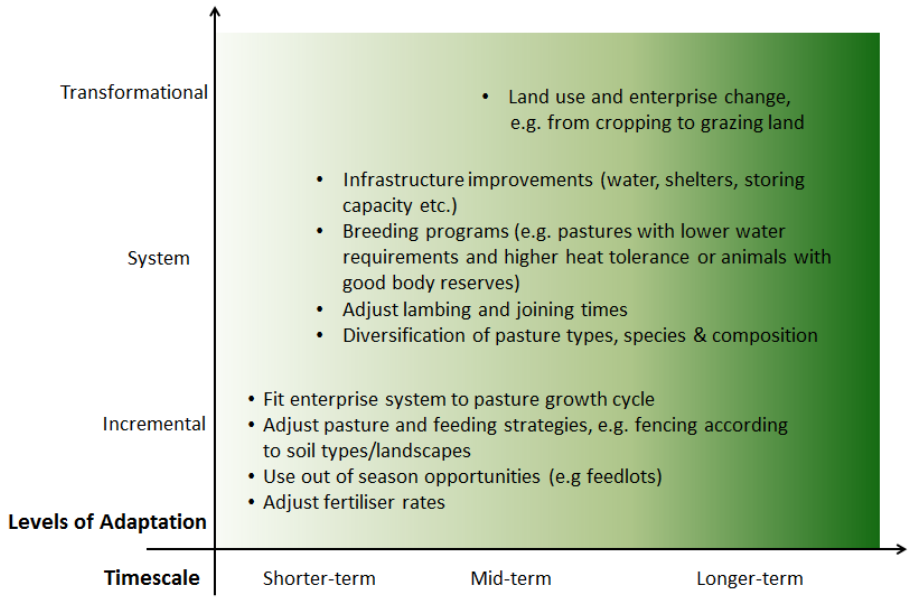


**Figure 38: Possible management strategies for livestock and pastures under climate change**
(Own representation based on interviews with sectoral experts and literature, e.g. Howden (2007))

**Crops and soils**

According to the interviewed sectoral experts more and earlier heat days in the season and changing precipitation pattern trigger increasing stress on crops/soil, thus impacting productivity and requiring adjustment in farm systems. Beside some benefits of the drying climate for the study area such as more viable cropping options, interview partners pointed to the projected declines in crops yields in the mid to long-term future if farmers do not adapt to the changing environmental conditions. Therefore, the interviewed sectoral experts suggested that adapting crop and soil management to increasing climatic variability and extreme events can lower climate related risk and help making use of opportunities by operating closer to the production potential. These may include going for better adapted varieties to changing seasons and higher/extreme temperatures with less water requirements, adjusting sowing practices and the crop calendar to changing climate conditions or improving weed control programs. Interviewed experts furthermore suggested making crops more flexible by incorporating seasonal climate forecast such as adding nutrients during good seasons and holding back expenditures during poor seasons. Also the use of conservation methods such as minimum or zero tillage to store soil moisture, stubbles retention and maintaining soil cover by protecting resources were recommended in dealing with increasingly variable climate conditions and an increasing risk of dry spells in the study area.

According to Collis (2016), Australia is in the frontline of climate change impacts as crop yields have been among the most affected compared with other grain-exporting countries. Yields are determined by weather, management influences and stress factors such as pests and diseases (Schauberger et al. 2017). Rising temperatures, higher risks of earlier extreme heat events and changing precipitation patterns bring changes in the profitability of different crop types and changes in the diseases risk for crops (Collis 2016). Temperature stresses for plants can arise from above optimum average temperatures for an extended period of time between weeks to months or between one to several days with very high maximum temperatures (Barlow et al. 2015).
However, economic crop models show (e.g. see Wiebe et al. 2015) that the magnitude of climate induced yield changes differ among climate scenarios, but losses generally increase with higher emissions pathways. Impacts on production vary from slight increases in production under modest changes in climate (likely in the shorter term) to dramatic reductions on production and farm profitability with more substantial changes in climate (more indicative in the longer term) (Thamo et al. 2017). The study of Anwar et al. (2015) used different global climate models and future scenarios showing that impacts of climate change vary among cropping enterprises. An example is with wheat production which is typically considered less sensitive to climate change than other cropping enterprises showing that plants appear to have some capacity to acclimate to heat events.

Furthermore, changes in both crop biomass and grain yield are strongly associated with changes in precipitation for multiple key crops (wheat, barley, lupin, canola, field pea) in south-east Australia. Out of the five crops, field pea was the most sensitive to projected future climate changes with a decrease in yield ranging from 12 % to 45 % depending on location. Beside the rainfall amount itself, higher temperatures contribute to changes in crop productivity mainly due to advancement in flowering dates and crop phenology (Anwar et al. 2015). Climate variability and extreme events do not only impact plant growth and yield production, but also affect quality as high temperatures especially affect the protein content of grains (Hurkman et al. 2009). Climatic shocks can result in physiological damages on plants with heat shocks reducing grain number and size due to reductions in the duration and rate of grain filling (Barlow et al. 2015).

Regarding increased temperatures and elevated atmospheric $CO_2$ concentrations, impacts are considered as generally positive on grain yields within the Mediterranean environment of Australia including Corangamite, but strongly vary with seasonal distribution of rainfall. Different studies show a slight increase in yields from the combination of increased temperature and elevated $CO_2$ as long as water and nitrogen is not limiting plant growth. However, a temperature increase with limited water supply reduced yields and the yield response to nitrogen fertiliser under elevated $CO_2$ with plants likely to be less nutritious due to reduced protein levels. Thus, higher atmospheric $CO_2$ concentrations as potential plant fertiliser are unlikely to offset rainfall declines. However, despite a general simulated positive effect of elevated $CO_2$ levels for rangeland productivity, the effectiveness of $CO_2$ fertilization still remains a major uncertainty regarding the stimulation of photosynthesis in C3 crops including wheat and C3 grasses. Thus, due to discrepancies between observed and simulated wheat yield data, the range of possible outputs under future climate change scenarios should be interpreted cautiously (Weindl et al. 2015; Asseng et al. 2004).

Furthermore, the general shortening of the crop season by up to 6 weeks due to warmer winters (especially during pre-flowering) is associated with an accelerated crop cycle, less time for resource acquisition including solar radiation/water/nutrient utilization and a decline of total biomass, leading to potential yield loss (Hatfield, Walthall 2015; Zheng et al. 2012). The study of Zheng et al. (2012) revealed a large spatial variability of heat and frost events and associated flowering dates across the Australian wheat belt under current climate scenarios for 2030 and 2050 as the sowing and flowering window with a risk less than 10 % for frost under 0 °C and less than 30 % for heat above 35 °C around flowering will shift by up to two months in 2050 (Zheng et al. 2012).

Climate change also affects soil structure, stability, water holding capacity, nutrient availability and erosion thus affecting growth rates of plants. Also the reduction of autumn rainfall in combination with higher temperatures trigger reduced stored soil moisture contents, thus affecting surface runoff over winter and springs with significant impacts for agricultural production (Barber 2009).However, impacts of climate change on soils are considered as more of a slow process which are difficult to quantify (Karmakar et al. 2016).

**Table 12: Some shorter and longer term impacts of climate change on crops and soils**
(Own illustration based on interviews with sectoral experts and literature)

| Shorter term Impacts | Longer term Impacts |
|---|---|
| • Temperature and water stress<br>• Shortening of the crop season: accelerated crop cycle & advancement in flowering dates and crop phenology<br>• Reductions in plant growth and yields<br>• Reductions in grain quality, e.g. protein content<br>• Crop damage, e.g. grain number and size or mortality<br>• Reduction in soil moisture | • Variation of the quality and quantity of crops<br>• Change in pests and disease distributions<br>• Soil erosion and lower water holding capacity<br>• Increased volatility of production and prices<br>• Increased costs through monitoring programs |

Although Australian crop producers have a strong record of innovation with yields approximately doubled from around one to two tonnes per hectare since the mid-1980s across the Australian wheat belt, productivity of agricultural land may be reduced in the long-term under climate change which requires farmers to have more efficient and sustainable resources management (Thamo et al. 2017; Asseng and Pannell 2013; Turner 2011). There are many potential ways to alter crop management as either single or combined adaptation measures have the substantial potential to offset negative impacts from climate change and take advantage of positive impacts (Stokes and Howden 2008). As aforementioned, many adaptation management strategies at farm level are extensions, intensifications or further refinements of already existing approaches of climate risk management (Barber 2009; Easterling 2007).

Adaptation measures may include improvements in crop varieties, rotations, farm technology, farm practices or land-use mix of which some implementations require new investment and significant managerial changes (IPCC 2007; Howden et al. 2003). Varieties with more appropriate thermal time and vernalisation requirements and/or a higher resistance to heat days and drought can help with higher risks of extreme events and water stress (Howden et al. 2007). Benefits of adaptation however vary with crops, temperature and rainfall changes (Howden et al. 2007). Also agronomic plant breeding research and innovation play a major role in delivering plant improvements to the Australian cropping industry and therefore reducing farmers vulnerability to changing climatic conditions. A major focus lies on breeding plants that use water more efficiency with a higher heat/drought resistance (e.g. improved root structures for better water accessibility or having fewer stomata on the leaf surface to allow less water to escape from the plant), higher water logging and salt/soil acidity tolerance, disease resistance or dual grain and grazing purposes to deal with climatic stress and with changing environmental conditions. The more rapidly this research achieve results, the more likely farmers can benefit from potential opportunities to increase productivity under increasing climatic stress (Barber 2009). The study of Zheng et al. (2012) supports the urgency to accelerate the 5 to 20 year process of breeding for new crop varieties that are better adapted to changing climate conditions.

Additionally, altering planting times, improving site specific crop management including allocation of land based on soil types (precision agriculture) and adjusting fertilizer rates to maintain grain quality can help dealing with changing climate related risks (Howden et al. 2007). Soil moisture conservation can be supported by crop residue retention, use of conservation tillage, other minimum disturbance techniques or controlled traffic (Barber 2009; Howden et al. 2007). Also reduced nitrogen application for crops is considered as good management response to changing climate conditions due to reduced crop yield responses to nitrogen fertiliser under less favourable growing conditions (Thamo et al. 2017). Under current climate conditions, Zheng et al. (2012) suggested early sowing and longer season varieties as good strategy. Earlier sowing of winter crops can also help to take advantage of any additional summer soil moisture (Collis 2016). However, adjusting crop management strategies is always a risk balance act for growers. To limit the risk of heat and water stress during grain filling, farmers tend to plant rain-fed crops earlier which may however result in yield losses if frost events occur during time of flowering (anthesis) (Barlow et al. 2015).

Howden et al. (2007) furthermore suggest improving the effectiveness of pests, disease and weed management practices by using more pest and diseases resistant varieties and species, an integrated pest and pathogen management and improved monitoring programs. Also rotation with breaking crops (following lupin, field pea or canola) not only increases yields by up to 0.5t/ha but also adds nutrients to the soils due to extra nitrogen and helps with improved root disease control (Thamo et al. 2017; Seymour et al. 2012). So far, weed risk assessment and management do not consider climate change, but the integration of decision support tools may help in understanding naturalised species responses to regional climate change and support active management (Rogera et al. 2015). The following graphs summarises suggested risk management strategies for cropping for different timescales and levels of adaptation.

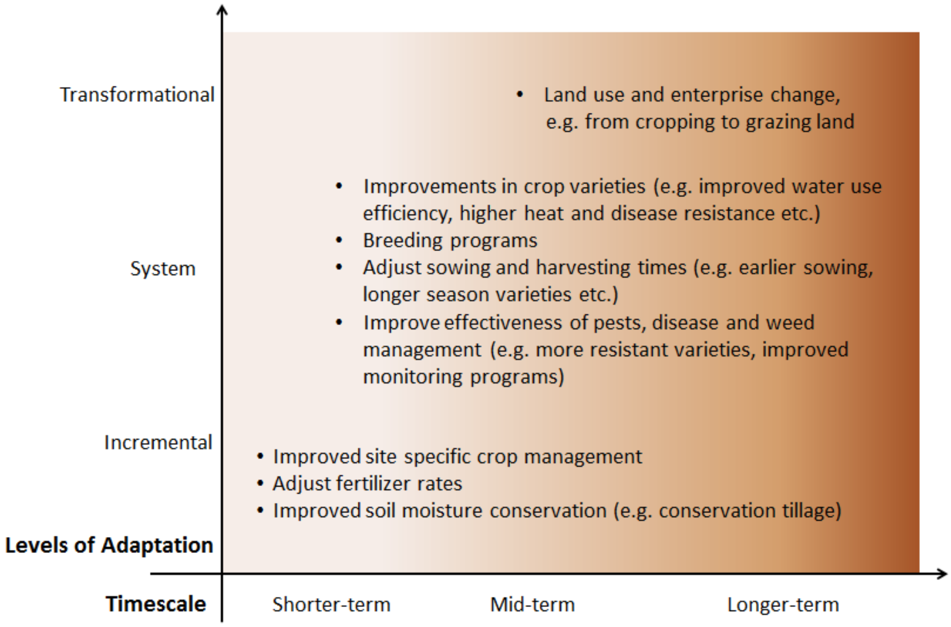


**Figure 39: Possible management strategies for cropping and soils under climate change**
(Own representation based on interviews with sectoral experts and literature, e.g. Thamo et al. (2017))

### Water and droughts

More than half of the farmers from the online survey started to fear a serious lack of water availability in future. With higher temperatures and changing precipitation pattern, interviewed sectoral experts suggested that climate change aggravates already existing water issues and is likely to affect future water security in south-west Victoria. Water stress comes along with impacts on production and financial outcomes due to a quicker use of soil moisture, decreases of runoff, drops of groundwater in some areas and slower fill up of dams. Several interview partners therefore assumed more water regulations coming up in future for Victoria to guarantee an equitable share of the resource.

According to RIRDC (2007), the Australian agricultural business sector is set up to deal with climate variability with dry conditions and droughts being an inevitable part of agriculture in the country. However, climate change will alter the frequency and intensity of droughts thus resulting in new risk profiles. This requires approaches to manage uncertainties and innovative ways to deal with a changing drought regime (Howden et al. 2014). Since climate extremes like heat waves slow down agricultural production while the costs and price squeeze typically continues, it may become increasingly difficult to remain viable after climate shocks (Rickards 2012). Higher temperatures and changes in precipitation not only result in reduced soil moisture levels, but also groundwater recharge reductions and surface stream flow reduction of drainage systems by up to 15 % for south-east Victoria as well as higher surface water evaporation rates thus impacting production (Barber

2009). Changes in the hydrological cycle due to climate change are typically combined with increasing demands for water, thus exacerbating water stress. Also unsustainable groundwater extractions might increase potential water stress risks (Oppenheimer et al. 2014). Growing competition for water resources will not only result in higher costs of water when the resource becomes scarcer over time, but can also result in more water pollution altering the hydrology, biology and chemistry of rivers, streams and lakes (Morton and Abendroth 2017; Barber 2009).
The impacts of droughts and water stress on crop production and yields, livestock numbers, commodity prices and farm household incomes can have economic impacts such as erosion of farm equity or increasing debt loads but also social impacts such as the possible loss of property ownership or the preferred lifestyle (RIRDC 2007). Thus, using water efficient farming systems, improving farm practices to improve water use efficiency and ensure access to reliable water supplies plays a key role in reducing potential vulnerabilities to reductions in water supply (Collis 2016; Hatt et al. 2012).

Therefore, sectoral experts recommended farmers to manage systems accordingly by making the most out of the time with water availability, having funds for droughts (e.g. feeding costs) and protecting resources that deal with higher frequencies of droughts. Additionally, increasing available water supply through improved water infrastructure such as bigger/deeper dams with greater storing capacities or connected pipes across paddocks without leakages, decreasing evaporation rates and buffer for drier years were recommended strategies. However, the online survey with farmers revealed that only 22.5 % of interviewed farmers in Corangamite have a proper drought management plan.

The Department of Primary Industries (2006) recommends planning in time when the season progress into a drought. This significantly helps farmers to reduce stress while decisions may close management options as prices for sale stock decrease, fodder prices increase or off-farm employment becomes more difficult. Besides staying flexible to dry times in short-term, longer term planning and budgeting enables farmers to increase business resilience. An example of this is listing financial and physical resources to calculate the effects of short and long-term strategies. Also preparing cash flow budgets for two to three years, acting quickly/decisively, regularly reviewing decisions, looking for opportunities and preparing to put animals into stock containment areas to preserve pastures and soils help to deal with droughts (Department of Primary Industries 2006).

### 6.2.3. Diversification to spread Risks

According to the interviewed sectoral experts, diversification is a good adaption option to maintain or improve farm equity which enables farmers to stay responsive to changing climate conditions while low profitability was considered to give less room for adaptation. Diversification of income sources in terms of on-farm enterprises or farm locations help balancing out climate risks and buffer against bad years.

According to McConnell and Dillon (1997), farmers have learned over time how to accommodate risks. However, remaining viable after climatic extremes might become increasingly difficult in the face of climate change as the frequencies and magnitudes of extreme events are likely to increase (CSIRO 2012; Rickards 2012). Therefore, business planning is a key to address the range of risks from climate change to create resilient farm systems (Agricultural Climate Resilience Project 2016). Farm profitability largely depends on how farming systems are adapted to new climatic conditions. Modelling changes on farm profit across a range of climate scenarios for 2030 and 2050 across the wheat belt of Australia showed that a) farm productivity and profitability for the majority of the scenarios decreased and b) adaptation to climate change can offset or counterbalance negative effects of climate change which increases economic returns to a certain extent. Thus, changing levels of agricultural production or altered prices are inevitable and require efforts to maintain farm profitability (Thamo et al. 2017).

A study from Kingwell and Pannell (2005) pointed out that diversification has enabled generations of farm businesses to cope with variation in climate and furthermore capitalise on changes in the relative prices of agricultural commodities. Diversification of portfolios of on-farm enterprises, off-farm investments, farm ownerships among multiple owners/investors or spatial distributions of farms enables farmers to spread risks from climate related impacts and lower potential vulnerabilities (Barber 2009; Kingwell 2006). Diversification as a risk management strategy works especially when below average income from one activity is offset by above average income from another activity which leads to more stable/total income for the entire operation. However, the effectiveness of diversification depends on the profitability of the various activities itself as all activities of the farm should be profitable before diversification works as a risk management strategy (Centrec Consulting Group 2010).

According to Centrec Consulting Group (2010), farms typically engage in more than one income producing activity to **diversify farm’s income sources** and to potentially reduce risks in total farm income. Howden et al. (2007) suggested diversifying income through the integration of farming activities such as having a mixed crop-livestock systems. Also according to Weindl et al. (2015), the integration of livestock and crop production is likely so increase farm resilience to climate extremes due to greater system and income diversity. Australia has not only a long history of mixed farming, but it still remains Australia’s main agricultural system despite the increase in the proportion of cropping land and a decrease in livestock numbers on Australian farms since 1995 (Bell and Moore 2012). However, since many farmers perceive livestock production as less risky than cropping, the trade-off between risk and return favours retaining livestock in the system (Thamo et al. 2017). Animals can also act as insurance against *hard times*, such as during droughts and supply farmers with a source of regular income. In combination with adequate new varieties and technology, mixed livestock systems remain a good way in dealing with impacts of climate change (Herrero et al. 2010). However, also if the integration of enterprises help in spreading risks, it usually comes along with certain trade-offs between farmers objectives. Benefits and costs from mixed systems still remain a major research challenge of both biophysical and economic models (Bell and Moore 2012).

Although not specifically mentioned by sectoral experts, having **off-farm income** can ameliorates some of the economic risk of farming as well and increase farmers ability to both recover from extreme weather events and make strategic investments in adaptation to climate (Schattman et al. 2016). Off-farm employment to supplement and stabilise the farm income has become increasingly important for farming families over the last two decades in Australia whose income has reduced due to declining profit margins or farm income variability (ABS 2003). Especially small farms with lower incomes are more dependent on off-farm employment compared to medium or larger farms to maintain the living standard (Barr 2000).

Furthermore, purchasing extra **land between different climatic zones** to diversify rainfall mix can present another form of risk diversification as enterprises can be switched according to environmental conditions and potentially help to avoid some limiting related risks (Barber 2009). Purchasing additional land in a region less exposed to adverse climate change related impacts can also be of interest in terms of changing land values which are larger in marginal cropping and grazing areas with few extra production opportunities (Kokic et al. 2005). However, Rickards (2012) points to risks that this strategy might bear: If a farmers from northern Victoria purchases land in the southern region as part of a general adaptation to the long-term drying trend, the farmers might find himself in a position with higher exposure to the risks of increasing extreme rainfall events or the negative effects of widespread wet conditions. Also taking the debt and the financial risk to pay it off bears risks for farmers while the geographic stretching through larger or spatially scattered properties requires more travelling which comes along with financial costs and dependency on a sound road infrastructure (Rickards 2012).

Using **insurance** represents another farm of risk sharing. While Australian farmers can only insure against hail and fire and not to the impacts of droughts, three studies concluded that multi-peril crop insurance was not feasible without subsidy from government as there are too many uncertainties and factors triggering low yields (e.g. time of sowing). This is also due to the fact that many farmers in Australia have farm management deposits which are used as tax-effective way to put funds aside for later withdrawal for times of low farm income. Also, many farmers have off-farm investments or spread risks by operating in different rainfall zones, thus representing strategies to cope with droughts as well as other causes of fluctuating farm incomes (Hertzler 2006). However, drought insurance based on rainfall events and farm products derived from the amount and incidence of rainfall is a more promising approach to limit systemic risks if the correlation between rainfall and income risk remains (Barber 2009; Hertzler 2006).

### 6.2.4. Employed Adaptation Strategies of Farmers in the Study Area

According to Rickards (2012), farmers awareness of climate change and associated climate related risks, which are influenced by direct personal experience with zero distance, socio-economic and political factors, tend to influence behavioural intentions and willingness to take upon adaptation actions (Hyland et al. 2016; Rickards 2012). However, risk perception is also influenced by prior beliefs about climate change. Thus, farmers who accept climate change and that it is human induced are more likely to perceive certain changes in climate than farmers who believe climate change is not occurring and is not human induced (Niles and Mueller 2016; Pahl et al. 2014). Thus, according to Arbuckle et al. (2015) and Howden (2007), farmers who believed that climate change is occurring and perceived a threat to farming are significantly more likely to support adaptation actions while farmers who do not accept that climate change is occurring or do not perceive it to be a threat to their livelihoods, will not likely undertake adaptive actions.

Since farmers in the catchment have been interviewed about perceived changes in climate, associated managements actions and their general view on climate change, the following hypothesis was generated during the research process and is discussed in the following:

- Farmers are adapting to perceived changes in climate independent of their acceptance of climate change

Interviewing farmers about their view on climate change resulted in no clear consensus among interview partners. Despite scientific evidence that humans cause global warming since the mid-20th century with 95-100 % likelihood interacting with underlying natural variability in Australia (BOM/CSIRO 2016), interviews showed that many farmers in the study area continue remaining uncertain or sceptical about the human influence on the climate system. Also if all interviewed partners could identify certain changes in climate such as changing precipitation or seasonal patterns, the majority of the interviewed farmers were uncertain about the *causes* for climate change. IP9 summarized:

> “I think it is obvious that climate is changing. I am not convinced to which degree mankind is causing that”.

However most interviewed farmers in the catchment agreed that

> “[…] climate has always changed in the history” [IP4]

and that impacts on agricultural production would take place anyway from natural variability. One farmer was also sceptical about actual climate data that might be adulterated, stating that:

> "[…] I think the BOM sometimes exaggerates and I am not very convinced of the measure techniques as it is apparently always the driest summer, spring and so on" [IP2].

Some farmers also assumed that climate change represents a big industry, creating jobs for many people including scientists.

However, other farmers from the interviews seemed quite concerned about climate change and associated impacts for agriculture. They believed that these risks were not new but significantly intensified by climate change as IP1 summarized:

> "[w]e are deeply concerned. […] it is going to be worse and drier with more extreme weather events".

Other farmers recently changed their mind about climate change as IP9 stated:

> "I was very much of a sceptic (about climate change) until 2 years ago […], when I decided we have problems".

These differences in farmers views on climate change are in line with two studies from 2009 and 2011 conducted in Victoria which were discussed by Graymore et al. (2016). The paper categorises Victorian farmers into three groups: farmers who believe that local changes in climate are part of the natural cycle, farmers who feel that the changes they are seeing in climate are related to anthropogenic climate change and farmers who are divided in their attitudes (Graymore et al. 2016).

Another study from Rickards (2012) in north-west Victoria summarized that the number of farmers who accepted a human-induced climate change has risen while the number of farmers who believed in natural climate change has declined between 2007 and 2011. However, the majority of farmers still attributed perceived changes in climate to natural climate variability with slight increases between 2007 and 2011 (Rickards 2012).

Similar to the study in north-west Victoria, farmers in the Corangamite catchment remained divided in their view on climate change. However, all interviewed farmers in the study area perceived certain changes in climate (see table 9, chapter 5) and associated risks for agricultural production. More unreliable and shorter springs were commonly associated with less time to finish off animals, to grow wool and a higher need to supplementary feed animals. Also a perceived shortening of the growing seasons (about May to October), earlier flowering times and more/earlier extreme heat events were associated with earlier ripening times of plants, a lack of pasture growth and production of dry matter to cut hay for animals. Several farmers furthermore noted higher input costs in keeping the farm running under changing climate and market conditions and thus more financial stress on their farm business. Some interviewed farmers also perceived spatial shifts in ecological communities which raised concerns about increasing risks of pests and diseases in the study area. However, benefits of a warmer and drier climate were noticed in terms of improved cropping options, improved access to land and the possibility to introduce more summer active crops that make use of slight increases in summer rainfall. The conducted interviews furthermore identified that almost three-quarters of the farmers expected higher precipitation variability in future with seasonal shifts while half of the farmers assumed a decreasing trend of water availability, triggering more insecurity for planning in future. In terms of temperature, almost half of the interviewed farmers assumed a continuous trend in increasing temperature with more seasonal shifts and heat waves triggering more insecurity for planning as well.

Making decisions in an increasingly unreliable environment was considered as one of the major challenges by interviewed farmers. However, farmers in the catchment employed several strategies to address the perceived changes in climate, expectations in future climate and associated risks for agricultural production. The majority of the interviewed farmers indicated to go for a mixed crop-livestock system to spread risks while only the minority went either for cropping or livestock production. Farmers also pointed to certain strategies to lower economic risks in terms of pasture and livestock production especially during drier times. These included: changes of varieties of grazing or cropping species to increase production, use of shorter season varieties, use of more deep rooted/drought tolerant perennials and summer active crops, work out carrying capacity along a feed budget plan or make use of rotational grazing to address animal requirements and to avoid diseases. About half of the interviewed farmers already changed from autumn to spring lambing due to better pasture availability and nutrition to maximize lamb survival and to minimize economic losses from supplementary feed in drier climates. Around half of the interviewed farmers already adjusted their crop varieties and sowing dates in the last two decades to minimize potential economic losses from more unreliable springs (e.g. earlier sowing) and to maximize long-term farm income as new crops are generally more drought tolerant and better adapted to environmental conditions. Also sustainable soil management (e.g. destocking in time to keep groundcover and avoid erosion) and soil moisture conservation methods (e.g. no ploughing, minimal tillage, direct drilling or controlled traffic) were employed by most farmers in Corangamite to support healthy soils, crops, pasture growth and to decrease exposure to increasing climate variability. To address increasing dry spells, making use of town water supply as a back-up was mentioned as a risk strategy as well. A few farmers also employed more transformational risk strategies including purchasing farm land in different geographic areas which helped to self-insure themselves against dry periods or event went out of business with climate change considered as one reason.

The following graph presents a brief overview of already implemented adaptation strategies of farmers in the Corangamite catchment to deal with climate variability and change. Comparing suggested strategies by sectoral experts and literature to those implemented by the farmers in the catchment displays that most adaptation strategies are in line with what farmers in Corangamite are already implementing.

**Table 13: Farmers perceptions of climate change related impacts on agricultural production and implemented risk management strategies**
(Own representation based on interviews with farmers)

| Perceived impacts of climate change on agricultural production | Implemented risk management strategies |
|---|---|
| • Higher input costs to keep running the farm and more financial stress on their farm business<br>• Earlier flowering and ripening times of plants, lack of pasture growth and production of dry matter to cut hay for animals<br>• Less time to finish off animals, to grow wool and a higher chance for the need to supplementary feed animals<br>• Spatial shifts in ecological communities and increasing risks of pests and diseases<br>• Benefits from improved cropping options, improved access to land and the possibility to introduce more summer active crops to make use of slight increases in summer rainfall<br>• Future expectation: higher precipitation variability, increasing temperatures and more heat waves, more seasonal shifts → decreasing trend of water availability & more insecurity for planning | Incremental Adaptation:<br>• Adjustments in sowing, harvesting and lambing times<br>• Changes in stocking density & rotational grazing<br>• Changes in pasture composition (e.g. summer active crops)<br>• Improved soil, water and nutrient management<br>System adaptation:<br>• Diversification (production systems, farm ownerships etc.)<br>• Investments in infrastructure improvements and new technologies<br>• New crop and pasture types (e.g. more deep-rooted perennials, higher heat tolerance and water use efficiency etc.)<br>Transformational Adaptation:<br>• Diversification of farm land in different geographic areas<br>• Sell farm<br>• Off farm income |

However, comparing implemented risk management strategies by farmers with suggested adaptation strategies of interviewed sectoral experts and literature revealed that the majority of interviewed farmers in the catchment are already adapting to climate change without classifying it as such, but rather as part of good risk management to climate variability. One third of farmers from the online survey stated to not adapt to climate change. Interestingly the same farmers indicated to use crop varieties with higher tolerance to heat extremes, lower water requirements or to make use of improved soil and water conservation methods which both helped farmers in reducing exposure to climate shocks. IP8 summarized:

> "Well, we are not doing anything to be quite frank […] although I believe that subconsciously I am probably doing more than what I can actually explain".

However, about two-thirds of the farmers either fully agreed or partially agreed that adaptation to climate change is important which indicates a general high awareness of farmers regarding risks associated with climate change and the needs to adapt.

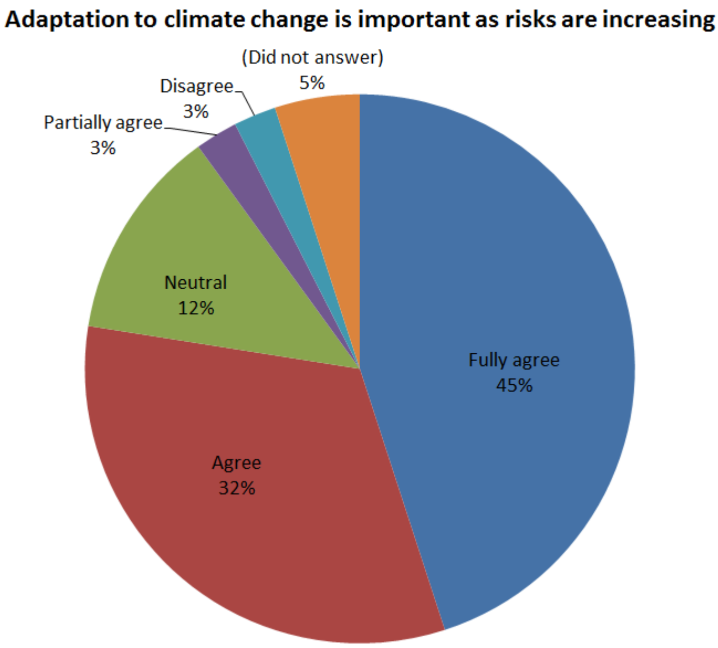


**Figure 40: Farmers answers regarding the importance of adaptation to climate change**
(Own representation based on online survey)

Additionally the two aforementioned studies from 2009 and 2011 conducted in Victoria concluded that there are few differences in the actions to address climate variability and climate change (Graymore et al. 2016). Thus, the study of Arbuckle et al. (2017) concluded that farmers who deny that anthropogenic climate change is occurring and do not support adaptive actions have very similar farm characteristics and management practices to other farmers who believe the existence of climate change  and support adaptive actions.

However, interviewed sectoral experts suggested that farmers who deny climate change and only attribute perceived changes in climate to natural variability, will be more vulnerable to future climate change as the magnitude and frequency of extreme events is likely to increase.

Walsh et al. (2014) suggested that the effects and risks of climate change for farmers will likely be felt more with increasing frequency, variability and intensity of extreme events in the coming decades as farmers of today have not yet experienced the extremes of climate change which are expected in this century (Naess 2013). Thus, the study of Howden et al. (2007) highlights the importance for farmers to accept that climate change is real and take actions upon to stay viable in the long-term as well (Parson et al. 2003).

### 6.3. Case Study: The Mt Hesse Farm

Based on interviews with sectoral experts and literature review, farm households are affected differently in sensitivity and vulnerability to the adverse consequences of climate change due to differences in geographic locations, socio-economic factors, farmers perception of climate related risks and associated management strategies. Thus, based on different factors discussed in chapter 6.2 which were considered to increase farm resilience to climate change, the following hypothesis has been generated during the research process and will be discussed in the following:

- The Mt Hesse farm is well set up to deal with future climate change

The following part discusses four main categories a) geographic and climatic factors, b) socio-economic factors and c) current and planned risk management strategies of Mt Hesse. The fourth part summarizes the most important aforementioned factors along the vulnerability and resilience context under a changing climate to provide potential recommendations.

**Geography and climate**

The farm is located in a Mediterranean climate with most of the annual rainfall falling during the winter time which is not (yet) affected from the southwards movement of the uniform climate (green area) where rainfall is reasonably consistent during the whole year (see figure 31/32). While farms in northern Victoria are already receiving much more summer rainfall compared to about 30 years ago (IP35), the majority of the interviewed farmers in the catchment nevertheless already perceived more summer rainfall as well. IP35 suggested that the southward shift of rainfall zones will continue in the future meaning more rainfall during the year with an increase in summer rainfall for Mt Hesse as well.

Looking at historical climate records for of Mt Hesse (chapter 5.1), the temperature and precipitation development over the last century closely followed the temperature and precipitation development of the catchment area. Despite insignificant seasonal rainfall anomalies over the last century expect for moderate evidence regarding increasing summer rainfall at Mt Hesse, the study area including Mt Hesse faced a drying trend in rainfall since about 1960 especially during autumns and the Millennium drought (CMA 2017). Compared to the catchment, both the decreasing number of cold days below 5°C per year and the increasing number of hot days above 30°C per year were significant over the last century. Regarding the seasonal anomaly for minimum and maximum temperature from 1900 to 2014, Mt Hesse faced a significant increase in seasonal minimum and maximum temperatures similar to the catchment except for spring maximum temperatures.

Despite inherently remaining uncertainties about climate projection and future developments, the already observed drying trend is projected to continue for south-west Victoria including Mt Hesse (Climate Commission 2013). CSIRO (2017a) projects the average mean, minimum and maximum temperature continue to increase in all four seasons with longer hot days/more warm spells and fewer frost events with very high confidence for the Corangamite including Mt Hesse. Rainfall projections are much more complex and not as clear as for temperature under different scenarios (figure 28). However, rainfall is projected to decrease especially during winter and spring with less clear projected changes for summer and autumn rainfall despite a projected tendency for decreases in autumn rainfall and possibly slightly wetter summers for Corangamite including Mt Hesse up to 2030 (CMA 2017). Higher temperatures and potential evaporation is projected to increase in all four seasons with relative humidity projected to decrease through the cool seasons which is influenced by changes in rainfall and associated changes to cloudiness (CMA 2017). According to Thornton et al. (2014), the projected trends for temperature and precipitation come along with changes in runoff and may potentially increase losses in agricultural production also at Mt Hesse. Thus, as climate change interacts with natural climate variability and is likely to increase extremes of natural variations, managing climate variability and associated risks will become even more important for Mt Hesse to reduce potential vulnerabilities (Harle et al. 2007; CSIRO 2001).

**<u>Socio-economic factors</u>**

The German textile company Südwolle Group acquired the Mt Hesse farm following 120 years of local family ownership which is considered one of the largest wool producers in Australia nowadays (Südwolle Group 2017). The current farm manager of Mt Hesse took on the farm family business in its 4th generation. According to Rickards (2012), family farming over generations and **inter-generational links** are known to strengthen people's commitments to farming in both a geographic and occupational sense. In regards to farm succession the desire to have a successful farm is important in handing the farm over to children which might be a *critical* point facing the current ownership structure and uncertainties regarding the management of future generations. However, due to the inter-generational link and the long history of family farming since 1882 at Mt Hesse, knowledge regarding local climate related risks, associated impacts on agricultural production as well as proved management strategies to date could typically be passed on over generations which is considered to increase adaptive capacities to climate change (Rickards 2012).

The **geographic position** of the farm does not only facilitate marketing of products, purchasing of production requisites such as fertilizer and low costs of transport to markets, but also allows to grow high quality nutritious pastures and legumes (e.g. Lucerne and clover) within the high rainfall zone to feed animals and run relatively high numbers of sheep per hectare (AWI 2017). The sheep industry is also considered to have the greatest opportunities to diversify out of wool production in the high rainfall wheat-sheep zone in which the farm is located thus offering certain advantages in terms of diversification and production opportunities under changing climatic conditions (RIRDC 2007).

For most commodities, larger **farm sizes** are generally linked to higher rates of return thus making larger farms more economically viable than small farms (ABS 2003a). As Mt Hesse covers 3500 ha of land, large farm businesses have improved abilities to spatially diversify to capitalize on or deal with climate variability and change. Farms with spatial diversification options of enterprises combined with economies of size and scope are considered to be better set up than small farm businesses with limited opportunities for spatial diversification who could be restricted to on-farm responses to climate variability and change (Kingwell 2006).

Since the German textile company Südwolle Group acquired Mt Hesse, the farm has an **international background** since 2002 and might be considered to be placed in an advantaged position. Interviewed sectoral experts considered multinational farms and farms with external foreign support less vulnerable to the adverse consequences of climate change due to their financial background and/or mostly bigger farmlands to spread risks which gives more room for adaptation. Kingwell (2006) also suggested that farm wealth and size determines economic output and therefore how well a farm is able to respond to climate change. According to Hogan et al. (2011) and Rickards (2012), access to financial resources is considered as an important factor in determining adaptive capacities of farmers while a lack of financial resources can keep farm family households in a situation of negative lock-in resilience where farmers are unable to make necessary changes. Farms with greater land tenure security (ownership or longer term agreements) also have a greater ability to recover from farm site improvement investments (Schattman et al. 2016). Therefore, smaller family owned farms may have to avoid normal expenses during dry spells/droughts or have to take on distant off-farm work that persist to the family farm business and livelihood. However the financial position of Mt Hesse allows for certain forehead positions regarding abilities to react in short-term, such as during extreme events or to make larger investments that benefit the farm in the long-term future (Rickards 2012).

According to several interviewed experts also the **interest in understanding and assessing risks** emerging from climate change significantly supports the implementation of adequate location-specific risk management strategies and thus support overall farm resilience. Thus, the interest of Südwolle as a global player in the wool industry and the general manager of Mt Hesse in long-term consequences of climate change (expressed through the donation and support of this study project) was considered an important step in assessing risks and dealing with changing business risks under climate change to increase resilience (Harle et al. 2007; RIRDC 2007).

According to Rivera-Ferre et al. (2016) also farm labour allocation and labour flexibility helps managing climate risks. As sectoral experts identified dependencies as potential constraints to adaptation, the Mt Hesse farm is in a favourable position with its **business structure.** The general farm manager typically plans, directs, coordinates and performs farming activities and manages physical and natural resources, business capital, maintains/evaluates records of farming activities, monitors market activities and plans production to meet contracts or market demands (ABS 2003). Beside the farm manager, the farm has one permanent manager for livestock and another for cropping, both taking care of the daily business and keeping the farm in a flexible situation. This labour allocation enables the farm to respond in short-term to extreme climatic events which potentially lowers risks/vulnerabilities from external dependencies on extra staff in a last minute crisis on short-term basis (e.g. to accelerate harvest during wet conditions or use dry windows of opportunities) including the availability of contract labour (Rickards 2012). According to the Mt Hesse farm, besides having a network of professional consultants, contractors, customers, suppliers and industry peers in place, education and improvement in skills of the people in the business is essential and on-going to support long-term farm resilience.

**Farm management strategies and planned activities**

Many of the recommended **risk management strategies** of interviewed experts and literature review dealing with climate change are already implemented at Mt Hesse. The farm management employed a mixed crop-livestock approach to mitigate risks to either enterprise, introduced improved pastures and changed species composition, e.g. by introducing summer active pastures. According to Mt Hesse, the current productivity of the farm accounts for 26,000 dry sheep equivalents (DSE) on 2,300 ha land (11dse/ha). The stocking rate refers to the number of livestock on a paddock or a whole farm and is expressed as an indication of animal number per unit area which is expressed for sheep by *dry sheep equivalents* (DSE)[3] per hectare (ha) (MLA 2016b). The farm management also adjusted lambing and sheering times. While in the 1990s the lambing time on Mt Hesse was in May due to the demand for short and fine lamb wool, however the management changed lambing times to August to suit changing pasture growing pattern, due to quicker wool growth rates of lambs and to facilitate the large cropping program sowing. Also sheering times were adjusted over the decades but mainly due to management reasons. Furthermore, the property has been extensively referenced to land class areas and soil types in order to better match enterprises to land class areas, improve pasture utilization and have less wastage when cropping. Also a strip grazing cell system has been introduced to better match the growth of pasture to the livestock production needs, to protect resources and avoid soil erosion. The crops have a synergistic relationship to the livestock enterprise. Thus summer fodder crops were introduced to make use of more summer rainfall. Additionally, crop rotation supports weed management while soil conservation methods help to limit soil degradation, lift production, control weeds and improve yields. Also a pest and diseases monitoring program helps to

[3] A DSE is used as a method of standardising an animal unit and is the amount of feed required by a two year old, 50kg Merino wether to maintain its weight, thus one 50kg dry sheep is equivalent to one DSE whereas a lactating cow may be equivalent to as much as 25 DSE MLA 2016b.

control stock and crop health. Livestock water supply is adequate with a number of large dams and 16 windmills on sub artesian wells/bores spreaded throughout the property. Water supply for domestic needs is catered with 90,000 gallons of storage for rainwater and a large roof area for supply. The biodiversity of the farm is supported by a diversification program of flora and fauna through tree planting and wetland management programs. The following table summarizes employed farm management strategies to deal with climate and production risks.

**Table 14: Employed management strategies at Mt Hesse**

| |
|---|
| **Sheep and pasture Management:**<br>• Match stocking rate to carrying capacity through:<br>    • use of a feed budgeting plan<br>    • manipulation of pasture growth<br>    • sell stock or cutting extra hay<br>• Adjustments of lambing times to improve pasture utilisation<br>• Adjust fertilizer rates to maximise potential growth over winter during periods with enough soil moisture<br>• Tree planting for shelter to protect animals from heat, wind and infertility<br>• Laneways to ensure stress free sheep movement on hot days<br>• Further sub-division of farm land to get greater utilization of pasture grown and for facilitated management<br>• Cell grazing system to better match the growth of pasture to the livestock production needs<br>• Use of sheep working yards in a shed giving protection from adverse weather for people and sheep<br>• Improved pasture species diversification & composition, e.g. deep rooted winter active perennial pastures/ summer fodder crops<br>• Rotational grazing to better manage sustainability of existing pastures<br>• Matching enterprises to landclass and soil type areas through fencing to improve pasture utilization<br>• 1000 t storage capacity for grain and 1500 t of silage buried for the long-term to help manage seasonal risk |
| **Crop and soil management:**<br>• Introduction of summer fodder crops to better utilise summer rainfall<br>• Drainage system (raised bed) to grow cereal and oilseed crops on *wet* farm areas<br>• Crop rotations<br>• Soil conservation methods, e.g. direct drilling to limit soil degradation, lift production, control weeds and make cropping more sustainable |
| **Pest and diseases management:**<br>• Monitoring program to control stock and crop health<br>• Crop rotation to limit disease build up and weed resistance |
| **Water management:**<br>• Supply from bores by windmills → no reliance on run-off<br>• Water storage in 45000 litre plastic tanks<br>• Use reticulated bore water system<br>• Increased storage capacity for fresh water (from the domestic roofing) for domestic use |
| **Landcare management:**<br>• Diversification of flora and fauna through<br>    • Tree planting program<br>    • Wetland management |

To deal with seasonal climate variability and other farm business risks especially under projected climate change impacts, the farm management of Mt Hesse demonstrates a high interest and willingness to adopt new practices and technologies which is presented in the following.

The vision of Mt Hesse shifted towards a profitable Merino sheep flock in the future to create a sustainable business model. The aim is to increase cash flow and overall farm resilience. The farm aims for more transformational adaptation systems by increasing the carrying capacity from 26,000 DSE on 2,300 ha (11 DSE/ha) to 40,000 DSE on 2,900 ha (13 DSE/ha) by reducing the cropping program and area from 1,100 ha of mixed cash crop to 500 ha of a synergistic cropping program in the mid to long-term future. The improvement of the carrying capacity of the property will support the growth of the ewe flock. Thus, all resources of Mt Hesse are planned to be directed towards producing wool and sheep meat rather than a dual enterprise system. Managing sheep will include continuously matching stocking rates to carrying capacity and to make use of new technologies such as improved pasture and sheep genetics to support a self-replacing Merino flock that target more lambs with higher growth rates.

However, a continuation of the cropping program is planned to alleviate short-term feed deficits during dry times and to replenish long-term silage drought reserves. The cropping program is planned to be designed to meet the needs of a growing sheep flock rather than improving total yield and quality of mono-culture cereals and oil seed crops. The change from cash crops, which was purely grown to be sold without grazing or being stored for sheep feed reserve, to a synergistic cropping program in which wheat, barley and oats can be grazed in winter until the seed starts to develop in the stem, will supply feed grains for animals. The cropping program will include a summer forage crop phase to take advantage of summer rainfall with legumes and cereals grown for grazing in the winter and supplementary feed production. Storing capacities of 1,000 t for grain and 1,500 t of buried silage helps to address seasonal risks and manage feed shortages in the long-term.

The pasture renovation program will include increased areas of diversified pasture and sub-division of existing pasture paddocks, which will help for better pasture utilisation, improve sheep husbandry and simplified management. New improved pastures varieties and species will give better overall productivity with extra growth in the winter and summer, such as the introduction of more deep rooted perennial pastures which will help to improve ground cover over summer and autumn, support improved access to available nutrients and furthermore be able to react productively to unseasonal conditions. Ecosystem management will include an on-going tree planting and wetland management program thus aiming to improve overall diversification of flora and fauna and provide shelter for animals against heat and wind.

The following graph summarizes risk management strategies that are planned in the short (to 2018) to longer term future (beyond 2018) at Mt Hesse.

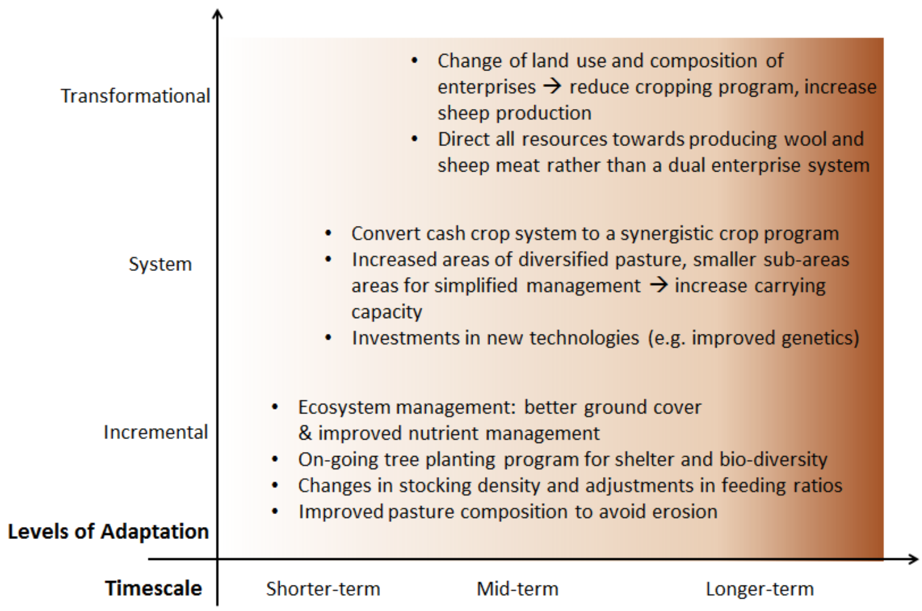


**Figure 41: Planned risk management strategies at Mt Hesse**
(Own representation based on Mt Hesse data)

## Summary and recommendation

The farm already faced increasing temperatures with more hot days above 30°C, decreases in rainfall and higher seasonal variabilities over the last couple decades. However, geographic and socio-economic factors including the farm location/size, the inter-generational link, the international background, the business structure and also the pronounced interest in climate change related issues in combination with current employed and planned management strategies at Mt Hesse can be considered to support adaptive capacities to climate change.
Nevertheless, although the Australian agriculture including Mt Hesse has developed in a way that includes managing a highly variable climate and associated business risks, scenarios for the study area suggest a further increase in temperature with higher frequencies and longer durations of dry spells and droughts. Thus, the Mt Hesse farm may face *new* challenges with altered production risks as impacts on livestock numbers, crop yields and farm incomes need to be considered in the adaptation process to stay resilient in the long-term future as well (RIRDC 2007; Harle et al. 2007).

Also if the continuation of a mixed enterprise system (wool, lamb and mutton production in combination with cropping) can help balance out climate related risks, the planned shift towards sheep production and a reduction in the cropping programs need to consider projected impacts on the sheep industry under climate change (Hogan et al. 2011; Martin et al. 2005).
Sheep are commonly kept as a form of income insurance against possible crop failure which explains their increasing prominence among agricultural enterprises systems in Australia (Rickards 2012). Although increasing climatic variability is likely to increase stress on landscapes, sheep and cropping

production, scenarios suggest that the sheep industry as a whole is likely to be relatively robust and that productivity in the high rainfall zones including Corangamite might even increase in the future under moderate climate change. However, according to Harle et al. (2007) climate change is likely to have implications for the Australian sheep industry mainly through effects on forage and water resources, land carrying capacity and sustainability as well as animal health. Despite uncertainties about possible changes in groundwater availability and its connectivity for the study area including Mt Hesse, surface water resources are projected to decrease and become more variable. Also, rising temperatures and increases in summer rainfall may trigger new risks for diseases and tropical parasites. Thus, planned activities at Mt Hesse may incorporate direct and indirect risks deriving from a changing climate into the decision-making process, including potential changes in the growth and quality of pasture and fodder crops or spatial shifts in the diseases spectrum to control stock and crop health (Harle et al. 2007).

Generally, the financial performance of sheep producers is largely determined by the scale of farm operation with mixed enterprise wool producers achieving generally higher rates of return than specialised producers within different farm scale groups. Mixed enterprise sheep and wool producers generally have a broader range of diversification options and viable production alternatives than specialised producers. These include quicker response options to price movements and seasonal conditions through adjustments in the enterprise proportion of wool, prime lambs/mutton and grain crops. As wool prices in real terms are likely to continue to trend downward over the long-term, specialised producers will depend on the adoption of farming practices to realise significant productivity gains to ensure future viability (RIRDC 2007).

Facing increasing risks of failed yields and associated feed gaps under more climatic extreme events, abilities to store grains for fodder might decrease. Thus, to avoid the need to purchase fodder at the market during times of high prices, the amount of on-farm storing capacities might need to be adjusted in the mid to longer term future to lower potential vulnerabilities from external dependencies (Thornton et al. 2014; Harle et al. 2007).

The continuation of the Landcare management at Mt Hesse will help to reduce direct thermal stress on animals and reproduction as well as indirect effects on animal health and growth especially as the number of hot days is projected to increase. As heat stress can especially reduce ram fertility, increase lamb mortality and affect ovulation rates in ewes, rising temperatures have the potential to exacerbate this situation. Thus, adequate management such as stronger selection for plain-bodies sheep which are more heat tolerant than wrinkly ones, preferential supplementary feeding, ultrasonic scanning of ewes during pregnancy to provide targeted supplementation, shifting mating time to ensure that lambing coincides with changes in peak forage availability or other beneficial management may be considered. Also changes in pasture yields and quality influence fibre diameter with potential decreases in response to variation in forage availability and quality accompanied by a rise in the incidence of tender wool. In areas with improved pasture yields or changes in pasture compositions vegetable faults may increase thus likely to have consequence for clean wool yield and prices due to increase costs for removal. Reduced rainfall and greater inter-annual rainfall variation will not only increase the risk of land degradation and erosion, but also increase dust contamination of the fleece and therefore potentially the amount of short/knotted fibres during the carding process which can reduce the fibre length and spinning quality of the wool (Harle et al. 2007; Crimp et al. 2003). Since coarser wool is generally less vulnerable to the impacts of dry conditions than finer wool and incurs less price discount, a displacement of finer woolled sheep by stronger woolled Merinos might be an option to consider if rainfalls continue to decrease. However, this option would result in a drop in wool income and furthermore increase more direct competition with New Zealand. Additionally market forces and demands for finer or coarser wool need to be taken into account especially in the light of increasing pressure on the wool market from alternative fibres such as synthetics (Harle et al. 2007).

Also identifying stocking rates and density that a farm can sustain under climate change is an important factor in increasing farm profitability. Making use of predicted seasonal plant growth pattern, such as available pastures models for farmers and using a fodder budgeting plan might help to achieve optimal stocking rates and pasture utilisation. Also monitoring grazing and removing livestock before reaching critical limits for pasture mass, height and ground cover and assessing regrowth is important in lowering potential vulnerabilities to the farm system (MLA 2016b).

Comparing recommendations from interviews with sectoral experts and literature reviews (chapter 6.2) can support the assumption that the Mt Hesse farm is well set up to deal with the adverse consequences of climate change. However, with more frequent and severe climate shocks projected in future, Mt Hesse needs to integrate long-term climate change into the decision-making process as risks for sheep and crop production may increase. Especially the shifting focus on sheep production may require taking into account changing risks for the livestock sector deriving from direct and indirect impacts of a changing climate. Thus, staying flexible in responsiveness to changing conditions and frequently adjusting management actions will help dealing with the adverse consequences of climate change, lowering potential vulnerabilities and support the long-term resilience of the farm (Howden et al. 2007).

# 7. Conclusion and Outlook

This last chapter summarises the key findings of this dissertation and continues to draw conclusions with some thoughts on limitations of this work and possible future areas of research.

## 7.1. Summary of Findings

There was no other comparable study conducted in the Corangamite catchment analysing farmers risk perception under climate variability and change and associated farm management strategies in combination with interviews of sectoral experts discussing adaptation strategies for farmers in the study area. Results from interviews with farmers and sectoral experts were presented, summarized and subsequently discussed in several figures and tables contributing to scientific research in order to better understand risks associated with climate change and complemented available literature in terms of climate change adaptation.

The picture of global climate change has become clearer in the past few decades in Australia. The study area has been undergoing significant shifts in higher temperatures since the 1950s with increasing numbers of hot days per year within the last century. Also the severity, duration and frequency of heatwaves have increased. The region has faced a drying trend in rainfall especially in autumn with slight declines in winter/spring rainfall, a small increase in summer rainfall over the last two decades and a reduction in the frequency of very wet years. The wet decades of the 1950s and 1970s were followed by the Millennium drought lasting from about 1995 to 2010/11 which has been the longest period of rainfall deficits on records (CMA 2017). Despite inherent uncertainties regarding climate change scenarios as pathways depend on emissions, socio-economic developments and natural climate variability, the temperature in the study area is projected to further increase in all four seasons with more extreme hot days and warm spells, fewer extreme cool days and increasing risks of droughts. Also decreases in winter and spring rainfall with unclear projected changes for summer and autumn rainfall are projected (CMA 2017; BOM/CSIRO 2016). As Australia is considered vulnerable to climate change, the country including the study area will face increasingly severe impacts under higher levels of warming (Climate Change Authority 2012).

Farmers in Australia are exceptional in managing a highly variable environment. Nevertheless, there is an increasing urgency to focus on adapting agriculture to future climate change. According to Sheppard et al. (2016), there is no need to reinvent the wheel as many adaptation options to climate change are on-going variations or extensions of existing climate risk management strategies on farm levels. However, integrating new emerging risks from climate change in the overall farm risk management framework might further increase farm resilience and help to reduce potential vulnerabilities from climate related impacts (Howden et al. 2007).

Interviewed farmers in the study area perceived various changes in climate and associated risks such as seasonal shifts, more unreliable and shorter springs, earlier heat extremes and a decrease in rainfall over the last decades. Although the general drying of the study area was perceived as beneficial in terms of new cropping options, impacts on agricultural production included higher risks of failed yields, less time to finish off animals or to grow wool and a higher chance for the need to supplementary feed animals. Thus, farmers perceived main challenges around higher input costs to keep running the farm under changing climate and market conditions, more financial stress on the farm business and the increasing difficulty to take decisions and plan for the future in an uncertain environment. However, although interviewed farmers remained uncertain about reasons for perceived changes in climate in terms of natural or anthropogenic influences, farmers in the catchment nevertheless showed very similar farm management practices to deal with their environment. Employed strategies in dealing with perceived changes in climate were mostly variations or extensions of already existing on-farm climate risk management strategies and were commonly attributed as adaptation to climate variability rather than a specific adaptation measure to climate change which is found to be part of a perceived psychological distance to climate change.

The interviewed sectoral experts identified several factors influencing farmers risk perceptions which may impact their local risk assessment and thus on farmers motivation and interest to deal with climate change related issues. Besides personal experience with perceived environmental conditions, also socio-economic and political factors were considered to influence farmers risk perception. Potential constraints in adaptation identified by the interviewed partners referred to a perceived psychological distance to climate change and uncertainties in climate projections as well as a lack of capacities and assets, internal and external dependencies or farmers attitudes. Overcoming constraints to increase adaptive capacities may require among others raising farmer awareness of changing agricultural production and business risks under climate change through the gathering of information (Howden et al. 2007).

However, the interviewed sectoral experts pointed to changing ecological and socio-economic risks under climate change and suggested to adjust present and future forms of farm management practices to deal with climate related risks. Adaptation was generally considered as an on-going process over short,- mid to long-term, requiring incremental or system adjustments under moderate climate change or even more transformational adaptation strategies under more severe climate change. Thus cooperation, sharing of information, and participation in workshops/educational platforms support farmers in better understanding changings risks under climate change, improve management skills and support adequate decision-making processes. Setting up an agricultural system that can survive more climate extremes such as adequate environmental planning and adjusted climate risk management can help farmers in maintaining a healthy and resilient farm environment. Also a diversification of income, such as mixed crop-livestock enterprises can help spreading risk and buffer against dry times while adopting in time might provide a certain competitive advantages especially when more transformational adaptation strategies such as acquiring new farm land in other geographical areas are considered. Maintaining farm equity was considered to facilitate quicker responses to extreme events and longer term adaptation such as infrastructure investments.

This dissertation also included a case study which was the Mt Hesse farm in the heart of the Corangamite catchment. Despite the fact that this dissertation was funded by its owner, the Südwolle Group, the author of this thesis strived for best possible *objectivity* to analyse the farm in the face of climate change. Climate and socio-economic factors as well as current and planned farm strategies were discussed alongside conducted interviews and scientific literature to analyse the farm in terms vulnerabilities and resilience.

The Mt Hesse farm is facing similar trends in historical climate and future projections to the whole study area as the farm. Since Mt Hesse was founded in 1882, climate knowledge and proved management strategies could be passed on over generations while the big farm size of 3,500 ha is typically linked to higher rates of return thus making Mt Hesse economically more viable than smaller farms (ABS 2003a). As an international business with ownership to Südwolle Group since 2002 it has a stable financial background which is considered an important factor in determining adaptive capacities of farms that deal with the adverse impacts of climate change (Hogan et al. 2011). Farm equity and financial stability increase the abilities to keep track of modern technology and help making investments in farm infrastructure or Landcare/biodiversity that help with more variable seasons under climate change. Also the farm structure was set up with a general farm manager and permanent manager for livestock/cropping which may potentially lower dependencies on external staff and increase the ability to better react in short-term if seasonal conditions unfold unfavourable or extreme events are occurring. Current and planned farm strategies are furthermore in line with recommendations from interviewed experts and literature that deal with current and near-future climate change, supporting overall farm resilience. However, risks may emerge from impacts under more severe climate change thus requiring Mt Hesse to stay flexible and continuously adjust on-farm decision making processes and farm management practices.

### 7.2. Limitation of this Work

This thesis provided a broad overview of climate change related risks for the study area and aimed to provide an application-oriented framework which may benefit farmers in the Corangamite catchment in order to better understand potential vulnerabilities and to take upon adaptation measures that increase farm resilience. However, as this thesis covered different environmental, social, economic and psychological issues, some topics might have been worth analysing more in detail.

In terms of climate data, the **SILO data** analysed for this study were available from 1889 to 2014. As the observation network has changed over time and was in particular sparse before 1910, climate data sets may be affected where data have been interpolated from other stations in the region. Therefore, climate data before 1910 cannot be assumed to be comparable with post-1910 data. Furthermore, the instrument shelters in Victoria were standardised around 1908. Before 1908, a wide range of shelters (or non-shelters) were in use and many of them were prone to over-reading maximum temperatures (BOM 2016).

Regarding the conducted interviews for this study, it has to be considered that the knowledge of all interview partners regarding certain issues was always limited to individual experiences or their field of sectoral expertise making interviews somewhat subjective. Therefore, views and opinions must be considered carefully and may not reflect the opinions of other farmers in the catchment nor other sectoral experts working in the private, research or governmental area.

Furthermore, the **qualitative interviews** with farmers in the catchment might have been potentially affected by different factors including:

- The sampling and selection of farmers for the qualitative interviews was supported by the farm management of Mt Hesse. Thus, the selection may have been subjective in terms of who was regarded interesting to interview and biased towards a set of interview partners who were more connected with each other compared to randomly selected interview partners.
- The qualitative interview with farmers represented the opinions of a very narrow group of farmers as the selection only included men who typically operate as farm managers, although some wife's joined the interviews and annotations often differed from their husbands opinion. Furthermore, most interviewed farmers were 50 years old or older. Opinions and views might have been different from younger farmers or women who tend to be more open to the issue of climate change. Also the farm experience differed among the interviewed farmers; while some only worked for a decade on the farm, others kept on the family business in the 2$^{rd}$, 3$^{th}$ or 4$^{th}$ generation, thus potentially creating different perspectives and perceptions on climate due to inter-generational knowledge transfer.

Regarding the **quantitative online survey with farmers**, a relatively diverse and extended interview questionnaire was developed. Also if results from questionnaires can usually be quickly and easily quantified, farmers may have read differently into each question and replied based on their own interpretation of the question. Although it was reduced and simplified several times in advance before uploading it online, some terms may have not been clearly differentiated (such as neutral/unsure) which may have affected the interview answers.

Regarding the **interviews with sectoral experts**, some limitations may include:

- The selection of interview partners was somewhat subjective as the author of this study conducted an extended internet research prior to the second field trip to Australia to detect interesting interview partners with a certain sectoral expertise for different research questions. Other interview partners were found via *snowball system* with other respondents recommending others, which also may be biased towards a set of respondents who are more connected with each other.
- The interviewed sectoral experts were not directly affected by the impacts of climate change. Consequently, they represented sectoral experts in a certain field with certain scientific background knowledge, but their views must be considered carefully and might not necessarily reflect the opinions and ideas of people in the Corangamite catchment, where the impacts of climate change are directly felt.
- Due to the heterogeneity of the interview partners to gain a range of different perspectives and different sectoral expertise backgrounds, a certain representation of each *group* might be lacking. Some interview partners were sectoral experts in climate science, others in sheep husbandry and then again others in socio-economic or cultural issues of the Australian farming communities. Each single interview represented a highly specific knowledge of a sectoral expert (which is also a great advantage for this study) with views and opinions not necessary being representative for other experts in this area.

Furthermore, the development of questions for the interviews and the questionnaire itself imposes a level of researcher's impositions by making decisions and assumptions of what is important. Also the process of coding open-ended questions provides the possibility of subjectivity by the researcher which, despite best efforts in being open as possible, also applies for the process of interpretation of interview data. Therefore, the results and the discussion of this dissertation have to be considered in the face of a certain subjectivity of interpretations as an inherent part of qualitative research (Flick 2009). However, this dissertation provides a comprehensive wraparound overview of the issue of climate change in the catchment and aims to raise awareness for the topic to support sustainable risk management within the farming community of Corangamite.

## 7.3. Future Areas of Research

According to RIRDC (2007) further climate and economic research may be needed on the nature of risks associated with climate change to increase farmers ability to manage short and long-term climate variability and change. Also a closer attention to farm production changes in inter-annual variability associated with climate change might be interesting. In terms of climate science, there is a need for improved weather and seasonal forecast, the provision of more detailed climate modelling information on finer grid scales and also advanced information about the causes and pattern of drought occurrence and long-terms shifts in climate. However, the economic research could provide more information about the relationship of cost-benefits in terms of adaptation actions for farmers especially in the face of prediction uncertainties. According to Howden et al. (2007) there are yet relatively few studies assessing the likely effectiveness/benefits and adoption rates of possible adaptation strategies.

Regarding a geographic dimension, it might be interesting to compare different affected areas in Victoria or even in Australia in terms of how perceptions and views differ regarding climate change related risks and different farming climate risks management approaches that deal with perceived changes in climate. It might also be highly interesting to assess the future role of millennials in terms of how they trigger a cultural transformation, formation of the future of the agricultural sector and if or how local farm risk management practices changes over time with a more climate change awareness generation. With climate change altering production risks, not only comparing changes in the perceptions between generations but also their consequences for succession between generations might be interesting to further investigate as well.

Harle et al. (2007) points to the fact that there is relatively little data specifically on the impacts of climate and pasture change for sheep meat and wool production, as most studies have only involved the beef industry of Queensland. Future research might also be needed in order to understand how competition between wool and prime lamb industry may affect relative productivity of wool under climate change scenarios including market influence and socio-economic dynamics (Harle et al. 2007). Thus, further investigation of climate change impacts may be beneficial for farmers in the study area to better assess possible implications on their sheep enterprise.

In consideration of projected declines in rainfall and more heat extremes for the study area, further research could examine changes in Australia’s regional water governance as sectoral experts in this study assumed more water regulations coming up in the future with increasing competition over water resources.

## Acknowledgement

The study and completion of this Doctor thesis would not have been possible this way without the ongoing support and advice from many people. While it is impossible to mention all names, the following were of great assistance towards my success in this work.

First and foremost I would like to thank my donor Südwolle, including the whole Steger family for their support and trust in me and this study. I would especially like to thank Klaus Steger for his support und our great and interesting time together on the Mt Hesse farm at the beginning of this study. I would also like to thank Martin Steger for his time, ideas and discussions which gave me positive input and supported my motivation for the importance of this thesis.

I would also like to thank all my interview partners in Australia for the willingness to support this study and for the time and patience to speak with me. The form of this study was possible due to the open mindedness of all people involved with all interview partners being a valuable source of information for this study. Especially farmers private experiences and thoughts may have touched sensitive topics while sectoral experts shared their sectoral expertise and personal opinions about climate change related risks in agriculture and possible adaptation measures. It was therefore a great honour to the author of this study to gain deep insights and opportunity to speak to people whether directly affected or represented as an *outside-standing* sectoral expert.

I would especially like to mention David Kinninmonth, Ed and Marco from the Mt Hesse farm who supported me in this thesis and made my time on the Mt Hesse farm so interesting and diversified.

I am very grateful to my supervisors and advisor Prof. Dr. Jürgen Scheffran, Dr. Frank Wechsung and Prof. Dr. Hermann Lotze-Campen who deserves special thanks for their ongoing support and valuable ideas during the research process. I would also like to thank my Australian supervisor Prof. Richard Eckard for our valuable discussions and all his valuable knowledge.

Furthermore, I would also like to thank Elisabeth Vogel who helped me with editing the bulk of climate data in the beginning upon which I was able to analyse them accordingly and furthermore Bernhard Schauberger, who provided temperature and precipitation data for climate scenarios for this study area.

I am most grateful to my family Christiane, Hans-Henning, Michaela and Can-Luca for their patience and encouraging support during my whole study.

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# Annex A – Interview Outlines

## Farmers Interviews

- Do you perceive changes in precipitation, e.g. amount and timing of rainfall, seasonal shifts, changes in the timing and amount of autumn break?
- Do you notice changes in temperature, e.g. changes in the number of heat and cold days/frost events?
- Do you notice changes in the length of the growing season?
- Do you notice changes in extreme weather events, e.g. droughts, floods, heavy rainfall events, unusual strong winds?
- Do you perceive changes in water supply (groundwater, river flow) or quality (salinity)?
- What are the main associated impacts on cropping and livestock production?

- How are you managing/responding to droughts in terms of cropping and livestock production?

- Did you change the time of sowing dates in the last 15 years, if yes why?
- How do you deal with the summer feed gap?
- How do you manage soils?
- Do you have specific water management strategies?
- What are your main pasture management strategies?
- Did you change the times of shearing and lambing in the last 15 years, if yes why?
- Do you prepare the farm business for upcoming events, such as El Nino?
- Do you make use of climate models that predict droughts or agricultural decision-support tools that help you to make climate-related decisions (Apsim, GrassGro etc.)
- Do you use crops types or breed sheep that are more drought tolerant?
- What is your personal opinion about climate change?
- The BOM predicts it is getting hotter and drier in this area. What do you think does it mean for your farm business?
- If you think about the future of your farm, what are your main concerns?

**Sectoral expert Interviews**

(Interview template was slightly adjusted according to sectoral expertise of interview partner)

- Which trends in climate can be identified for south-west Victoria?
- Why is the climate changing in the study area?
- What are impacts and risks for farmers in the study area?
- How do you estimate farmers resilience to changing climate conditions?

- Which factors influence farmers risk perception and their view on climate change?

- What does climate change mean for livestock production/cropping/pasture/soils/water and overall farm resilience?
- What options do farmers have to increase resilience of production systems to seasonal weather variability and long-term climate change?
- How does sustainable farm management look like under climate change and how can farmers adapt in terms of livestock/cropping/pasture/soils/water management?
- How can farmer ideally prepare for shocks and what makes a farm resilient?
- How is it possible to adapt to future uncertainties?
- How important is farmers awareness about climate change?
- Are farmers who deny climate change more vulnerable to the impacts of climate change?
- What are opportunities and what are the main constraints in effective cc adaptation?

## Annex B – Quotes from Interviews with Farmers

Summary of comments on changes of weather pattern

| IP | Quote | Generalisation |
|---|---|---|
| | **Precipitation** | |
| IP1 | Yes it changed. Where we were it was always highly variable anyway, so we had quite long drought periods where we were farming and rainfall was about 21 inches but we did not get this for at least 10 years probably longer so we got about 17 inches which is quite significant especially if it falls at the wrong time. It is looking at the total amount is not a very good guide to say anything about changes in rainfall, because in one year you get a big fall of rain in February while another year you get rainfall in January which does not help you anyway, as it is at the wrong time and it would better to have it in spring or the winter to fill the dams. | -Highly variable anyway<br>-Decline in rainfall for last 10 years at least<br>-Sometimes rainfall at the "wrong time" |
| IP2 | There is a lot of change, we are very dry now. I don't know it statistically but I would say we only get about half the rainfall in some of the areas here. Other places like Mt Hesse are probably wetter and they would not even be able to grow crops because it was too wet. But we see crops grown now in the western district where they are growing canola and wheat while back in the older days it was just grazing country because it was too wet for growing crops.<br>-Farmers don't mind so much about a dry summer or autumn but you cannot have a dry spring, you must have a wet spring. The last few years the springs were too dry and had a big effect.<br>-At the moment we are in a very dry spell. Hopefully we get out of it.<br>- I have seen some changes during this time, for instance a 13-year drought in the late 1980s and since then it really has not get out of this drought, it is still very dry and I can show you dams that were never dry before. We are still going through a very dry time. About the causes I am not really sure. | -Dry spell<br>-Drier springs<br>-Cropping possible due to drier conditions |
| IP3 | […] from the previous 15 year to now, they are drier<br>-The only thing I noticed is that the very dry season is becoming more frequent. So we are used to be in a dry period roughly every 22 years, while now it is probably closer to 15 year, maybe 12 or 13. | -Dry spell for last 15 years<br>- Dry season becomes more frequent |
| IP4 | -It is generally very variable but we had two dry springs in a row which is most unusual. That has probably the most effect, we are most used to bad autumns or late autumns. Last year we had summer rain made up for a bad spring a bit and then we had later a poorer winter.<br>-For quite a few years in the last 10 years, we had quite a lot wet years and they were probably in many ways as hard, except of having water. Anyway, I would definitely say we are on the dry side for the last 10 years.<br>-Thinking back of the past, it was not possible to crop here some decades ago as it was much too wet and paddocks used to be flooded, farms were under water. There is a big drain channel at Mt Hesse and this was put in because the whole country side was about to flood in about 1952. It used to be much wetter in the past. There seems to be about 10-years cycles in average of drier and wetter times.<br>-I think, it is getting a bit more extreme, […] like all the rain we had last summer was particularly unusual which was a tough time for us.<br>-I wouldn't have thought that the variance is of a great difference except the two failed springs now, which surprises me a lot. Autumns always were challenging<br>-I think, for the whole of October, which is our prime spring growth month, we didn't have any rain except for the last days, so we went 5 nearly 6 weeks without any rain which is most unusual.<br>-15 inches of rainfall was sort of a cut off where we probably didn't get crops depending on when it falls, we can have very good crops with that amount of rain but that is where you get into a dangerous period and that appears to happen about one in 15 years. | -2 failed springs in a row, more summer rainfall, autumns always challenging<br>-Dry spell for the last 10 years<br>-too wet years are also challenging<br>-More extremes<br>-In the past it was not possible to crop as it used to be much wetter, drainage canal at Mt Hesse<br>-10-years cycles in average of drier and wetter times |
| IP5 | -When you study the rainfall records we have, we are definitely going through a period of dry.<br>-25 years ago when we arrived on the farm, it was a very wet year and we only had very few wet years since then.<br>-What I can say from my life experience is that we are not getting in the last 10 to 15 years is long sustained periods of rain. Having growing up here, we got here 4 to 5 days rain when I was a child, but we very rarely get a rain event that lasts more for 12 hours nowadays. That is for me the biggest difference<br>-we are just not getting sustained rain anymore, it is just not as much as it was before. | -Dry spell<br>-Lack of spring rainfall<br>-Shorter rain events<br>-Decline in surface water |
| IP6 | -Yes there are definitely changes. If I look at the long-term averages from rainfall, especially from 2000 to now this has become a much drier period through the 1960s and 1970th, this area had usually 800 or 900mm per year, some years even more. The average for the last year was only about 600 or 620mm per year, and if I look at the last 4 years, it is more 400 to 450 mm. That is quite a change.<br>- I think droughts are probably the most extreme weather events. But it has been always part of Australia, droughts and floods, bush fires as a results of the dry | -Dry spell since 2000<br>-decline in the total amount of rainfall<br>-Droughts as part of natural cycle |
| IP7 | -If I remember the last 25 years, it is getting a little bit drier every year. We used to be very wet in this area and now our rainfall has dropped by about 30%.<br>-We obviously get less rainfall and less rainy days<br>-In general, the weather is getting more extreme. When it rains, it rains a lot and when it stops raining it stops all together. There doesn't to be general rain and our weather seems to come from a different direction. It used to come from the south west and now it seems we are getting from east and north but not general weather from the south west. So I think that has changed. | -less rainfall and less rainy days for the last 25 years,<br>-changes in rainfall pattern: more extreme |
| IP9 | -From memory, the autumn break has always been fairly unreliable, but it is even more now and it is coming later than it has been in the past. I would say we get less rain altogether, especially in spring where we don't get enough rain. | -Autumn break getting more unreliable, less rain |

| | | |
|---|---|---|
| | - We get droughts more often than before. In the past there seemed to be a cycle of about 10 to 15 but now it seems to be every 5 years or so. | altogether, especially in spring, more droughts |
| IP10 | It keeps changing. Sometimes we have a good summer like 3 or 4 years ago, sometimes it doesn't rain until June. There is no consistency, there are no patterns. In the 1980 but also 1967 were very dry autumns, 1968 was the worst drought I can remember. 1982 was bad and it is not good at the moment as well. | -No consistency, dry spell |
| IP11 | I have Hamilton rainfall records from 1883. If we don't get good rain in October, it is getting very serious for us. There have been some failed springs in the past. The next question is, are they getting worse? 14mm in 1879, 1896 only 13mm in October, 1914 10mm which was the lowest October ever, 1967 14mm, I remember that, that was very bad. 1982-1984 were 3 bad years for farming. I can't really see any pattern, expect very recently in the last 10 years, from 2006 to 2014.<br>-Wet times can be just as bad as the dry times and stocks actually do better in dry times, every winter is a problem for us. The thing that I have noticed most is that we are getting this periods where it rains a month or 6 weeks and then it doesn't rain. I haven't really seen that before. | -Hard to see trends, expect the dry spell since 2006<br>-changes in rainfall pattern: rain for weeks and then it stops |
| IP12 | Total rainfall has not changed that much I would think. It is a bit hard to say whether it is just a normal cycle or where the total rainfall goes. But the autumn breaks are definitely later. And the springs end earlier.<br>-We maybe get a bit more summer rain that that doesn't help much of we have dry winters. And summer rain in this part of the world is also not very good to us | -No change in total rainfall<br>-Autumn break later, spring ends earlier, bit more summer rainfall |
| | **Temperature** | |
| IP1 | Many people would go surf in Lorne which means the water temperature is much warmer than it used to be. When I think back, there is a change in the summer time with higher water temperatures in the ocean.<br>-This year it was very early to have these high temperatures and I can't really remember when we had a run of such a hot weather for Christmas and leading into Christmas, but that seems to be happening more.<br>- This year it was very early to have these high temperatures and I can't really remember when we had a run of such a hot weather for Christmas and leading into Christmas, but that seems to be happening more. | -Higher water and air temperature in summer<br>-More and earlier heat extremes |
| IP2 | -The winter are getting milder, expect for this year which was quite cold. It is strange this year, as we had a very cold September that was when the Canola was flowering […] while the October was very hot and very dry. It basically burned the faber beans and they stopped flowering and afterwards everything frizzled of and a 37 degree hot day in spring is very unusual.<br>-I don't think it is getting colder but we are getting more hot days. But I remember being a child, we once had a very hot Christmas and we were lying on the floor. So it is not unusual to have high temperatures. Australia is an island and when we get Antarctic winds coming up it is getting very cold while when this massive land heats up and winds blows its down we get extreme heat. So we can get variables dependent on what direction the wind blow and we have no control over it. | -Milder winter with exceptions<br>-Sudden changes: e.g. very cold September and very hot October in 2015<br>-more heat days, but heat usual in Australia |
| IP3 | We are not getting as many frozen paddles on the ground in the winter. | -Less frozen paddles |
| IP4 | They talk about one degree global warming, but actually one degree in the winter would be good because it gives you more growth. The fluctuation is so great, I am not really sure about that.<br>- Two years ago we had a week about forty degrees which is most unusual. In the last two summers, the fluctuations were hitting the high seasonal peaks. I think, it is getting a bit more extreme | -1 degree temperature increase would be good for growth<br>- More heat extreme |
| IP5 | -There is no doubt that the temperature is going up.<br>-And certainly, there are different varieties and species of birds that come south from north because of the warmth we didn't have.<br>- In terms of heat waves, it is certainly getting hotter. We had 45 degrees some days ago (December) and even the bird were struggling. I mean it has also happened before. But what I think is you would normally get a cool change at the end of a heat wave and lot of the times you would get a good rain with it. | -Increase in temperature, birds are coming further south<br>- More heat extreme |
| IP6 | -There haven't been dramatic shifts in temperature or frost. The winter we have had actually been milder and we just have burst of hot weather.<br>-I am not certain about changes in temperatures. 2014 was not very hot, we did not have any bad heatwaves but this year, 2015 wasn't that hot or that cold. | No dramatic shifts, milder winter |
| IP7 | Temperature I am not sure about. We obviously get less rainfall and less rainy days, but average temperature I am not sure about. It has always been hot in the summer and cold in the winter. | -Unsure about changes |
| IP8 | That's a difficult one, because I don't look at statistics. My feeling is that winters are getting colder, although I think that is statistically not correct. Maybe it has something to do with the fact that I am 54 and I just feeling the cold a lot more than if you are 24. This winter especially has gone very cold.<br>- I think one extreme weather event are these extremely hot and windy days like Christmas day was, which are just earlier than what you would expect. You would expect them in January or February. Something is happening. I was a bit of a sceptical person, but I am certainly convinced now that we have issues.<br>- In terms of heat waves, we seem to get some very hot days in November and December, which we didn't used to get. So I guess there is something potentially happening as well. It makes farming even more difficult as it is anyway, which shouldn't be. | -Unsure, but winter feel colder<br>- More and earlier heat extremes in summer |
| IP9 | I would say we get longer hot days. When I was a kid we used to get 3 or 4 very hot days and then you would get a thunderstorm and then it would cool down for some days and get hot again. While nowadays you might get 10 hot days. I think the weather is becoming more extreme now than I remember 30, 40 years ago. | -More and longer heat waves |

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| IP10 | I would say the winters are getting milder over the last 10 years, although we did have a very frosty winter some years ago. | -Milder winter |
| IP11 | I don't really notice any change. I think we work so much in air-conditioning and when you get out of a cooled car or house, you think it is very hot. When I was a child there was no air-conditioning and you just learnt to live with the heat. When I was a child we also had very hot days and it used to get so hot at night that my mother would take me out of the bed and put me on the floor to sleep. I don't think it is getting hotter, I think we are getting softer because we regulate the way we live. | -No change |
| IP12 | When I was very young, I was kind of used to get very hot weather, but talking to my father I do not think we had so many days over like 37 degree, but in the last few years we regularly get over 37 or 38 or even 40 degree. I can remember when I was younger, we got only 1 or 2 days over 40 degree my first 20 or 30 years of my life and now we get it at least once or twice per year, so that has definitely changed. | -More hot days |

Summary of comments on changes in water supply and quality and water supply on farms

| IP | Quote | Generalisation |
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| | **Changes in water supply and quality** | |
| IP1 | -Clearly water is a massive issue. It has always been an issue in Australia anyways which refers to the rivers, the dams and the groundwater.<br>-But when you walk along the river you would see how little water there is running through, and big pumps going to the farms and it is just unsustainable, some people are even pumping water without a license. The water which goes to Geelong is all collected in the West-Barwon dam and it runs through an open channel which leaks very badly to a reservoir outside of Geelong which is quite shallow as it has very high evaporation rates, so only like 19 % of the water that is collected gets used in Geelong and the rest just disappears. This is scalandolous and a massive waste. And there is a massive desalination plant in Gippsland and they are talking about pumping the water from there to Geelong which is just crazy. Well they should just send to water via pipes.<br>-Groundwater seems to be dropping and the creeks and swamps are also drying up. For instance, Barwon river that provides water to Geelong has a lot of digs, bores which has to be treated as it contains a lot of iron. There are people that believe that the drainage of the aquifers has let the swamp to dry out. There is a lot of acid sulphide produced and now the creek is crystal clear creek but it is completely polluted and unusable. So that might be an affect from draining. What is happening is, that people bore deeper and deeper to get what they need. | -Water deficits common in Australia<br>-Problems: Water pumping without licenses, leaking water infrastructure, increase of fertilizers and therefore water pollution<br>-Dropping of groundwater, creeks and swamps |
| IP3 | -Our groundwater has some degree of salinity. Some of the ground water has dropped while other areas remain the same. We are not drawing a lot of water because it is livestock and they are using a lot compared to the area where we are drawing from. I have not noticed that it is getting any saltier.<br>-We are not relying on groundwater and a lot of people do and they are running out of water | -No change in water salinity<br>-In some areas groundwater dropped |
| IP4 | There is no run-off for the last three years, so all the dams are empty so if we did not have the underground water, although the quality is not good here due to its salinity. The stock can drink it but we can't use it on the garden. That's why we installed the desalination plant 15 years ago for the pigs. Cows and sheep are fine but pigs need fresh water and the garden as well. | -Dropping surface water<br>-Desalination plant for livestock and garden |
| IP5 | -We don't have surface water this year. We rely on underground water for our stock.<br>-Our lake on the property is more empty than it has any water in it. We have a 15 ha lake that used to be our water supply but it has been dry now for the last 3 to 4 years. | -Dependent on groundwater<br>-Empty dam for the last 3 to 4 years |
| IP8 | We have got areas that are just fed by surface water, filled dams and they have never been dry in 100 years, and we don't have some water in there now which is quite extraordinary to me. And there is one creek that guarantees to run every year probably 3 times but it hasn't any more for 3 years. Something is definitely happening. | -Drying up of surface water, e.g. dams and creeks |
| IP10 | I would say that 5 or 6 years hasn't be as much winter rain and the results of that is, we pump out of the creek to fill our dams, the creek has to be flooding for water to get the salinity now. But the dams are empty for the third summer. Our bore water that we use for the sheep is too salty for the garden. | -Drying up of surface water for the last 5-6 years, e.g. dams and creeks |
| IP11 | One of our property has a natural spring that out of the ground flows about 1 million gallons of water per day. But it has slow down a bit, maybe 20-30%. We know that the old spring around has stopped running. But we know that this spring was not running when the first white man came here in the late 1830s during a drought, the drought broke in 1844 I think, and the spring started running and has not stopped ever since. We know that based on what he wrote to his diary. He claimed it as a miracle when it started bubbling out of the ground. We also have about 15 wind mills, the bores are between 40-120 feet deep and we have not seen any slow down of the water. But this place has got 55 dams and in 2006, 51 were empty. It was pretty frightening I can tell you. | -Slow down of natural spring by around 20-30%<br>-51 out of 55 empty in 2006 |
| **Water supply on the farm** | | |
| IP1 | We operated mostly on bore water because it was a fairly flat property so we did not have much runoff for dams. We had a few dams but they often ran dry in summer time so the bores always got us through very lucky, because our area was close to Mt Gellibrand and the further you get away from the mountains the saltier the water got. So at Mt Hesse the water was quite salty and up north it got saltier and saltier. So we could water our stock with the bore water from the farm as the Mt Gellibrand is a quite good recharge area. | Relying on bore water for stock supply, lack of surface water |

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| IP3 | We have converted the whole farm to be relied on bores rather than groundwater, so that is our strategy we have installed. We found a freshwater bore which pumps 4,5km back to the house to keep the garden greens. | Relying on bore water |
| IP4 | There is no run-off for the last three years, so all the dams are empty so if we did not have the underground water, although the quality is not good here due to its salinity. The stock can drink it but we can't use it on the garden. That's why we installed the desalination plant 15 years ago for the pigs. Cows and sheep are fine but pigs need fresh water and the garden as well. | Lack of surface water, installation of desalination plant |
| IP6 | We depend on town water, which is piped down here. I suspect there is underground water but it is very deep. Some of our neighbours do. | Using town water |
| IP7 | We did have livestock supply from bores and mills which were quite shallow. The deepest one on this farm was about 40 feet, they were quite fresh but no drinking water. But those supplies have actually dried up and we have put on a town water supply through the whole farm. Because the underground water that we have that we pump from deeper is very salty and not fit for livestock, so now we use tab water that comes from the Otway's around 60 Miles away. We have dams as well but most of them are dry now. So we can't rely on those either. Desalination plants are very costly but we are always looking at other options. | Bore water unreliable, town water supply backup |
| IP8 | Not really, because we are fortune enough to have portable water. So we have a town water schemes on one place and the other place has 4 bores, so I guess we have got the capacity to make sure the bores are pumping better than they ever pumped before. But we have got a forehead position, while a lot of people only have surface water, no underground water at all or availability of town and they are in a serious trouble. | Town water supply and bores |
| IP9 | The groundwater level seems to be dropping and the salinity in some of the bores in increasing. There have been several droughts in the past, I don't know if the water levels are dropping during every drought or if that just happens lately because of the general change of climate. We have got 2 bores on the farm that we use, one well that we hoping to bring back into use and town water. 30 years ago we used to be self-sufficient for water, we had 3 wells that used us to supply but they are too salty now and don't have enough quantity. | Town water supply and bores, water gets saltier |
| IP10 | We have domestic water from the roof and tanks on our buildings. We have bore water that is not very deep and that does all the stock, but we couldn't use that for our garden. | Bore water and rain water at house tanks |
| IP12 | Our rivers are getting saltier but I think that has to do more with land use than climate change and groundwater is also diminishing but I would say there is not a change in the total amount of rainfall, so it has probably also to do with the way we use it. Groundwater was for stock water and we also had dams and rivers and our domestic water was from the roof. | Groundwater and surface water |

Summary of comments on the length of the growing season

| IP | Quote | Generalisation |
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| | **Length of the growing season** | |
| IP2 | -I think all the seasons are getting a bit different. Like the autumn break starts generally later now than what is used to be.<br>-One thing that has changed is that the gum tree used to flower around Christmas time but a lot of the trees are flowering now a month earlier. It has changed the timing of the flowering of the Eucalyptus as well<br>-Also now in this time of the year, it is about 6 weeks to early that plants flower. And some trees flower every year and they should not do that and just flower every second year as they go through a growth and a flowering cycle | -Autumn break tends to start later<br>-Flowering time about 1 month earlier<br>-Unusual flowering of trees |
| IP3 | -[…] the previous 15 year to now, they are drier and that would move our lambing forward because springs are not reliable anymore as they used to be.<br>-I would say that growing season is shorter than it used to be, simply because the springs are cutting out earlier. The springs are shorter so we are going into summer quicker.<br>-One of the problems in terms of cropping is, we are getting hot days earlier which is affecting flowering. With the livestock, the shorter springs gives us less time to finish the lambs. Also for the wool, shorter growing periods mean that there is more chance of a break in the wool. | -More unreliable, earlier und quicker springs (less rain)<br>-Changes in flowering |
| IP4 | -I think, it is getting a bit more extreme, but I am not sure about that although you start wonder a bit, like all the rain we had last summer was particularly unusual which was a tough time for us. This is a fairly reliable country, but having two bad springs in a row was a bit surprising. You are not surprised about getting one occasionally, but normally the second year is always ok, but not this year.<br>-That's the problem with the spring. It is obviously terminating earlier than the normal, whether this is a trend but it is very hard to say because we don't keep temperature records and it is always fluctuating so much so we don't really record any differences. | -More summer rain<br>-More unreliable springs, ends earlier |
| IP5 | I would say that within the last 5-10 years our cropping season is almost a month earlier than it used to. Our crops rely on spring rainfall so we have reliance in September, October and November, but particularly October has usually good rain for crops but for the last 3 to 4 years we hadn't had that. So we had some very difficult cropping years. | -Unreliable springs in the last years |
| IP6 | The two most noticeable changes have been the autumn break which seems to come later and later and almost doesn't really come and a lot of people would wait the sowing for autumn in March, April, and May. If it hasn't rain by the 25th of April, you have a serious problem. We have not had any spring for the last two years, which is our major growth period. | -Autumn break tends to start later<br>-Unreliable springs |
| IP7 | I would say the growing season has changed a lot and shifted between 4 to 6 weeks. About 35 years ago we used to sow in June or July because we knew we will get rain in November to make them finish | -Shift of growing season of 4-6 weeks |

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| | and now we are back to finish in September, October, so we have to fit our sowing dates to climate change. | |
| IP8 | Autumns don't seem to be that similar to how I remember them, but springs and also a bit winter has really let us down the last 3 years, so quite extraordinary. So something is changing.<br>-It has been depleted enormously because the springs are not happening as usual anymore, so our growing season is 6 weeks to 2 month shorter than we are accustomed to. This of course has massive consequences on grain yield and animals production, such as wool and meat. | -Change in autumn break<br>-Unreliable springs<br>-6-8 weeks shift in growing season |
| IP9 | From memory, the autumn break has always been fairly unreliable, but it is even more now and it is coming later than it has been in the past.<br>-I would say it is an average shorter than it used to be in the past. | -Unreliable autumn break<br>-Shorter growing season |
| IP10 | The length depends on the autumn break and spring rains. October has not been good for the last 2 or 3 years, which has shortened the growing period. Winter growth is not too bad. | -Bad springs in last years |
| IP11 | I can't see any change in the length. | -No change |
| IP12 | But the autumn breaks are definitely later. And the springs end earlier.<br>-The timing we were doing hay making has moved forward, normally it started at the 21 of November, while now it is the 3rd of November. This is because everything and the grasses start to flower 3 weeks earlier than they used to 30 years ago. That is probably the most noticeable thing and the most dramatic change you can see in such a short period of time. So the growing season is getting shorter.<br>-I think the most noticeable thing is the different flowering times, such as tress as brottles that used to flower in August, while now it is flowering in June and the next year they are confused and it is all over the place. The nature seems to notice it more than we do. | -Later autumn break<br>-Springs end earlier<br>-3 weeks earlier flowering times<br>-shorter growing season |

Summary of comments of farmers opinion about climate change

| IP | Quote | Generalisation |
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| | **Opinion about climate change** | |
| IP1 | -We sold our farm 3 years ago. One reason for that was climate change. There were some weird issues with the crop and grazing area, starting to potentially to arise.<br>-We find that things are changing, for instance kangaroos are coming further south and also quite big flocks of Kakadu's and one reason for this is, the cropping is coming further south as the rainfall further north decreases. So they might move south to more reliable rainfall areas, for instance do they are growing crops as canola now which they would not consider like 10 years ago. That would have been too wet and the climate is changing.<br>-We are quite firm believers in climate change and lots of people you would perhaps do not share that same view but we think that floods and droughts are caused by climate change.<br>-We are seriously worried about the future climate for our kids and grandkids and they are concerned as well.<br>-The more we look at this, the more we realize what terrible things we have done to Australia for the last 200 years, we basically destroyed the whole environment as well as most Aborigines as well. Our thinking is quite controversial, not many people do believe that.<br>-We are deeply concerned. Most other farmers would deny it. I think it is getting increasingly difficult also to adapt as it is going to be worse and drier and more extreme weather events. And also a lack of underground water. There are so many issues in Australia. […] It is an area with quite low rainfall and light soils that would just blow away. Everything is driven by economic interests. Over grazing is also a problem and people don't treat their land with respect. | -Deeply concerned about climate change<br>-Sale of farm, among other due to climate change<br>-Cropping and animals coming further south<br>-Worrying about future generations |
| IP2 | - are still going through a very dry time. About the causes I am not really sure. But if you read books from the past, you realize that even then they had very big droughts.<br>-People don't realize that the media and the whole communication have changed a lot. We nowadays see floods in Argentina in the TV while back in the 1950s most people would not even know where Argentina is.<br>-I think the weather is highly variable anyway and how much is manmade and how much nature is really hard to understand what is going on.<br>-the amount of power, heat and gas is much smaller from under the sea and human do not really have much of an influence when you compare that and for instance can come out of a volcano. Another thing is that the sun varies in strength.<br>-Well, in some way I can see a change but on the other hand I realize that we live in a country that has gone through a lot of changes for a long time. It is definitely windier here to what is used to be. But I do suspect that the natural forces such as sun cycles are greater to what man-made influence is.<br>-But I think the BOM sometimes exaggerates and I am not very convinced of the measure techniques as it is apparently always the driest summer, spring and so on.<br>-when I went to glaciers in New Zealand it was actually growing | -Uncertain about climate change, probably natural causes but not manmade<br>-Change in perception through media<br>- Floods and droughts are caused by climate change |
| IP3 | Cyclically it has been like this before and in our records it has been like this before.<br>-I think in general, that climate is changing all the time. And farmers for hundreds of thousands of years have managed this, it changed their system to cope. I mean in the northern hemisphere they are growing crops under the snow that is also managing the climate. It is interesting that the Lake Murderduke is just about to dry out. All that means that we had a run of dry years and it has been always dry before, and then it has been full again and then dry. That is an ongoing cycle. We just have 150 years of records, how do we know, it is just a too short period of time. Whether this is man-made or not, I can't really tell, nobody can. However, we can always have wet years as well.<br>- We have the most variable climate in the world | -Climate is always changing |

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| IP4 | -Certainly the extremes are there but they have always been there<br>- I don't think we have moved away from the variation that have always been there also in my family life.<br>-I am sure about the actual climate change and we are absolutely convinced that we do have to improve our ways and clean things up and use new ways of energy.<br>-Even if I am not 100% convinced about climate change, although this year you really start to wonder but maybe the extremes are greater. But maybe also because we are so available to the world, we hear a lot more bad things we wouldn't have heard about in the past.<br>-Well obviously scientists are very pro climate change because that is the topic where they get research funding from. I think it is hard to say in a long term what is really changing regarding our short time of history in the world. But if the fluctuation gets greater here, then we will have some real problems. | -Changes noticeable, but climate has always changed<br>-Change in perception though media<br>-Researchers are interested in cc because of fundings |
| IP5 | - When you study the rainfall records we have, we are definitely going through a period of dry. But I think that is just climate variability and not climate change. Unfortunately Australia's rainfall records don't go back far enough<br>-There are a lot of signs that are refusable such as the polar ice caps but what no one really knows is if that is just variability and that normally would have taken place anyway. What I really believe is that whatever we humans do, we have to do better for the future of the planet. Whether you believe in climate change or not, there are better ways of producing electricity rather than coal for example. I think the change is not such a big issue but human must be able to survive on this planet.<br>-I mean you can't argue that our atmosphere is different to what it used to be 200 years ago and beside the fact scientists are being paid for research in climate change, there is no doubt that the temperature is going up.<br>-I am sceptical about climate change; I think it is an industry that creates a lot of work for a lot of people. And you tend to hear more about climate change from a negative point of view. The climate sceptics tend to try to listen to both and it is hard to find a balanced view on that.<br>-What I have noticed in the last couple of years is despite of having a lot less moisture, our trees seem to be growing very well and they are flowering very well. So I have read that the slight increase of carbon dioxide is actually promoting growth of trees, which seems positive.<br>-And certainly, there are different varieties and species of bird that come south from north because of the warmth we didn't have.<br>-But we are optimistic; you have to be optimistic when you are a farmer, so we are always looking at the bright side. Sometimes it is hard.<br>-I believe in climate change and during the 50 years of farming we have gone through periods of very dry years. If I was advising my children and grandchildren I would tell them to be aware that the climate is changing. But I don't think that is a reason to panic. With climate change there will be always areas in the country that might be better suited for farming, so we don't have to stay at this one spot. My thought would be, be aware of climate change but also of new opportunities. | -Scientists are being paid for research in cc<br>-CC creates work for a lot of people<br>-Keep cc in your mind but don't panic and also look at opportunities |
| IP6 | I think droughts are probably the most extreme weather events. But it has been always part of Australia, droughts and floods, bush fires as results of the dry<br>- The weather pattern are definitely changing. Whether it is driven by man-made changes or whether if is just a trend, I suspect it both, but I think man is accelerating it.<br>-I think it is fair to say that I don't understand it in terms of its full implications and what it exactly means. 5 years ago there was a massive rain event in January here and there was grass literally everywhere and then it went very dry again. It is the unpredictability of what is going to happen is probably the hardest. I think there is an overall trend of climate all though historically that continues to change. This are here was a lake once. But I think man is doing its best to push it along as well. Things do need to change and improve. | -Changing weather pattern, uncertain if climate change is manmade or not<br>-Problems in understanding the science of cc |
| IP7 | We had to change our business. Beside livestock we can also crop now although we were never able to grow good crops 30 years ago. Now we can grow good crops. In the past we used to grow crops in the front part of the property as it was always a bit drier because of the soil types but now we are able to grow crops up to the back of the farm which used to be very wet. We used to loose crops there as they have been washed out, but now we don't. We used to have swamps in the backyard of the farm and we built that course ways so we could drive around without having water coming into the vehicle and now we haven't use this course ways for many years. It just doesn't rain enough to fill up the swamps. So it is definitely getting drier. About a quarter to a third of this place was even to wet to drive around like 30, 35 years ago and now we can grow crops and drive everywhere. It is kind of an advantage at this point without getting any drier, it might go the other way and we are worse off. But this year has been a rotten year. We can crop and graze the areas that have been under water and manage them a lot easier as they are accessible to us in winter now<br>-In general, the weather is getting more extreme. When it rains, it rains a lot and when it stops raining it stops all together. There doesn't to be general rain and our weather seems to come from a different direction. It used to come from the south west and now it seems we are getting from east and north but not general weather from the south west. So I think that has changed.<br>-I think the weather is getting more unreliable for us for farming as it hasn´t been for the last 20 years where it is getting a little bit drier every year. I don't know what the future holds for us in this part of the world but I guess we just have to adapt our management to changing climate conditions. I don't think any long-term planning is going to be effective at this point. We just have to take it as it comes. | -Drying up of farmland created new opportunities<br>-Weather gets more variable |

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| IP8 | -I was very much of a sceptic until 2 years ago, I have just put it down to a very dry year and that things would turn around. […] this was kind of a wakeup call for me that something serious is happening here, climate change. That was the point when I said to myself, get your head out of the sand and we have to do something about it. That was like 12 or 14 month ago when I decided we have problems.<br>-Well, we are not doing anything to be quite frank. I guess to actually recognize and respect it, acknowledge it that is a bit of a challenge in itself. I am not at this point now. But I worry about it, everything we do now is in the back of our mind, whether that is buying a property in terms of having a look at the rainfall area or even in a very wet area. Things like that pop up occasionally and that sorts of change your mindset. That's what I am doing about it, although I believe that subconsciously I am probably doing more than what I can actually explain. | Recognizing the fact of climate change |
| IP9 | It is a worry. I think it is obvious that climate is changing. I am not convinced to which degree mankind is causing that. I think we are not totally responsible for climate change but partly. There have been ice ages and very dry periods in the past as well going back thousands of years; there has always been a huge variability. The same about the hole in the ozone layer, which suddenly appeared or is it rather that we suddenly got the technology to be able to see it. I think some of the things that are happening are caused by us but a lot is caused by the climate itself.<br>-But lower rainfall has been a benefit to us in some ways, because huge areas of the farm used to be very very wet in winter and usually in spring too, soils very salty and unproductive to species and now with the drier years and the dropping of the water tables the soils has lost a lot of its salinity as it has gone further down into the soil I suppose and we can grow crops now in paddocks that we never were able to. | -CC is a concern, humans are partly cause of cc<br>-New opportunities |
| IP10 | I think climate is a cyclic thing and we are at a burden dry cycle at the moment. Whether that is man-made or not, I am not in the position to judge or have an opinion about it. But my opinion is, there have definitely been several seriously dry periods in the past, the lake here in the area also dried out in the past and filled up again with water. I tend to think that these dry patches come and go. | -Uncertain whether cc is manmade or not<br>-Dry patches come and go |
| IP11 | I can't really see big changes in terms of weather pattern. We have droughts before, severe dry years, we had wet years. If we had this discussion in 1946 which was a very dry year, with nearly the whole rainfall in the first 3 month which is catastrophic. It annoys me when people say something hasn't happened before. If you look at the Luna banks, which is soils that has been blown out of the lakes in droughts so over thousands of years and deposited here. But I don't know to which extent it is getting worse. | -Big changes in weather pattern that have not been seen before |
| IP12 | It is obviously happening and I am sure we are cause of it. The degree of how quickly it is happening I was a bit sceptical about for a long time but I think I am not anymore because it seems obvious that things are happening faster than we though they was. This year it was 0.9 degree higher than the average which is a big difference. There are also seasonal shifts in winegrowing areas as people cannot grow the same varieties anymore, a lot of them are moving down to Tasmania. I think deserts are moving further north in the northern Hemisphere and further south in the southern Hemisphere. | Worrying about the pace of changes in climate |
| IP13 | The way I operate my business, is that I include the risks associated with projected climate change. I built that into the way I plan my business on short and long term, it is very much at the forefront, the way I plan and budget my enterprise. Climate is the thing that I base pretty much everything on. Commodity and pricing play a role but the overlong terms up to 20 year is, my approach is not to change enterprise too much, it is about finding what works and what exposes you to the least risk or the risk you are comfortable with in terms of climate change and seasonality and climate in general and also to balance this with the long term demand for this product. If I go for sheep and wool, this is a pretty solid thing to be growing. The world won't suddenly stop the need stream of protein. I don't worry about little changes in the commodity prices because over the long term they are fairly steady. The input costs are quite a different story. They tend to go up as a result of competing interests for energy input.<br>- Adaptation to climate change is a conversation killer, around farmers and rural community. If I start talking about climate change, they door starts swinging in the pub and everybody stops and the piano also stops playing. I know that people who give a presentation title their presentation differently and not climate change. There is something psychological going on there. | - Includes risks associated with projected climate change into business plan on short and long term to balance this with the long term demand for a product<br>- Adaptation to climate change is a conversation killer around farmers and rural community |

Summary of comments in terms of perceived Constraints to Adaptation

| IP | Quote | Generalisation |
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| | **Main challenges in agriculture** | |
| IP1 | Clearly water is a massive issue. It has always been an issue in Australia anyways which refers to the rivers, the dams and the groundwater.<br>-But when you walk along the river you would see how little water there is running through, and big pumps going to the farms and it is just unsustainable, some people are even pumping water without a license. The water which goes to Geelong is all collected in the West Barwon dam and it runs through an open channel which leaks very badly to a reservoir outside of Geelong which is quite shallow as it has very high evaporation rates, so only like 19 % of the water that is collected gets used in Geelong and the rest just disappears. This is scalandous and a massive waste.<br>-Certainly, yes but whether you can say it is from climate change is really hard. Tussock is spreading around because of birds and vehicles and one of our weed problems we are facing is this annual ryegrass resistant to round up (glyphosate chemicals). I think this came down to the farms because it was carried down by harvester machines that come down the whole way from Queensland to Victoria and bring down this resistant problem. They are meant to clean them between each property but some don't. But perhaps they have taken hold maybe due to overgrazing or bearing the ground which also might be of a problem. | -Water decrease & high evaporation rates though bad infrastructure<br>-Weed & resistant problems<br>-Overgrazing |

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| IP2 | Farmers don't mind so much about a dry summer or autumn but you cannot have a dry spring, you must have a wet spring. The last few years the springs were a bit too dry and it has a big effect. […] At the moment we are in a very dry spell. | -Dry springs in last years |
| IP3 | One of the problems in terms of cropping is, we are getting hot days earlier which is affecting flowering. With the livestock, the shorter springs gives us less time to finish the lambs. Also for the wool, shorter growing periods mean that there is more chance of a break in the wool. | -Earlier flowering times<br>-Shorter springs give less time to finish lambs<br>-Higher chance of break in the wool |
| IP4 | The lack of growth and production and dry matter is critical because of the stocking rate that we expect to support or the yields we expect to growth and budget for, has a profound effect on our financial results.<br>-Obviously, through the effects of spring we might have reduced production. And the reliability will suffer.<br>-But as we had such a tough year, we had to spend a lot of money to keep everything. Our main focus is to keep the breeding animals in good breeding conditions.<br>-What normally happens is during dry years is that the grains prices go up which hasn't really happen this year. So we can have an average yield and do very well. There are so many effects that influence our yearly results. The challenge is, you sort of have to take a decision before you know how the weather is going to be like. | -Lack of growth in dry matter has profound financial effects to keep everything<br>-Spring rainfall gets more unreliable<br>-Take decisions despite a lack of predictability |
| IP5 | We have got a lot of endangered species in legumes, animals in Victoria. But our biggest problem is invasions weeds which has nothing to do with climate change. The worst weed we have got here is serrated tussock, which actually came from South America with the sheep in the 1950s.<br>-Chemicals are our biggest problem, they are very dangerous and there were times, where we have used DDT and now I am sure there are residuals all of the chemicals I have used. I am very anti. And that's why our cropping is becoming very difficult because we have resistance with some of the grasses to round up and that is going to be a very big challenge. We still use chemicals but reduced and it is becoming more difficult because of the resistance. | -Invasive weeds<br>-Chemicals and resistance |
| IP6 | This country can grow a lot of grass if it gets an even spread of rainfall but if you have long dry stretches it doesn't tend to work.<br>-It becomes quite challenging when you get dry periods like this, to generate enough feed to feed your animals. You have to change your farming practices to match the circumstances.<br>-The lack of predictability. We have to change or methods to accommodate. The weather patterns are definitely changing. Whether it is driven by man-made changes or whether it is just a trend, I suspect it both, but I think man is accelerating it. It becomes quite challenging when you get dry periods like this, to generate enough feed to feed your animals. You have to change your farming practices to match the circumstances.<br>-If you don't get an autumn break it is very hard to grow crops. Due to the 2 bad springs in a row, we were not able to cut any hay. The grass starts to grow but there is not enough soil moisture. In a good season here we would cut around 3000 bales of hay, in an average season maybe 1800-200, this year we have just cut 400, last years the same, because of the failed spring. | -Lack of pasture growth due to uneven rainfall & lack of feed fodder, lack of soil moisture<br>-Lack of predictability and match farming practises to circumstances |
| IP7 | The main challenge is the shortening up of the growing season and we don't get a spring. So when we have livestock production we need to fatten them in spring. We have to be prepared to feed livestock to finish them off rather them finish them off of grass. That's the main change in the system. | -Shortening of the growing season<br>-Higher chance to feed livestock |
| IP7 | I don't see how we can change our management as the weather is so unreliable at this point. | -Unreliable weather |
| IP8 | The main problems are the failed springs, but I know there are other parts of Australia that are getting even better spring than in the past. The springs are a key issue, that's where you get your yields, your grass to fatten the cattle or to grow your wool. That's the important one, letting us down. I mean water has always been kind of a problematic, but the springs that have been really collapsed. | -Failed springs & impacts on production cycle |
| IP9 | I think you have to be aware there is more variability and try to cope in such a way that if it is dry you can make use of the dry and if it is wet you can do this to make use of the wet. You have to be more prepared for changes. | -More variability means more flexibility |
| IP10 | Well autumns are always a challenge. We expect to feed sheep every year in the autumn, we are also feeding at the moment which is earlier than usual, depending on when the autumn breaks comes, depend on how long you feed the sheep, so nutrition's is the main thing. | -Unreelable rainfall and higher chance to feed livestock |
| IP11 | Wet times can be just as bad as the dry times and stocks actually do better in dry times, every winter is a problem for us.<br>-The dry spring in October, November, December are very difficult. Unless you are very lightly stocked but if you are heavily stocked you need enough feed and water. Anyway, people have to do much better. | -Wet winters<br>-Dry springs & livestock management |
| IP12 | Mainly the shorter growing seasons. In southern Victoria the growing season is from about May till end of October or mid-November and if it gets any shorter than that risk is high that you do not get enough growth you rely on. And that is a problem because in this area we have a high stocking rate compared to the rest of Australia. Therefore we are pretty dependent on having a reliable growing season and if it gets shorter it makes it harder. | -Shorter growing season & lack of pasture growth<br>→ impacts on livestock production |
| IP13 | I don't worry about little changes in the commodity prices because over the long term they are fairly steady. The input costs are quite a different story. They tend to go up as a result of competing interests for energy input. | -Increasing input costs |

Summary of comments on pasture and crop management

| IP | Quote | Generalisation |
|---|---|---|
| | **Pasture and Crop management** | |
| IP1 | As we had Merino sheep and they are very good in dry environments it made it much easier for us. I am not sure that cropping ever made us much money over a long period of time but it gave us more flexibility because we did not have to buy feed in so we had grains for our stocks and stubbles to graze. I would say Lucerne is very helpful when you do not have a lot of water and we also had phalaris which is a very tough grass and almost unkillable and helped us to go through difficult periods of time | -Using summer active pastures<br>-Mixed livestock-cropping to reduce risks |
| IP3 | We actually had some different species in these areas that actually can tolerate salinity.<br>-Yes definitely. Well all the grass species we use are deep rooted perennials, we rely on annuals, all the clove have a growth habits that suits the Mediterranean and they have all come from the Mediterranean and they have being breed for Australian conditions. So that climate is exactly the same as ours and we use cultivars of similar growth habits.<br>-I reckon that just by changing the varieties of grazing on about half the farm we can probably increase production by 30%. So we are improving the pastures on non-arable areas on the farm by clearing them from rocks, putting proper drainages and sowing new pastures. | -Different salt tolerant species<br>-Deep rooted perennials that suits the Mediterranean region<br>-Changing varieties of grazing species to increase production<br>-Putting drainage |
| IP4 | At the moment there is not much grass to manage. When it stops to grow it is quite hard to manage it accordingly. But ideally we eat the paddock out and then move on to another one. – We use short season varieties.<br>-And we use more mechanical weed control rather than chemical, so that is a big difference. And our rotation has changed with the beans coming in. | -Rotational grazing<br>-Short season varieties<br>-Use mechanical weed control rather than chemical |
| IP5 | In terms of the feed growth cycle, we have a sophisticated New Zealand system. We work out the productivity each year on each paddock and we also have a feed budget that we work out in terms of how many livestock we have, lambs, how much grass and we decide how to cope.<br>-Rotational grazing. We have a large area of land that we have sown to Lucerne, which is especially good for the younger sheep. We use native pastures during winter when we can use them. Under the structure we have with the environmental offset we are not allowed to have animals on them during the spring. Our pastures are also fertilized.<br>- We are trying new varieties of fodder crops which haven't proved yet, but we are trying. | -Copy of New Zealand feed cycle system<br>-Use feed budget to manage carrying capacity etc.<br>-Rotational grazing<br>-Use native pastures and fertilizer<br>-New varieties |
| IP6 | We are doing trials of different and grass types to grow feed for longer periods that haven't been growing here before, we are taking advantage to destock earlier and putting in summer type crops to have feed when it is dry are our main strategies. We try to get more summer active crops. We work in conjunction the Department of agriculture, with agronomists, sectoral experts, farm discussion groups and so on.<br>-We use different grass varieties, different fertilizer, compost, gypsum and lime to break the soil down<br>-We are moving away from annual grasses to perennial grasses. So have put in some harder varieties that can sustain the dry summers, such as fescues, phalaris and some of the clovers. | -Different and new grass types and varieties<br>-Destock earlier<br>-Putting in summer type crops<br>-Moving away from annual to perennial grasses |
| IP7 | We use a rotation system with our cropping paddocks; we sow them down every 3 to 4 years as the management dictates. Well nothing is tolerant to this sort of drought, when it doesn't rain there is nothing you can do about that. But we would put in some other species such as more active summer growing species. | -Rotation system of cropping paddocks<br>-More active summer type crops |
| IP8 | We don't have a lot of pastures, but what pastures we have got is either native pastures and we certainly do have pastures management structure to go around native. Otherwise we have go a lot of Lucerne, not for cutting for hay but just for stock grazing which covers mainly our requirements.<br>- […] native pasture perform ok anyway during dry times and Lucerne is a very deep rooted perennial which performs remarkably well during dry periods. It picks ups some summer rain and it blossoms. | -Native pastures, deep rooted perennials<br>-Pasture management plan<br>-Lucerne as summer active plant |
| IP10 | We have fertilizer and we continuously sow perennial grasses. We find they are better and more productive than annual type grasses and native pastures.<br>-Yes the perennial grasses are drought tolerant; we gave up growing grasses that were not drought tolerant 30 years ago. We worked out which ones would persist and we found that phalaris and the fescues would persist the dry times. We continuously are planting new varieties that are drought tolerant and productive. | -Perennial pastures, away from annuals and native pastures<br>-More drought tolerant grasses |
| IP11 | We are sowing down good species of grass that are tougher to drought. There are new varieties that handle the dry very well but also the wet. We started introduction new species about 15 years ago. My father was different he just tool it how it comes, but we are planning more for what might go wrong. We also have a good fertilizer history. Good quality water and nutrition, we must have good heathy animals. | -Drought tolerant species<br>-New varieties about 15 years ago<br>-Proper pasture management to plan for difficult times |
| IP12 | We used new cultivars of ryegrass and clovers which were more productive. We did a little bit of rotational grazing which is also a good management. | -New varieties<br>-Rotational grazing |
| IP13 | Essentially, we grow a lot of perennial plants and a lot of browserable shrubs, salt brush and this sort of bush which makes benefit out of rainfall. | -Perennial plants |

Summary of comments on sowing dates

| IP | Quote | Generalisation |
|---|---|---|
| | **Sowing dates** | |
| IP1 | It was always pretty much the same, although we changed it a little bit from year to year which was more a management thing | -Year-to year variation |
| IP3 | No not really. There are a number of things to take into account if we talk about management. One of them is agronomy so if the weeds are germinating we have to kill the weeds before we sow the crop otherwise we use all the chemicals in our valuable crops. So we have to wait for germination and therefore we can´t really sow until we had a large autumn break and that really settles the timing and we try to get it down as quickly as possible. But that is all what we do. | -Kill weeds before sowing, wait for autumn break |
| IP4 | It is coming earlier because our weed control is better so we can do that. We sow in April, May and it used to be later in May or June. | -Now in April or May instead of later May/June |
| IP5 | Yes certainly, we sow different varieties and sow much earlier than we normally do. Also because we are very dry now. Our biggest problem is the lack of rain in late spring and by getting the crops in early, we hopefully can pick up the winter rain and there is a bit of residual soil moisture to grow the crop. We have sown everything by end of May, beginning of June while in the past we used to sow in July or mainly August. You always need to be flexible in your farming program; you have to take opportunities of wet or dry years. It is always manageable in the situation as long you can recognize a window where you can make money, e.g. by selling all your stock very early so you are not feeding or maybe by purchasing stock. There are always opportunities in dry and wet years. | -Sowing time earlier than in the past due to lack of rain in late spring, picking up of winter rain<br>-Now end of May/beginning of June, past: July or August<br>-Use opportunities of dry and wet years |
| IP6 | We sow when we have enough moisture, although some people are sowing in advance before the moisture is coming. We only crop for feed not for commercial crops. Normally we sow in the end of April, into May. Pasture is sown between April to June, and new summer crops any time from October to December. In the past we didn't do summer crops and we used to sow a little bit earlier than April. Probably would not sow beyond the end of May, so we are going back a little bit for pasture. Previously paddocks would often become too wet in June to do anything with but it is no longer that way. We use different varieties to suit the conditions of the paddocks as they are not as wet as they historically have been. | -Dependant on soil moisture<br>-End of April into May, past: earlier than April<br>- Use of different varieties to suit the conditions of paddocks |
| IP7 | -We tend to sow our crops later in the year in July and August, but we can't do that anymore so we are going back to sow in the start of May. This is because we are not getting the rainfall through the spring anymore, so we sow it earlier to catch the last of winter rainfall because the spring rainfall is becoming more unreliable | -Sowing now in May, past: July/August to catch last of winter rainfall |
| IP8 | Yes we have. We probably come slightly earlier than where we were. It has probably more to do with the varieties of cereals we are growing more than from a climate perspective. But as the springs are starting to finish earlier so in the last I would say 15 years we have come a month earlier, so we have pretty much everything in by the end of May while in the past it was more in June and July. | -Sowing earlier by end of May, past: June/July |
| IP9 | We are sowing earlier now for sure. About 30 years ago we sowed barley in August, while now we sow barley in May. That's because of the increased unreliability of the spring to finish the crops off. If you sow earlier you have more chance to pick up winter rain. | Sowing earlier in May, past: August |
| IP10 | Not really, they are always sown at around the same time of the year which is autumn, late April, May. Cropping has become more scientific over the years; we involve more and more technology. We believe in getting them in as early as possible and get away in the winter. Sometimes the winter are getting very wet, like 4 or 5 years ago. Crops struggle through that winter, some of them did not survive, like some of the legumes because it got too wet. So it's good to get them in early. | As early as possible |
| IP12 | Probably not that much. We changed crop varieties. We used to grow oats mainly because they are quite water tolerant and we have moved to wheat and canola, because we had drier winters and they can handle it. | No big change in sowing dates |

Summary of comments on soil management

| IP | Quote | Generalisation |
|---|---|---|
| | **Soil management** | |
| IP1 | We tried not to graze down the pastures and sometimes when you plower a paddock it will just blow but you always try in time your operation so that it is not going to disappear over the fences to the neighbours place. […] So they were very scared to ploughing up another paddock and if it was not going to rain, they would lose another paddock. So we did not plower and just used minimal tillage or better direct drilling.<br>-We had different strategies and were quite traditional in that respect. | -No graze down of pastures to avoid wind erosion<br>-No plower but minimal tillage or direct drilling |
| IP2 | What we and the Australian Government should do is more Landcare plantings; you would also find that on Mt Hesse. These wind rows of trees stops or slows the wind down and for me as beekeeper the productivity becomes so much better. | -Landcare plantings to avoid wind erosion |

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| IP3 | It is all direct drilled, so we don't do any tillage so that we don't waste moisture. But this is also for a number of reasons. The soils are very shallow so we don't want to cultivate them as it breaks down the soil structure quite quickly. Down here it gets very wet in the winter so we had had some raised beds for cropping to make the water run off quicker and that works with controlled traffic. However, a lot of them have been pulled out because we had a lot of dry years in the last 15 years.<br>-Maintaining 80% of groundcover and to do that we get the sheep off the pastures before it gets too low. The more exposed the soils are the higher the chance of wind erosion and sun damage too as the soils can get very got. | -Direct drilling to avoid wasting soil moisture<br>-Raised beds for quicker water runoff during winter<br>-Controlled traffic<br>-Keep 80% ground cover to avoid erosion, get off sheep in time |
| IP4 | We have been minimal cultivation for a very long time. I remember David coming here when he was very young, he couldn't believe we were starting a paddock without ploughing it. The raised beds are a result of the wet seasons and that is giving us much better productivity on the clay soils which we have and even this year we had a relatively good yield on that country while our good free draining soils with haven't had enough soil moisture but that varies on an annual basis. We are very conscious of looking after the soils, but do a control traffic system to avoid too much soil compaction. That's our philosophy of our soils; if we don't have a future of good soils we don't have a future in farming. We also conduct soils tests annually. | -Minimal cultivation without ploughing<br>-Raised beds<br>-controlled traffic system to avoid too much soil compaction |
| IP5 | We do manage our soils, agronomy is most important. Most make use of lime and gypsum to improve quality of the acidity. We also make use of controlled traffic to control compaction, understanding the science of soils is becoming more and more accurate, especially to understand which what of your paddock needs what. We also shift the pigs every two years and use the fertility that is build up to crop, which is quite sustainable. This shifted rotation is part of our sustainability. | -Controlled traffic system<br>-Rotation shifts of pigs for fertility reasons |
| IP6 | We look at different soil techniques to try to encourage the roots of the grass to go down deeper to access moisture further in the soil. We use different grass varieties, different fertilizer, compost, gypsum and lime to break the soil down. This particular area has very heavy soils; rots are shallow which is a problem during dry times. You can get the bacteria working in the soil and the roots would go down further, that's why Lucerne is doing very well as the roots go down up to 5m. | -Using different soil techniques<br>-Encourage roots to go down deeper for moisture access<br>-Planting deep rooted perennials |
| IP7 | We do some tillage but not a lot but mostly minimum tillage. We don't do fully cultivation anymore, very rarely. If we do that we have a row grass resistance problem or weed problems we really need to get rid of by mechanics rather than by chemicals. | -Minimum tillage<br>-No full cultivation anymore avoid resistance problems |
| IP8 | We use a lot of chicken manure and have been a big advocate for the use of that over the years, which has helped enormously with every aspect of fertility in our soils and also getting our balances more in line in what they should be. We are very conscious of our soils are worry about how to go about it and we are also frequently doing soils tests to make sure we are on the right track. | -Chicken manure to fertility reasons<br>-Soils tests |
| IP9 | We are farming more here than they do in northern Victoria, as we have to think about conservation water and not leaving the soils bare too much, so the soils don't blow away. | -Avoid are soils and erosion |
| IP10 | […] try to cope in such a way that if it is dry you can make use of the dry and if it is wet you can do this to make use of the wet. You have to be more prepared for changes. | Use opportunities of wet and dry times |
| IP12 | We cropped differently. We used minimum tillage instead of ploughing it and full cultivation, this was for moisture conservation. And we also started putting in raised beds which allows the water to escape though the beds to get rid of excess water quickly. It is quite expensive to keep them and you also can't put sheep on the paddocks to graze the stubbles. | Minimum tillage instead of ploughing and full cultivation for moisture conservation<br>-Raised beds |

Summary of comments on shearing and lambing times

| IP | Quote | Generalisation |
|---|---|---|
| | **Shearing and lambing times** | |
| IP1 | We certainly did, we changed from autumn to spring lambing and that was because of the feed and they would get the best nutrition. And we had two sheerings in the year because sheering was getting much too long and decided to sheer the female sheep in spring and male sheep in autumn. | -Change from autumn to spring lambing due to feed availability and nutrition |
| IP 3 | -The previous 15 year to now, they are drier and that would move our lambing forward because springs are not reliable anymore as they used to be.<br>-We changed it, no mainly because of seasonal influence, well to a certain extent but we want to sheer before we join the rams which brings it into January and we want to be close enough to the autumn break. We used to sheer in May, but logistically it was easier to sheer in February and January.<br>-lambing time is earlier, so we have done a lot of stuff to cope with a dry climate already | -Lambing times moved forward due to unreliable springs and drier climate<br>-Sheering now in January/February, past: May due to logistically reasons |
| IP4 | Yes it is all spring lambing now, while before we had autumn lambing. So a change from autumn to spring lambing to get a better usage of the feed, so we don't have to feed them much in winter. But this gives a problem this year; we have a lot of rams to feed. | -Spring lambing , past: autumn lambing due to better feed usage |
| IP5 | The spring is the period of most growth and also a little bit the autumn. That's the window we work on for most of our conserving fodder making silage or having our lambing in there. We reckon that in a year we only have got 2 or 3 month in which to grow feed which we can rely can. Our whole production system for our grain and livestock is dependent of making sure that we optimize that time of growth by harvesting and storing grain or silage or by fitting our lambing or carving in that period. | -Spring lambing during time of most pasture growth |

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| IP7 | We have changed our lambing season, so we are lambing earlier and we try to fit everything with the weather.<br>-We are actually lambing 3 times a year. We lamb in March, June and September, and we try not to lamb too many in the summer. So we have a constant supply of lambs coming through the systems and we don't have our cash flow coming only once per year which is hard to manage. | -Earlier lambing, 3x a year in March, June and September, not in summer |
| IP10 | We used to lamb in the autumn, but like 20 years ago we changed lambing to the spring which also means we have to change our sheering dates a bit. We used to sheer in mid-August, now we change in July. Autumns lambs used to struggle in the winter, where they got worms. So we avoid having lambs during that difficult time through July and August, into early September when the worm burden is the greatest, so we want to have the lambs more mature, so they cope better. Sheering in winter also suits, sheep are acclimatized to the cold in the winter. It suits with the lambs, so they have got 10 month wool on it when it comes to the shear. I try to keep things simple. Not too many enterprises at the same time. | -Change from autumn to spring lambing to avoid worms during winter time<br>-Sheering in July, past: mid-August |
| IP11 | Yes we did, but not for climatic reasons, just a commercial reason. We found that shearing in November traditionally when a lot of other people sheering as well, it is getting difficult to find shearer, now we are sheering in June, we have not troubles getting shearers. And also sheep come off shears in the winter, as they are used to cold weather, you don't get this sudden changes of weather like you do in October or November; some of the sheep losses due to sudden changes were very horrendous. Once I lost like 3000 sheep in a night and sometimes I would go out at night and push sheep behind plantations of trees until the sun comes out. And we are also not lamb in the autumn anymore; it is always a big discussion about the best time of the year to lamb. Getting pregnant ewes through the autumn is quite hard work. We are lambing in August and used to lamb in May. The ewes are in a lot better natural conditions. | -Sheering in June, past: November due to commercial reasons<br>Lambing in August instead of May due to better natural conditions |
| IP12 | Yes we did but not for climate reasons, just management reasons. We used to lamb in the autumn and shear in the spring, but we swept to shear earlier in the year and changed to lambing in the spring to have more feed for the lambs during tough times though late winter and early spring when they are under most stress you get most feed. So there is more grass available while if you lamb in the autumn you have to feed them with hay and it is much harder to keep them and so you can keep more stock basically. | -Spring lambing instead of autumn lambing |

## Annex C – Quotes from Interviews with Sectoral Experts

Summary of comments about the climate systems and its variability

| IP | Quote | Generalisation |
|---|---|---|
| | **Climate System, changes in weather patterns and long-term climate** | |
| IP14 | Let's say 50 years plus, or 50 to 100 years, when it is really possible to identify trends that are externally forced, e.g. through increasing greenhouse gases. Shorter timescales face the problem of high variability and then it it's hard to detect e.g. attribute changes to greenhouse gases. The variability for rainfall is much larger than for temperature, but for temperature you can see also trends within 10 or 20 years timescales but rainfall is highly variable, so you really need to look at long time scales to identify changes.<br>- Globally we talk about the instrumental era which goes back to 1900. […] If you want to go further back, scientists use proxies such as paleo climatology that use proxies based on plants, sediments, pollen. But proxies are not as exact as instrumental measurements.<br>- There are some variabilities in the climate system that are very slow on a 50 to 60 year time scale such as oscillations in the Atlantic and there we are just at the order to understand it, so we don't really understand properly how those cycles influence climate and there are some limitations obviously but looking into long term changes and anthropogenic influences is definitely enough because this coincides with the times since the significant greenhouse gas emissions since the industrialization. So if we talk about climate change and climate trends in terms of global warming then 1880 is already quite a long period.<br>- Climate change alone is just exactly what the words are, a changing climate. Not saying how it is changing or implying human influences. It also includes climate variability like ENSO and slower variabilities in the climate system. I think what people often confuse is the general climate changes versus global warming which is a warming of the global temperatures and this is of course largely human caused.<br>- Yes it depends on which extremes we talk about, as for example cold extreme are becoming less frequent. Droughts are really tough, but temperature extremes are definitely becoming more extreme in a warming world as the variability happens on a higher temperature levels which means that hotter events are even becoming hotter. Yes, temperature is becoming more extreme and also for precipitation extremes, temperature changes almost everywhere and gets warmer. Precipitation is a bit more variable also in space, so we have areas where precipitation areas increase but also areas where it decreases but on global scale there are much larger areas on the globe where precipitation is increasing and extreme rainfall events are also increasing due to a higher temperature and the ability of the atmosphere to store more water vapor. Hotter years are also becoming more extreme. In Australia, the south western area is becoming drier over the last decades. All kind of variability such as El Niño for example is a very important driver of temperature extremes but then you have the whole variability due to human's activity on a higher level.<br>- What in a warmer climate, you have higher evaporation even if you have the same amount of rainfall that might intensify droughts. But on the other side, a warmer atmosphere can hold more water which means that the potential for heavy rainfall is also increasing, so rain events might become more extreme. | -At least 50 years plus needed to attribute changes in the atmosphere to human influences<br>-Variability for rainfall much larger than for temperature<br>-Proxies serve as source of information about climate before 1900, based on plants, sediments, pollen<br>-Some very slow variabilities in the climate system on a 50- to 60 year time<br>-Differentiation between climate change and global warming<br>-Cold extremes become less frequent, more temperature extremes<br>-South-western Victoria becomes drier<br>- A warmer climate means higher evaporation and can hold more water which means that the potential for heavy rainfall is also increasing |
| IP15 | […] you have seasonal cycles and you can determine trends against 130 years. In Australia, most of the variability such el ENSO, IOD, SAM introduces longer term variability to climate. It can be therefore much harder to determine trends. There are a number of studies looking at extreme weather events over Australia where the changes that has been observed in the system, but it is hard to say if there have been statistically significant changes in rainfall due to human activity over Australia. I don't think we know.<br>-Over Victoria it is a different question. So there is extremely good evidence from studies around the world demonstrating with very high levels of statistical significance that there are the emergence of extreme events which really just would not occur naturally. Over Victoria, I suspect the evidence around temperature is very good but we probably don't have the data for rainfall with sufficient data to be confident how rainfall changed. | -Australia's climate mostly influenced by variability such as ENSO, IOD, SAM<br>-Hard to say if changes in rainfall can be attributed to human activity over Australia<br>-More extreme weather events in general, lack of profound information for Victoria |
| IP17 | What we see in rainfall is not quite safely, whether what is happening with temperature more clear. The Csiro and BOM often use 1950 as a starting date. The rainfall has always been very variable. But if we take a longer term perspective, it is temperature that is increasing but what is happening with the rainfall? Temperature leads to more evaporation, which will reduce moisture levels. Most farmers feel poorer springs and also poorer autumns and winters.<br>- Seeing trends in rainfall is a lot more difficult and to model than it is for temperature. It is much harder to say whether it is natural variability, as the years to year variation is very high. | -Trend for temperature change (increase) more evident than for precipitation change<br>-Rainfall has always been very variable<br>-Higher temperature increase evaporation and moisture level reduction |
| IP19 | I am lucky enough to deal a lot with historical climate data sets, the rainfall and temperature datasets for Victoria. The temperature sets are unequal, the warming has been going up by to 1 degree, which seems very little but it is not in the historical levels and signs really have manage to move farms in the south west slightly north of the great divide and northern Victoria in terms of temperature. Much of that extra heat is in winter and particularly in spring and even if the rainfall was the same, […]. But the rainfall story is a bit more complex, while the temperature is easy […] And of course there is a great variability around temperature, of | -1° C warming in the last century<br>-Temperature increase mainly in winter and spring<br>-Uncertainties about changes in rainfall pattern (decrease) and climate change effect<br>Rainfall in Victoria related to |

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| | course we have normal winter and springs but the majority are warmer. Rainfall is more interesting, because it is following patterns for a long time, we have had drier periods like we experience during the millennium droughts in the past, in World War 2 and back in the early 1900. And the questions about if rainfall has definitely changed for the lower amount is difficult to say. It might come back to normal level, maybe later, but there are certainly lots of things that are suspect about the lack of rainfall due to the reasons why perhaps it hasn't been happening as well as we like. Whether it rains in south west Victoria is related to 2 things: it is related to the moisture sources in the Ocean to the north of Australia and related to the triggers that come through south west Victoria and hopefully brings that moisture down from the tropics. In many respects the moisture sources to the north of Australia are getting warmer, particularly over summer. And in terms of variability of this moisture sources in terms of ENSO and la Niña and the negative and positive Indian Ocean Dipole is that we are having in the last 15 years more cooler water to the north of Australia and during the critical time in spring which is really cut of the moisture source in terms of the rainfall. In terms of this moisture source it is arguable that it may or not may be a climate change effect, it is hard to know. What perhaps has more fingerprints of climate change is the predominance of high pressure over winter and spring which is very much a climate change effect as a direct effect of warming oceans to the north of Australia, stronger high pressure systems over southern south eastern Australia which is a measurable trend over 100 years and very closely follows the average temperature of the world as it goes up, the pressure over south eastern Australia goes up. There is really good physical principles why that would happen and it is probably the most measurable effect of climate change, particularly on south eastern Australia and perhaps no other parts of the world. These high pressure systems dominate our rainfall patterns, they chase the rainfall systems away and that is getting stronger and more stable such that the frontal systems bring rainfall and the low pressure systems that bring the rainfall down from the tropics are less prevalent and push further south from southern Victoria. The other thing is the southern annual mode which is the measurement of how close the frontal system come to southern Victoria and there is a 50 years trend of those moving further away as well, particularly in summer and perhaps also in autumn, not so much in winter and spring but that effect might also be a natural variability but my recent research suggests that is it all a climate change signal.<br>- I would say there has been a lack of reliable autumn break in the last 15 or 20 years and it is at the moment it is uncertain whether this is an climate change effect or just natural variability. It is suspect that it could be climate change but it is probably too early to tell. | moisture sources in the Ocean to the north of Australia<br>-Predominance of high pressure over winter and spring is very much a climate change effect as a direct effect of warming oceans to the north of Australia which is a measurable trend over 100 years and very closely follows the average rise in temperature in the world<br>-Changes in SAM might be climate change signal<br>-Lack of reliable autumn break maybe a climate change effect |
| IP21 | -People would argue we get more of this big rainfall event in summer like in the last 4 or 5 years but then you get a dry summer in between. Winter rainfall has not really recovered; we had the big drought from 2000 to 2010. Increases of summer rainfall have kind of made up this gap. But that is not quite as effective. Some farmers in western Victoria are running out of water and they have to car their water. Western Victoria used to be drought proof with reliable winter rainfall may not be the case anymore.<br>- Along with the extra summer rain, there is an increase in temperature.<br>- We are just talking about a 2 to 3 weeks shift which does not require any transformational changes yet. | -More summer rainfall<br>-Increase in temperature<br>-2 to 3 weeks shift in growing season |
| IP22 | The models show that the planet gets warmer and the subtropical ridge over South Australia gets stronger. And when farmers see that the autumns break have not been good as they use to be and when you then show them changes in pressure pattern in south Australia, you can show them that there is a trend<br>- Farmers notices stronger pressure systems over Victoria and if you show them actual measurements on that, that is always good. You can explain 10% less rainfall due to higher pressure systems and higher temperatures and it is always good to link explanations to what farmers perceive anyway.<br>- Since 1997 basically a change in the cold fronts which is important for Victoria rainfall. They are driven from the southern Ocean, SAM. Before that, if farmers knew about a cold front in Perth, they knew it was in south Victoria about 3 days later but since then there is a change of cold fronts shifting south and not eastwards anymore, they have observed that change which takes a portion of the rainfall away. We were hoping that was more a short term thing. Autumn rain is more unreliable than in the past and spring is our fastest warming season with 7 out of 10 1-3 degree warmer than to the last 100 years which is quite unusual. Summer is getting bigger.<br>- Although spring is the fastest warming season, but springs frost are as bad as they have always been. That was not really supposed to happen with the climate projection. It because of the pressure pattern, pushing cold fronts further south which trigger frost condition. In spring we might get earlier flower times of crops but at the same time there is a frost risks, but this is mainly for northern Victoria. | -Increase of subtropical ridge over Australia, trend of stronger pressure pattern in south Australia, therefore less rainfall<br>-Trend of shifting cold fronts south and not eastwards anymore, less rainfall<br>More unreliable autumn rain<br>-Spring is fastest warming season<br>-Longer summer<br>-Frost pattern did not change because of pressure pattern, pushing cold fronts further south<br>→ change in risk profile for cropping |
| IP23 | The conditions have warmed; there is a general warming of minimum and maximum temperature. That has shortened the growing season and in addition to that there have been some significant changes in the rainfall, we have had a drying trend in that region and an increase in the favour of the sort of rainfall for agriculture.<br>- And certainly the last season have been very characteristic of that pattern. It is an interesting paradox, while we have this warming trend in Victoria, what we had have is a change in temperature and the rainfall extremes. From the rainfall extremes point of view we see that rainfall is becoming more episodic but longer drier periods and short intense rainfall events | -Temperature increase, increase in the variation in temperature extremes<br>-Shorter growing season<br>-Drying trend over Victoria<br>-Change in rainfall extremes: more episodic, longer drier periods and short intense rainfall |

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| | and that is very ineffective for agricultural production because a lot of that rain runs off and it not taken into the soil, that is quite problematic. In terms of the temperature, we see that despite the warming we have an increase in the variation in temperature extremes, so heat waves which puts stress on animals and crops but we also have an increase in some area in the cold extremes which are frosts, which is an area I am particularly interested in, paradoxically when there is that warming going on we have a broadening of the frost window and over the last decade frost have actually been occurring on average much much later in the season and they coincidence with the period of which the crops are most vulnerable which is what they call anthesis, where you head emerges from the cereal crop and then you can get significant losses because of this frost events.<br>- The frost is kind of a climate paradox, the climate change is actually driving the increase of frost variability so it is one of those outcomes which is quite surprising from a climate change of view.<br>- *What about the area around Colac?*<br>They also have frost events but it is not as extreme, but as you move into the drier northern part of Victoria such as Wimmera and the Mallee region, the frost is a particular issue.<br>- *Why are the frost events increasing?*<br>Basically what we are seeing is at the global scale the atmospheric warming has an influence on the way which the major Hadley and Walker circulation are affected, we are seeing an acceleration of the Hadley circulation and a broadening of the area, over Australia we have belt of high pressure, called the subtropical ridge and that has been broadening and shifting further south and intensifying. What you find is that the intensification of the ridging high increases the stable atmospheric conditions, which triggers radiative frost and the southerly displacement of the subtropical ridge means when the high pressures drawing air masses over the continent, air masses tend to be coming from further south than they have in the past which is much colder and drier. So 2 things are going on, increased atmospheric stability and an increase of evection of cold air, that is the interaction. | events → ineffective for agriculture<br>-Broadening of the frost window in Victoria, especially in north V. due to broadening and southward-shifting of the subtropical ridge |
| IP24 | - Although there is some change in the seasonal pattern of climate change, e.g. the middle of winter might not be so cold. | -Change in the seasonal pattern, milder winter |
| IP25 | The clear signal is in temperature, so we have a warming of 0.9 degree since 1910 and Victoria and without influence it would be close to 0 degree increase in temperature. 1910 is our starting point for national temperature records in Australia, partly because we had a major change in instruments between 1890 and 1910 […]<br>- If you look at temperature is given from normal, it tends to be quite smoother at long distances, whereas rainfall tends to be much more variable at short distances, so you don't have so much confidence about what the rainfall is doing. For temperature there is a much higher chance to reconstruct it further away from weather stations.<br>- For extreme temperature we have clear signals, there is more extreme heat and less extreme cold.<br>-Although there are some interesting things in Victoria we have seen that the frequency of extreme cold level stays fairly stable over the last 30 years but dropped for most areas of the country. We think that is largely because the climate is becoming drier and during clear nights you have more chance for frosts. And we would expect to see an increase in the proportion of extreme rainfall but we don't really see a lot of clear evidence in the observed data. Because extreme rainfall events by definition are very rare. Particularly southern Victoria has seen a decline in rainfall over the last 20 years. It was fairly stable on a long term basis until the 1990s and since 1997 south Victoria is quite dry. We had the Millennium droughts and 2 relatively wet years in 2010 and 2011, which was wetter than normal for south Victoria but also not particularly unusual, maybe 10 to 20% above normal and not 50 or 100% above normal as further north. And since 2012 we have gone back to rainfall fairly similar to what we had in the 1997 to 2009 period. It has not really getting much public attention because the rain in 2010 and 2011 filled up most of the dams, so we did not have the same issue with water shortages that we had from 2006 to 2009. | -0.9°C increase in temperature in Victoria<br>-1910 as starting point for national temperature records<br>-Easier to detect trends for temperature than for rainfall, which is much more variable at short distances<br>-More temperature extremes<br>-Frost doesn't decline despite warming in Victoria-<br>No clear evidence in the increase of extreme rainfall events, as definitions are very rare<br>-Decline in rainfall over last 20 years |
| IP26 | Well besides increasing temperatures, also changes in precipitation pattern and extreme events as well as shorter growing seasons and a general dryness.<br>- There are drier conditions and hotter springs and summer. | -Increasing temperatures (spring and summer), changes in precipitation and extreme events, shorter growing season |
| IP27 | Other impacts include higher temperatures and more extreme heat. | -Higher temperature and more extreme heat |
| IP30 | It is the rate of change that concerns me. The rate it is changing, we have not seen that before. | -Change in the rate of change |
| IP32 | The ecosystems have been adapted to very stable climate since the last ice age and now the rate of change is dramatic compared to all the natural climate changes before, also the end of the ice age has not been as dramatic. Now it occurs on much smaller timescales than before. | -Dramatic rate of change compared to historical climate changes |
| IP35 | I also worked on climate extremes, heat waves, heavy rainfall events, but particularly in the context of the role of human caused climate changed and there is a clear signature associated with individual heatwaves and record temperature over month and seasons and human caused climate change. We have shown the role of climate change in increasing frequency and intensity of records monthly and seasonal temperatures and on single dates. I was also involved in weather associated with bush fires and there were big bushfires in the Otway region in December 2015 and those sorts of conditions of high temperatures, low humidity and strong winds are typical of extreme fire danger and they are becoming more frequent. | -Heatwaves associated with human caused climate change<br>-Higher frequency of extreme events<br>-Earlier spring<br>-More summer rainfall, fewer in winter and spring<br>-More frost in parts of Victoria |

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| | And that increase in frequency and intensity of bushfires is what we expect from human increased climate change as well. In terms of the growing season we found that warming of the climate, for a temperature definition of the growing season leads to increasing duration of growing season. Typically the farmers notice more the earlier start of the season as at the end of the season it may not be as obvious. We looked at an insect as a marker of the start of the growing season in spring. […] The hatching is now 10 days earlier start off spring over the last 60 years, which is also relevant of agriculture. […]. We had the millennium drought, followed by a very wet period with lots of flooding and since then we are back in a dry period. Even in that wet period, the winter time rainfall was below average, it was the summer rainfall where the rainfall was high not in the winter.<br>-Over the last 100 years we found a decrease in frost but over the last 20 years in increase in frost. It is associated with the decline in rainfall, because less rainfall means less cloud cover which means colder nights, because you get more loss of radiation at night. So in winter and spring we tend to get less rain, fewer clouds which lead to more frost in parts of Victoria.<br>- I also looked at rainfall changes and it is much harder to do attribution on rainfall because it is much more variable but particularly for the winter fall rainfall there is a significant reduction both in southwest of western Australia and Victoria with declines in winter fall rainfall. And that appears to be the contribution from changes in the circulation with the southward shift and the storm track which has major impacts. | |
| IP37 | What we have seen is increased temperatures, there tends to be an increasing frost risk as well and increases in other extremes such as rainfall. That overlays an existing climate variations and cycle which generates variations in a matter of course in terms of productivity. Compared to the rest of Australia, south west is a fairly stable environment which means that farmers can put in a lot of inputs. So they can have relatively high production systems compared with other parts of Australia. | -Increasing temperatures<br>-Increasing frost risk in parts of Victoria, increase in extreme rainfall events<br>-Compared to the rest of Australia, south west is a fairly stable environment |

Summary of comments on causes for global warming

| IP | Quote | Generalisation |
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| | **Causes of Global Warming** | |
| IP14 | There are some variabilities in the climate system that are very slow on a 50 to 60 year time scale such as oscillations in the Atlantic and there we are just at the order to understand it, so we don't really understand properly how those cycles influence climate and there are some limitations obviously but looking into long term changes and anthropogenic influences is definitely enough because this coincides with the times since the significant greenhouse gas emissions since the industrialization. So if we talk about climate change and climate trends in terms of global warming then 1880 is already quite a long period.<br>- There is one degree global average increase of temperature and if you see typical model of variability like ENSO, Southern oscillation or slower modes like the pacific decadal variability that have a strong signature on global average temperature, they would not account for 1 degree, they would account maybe about 0.1 degree on average over long term, so basically it is pretty safe to say that 90% are attributed to human activity at least. Those variabilities would normally be cycles, so after years or decades but they would also go back. But what we are seeing is that we have a continuous increase over more than 100 years and this is not possible to explain by the normal modes of variability in the climate system that we know. | -Natural cause such as the oscillations in the Atlantic Ocean<br>-Coincidence between greenhouse gas emissions since the industrialization and long-term climate trends<br>-Natural causes would not account for 1 degree temperature increase but only for like 0.1 degree |
| IP15 | *How much of the climate change can be attributed to humans globally and in Victoria?*<br>On global scale it is between 80 and 120% of the climate change can be attributed to human activity, which is also in the last IPCC report. 120% is because we also emit aerosols which cool and mask the warming due to carbon dioxide. So humans contribute to 80 to 120% at the global scale. Over Victoria is a much more challenging question. There are detection and contribution studies for Australia. It is usually a small number for sure because there are many things that affect the regional climate that emerge over the nature for the complex climate system. It can be very hard to contribute specific changes particularly with the rainfall, which farmers are probably most interested in, temperature is easy, rainfall is hard.<br>-There are a number of studies looking at extreme weather events over Australia where the changes that has been observed in the system, but it is hard to say if there have been statistically significant changes in rainfall due to human activity over Australia. I don't think we know. | -On global scale, 80-to 120% of the climate change can be attributed to human activity<br>-Over Victoria it is harder to say as not so much for temperature but for precipitation<br>-Hard to attribute changes in rainfall statistically to human activity over Australia |
| IP25 | For a relatively young period you have observational data but you can also have a look at ice cores in the Antarctica which gives $CO_2$ records going back to hundreds of thousands of years. $CO_2$ levels is pretty similar globally, so if you have one good sign globally that is quite enough but for other variables you need much more localized measurements such as temperature and rainfall goes back to 1850 in Australia. We have El Niño records going back to the 1700th Century. | -Sources for climate information: Observational data, ice core in the Antarctica |
| IP29 | As it is hard to say what human induced climate change is and what natural, we are very careful in the way we communicate. | Hard to distinguish between human and natural climate change |

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| IP32 | From global climate change we can attribute from the global surface temperature increase basically everything and you can even say about 130% of the observed temperature increase is caused by anthropogenic greenhouse gas emissions, as a cooling effect. Solar and volcanic source are the 2 main natural forces over time. For Australia it is a bit more difficult. If you run the climate model with natural forces and greenhouse gas forces, there are some features of the Australian climate that are not well represented in the models such as El Niño. We can also look at what is the occurrence of drought with and without anthropogenic greenhouse gases and aerosols to look at the differences.<br>- The increased CO2 concentrations and the observed temperature increase are basically all anthropogenic. | -130% of the temperature increase caused by anthropogenic greenhouse gas emissions |
| IP35 | I did attribution studies in Victoria to show that changes in temperature were due to human induced climate change, which has been published 15 years ago. I also looked at rainfall changes and it is much harder to do attribution on rainfall because it is much more variable but particularly for the winter fall rainfall there is a significant reduction both in southwest of western Australia and Victoria with declines in winter fall rainfall. And that appears to be the contribution from changes in the circulation with the southward shift and the storm track which has major impacts.<br>-For rainfall, there is very strong variation. We have rainfall and temperature data back to 1860. We only have high quality instrumental data back to 1900 but in earlier times there are sources as well. First, we have to look at what is the year to year variability and then assess whether the changes that we see long terms trends are consistent with a range of different causes which might be human induced climate change or changes in the frequency of el Niño or la Niña or changes in the amount of sunlight from the sun or just natural variability. We can use a number of indicators for that. We mainly look at climate model simulations in response to changes in the different forcing factors, the model run include changes in greenhouse gases and other human influences or removing them. And not just one climate model but lots and lots of different climate models from all over the world, Germany France, USA etc. We do the comparison, make sure the models are able to show the year to year variability and then we look at long term changes, which is called attribution of climate change. We have done that for Australia and Victoria and we can show that human caused climate change in the dominant influence in the warming in Victoria and Australia. Without human influences there was no temperature increase. We also do that for years, month and even for individual days. Of course there is a massive variability for individual days but warming makes the hot extremes more frequent. October 2015 in Victoria was the hottest in the instrumental records and in Australia. We looked at what were the chances for this sort of extremes in a world without climate change or in a world where we changed the climate for Victoria and Melbourne. It was at least 6 times more likely for these temperature records to occur due to human caused climate change than it was due to natural climate variability. | -Harder to do attribution on rainfall than for temperature, regarding human induced climate change |

Summary of comments on climate scenarios

| IP | Quote | Generalisation |
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| | **Climate Scenarios** | |
| IP14 | Seasonal scale forecasting is a tough thing as there are lots of processes in the climate system. –Seasonal forecast can't be accurate it basically gives a probabilistic chance of getting warmer and drier times. El Niño is the major driver for seasonal variability especially at the eastern side of Australia. The prediction is good but still a bit difficult. | - Seasonal forecast can't be accurate it basically gives a probabilistic chance |
| IP16 | Weather forecast is nowadays pretty good, seasonal forecast is an area that needs more work. […] Well, the accuracy of weather forecast pretty much depends on the time scale. 1 to 10 days is pretty good those days and most farmers feel comfortable with this time frame and there is significant effort going on to further improve it and especially in predicting climate extreme events which is very important for farmers, such as heat extreme and also seasonal forecast from a 2 weeks to 3 month period is also a key issue for farmers. The BOM is now able to run models at higher resolutions which are a significant improvement in the accuracy of forecasting. So the next years will be very exciting as there is a lot going on and improving the forecast for Australia. | -1-10 days forecast pretty good, seasonal forecast very important to farmers, still improving<br>-Further improvements can be expected the next years |
| IP20 | In that region around Colac and western Victoria general, what we see in all our future climate impact scenarios is the onset of summer coming earlier, so the beginning of spring being earlier. In most scenarios it says you get rainfall right into November and the 2050 scenario say you would not expect any rainfall after beginning of November, so end of October will probably end your rain and it is dry from there on or very sporadic from there on. But at the same time the midwinter temperature are slightly warmer but you still get enough rainfall from June to September, which will also be fairly reliable in future scenarios. During the millennium drought, the winter rainfall was much lower but they still growth as much grass in winter. So if you say they will lose 3 weeks out of November by 2050, but they have warmer winter and they still have enough moisture you are growing more grass in winter, so your annual grass production is probably the same as it is now, because you growth more in winter and less in late spring. Most farmers feel they can cope with that. Less reliable autumn breaks, instead of coming though by the mid of May, you start getting reliable rainfall from mid-June. | Scenarios for wester Victoria: onset of spring and summer coming earlier, slight increase of midwinter temperatures, fairly reliable rainfall from June to September → no decline in grass production, but more growth in winter and less in late spring Reliable rainfall from mid-June |

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| | A lot of farmers have changed to dry sowing, waiting for rain. Which is expensive but it works. | |
| IP21 | In the next 20 years there might be a rainfall decline in spring by about 10 %. The extremes are changing, it is projected to be more rain during some days with more dry days in between. The rainfalls are concentrated more in this larger events with more dry spells in between. We compare the average change and try to incorporate extreme events and variability, the impact is larger instead of just taking the average change. 70% of the impact is shown when you incorporate the extreme events. You see there is a more of a negative impact on pasture production. My feeling is that some of our previous work underestimates the potential impacts, because we have not captured the extreme events. Extremes are really hard. | -Rainfall decline in spring<br>-Changing rainfall pattern: dry days in between, more extreme rain → impacts on pasture production (possibly less pasture production) |
| IP24 | Climate projection suggests higher temperature, lower rainfall but higher CO2 levels. Those 3 factors are not always working in the same direction because if we have lower rainfall and higher temperature that might reduce the plant yield but the higher CO2 levels might increase plant yields. | -Higher temperatures, lower rainfall, higher CO2 levels |
| IP25 | It will become warmer but actually warming rates to be below the national average warming rate, so particularly in winter and that is largely because of the southern Ocean and of course the warming depends on the emission pathways that will change climate in about 30 years later. For rainfall the projections go quite strongly towards decrease in rainfall, particularly in spring and winter, but with no clear signal in summer and autumn.<br>-Which means the decline is during the most important production time for farmers…<br>Yes exactly and also during the time for the most important water supply, as maybe 80 to 90 % of our annual inflow is between June to November. That is a really important period. | -Higher temperatures, decrease in rainfall, particularly in spring and winter, no clear signal in summer and autumn<br>- Decline is during the most important production time for farmers |
| IP27 | The modelling until 2050 suggests a reduced rainfall by around 5 – 10% | -Decline in rainfall |
| IP28 | - What are limitations of forecast?<br>We don't have a complete knowledge of oceans and atmospheric conditions at the start and there are also observational uncertainties, so the chaos affects the forecast. Then you also have the actual model. Errors in the initial state of your model limits how good your forecast is. You need to represent chaos or uncertainties in initial conditions but you can also have a multi model. Something is also not predictable, also if you have good model, but the chaos theory means you are not going to be able to predict exactly. And we still don't understand everything that is going on in the climate system. Tiny littles changes because of chaos makes a difference to the forecast. We don't have very much information in the Ocean which is also of the challenges. We run them all in the past and calibrate them then, so the model doesn't drift as much for the forecast.<br>-Skills really depend on the region and the season. The forecast for predicting maximum temperatures or heat extremes are really good in spring time, but not good in the end of summer. That is due to the influence such as El Niño have a stronger influence in the spring month, the drivers that give you your predictability are more active at a certain time. We have higher skills in temperature than in rainfall. And in our current system we tend to have more skills over eastern Australia compared to Western Australia. This is for example because the communication between what is going on in the tropics in Asia and how this is transferred to Western Australia in our current model is not very good. So forecast depends on the variable, on the region and the season and how far you are forecasting.<br>- The BOM is getting a new super computer, as a major constraint for us is the lack of computer power. So we can increase our modelling and it is much more complicated. The blocks of our current models are 250x250km and the new model is 60x60km2 which is a massive improvements. Our current models has 17 atmospheric models going up while our new has 85 layers and ocean models have a 200x100 grid, whereas the next is going to 25km2 and as the ocean affects the climate this is also a major step forward in improving forecasting. In our current system, Tasmania is just part of the ocean. | -Limitations of forecast: Lack of knowledge of oceans and atmospheric conditions, observational uncertainties, errors in the initial state of climate models, dealing with chaos theory, still lack of knowledge in the general climate system, lack of computer power<br>-Skills depend on region and season |
| IP31 | In terms of projection, we are expecting less rainfall in winter and spring and temperature increase in all seasons. More hot days over 40 degrees. Less frost days. Our rainfall will drop by about 20 % until 2090. The rainfall we get will come in more intense events, more impulse which might trigger floods. We can already see some of those trends. We had a very harsh fire weather climate. Everything about the Corangamite catchment you find in the document I sent you via Email now. | -Temperature increase, less rainfall in winter and spring, more hot days over 40 °C, more impulse rainfall events |
| IP32 | Projections say that there will be less rain in some of the already dry areas | -Reduction in rainfall |
| IP35 | {…] changes in the climate would causes these ecological zones to shift southward. | -Ecological zones shifting further southward |

Summary of comments on impacts of climate change

| IP | Quote | Generalisation |
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| | **General impacts of cc on south-west Victoria** | |
| IP15 | Well there have certainly been changes in temperature and quite impressive rainfall variabilities. […] If just germinating plants get hit by a 40 degree day, the farmer will lose its crop. And it is those emergence of new threats earlier in the season that reduce the productivity of farms from maybe 3 to 2 good years within 5 years which might put some farmers out of business. It won't put the multinational out of business because they hedged they have bought enough land over big enough areas that they have cushioned themselves against this extreme events and while they may lose their productivity in Victoria they may | -Changes in temperature and more rainfall variability<br>-New threats earlier in the season → possible reduction of productivity<br>-Risk grows especially for smaller farmers not so much |

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| | have a very good year in NSW. So they can afford certain risks while the smaller farmers have much more vulnerability. A big farmer can lead transform certain farm areas to other enterprises for 2 or 3 years. | multinational |
| IP17 | I think the principals how farmers are managing are changing. If the projections map out it will have a much bigger impact on the drier areas of Victoria and Australia, even farms as Mt Hesse which are reasonably dry in climate, they will potentially impacted a lot more because the drop off in rainfall and reduction that already limited growing season, will have a major impact such as pasture growth.<br>- We modelled different areas in Victoria. For north Victoria it does not look good because that growing season will be substantially shorter and it will change the number of stock you are able to run and you might consider an enterprise change because with a western Australian type of climate with a growing season from May to October rather than April to November.<br>- Droughts in northern Victoria are much more common than in southern Victoria.<br>- We see that climate change has much bigger impact on a drier environment such as northern Victoria. | -Impacts bigger on the drier areas of Victoria, as less rainfall affects pasture growth<br>-Impacts much bigger for norther Victoria (shorter growing season will change the number of stock you are able to run) than south-west Victoria |
| IP19 | - Climate change gives a bit more extra variability which means that things are wetter in time than normal and probably in summer and things will be drier in time in winter and spring. And it is getting warmer and hot shocks are becoming more frequently such as last October. | -Climate change triggers variability and extremes |
| IP20 | Farmers in Tasmania are actually quite happy about climate projections as it is getting warmer with increasing rainfall and they are the farmers that get harder hit. But Tasmania has just gone through a drought, a drought that a mainland farmer goes through every 6 to 10 years and it is nothing unexpected. In Tasmania is has been a disaster this year as the farming systems are not designed to cope with that variability as the rainfall in northwest Tasmania is fairly reliable. We are doing a lot of modelling of different climate scenarios. And for the mainland area for example where climate change signals say it is going to dry up 3 weeks earlier in November, you lose something there but you might get more growth in winter because it is getting slightly warmer and there is still enough moisture. Gippsland starts to look like more than western Victoria, which is very dry in summer. And as it warms up in western Victoria, it starts looking like South Australia. And South Australia starts more looking like Western Australia.<br>-We have to give them the message, that the variability is increasing due to climate change and extreme events is where you danger lies, not really that gradual change in climate that is not a big threat<br>-Impact of changing ecozones much greater for north than for south Victoria, as north Victoria meanwhile receives half of the rainfall during summer | -The more farmers are unprepared for certain events, the higher their vulnerability to shocks<br>-Dry up 3 weeks earlier in November → potentially more winter growth due to slightly warmer temperatures with enough soil moisture<br>-Variability is increasing, the danger lies in extreme events (increase of number of heat days) not in the gradual change<br>-Impact of changing ecozones much greater for north than for south Victoria |
| IP21 | It is hard to say and put a number on it because the inter-annual variation is very substantial. In the longer term we will probably see a trend of lower input systems which means for example lower stocking rates to feed your animal, systems which don't take as much advantage in good years but are not as exposed in poorer season, so less risk prone and trading off some profitability. | -Probably a trend of lower input systems in the long-term |
| IP22 | The increasing variability of seasons is challenging for farmers especially if they grow less grass in spring, they might lose money as they spend more on feed. If they think it happens more often they will start to worry about it, which means to make bigger investments to their farm. There might be changes in land values. In the early 1990, it was quite wet and waterlogging was a big issue.<br>- It is the lack of some really wet years that filled up the dams.<br>- In south west Victoria there will be more water regulation coming as we used to be a quite wet landscape in the past. As the resource becomes more constraint there will be more authorities. The issue of equitable share of water will increase especially if we talk about a declining resource.<br>- Land value shifts are driven by the markets it is getting harder to make a full time living out of just wool.<br>- The bigger challenge is, the summer gets bigger, we get gains in the cooler seasons but then we rely more on spring. And if summer gets bigger, that feed gap for livestock becomes a problem. There is quite profitable business in north Victoria with cropping and sheep production as well. So it is not all about climate, but you need the right system to handle things. One of the benefits we have is good infrastructure and roading, stable governments in comparison to some other parts of the world.<br>- People in northern Victoria will suffer more, while down here it is still cool. The vulnerability the systems here are less used to droughts because that is a 1 in 30 year's event. If that happens more regularly, dairy farmers who live in a high rainfall environment could actually be less adaptable than a low rainfall Mallee farmer who is dealing with droughts more regularly. So the bigger the shock to a system you are not used to, the more vulnerable the system.<br>- Farmers with external foreign support have more buffer while smaller family business have not this buffer and backup and might be more exposed to climate change. It is about good risk management.<br>- Climate change just adds extra stress on land use or particular enterprises which is already having trouble being profitable. There might be extra costs such as to spend more on getting water to their stock and buying in extra feed during an extra drought. So that economic business management is very critical. | -Increasing variability of seasons might increase expenses for feed<br>-Changes in land values<br>-Lack of rainfall that fill up dams<br>-As water resources become more constraint, there will be more water regulations coming<br>-Bigger summer means an increasing feed gap for livestock<br>- The bigger the shock to a system you are not used to, the more vulnerable the system<br>-Small family farmers might struggle more than farmers with external foreign support<br>- Climate change adds extra stress on land use or particular enterprises → There might be extra costs such as to spend more on getting water to their stock and buying in extra feed during an extra drought |

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| IP23 | In that area you are interested in, there has been a big change in the land values. 20 years ago, the value of soil that could retain a lot of water, so more clay type's soils that land value is very high. What we have seen in terms of the increasing frequency of drier conditions is that the land value has actually changed. | -Change in land values also due to the increasing frequency of drier conditions |
| IP25 | When you have a longer term trend, 20 % rainfall drop over the century does not mean a decline of 2% every year but what it means is that you are likely to see more droughts and more intense droughts and you still may get the wetter years but not as often and as productive. Effectively we are talking about a shift in risk profile. A lot depends on how marginal your farm is located. There are places in south west Victoria that are too wet, so a drier climate might be nicer. But a drier climate might mean a reduction in profitable yield years and it has an influence on how viable is your business.<br>- *What do you think does climate change mean for agriculture in south western Victoria?*<br>It will depend on where a farm is located and largely impacts will be seen by more marginal locations. There are places where the agricultural set of land will change and you will have areas that are cropped not but becomes suitable only for grazing. Grains might be reduced and there will be a change in land values which of course involved transitions costs.<br>- And if you have a situation where the date of the last frost is not changing much but the 35 degree day is coming forward by 2 weeks, they have to work with this new time window which is quite challenging.<br>- It is largely about a shift in risk, especially for rainfall which is not easy to model and the band of uncertainty is wide. | -More and more intense droughts, wetter years might be less productive<br>-> Shift in risk profile, marginal locations might be more impacted<br>-Cropped areas might become more suitable to grazing land<br>-Change in land values<br>-Early spring heatwaves as risk<br>-new time window: date of last frost not changing but the 35 degree day is coming forward by 2 weeks → Shift in risk |
| IP30 | -Larger farm businesses less affected by climate change impacts than smaller farms | -Impacts also depend on farm size and structures |
| IP32 | Projections say that there will be less rain in some of the already dry areas which will have devastating effects for the farmers.<br>- Australia is likely to be in the frontline in terms of impacts of climate change<br>- The risks of climate change are tremendous, the opportunities on global scale low. | -Less rainfall has devastating effects for farmers<br>- Australia is likely to be in the frontline in terms of impacts of climate change<br>- Climate change means more risks |
| IP34 | As the climate is becoming warmer, the pest and diseases spectrum is shifting in growing regions.<br>- I think climate change has a big impact on the agricultural sector. | Pest and diseases spectrum might shift in a warmer work |
| IP35 | The grazing areas moving further south and wheat areas as well.<br>{…] ecological zones are shifting southward. | -Southward shift of grazing and cropping areas in Victoria |
| | **Cropping** | |
| IP15 | There is a clear evidence of earlier growing seasons and earlier extreme events especially in temperature hitting large region of Australia. If just germinating plants get hit by a 40 degree day, the farmer will lose its crop. And it is those emergence of new threats earlier in the season that reduce the productivity of farms from maybe 3 to 2 good years within 5 years which might put some farmers out of business. | -Earlier growing season, earlier extreme temperature events→ emergence of new threats earlier in the season that reduce the productivity |
| IP16 | As the seasons are coming forward by nearly a day per year and therefore also the harvest is coming forward, basically the crops are being harvested a month earlier than 30 years ago. | -Seasons coming forward |
| IP19 | Much of that extra heat is in winter and particularly in spring and even if the rainfall was the same, our crop growth would be more rapid though winter and spring, crop growth would be earlier maturing and soil moisture would get utilized quicker and not go as far as it once did.<br>- I think with the hotter and drier spring that we have had, we have probably seen the prevalence of more crown rott which is a root disease that attacks the base of a plant and fills the plants water tissue with fungal and blocks the pipes and they can't get the water up to their heads anymore and transpire, so they basically. It is essentially much more prevalent in northern Australia, northern NSW and southern Queensland. We are seeing a lot of it but we certainly see an underlying current in some paddocks in one year's removing 5 to 10 % of yields perhaps. So we certainly see a little bit more of that that has to do with the dry and the warmth. We probably also see a little bit more aphids, particularly at the start of the season in autumn where we perhaps are having a bit more summer rain<br>-More summer rain means that we have more weeds growing in summer and more room for insects and fungal diseases over summer.<br>-Aphids like warm weather and stressed crops and they can attack the crops and pop up, it is problematic the aphids are coming in in autumn or spring and I reckon we probably more see aphid damage in crops and we need more spraying more than we used to in the past previous 20 years or so. I mean everything that related to cropping, related to pasture production as well. | -Higher temperatures in winter and spring → quicker growth rates, earlier maturing, quicker use of soil moisture<br>-Prevalence of more crown rott ( root disease) though hotter and drier spring<br>- Little bit more aphids, particularly at the start of the season in autumn, attack especially stressed crops during warm weather<br>- More summer rain means more weeds growing in summer and more room for insects and fungal diseases over summer. |
| IP20 | What we have seen in the Victorian Climate change adaptation program is the southward moving of cropping in western Victoria. If you are in north western Victoria, one of the biggest changes you have actually record in climate change is that the number of years where you get a failed winter crop has actually increased. While let's say 40 years ago, you might get failed crops out of 10, while now you get at least 6 failed.<br>- So wheat and canola are moving further south as it is more viable as it was too wet in winter in the past. […] So annual rainfall looks like it has recovered from the millennium drought but our winter rainfall has not, it is more of a step change. If that is true, wheat and canola south of Hamilton is viable long term. | -Southward moving of cropping in western Victoria<br>-Number of years with failed crops have increased in north-west Victoria<br>-South-ward shift of wheat and canola (not so wet anymore) might stay viable for long-term |

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| IP22 | Since the 1990 there is a lot more cropping as it is not so wet anymore, there has been expansion of dairy but most of them has been the extends of wool growing which is still profitable. | Cropping expansion due to drier conditions |
| IP23 | Agriculture relies on initially good starting rains and the follow up rains to actually maintain the crops though the maturity and the harvest. What we have seen in the last 5 years is certainly promising starting conditions with enough rainfall and soil moisture to start the crops growing but then very quickly, because of the temperature and lack of rainfall, those seasons tend to fail.<br>- heat waves which puts stress on animals and crops<br>- we have a broadening of the frost window and over the last decade frost have actually been occurring on average much much later in the season and they coincidence with the period of which the crops are most vulnerable which is what they call anthesis, where you head emerges from the cereal crop and then you can get significant losses because of this frost events<br>- They also have frost events but it is not as extreme, but as you move into the drier northern part of Victoria such as Wimmera and the Mallee region, the frost is a particular issue.<br>- In this region are some strong trends in temperature, rainfall because of that warming, evaporation has increased which increases the stress on the crops and animals of an agricultural point of view. | - Promising starting conditions with enough rainfall for cropping, but temperature and lack of rainfall trigger failed seasons<br>- More heat waves put stress on animals and crops<br>- broadening of the frost window → significant losses in production (more in Wimmera and the Mallee region)<br>- Higher evaporation rates increases stress on crops and animals |
| IP24 | The plant yield is a result of the 3 things combined and the plant yields were generally reduced despite higher CO2 levels.<br>- If we then use the scenarios of climate change, using the predicted new climate series that change the crop yield and the new farm profit and generally there was a reduction in farm profit under climate change without adaptation. | -Models suggest a decline in yield despite higher CO2 levels<br>-No adaptation means a reduction in farm profit |
| IP25 | I think people in Victoria have a good idea about low rainfall on crops and extreme heat can also be very damaging for crops, particularly in the early spring heatwaves and we had an unusual heatwave in the first half of October in 2015 which caused a lot damage. | -Risks from increasing early spring heat waves on crops |
| IP35 | Typically you won't grow wheat in south and north Victoria. There are certainly shifts. Southern Victoria in the western district used to be much wetter, they are starting to have the grazing areas further north are moving down. | -Spatial shifts in grazing and cropping areas coming further south |
| IP37 | There is another impact such as increasing frost risk for crops, particularly late frost which can impact crop yield, as frost damages the grain. | -Increasing frost risk (more in northern Victoria), late frost impacts crops |
| | **Livestock** | |
| IP16 | During a 1-day heat event in the past you could see that the amount of milk was reducing a lot for the next 3 to 4 month in Victoria, as the ryegrass died, so there are strong impacts of a short extreme event. And heat events are becoming more common as well. | -Heat waves kills pasture and reduces milk production |
| IP17 | With climate change, the risk of flystrikes is greater because the flies emerge when the temperature gets over about 17 degree Celsius. They generally emerge in southern Victoria in late September, but in a warmer environment they are going to be more active later in autumn and start a bit earlier in spring. Other diseases could also be more active; with a warmer climate tropical diseases might also come further south. | -Increasing risk of flystrikes, not only in late September but also later in autumn and start a bit earlier in spring |
| IP19 | There is kind of an issue with animals, particularly cows that hate heat and they can't sustain very high levels of heat, they struggle with the heat particularly the blacker cows like Angus. With the extremes of heat we are getting every year, and they were more extreme than they were in the past, makes life for a cow very difficult for a few days. | - Particularly cows (like Angus) are suffering from increasing heat waves |
| IP20 | - I always have a look at milk diagrams, as milk is a highly sensitive indicator of heat stress in a cow, reflects that night in the mild production. During the millennium drought we had a heat wave in November where we had about 40 degree for 5 days and the mild production for whole Victoria dropped and never came back for the rest of the year. So these cows suffered a heat event which effectively dried them out and then the lactation did not recover after that as it was after the peak of lactation. Last October we had a heat wave in the late 30 degrees and the cows where just about the peak of lactation and it had no effect at all. What was the difference? The difference was, the first heat wave had hot nights as well and was beyond the peak of lactation so it had a residual effect, cows never got a chance to respire at night because the temperature never dropped below 25 degree at night, so they were continuously stressed for about 4 days. While during the last heat wave, the night time temperature went down to about 16 degree and day time to about 40 degree, so they had a chance to respire and recover at night and drink water and secondly it was before the peak. So we start to learn what extreme events had which impacts. | - Impacts of heat waves on cows are higher when nights also stay hot and if they are beyond peak of lactation<br>-Impacts less strong if nights cool down and cows are before peak of lactation |
| IP22 | - If you have short springs more often, there is a higher risk of having to feed sheep.<br>- The global milk price is quite low and if the spring finish earlier and the farmers have to spend more on feed that might be a problem, years with loss. If this is getting more frequent. If they have to spend more money to produce milk, climate change will put more pressure on the systems which are not profitable. | - Shorter spring mean a higher risk of having to feed livestock → more pressure on farming systems and their profitability |
| IP23 | - […] heat waves which puts stress on animals<br>- […] evaporation has increased which increases the stress on the crops and animals of an agricultural point of view. | - Heat waves and higher evaporation rates puts stress on animals |
| IP27 | Other impacts include higher temperatures and more extreme heat. Heat days over 40 degree may have short term impacts on ram fertility, lamb survival will probably not be affected as they are born during winter, while wool quantity and quality depends on nutrition and | - Heat days over 40 degree may have short term impacts on ram fertility, wool quantity and |

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| | management strategies such as feedlots etc. | quality depends on nutrition and management strategies such as feedlots etc. |
| IP35 | […] historically the type of Merino that was brought to Australia 200 years ago. We have flystrike problems in Australia. The type of sheep we traditionally have in Australia is not a plain body Merino; it is normally a sheep with heavy and wrinkly skin. They are ok in colder environments such as in southern Victoria but in hotter environments it does not work anymore. They have fewer lambs and problems with flystrike. You don't need mulesing anymore and you breed a plain body Merinos sheep or handle other preventive measure such as scratching, insecticidal preservatives. In terms of adaptability of climate change, the traditional Merino sheep that we have in Australia for 200 years is completely unsuitable for what is with us now and in front of us. It has been accepted and I think it is a real mistake. If it gets hotter and drier in Australia, the already compromised animals are going to be more compromised. | -The traditional Australian sheep might struggle more in a drier and hotter environment with flystrikes etc |
| IP37 | But there is additional heat stress on animals due to changes temperature which tends to impact on production. | - Heat wave puts stress on animals |
| | **Pastures** | |
| IP19 | But certainly dealing with that variability of this autumn break that comes quite late is a real problem for grazing people because they don't get any pasture production in autumn and they have to hand feed at great expenses, grain and hay to their stock. The other issue is that the warmer and drier springs mean that the pasture production is very short and the ability to cut large amounts of fodder, hay, silage and save that for later is not easy either. | -Dealing with variability of autumn break and its impacts on grass producing challenging, chance to feed animals, shorter pasture production period |
| IP20 | […] so your annual grass production is probably the same as it is now, because you growth more in winter and less in late spring. Most farmers feel they can cope with that.<br>- Better winter growth, less growth on the margins<br>- If you asked them when they cut silage, there are shifts in the dates by about one month earlier. | -More grass growth in winter and less in late spring , less growth on the margins<br>-Shifts in dates to cut silage of about one month earlier |
| IP21 | The impacts we have mainly seen changes in the ways our pastures growth and also seasonal distribution of pasture growth. Increased growth rates in winter which is a result of cold temperature limitation being alleviated but also spring growing season tending to contract and being more variable as well. If our climate increases by 1 degree and rainfall decreases by about 10%, our studies basically shows changes in the pasture production pattern. | -Change in seasonal distribution of pasture growth, increasing growth rates in winter, more variable growth in spring |
| IP22 | The increasing variability of seasons is challenging for farmers especially if they grow less grass in spring, they might lose money as they spend more on feed. If they think it happens more often they will start to worry about it, which means to make bigger investments to their farm. | -Less grass growth in spring, increasing variability of seasons challenging for farmers, loose of money if they spend more on feed → bigger investment |
| IP24 | In some locations there was an improvement in pasture production, in one of our locations there was a slight increase where the income under climate change was not reduced as much. | -Some locations shows improvements in pasture production |
| IP26 | Slightly warmer in winter means better growth. The trouble now is, we got winter active species to try to get more winter growth. But if you get warmer winter with good rainfall you should get more winter growth. The pasture stops growing when it is getting too cold.<br>- Impacts can already been seen around pasture growth and persistence in most parts of Victoria. There are drier conditions and hotter springs and summer. | --Better winter pasture growth<br>-Changes in persistence of pasture |
| IP27 | The modelling until suggests a reduced rainfall by around 5 – 10%, and therefore impacts on pasture production, by around -10%. About 50% of annual pasture production occurs in a 6-week period during spring. With a 4-6 weeks shorter growing season compared to 1973-2000 baselines and a trend towards a later autumn break, there will be more pressure on the pasture growing season with later springs and earlier springs. Also a change in the peak of pasture growth from mid-November to October. The model suggests a slight increase in winter pasture growth.<br>-Most pasture growth occurs in spring (60 kg DM/ha/day) compared with autumn and winter (10-20 kg DM/ha/day). The GrassGro model shows big shift in the pasture production curve, with spring being earlier and less productive, winter being slightly more productive due to temperature effect, and a trend towards a delayed start to pasture growth in autumn.<br>- Also if there might be a marginal increase in winter pasture production, the overall effects are more negative | - Production occurs in a 6-week period during spring<br>-With a 4-6 weeks shorter growing season compared to 1973-2000 baseline and a trend towards a later autumn break → more pressure on the pasture growing season with later springs and earlier springs<br>-Spring earlier and less productive, winter being slightly more productive, trend towards a delayed start to pasture growth in autumn |
| | **Water** | |
| IP19 | Much of that extra heat is in winter and particularly in spring and even if the rainfall was the same […] soil moisture would get utilized quicker and not go as far as it once did. | Quicker use of soil moisture due to higher temperatures |
| IP20 | Historically farmers used ground and surface water. There are a lot of restrictions now on surface water, having your dam registered and there is quite lot paperwork on that. The problem with the groundwater is that the connectivity with the groundwater is poorly understood. There is a lot of extraction and the groundwater is dropping, we have no idea where the groundwater comes from, it could be the Otway's for Colac but it could also be somewhere up in central Victoria. And a lot of groundwater we are tapping in has actually being ancient groundwater, so it is not a renewable resource. There is a push for farmers to connect in to the domestic water grid, particularly for stock, not for irrigation because there would not be enough supply. For town water you are paying a using charge. But in the worst | -More restrictions now on surface water, such as registering dams etc.<br>-Dropping groundwater in parts which is sometimes even ancient groundwater and not renewable |

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| | case during a drought for instance, people in town would get the water first before farmer get it that is a problem. If Australia was food insecure, that might be a different situation. But if a few farmers go out of business and do not affect city supply for food, they don't care so much; Victoria exports more than 60 % of its produces. | |
| IP22 | Since 1998 groundwater is dropping. They went up in 2010 when we had a very wet year but the trend is dropping. Some of our local creeks and spring depend on groundwater, the catchment flow might also drop for south west Victoria.<br>- The millennium drought brought water decrease ahead<br>-2010/11 was Australia wettest summer, that filled up our reservoirs and all farmers said, we knew that will happen. But it was a very rare event down here. Our dams fill normally up in winter and spring, but not in summer. We were saved by a 1 in 50 year's event. But then our winter and spring rainfall has been less. So basically we are running out quicker of water than what the longer term projection would say.<br>- But climate is a bigger driver of drooping groundwater than from trees. In south west Victoria there will be more water regulation coming as we used to be a quite wet landscape in the past. As the resource becomes more constraint there will be more authorities. The issue of equitable share of water will increase especially if we talk about a declining resource.<br>-In terms of water, SW Victoria was a fairly wet environment, lots of shallow dams that farmers have would fill up regularly and would not fill up once in 25 years during a drought, while now even the smaller dams sometimes don't fill up properly.<br>- They are increasingly running out of water. That is a key challenge for some farmers.<br>- Part of the challenge of south west is that the water cycle is not well understood yet.<br>- But we have to think about how to sustain it with extra stress such as water shortages, infrastructure and good infrastructure facility to make farms viable. | -Trend of dropping groundwater<br>-Catchment flow might drop for south-west Victoria<br>-More water regulations coming up as water becomes more constraint<br>-Smaller dams do not fill up as quickly anymore than in the past<br>- Part of the challenge of south west is that the water cycle is not well understood yet<br>-Water stress might increase in future<br>-Lack of rainfall that fill up dams |
| IP27 | The water security will be also be impacted due to decreases in precipitation and less run off to fill the dams.<br>- Less surface and groundwater means less runoff.<br>-Farmers are already experiencing impacts of water shortages during summer and autumn | -Decreasing water security due to decrease in rainfall, less run off to fill dams |
| IP32 | With climate change Australia is already very much at the edge of water availability, it is a huge continent and at most parts farming is not possible as there is not enough water. | Climate change aggravates existing water issues |
| IP35 | The tricky part is that the inflow in reservoirs is different from just how much rainfall there is. We work with hydrological models to understand what is important for runoff and stream flow in addition to the changes in seasonality in rainfall. We found that summer rainfall is continuing to be quite high and in some cases even increasing but the wintertime rainfall is declining. What implications that has for water resources is interesting. There are more short intense rainfall events rather than winter time rainfall which are generally lighter. Most of the recharge of the reservoir and the groundwater happens with rain in winter. As there is a shift in seasonality. | -Summer rainfall continues to be quite high or is even increasing<br>-Wintertime rainfall is declining<br>-Most of the recharge of the reservoir and the groundwater happens with rain in winter. As there is a shift in seasonality |
| | **Pests and Diseases** | |
| IP19 | I think with the hotter and drier spring that we have had, we have probably seen the prevalence of more crown rott which is a root disease that attacks the base of a plant and fills the plants water tissue with fungal and blocks the pipes and they can't get the water up to their heads anymore and transpire, so they basically. It is essentially much more prevalent in northern Australia, northern NSW and southern Queensland. We are seeing a lot of it but we certainly see an underlying current in some paddocks in one year's removing 5 to 10 % of yields perhaps. So we certainly see a little bit more of that that has to do with the dry and the warmth. We probably also see a little bit more aphids, particularly at the start of the season in autumn where we perhaps are having a bit more summer rain<br>-More summer rain means that we have more weeds growing in summer and more room for insects and fungal diseases over summer.<br>-Aphids like warm weather and stressed crops and they can attack the crops and pop up, it is problematic the aphids are coming in in autumn or spring and I reckon we probably more see aphid damage in crops and we need more spraying more than we used to in the past previous 20 years or so. I mean everything that related to cropping, related to pasture production as well. | -Prevalence of more crown rott ( root disease) though hotter and drier spring<br>- Little bit more aphids, particularly at the start of the season in autumn, attack especially stressed crops during warm weather<br>- More summer rain means more weeds growing in summer and more room for insects and fungal diseases over summer. |

Summary of comments on benefits from climate change for the study area

| | **Benefits of climate change for south-west Victoria** | |
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| IP17 | For my family farm climate change is actually beneficial, particularly in western Victoria in the drier seasons farmers are enabled to change enterprises. | -Drier seasons farmers are enabled to change enterprises |
| IP19 | I think most of research would show that south west is going to be a much better place to be than anywhere else in Victoria. It has a much greater range of climate options to grow all sorts of winter crops than it once did.<br>-Generally there will be greater options for all sorts of crops, especially some of the legumes which still have the issue with waterlogging such as the field peas and chick peas and lentils, maybe they could become a greater possibility in the future. At the moment, the conditions are too wet to grow them. Faber beans and lupern are the only things that grow very well, but luperns hate waterlogging and faber beans like it.<br>- Lack of water logging, better winter grass production for livestock production that will be the | -South west is probably the best place in Victoria to grow all sorts of winter crops due to a greater range of climate options<br>- Greater options for all sorts of crops, especially some of the legumes with a drier climate<br>- Lack of water logging, better winter grass production for |

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| | expense for shorter spring production | livestock production that will be the expense for shorter spring production |
| IP20 | - Better winter growth, less growth on the margins.<br>- In terms of opportunities, if you are in coastal areas the opportunities are great because it is slightly warmer with still enough rainfall, most of the coastal areas of Victoria will improve in terms of their productive ability expect for heat waves and extreme events. | Better winter growth, less growth on the margins.<br>- Coastal areas: slightly warmer with still enough rainfall → potential improve of productive ability expect for heat waves and extreme events |
| IP22 | In the early 1990, it was quite wet and waterlogging was a big issue. With a drier climate it means, cropping is much more viable, which is a benefit.<br>- In the Winchelsea area, wet winters used to be bigger problems for crops and less waterlogging has been a benefit.<br>- Winter production is the main benefit for pasture and cropping. | -Drier climate: cropping much more viable<br>- Less wet winters and less waterlogging, benefit for crops<br>- Winter production is the main benefit for pasture and cropping. |
| IP23 | It is hard to say, I think the benefit comes from how responsive farmers are. You will always find success and failure stories, some farmers are successful during droughts, others have failed. That is also going to be the case for climate changes as well. You find that there will be a situation where the conditions are drier, some higher rainfall zone the land use pattern may change and I think if producers are able to adapt they can still be viable and successful. Rather than say this would be a benefit, it really depends on responses of farmers to climate change. | -Benefit comes from how responsive farmers are: if producers are able to adapt they can still be viable and successful.<br>-Drier conditions<br>-Changing land use pattern |
| IP24 | In some locations there was an improvement in pasture production, in one of our locations there was a slight increase where the income under climate change was not reduced as much. | In some locations improvement in pasture production |
| IP26 | Slightly warmer in winter means better growth. | Slightly warmer in winter means better growth. |
| IP27 | […] there might be a marginal increase in winter pasture production | -Might be a marginal increase in winter pasture production |
| IP37 | What climate change tends to do is probably open up the cropping options because of lower winter rainfalls, less problems with putting in tractors and soil compaction which is different the almost the rest of Australia, where less rainfall is bad. | -Open up the cropping options<br>-Less problems with putting in tractors and soil compaction due to decreased rainfall |

Summary of comments on adaptation and risk management

| **IP** | **Quote** | **Generalisation** |
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| | **General Recommendations Adaptation for Corangamite** | |
| IP14 | - Higher temperature doesn't mean that Australia become inhabitable but it just means you have to adapt […]<br>- […] if they adapt to certain forecasts they make much better than not doing anything. | -Need to adapt to higher temperatures |
| IP15 | Farmers are exceptional at managing risks. The risk that global warming is true is almost certain, far higher than any other risk they deal with and we just suggest to them that adding climate change as a factor to use as part of their decision making process leads them to minimize their vulnerability and increase their resilience and there is no reason why that would cost them a lot of money. If you go around the country you find farmers selecting new varieties and like 20 years ago farmers in NSW have selected cattle's that are able to deal with increasing temperatures and the wine industry has also been extremely active, for instance by buying land in Tasmania to grow warm weather wines. And big investments banks are also looking at where to invest in agriculture by minimizing their risk to climate change. If you have an individual farmers that doesn't believe in climate change so everything, they need to know that there are opportunities accordingly and if they choose to ignore this opportunities they are pretty stupid. Most farmers are superbly good informed about weather and climate but some has misled. Also if single farmers are able to demonstrate that the climate does not change in their particular area, hardly means that the problem should be ignored. Farmers are also adapting subconscious. I don't try to convince farmers of anything. If they are already observing changes and they are already adapting, it doesn't matter whether or not they accept climate change. They adapt to reduce vulnerability and increase resilience. The problem comes with those farmers who are on land where they have no ability to adapt. I have argued that the national party should standing on the roof screaming climate change is a threat to agriculture. Because there are many farmers that won't be able to adapt because their ability to adapt is too limited. If you have a farm that has a good profit and it goes from 4 good years in 5 years to 3 good years in 5 years and then 2 and there is a consequence they can't serve their land they go bankrupt. So it matters critically how a farmers understand its business model and how they take into account changing risks associated with climate.<br>- There is a program called the managing climate variability program from BOM to try to improve seasonal forecasts. Seasonal forecast are probability forecasts. They may say there is certain % chance of average annual rainfall but it might be the driest year measured. It is a probability it is not deterministic, there will never be deterministic forecast and in addition farmers do know about El Niño or La Niña but they seems to think an El Niño means drought on the east coast but it doesn't. It means there is a 30 % increase probability of drought. These | -Farmers are exceptional at managing risks.<br>-Adding climate change as factor to use as part of decision making process leads to minimize vulnerability and increase their resilience → there is no reason why that would cost them a lot of money<br>-If farmers deny climate change, they also chose to ignore opportunities<br>- Farmers are also adapting subconscious<br>- climate change is a threat to agriculture: have a proper business model and take into account changing risks associated with climate<br>-Some farmers have no or limited abilities to adapt<br>-Better skills in understanding seasonal forecast needed: difference between probability and deterministic etc. |

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| | are 2 different statements. So a farmer who decides not to crop because of El Niño and suddenly sees lots of rain and perfect conditions, become dismissive of seasonal forecast but it is really important that the farmers are properly informed what seasonal forecast means. If we could generate more skills in seasonal forecasting it would be of huge value. | |
| IP16 | I think first, they need to be aware of what is going to be the long term outcome and there are data around that show shorter seasons. | -Awareness needed of potential long-term changes: shorter seasons etc |
| IP19 | I speak more about climate variability than about climate change because I believe that the farming systems of farmers have to cope with the extreme variability of Australia's climate. We have the most variable rainfall in the world and some farms are already in the 4th or 5th generation so they are able to deal with that variability but whatever they do in the future, they also need to cope with that extreme variability as well.<br>- If farmers have farming systems that can cope with the current extreme variability, they are also able to cope with climate change reasonably well in the short to medium term. But as we get further and we get perhaps 2 degree of change that is going to require much more drastic changes in enterprises, where cropping for example is not viable and go more for extensive rangeland grazing. That is unlikely that that happens in south-west but it may happen in the northern areas of Victoria.<br>- For smart farmers that live north of the great divide in the drier area bought farms in southern Victoria that gives them a diversity of area, because if it is dry in the north is does not mean it is also dry in the south of the divide. So to have a part of their farm another one in a more reliable rainfall are south west Victoria. That certainly put pressure on land values, land prices in south west Victoria are pretty high which could be problematic for people that want to buy land. Certainly some wine people are spreading their risk by buying land in Tasmania. There are probably not too many croppers that have done this yet but it would not surprising to see that cropping people might start moving to Tasmania. But certainly people north of the divide are moving south of the divide, perhaps not shifting their whole farm but they are expanding their farm in a different area and that is definitely climate change adaptation, they might not doing that for that reason but it works for them into the future.<br>-Clearly the smart people make them as early as possible. They make the decision before they have to or they are forced to. A difficult decisions should be make before you are forced to make them, because everybody want to make the same decision maybe and the land prices in south west Victoria or Tasmania just go crazy and the smart people will be laughing. Changes need to be made and some of these changes are difficult. Some of the people have gone to continue with cropping and got rid of their livestock of their farm. Personally I think, that over 120 years Australian farmers have had a mixed cropping and livestock and that has been for a good reason that has balances out climate risks, particularly in drier springs, the ability to graze crops that are not going to yield much and just eat them off with stock, has proved to be a good thing to do. People who continue with cropping, they don't have diverse income, if their crops are bad they make no money. Some of them are arguing their crops are better now as they get rid of sheep, that the stubble retention is better, but there are still needs to rain and if it rains in summer they have to spray those weeds out and spend money which normally the sheep would eat. | -Farmers have to cope with extreme variability, also if they are able to deal with current variability in the short to midterm, they need to be able to deal with future extreme variability as well<br>-Diversify risk: e.g. people north of the divide are buying land south of the divide<br>-Take decisions before you are forced to: e.g. adapt enterprises, buy land in viable areas, e.g. before land prices go further up<br>-Mixed cropping livestock diversifies climate risk |
| IP20 | And part of adaptation in Australia to climate change is really coping with extremes. It is not the gradual change, I think everybody can cope with that, but it is the 3 years back to back to drought.<br>- You have to think about how do you get one more than income on the farm and how do you build your system as vulnerable in the bad times.<br>- So in general, if farmer need to adapt, there are ways to show them how to make the farms more economic feasible. They will change, when they need to.<br>- Incremental, system and transformational adaptation. Incremental means fine tuning to the current system, systems adaptation says for instance our ryegrasses doesn't work anymore we put in fescues instead or changing to early season varieties or we rotate with other pasture which is more of a fundamental change, transformational means we can't growth wheat anymore for example, we have to become a grazing property, or even sell your farm as you can't growth wheat anymore and move further south where it is possible, which means you can't do what you are doing anymore.<br>-The number of heat days will increase and you have to think about what agricultural systems can survive every day in summer over 30 degrees. So transformation is required. This means exactly, having most of your productive season over by November.<br>- For a wheat farmer you might say from an adaptation point of view, they should be crop and sheep farmer as the failed crop is the food for wool production, as there are still 2 tons of dry matter in a paddock which is just not a viable wheat crop but then at least it will allow them to get some income from wool production. That is where we have to start rethinking our single activity we do. 100 years ago there were not dedicated crop farmers, they were all mixed farms.<br>- Most inland areas they have to do fairly serious adaptation because we have already seen more failed wheat crops and worse heat conditions.<br>- The number of heat days will increase and you have to think about what agricultural systems can survive every day in summer over 30 degrees. So transformation is required. This means exactly, having most of your productive season over by November.<br>- And why wool for example has done so well in Australia, is when you get a lot of rain you get | -The risk lies not in the gradual change but in extremes<br>-Build a farming system that is able to withstand bad times<br>-There are ways to make farms more economic feasible<br>-3 different forms of adaptation: Incremental (fine tuning to the current system, e.g. change from ryegrass to fescues), system (e.g. change season varieties) and transformational adaptation (e.g. change from cropping to grazing)<br>-As number of heat days will increase, think of agricultural systems that can survive every day I summer over 30 °C: e.g. having most of your productive season over by November<br>-Rethink single activities on farm: Mixed-farming method to get both from each businesses (e.g. use dry matter after a drought for sheep and get income from there)<br>-The further inland the more adaptation required<br>.More heat days, have an |

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| | a greater volume of wool but the quality goes down, you get paid less as it goes to higher diameter fibre. If you have a drought, you get less wool but you get a higher quality and you get paid more. If you couple wool and cropping together you get the best of both worlds, because you get that system that can cope and you can still get a good price and get paid more for finer fibre diameter in a bad year.<br>- One farmer moved his entire operation to Tasmania for example. If someone is growing a certain type of wine and knows it does not work anymore here in 25 years' time they take big decisions. The company I am talking about wanted to expand and they wanted to go for a certain type of wine. It could work out for like 10 to 15 years but it would get harder. So the questions were not only, which the best place is now but also where the best place is in 25 years in terms of temperature and precipitation. Looking at the sugar content over time of a farmer that always took record shows that the ideal maturation date has moved to the left about 8 days per decade, there you can see a warming trend, bring maturity earlier in the season. This trend has been seen in all grapes. The evidence is there and it is not genetics that has shifted and cultural practices stayed the same, so it must be temperature or rainfall and that must be climate change. I think in the other industries there is not such evidence.<br>- So what we recommend to farmers is environmental planning such as shelter belts, land care and if you do all these things, add one extra thing in, try to design it in a way that it is compliant with the carbon farming initiative and get that extra income.<br>- Farmers have to change their thinking from for example wheat on wheat on wheat to diversifying their income, let's have some carbon farming income, some sheep and wool that can do well in a bad year and let's have some cropping. So there you have 3 different sources of income straight away that can buffer you against these bad years. It might not mean you make a profit in a bad year but at least you don't lose money. So you might have a loss in the cropping in a bad year, but not with the wool and from carbon farming you also get some income. I think that is where our farmers need to go, start to diversify. | agricultural systems that can survive this heat in summer, having most of your productive season over by November<br>-Mixed cropping: you get the best of both worlds<br>-If you want to buy land and plan to crop e.g. a certain type of crop, take into account climate scenarios<br>-Provide shelter belts for animals, integrate environmental planning and land care<br>Diversify income: mixed livestock cropping to buffer against bad years |
| IP21 | To maintain a profitable farm. Otherwise there won't be the money to keep things up to date, keep weeds under control, participating the local community. Adaptation is part of maintaining a profitable farm and also maintaining the environment or even improving it.<br>- Changes don't need to be dramatic, farmers can incrementally adapt to seasons as they go. There will be no unexpected climate change.<br>- But if I was a farmer and was making a decision about purchasing a new farm which has a timeframe of 20, 30 years I would definitely think about climate projections. | - Adaptation is part of maintaining a profitable farm & maintaining the environment<br>- Being open and flexible to change helps to maintain profitability<br>-Include climate projection into decision-making process |
| IP22 | You have to be profitable to be able to adapt and that is a key thing. If your term of trade is declining and you need to make improvements to stay profitable, climate change in that situation can make that harder. Climate change just adds extra stress on land use or particular enterprises which is already having trouble being profitable. There might be extra costs such as to spend more on getting water to their stock and buying in extra feed during an extra drought. So that economic business management is very critical.<br>- Windows open up in terms of adaptation. But windows have changed to make these changes, adapting to climate change means to adapt in steps.<br>- Try to find the right system that works sustainably. If you have high land values, the profitability of the whole business might change. One challenge is although if there is a technical solution to deal with hotter and drier climate, after you applied it, are you still a profitable business? It is responding to what the market and climate is doing.<br>- The main thing is to stay profitable to look what is the most favourable thing to grow, having infrastructure to get it to markets. Shifting your proportion of enterprise is important also with regard to profitability, which is part of an adaptation, whether if they call it climate change or market situation. Innovation to adapt is good but if it costs extra if you still get paid the same in the end, they would do that. In Victoria some farmers include more livestock into their cropping enterprise because in drier years when the crops fail at least they get income from sheep. So they can make more money from cropping in good years but having livestock gives them another income, which is diversifying risk. Climate change is a multiplier of extra stress. A top third of the farmers are really skilled and smart with good agronomists and advisors and they are quite confident about their ability to cope with climate change, make sure a good supply of technology. A bottom third of farmers have problems, climate change adds to their pressures. They might think about getting out of farmers. Many farms don't have a succession plan, kids maybe don't come back to the farms, and they are maybe not investing and being ready for future. There are lots of farmers that are not investing. During a drought, some farmers might struggle and their land becomes viable to the successful farmers next door. There are social impacts. Some people say you need the less efficient farmers to make way for the better farmers.<br>- Good business management, good supply of genetics and farm advisors for improvement. It needs to be linked into profitability. We rely on export markets. If for whatever reasons the export market drops, less profitability also means less room for adaptation.<br>- One of the challenge is, when everything is going really well for you some farmers get good advice and put money on their farm management deposit, other invest in real estate or other non-farming things or new infrastructure. Good business advice is important so when things go well invest in things for future if it doesn't go so well at some point, which is business risk. Which has always been there but climate change puts extra pressure on farms.<br>- The big challenge about climate change is, what you do differently today that makes your | - You have to be profitable to be able to adapt<br>- Climate change just adds extra stress our land use or particular enterprises which is already having trouble being profitable.<br>- Adapting to climate change means to adapt in steps<br>- Try to find the right system that works sustainably. Respond to what markets and climate is doing<br>- The main thing is to stay profitable, e.g. shift your proportion of enterprise<br>-Mixed farming helps to diversify risk<br>-Farms without succession plan and no investments struggle more<br>- Less profitability also means less room for adaptation<br>-Good business advice is important so when things go well invest in things for future if it doesn't go so well at some point, which is business risk: what you do differently today that makes your future better off<br>-Use information on risk management, provided by other farmers, workshops etc<br>-Mixed cropping livestock approach to diversify risks<br>-Maybe acquire or lease land in another district to spread risk |

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| | future better off.<br>- Last spring which was really dry, the lamb prices were really high because we have better export markets and value. That economic impact means even if seasons are tough, having good livestock prices is also an important underpinning for adaptation.<br>- We just deal with whatever happens, we have to get better with that. Last winter there was a very bad frost in north Victoria and South Australia. Farmers were talking to their advisor, there were workshops. People shared information on what happened and what they did and what you can do about it in case in happens again. This is a good example of how important networking is and share information also between agronomists and science. That was very practical and sharing learning. Farmers are often faster in their responses while science depends on funding.<br>- In Victoria some farmers include more livestock into their cropping enterprise because in drier years when the crops fail at least they get income from sheep. So they can make more money from cropping in good years but having livestock gives them another income, which is diversifying risk. Climate change is a multiplier of extra stress.<br>- For example buying land in another district to spread their risk. Leasing our farm to someone else might also be a decision. | |
| IP 23 | Farming is being driven to be more opportunistic type arrangement, in the past farmers have either being cereal grower or livestock or mixed and I think we see increasingly that farmers have to become much more flexible and responsive to these conditions, they can take the opportunity of there are good conditions evolve and they can then go to higher value production or if there are drier conditions, they can go more into a conservative farming approach. Having a balanced operation, having both livestock and cropping, seems to be a reasonably good way of trying to address the seasonal variability<br>- Beside the listed points, it more really to diversify your income and have that as a forehead position and trying to maintain good equity in the farm that you can respond, because if they don't have the equity in the farm they can't change their practice responsively.<br>- The way I try to explain it to a producer group is, most farmers have set up their business structures that they are profitable one year in 3, the business structure is set up that it is sustainable for them. If you ask farmers they say they can cope with a drought, but if you asked them , what happened if the frequency events changes, is your business structure still resilient enough to respond, farmers would say no and the farm management would have to change if we go from 3 to 1 profitable year in 5.<br>- That is one option but the overwhelming one is around looking at how you can bring in both livestock and cropping into your enterprise mix because the livestock is the more resilient to the drought conditions. In a good year, you are cropping more and you are making your money in those years and in the drier years you have livestock in the system that gives you your profitability.<br>- My suggestion is they need to start to think about the last 10 to 15 years as being analog for the future. They need to start thinking about what management activity have actually been profitable over the last 15 years and those that have been more profitable will be the sort of adaptation option will give profitability in the future.<br>- Unless you have a reasonable amount of equity in your property you are not able to be responsive and you are not able to adapt. Working on equity level on a farm or restructuring the farm to improve equity is probably a sort of a good adaption option. | -Become more flexible and responsive to climate conditions, take opportunities<br>-Mixed farming approach god way to address seasonal variability, livestock I more resilient to drought conditions<br>-Diversify income, maintain good equity in the farm to be able to respond, without a reasonable amount of equity in your property you are not able to be responsive and you are not able to adapt<br>-Be prepared and responsive for changes in the frequency of events<br>-Plan for the future: the most profitable management activities in the past 15 years will be the sort of adaptation option will give profitability in the future<br>- Working on equity level on a farm or restructuring the farm to improve equity is a good adaption option to be able to be responsive and adapt |
| IP25 | -If your farm is not in a particular marginal area, you might go on as you did previously<br>-Forecasts are based on probabilities and a 70% chance of increase in rainfall is already quite a useful information also if it's still contains uncertainties. They should know how their business risk is changing also if you can't tell for every single year. | -Farmers in marginal areas have to adapt more<br>-Be aware that business risks are changing, understand forecasts and their uncertainties |
| IP26 | Important in the long term as farmers need to make decision timely. | -Take decisions in time |
| IP27 | Today's best practice management strategies are the best response for current period and the short term, but longer term climate change may require adjustments to management systems<br>- In the long term it is important to take actions in time to prepare for the future. Producers can be prepared for longer term climate change by equipping them to deal with seasonal variability. This doesn't require them to have a "belief" in climate change, but taps into their need to make a profit under a more variable climate, which might just become more common in future. | Today's best practice management strategies are the best response for short to midterm conditions, but longer term climate change may require adjustments to management systems<br>- Take actions in time and prepare for the future |
| IP31 | We try to do to get the science and come up with a story how we think climate change will impact the region. Then we come up with adaptation pathways. We have a web portal and farmers can just click on their farm and see how climate change will affect their native vegetation, their soils and waterways. We hope to launch it in June this year. We have done a lot of modelling, so they can use it. There is a climate resilience community project, they are also doing work for south west Victoria where they look at social and economic impacts of climate change. But also if they don't believe in climate change, they believe in droughts. The government basically told us not to use the word climate change but you can't really ignore it | -Make use of information portals: e.g. climate resilience community project |
| IP32 | In terms of adaptation is seems good to adapt to the lowest one, the 2.6 scenario, that should be your minimum adaptation need. | -Adapt minimum to the lowest pathway of climate scenarios |
| IP37 | The opportunity is if you adapt well you make more money and you incur less risk which is positive. Effective adaption means probably that you operating closer to the production | -Adaptation means less risk and the opportunity to make more |

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| | potential of your farm, so the yield gap will close. If you don't adapt to climate change the yield gap will open up, which impacts profitability<br>- It gets a common terminology ("Yield Gap") in agriculture. It reflects the difference between what you yield or animal productivity is versus what it could have been, given the temperature and precipitation at a given season. If you plant crop in Victoria you may expect with a good management and no diseases, you make it 7 tonnes per hectare. But in reality farmers often get only 5 tonnes per wheat. So 7 would be the potential yield and 5 which is the actual yield is called a yield gap.<br>- Farmers know what their actual yield is with gaps information etc. You either have to look at high performing alternatives, so if your neighbour is producing 6 tonnes and you only 4.5, it is quite possible that there is a least 1, 5 tones yield gap, maybe even more. So you have to look at possibilities. If you plot rainfall against yield you can actually, the top of the underlies, the best that have anyone done in a given year and this should be close to your potential yield. You can also use a simulation model; run it which included your climate, your soil, fertility management and that will come up with a potential yield number. Then you can compare that with your actual yield. | money<br>- Effective adaption means that you operate closer to the production potential of your farm and close the yield gap |

Summary of comments on adaptation regarding livestock management

| IP | Quote | Generalisation |
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| | **Livestock Management** | |
| IP17 | Shearing time is quite flexible as long as it is not done just before lambing and put a lot of extra pressure. It does not bother me too much. Lambing time is an important driver of profitability. With regard to lambing time, it is actually a pretty important determinant of the number of stock you can run on your farm. Autumn lambers, the peak feed requirements for the sheep is when they are lactating and that is when they are most vulnerable. It does not make sense to lamb in autumn which is usually pretty unreliable and try to lactate over winter when the feed is usually pretty short. You can actually run more sheep if you have the lambing time later in the year, there is less feeding of the sheep from August, September is ideal. July is ok because peak requirements of the sheep are a couple of month later, for the meat breeds we lamb a bit earlier as they have to be finished by the end of the growing season. But for wool type types it is not as important to get the lambs as big by summer. So August, September is ok. And in cold areas where you get extended growing season, July to September is good. Now with climate change, if the winter is no longer feed limiting, then of course going a bit earlier is favourable because the lambs will be bigger by summer and if the season cuts out earlier, you need them to be in a certain weight to survive the drier period in summer. Climate change with warmer conditions could enable to shift it earlier in the year. At this stage, the change is not big enough. What farmer finds is that winter is no longer as limiting as it was. If farmers change their shearing and lambing time, it is not due to climate change, they tend to lamb earlier although we show that it is profitable to lamb later. 30 years ago, 90 % used to lamb in autumn, while now it is 50 %. Traditionally farmers try to get the lambs as big as possible by summer. Last winter was the coldest in like 20, 25 years. What is changed it, as I said wool producers lamb a little bit later than the meat producers, a lot of farmers have changed their enterprise to meat, which is due to higher commodity prices for lamb than for wool. That might be why farmers changed lamb times. At Mt Hesse they have a quite profitable wool flock which is as profitable as meat flocks, but that is not the case at all farms.<br>- Shearing time is one of the major things, it is mainly an issue with the young sheep. One PhD did his thesis about time of shearing near Mt Hesse, he is based on Werribee. The biggest impact on staple strength is spring lambing is better than autumn lambing because of the nutrition stress. August and September lambing, you get less tender wool than you get with May, June lambing. It is mainly an issue with young sheep. We found that feeding any amount of supplements won't stop the tender wool in young sheep, it is not cost effective. What the strategy is, the major break in the wool happens at the autumns break in other word when it changes from drier to wetter times, if you sheer your young sheep at that time then we you tend to get the break of the wool right at the tip, so the wool is not as discounted. 30 years ago it was not discounted when it was tender, but nowadays they measure it. So the best way to manage that is to shear the weaners close to the break, which caused the change in shearing time for a lot of people to manage that, so it is not such a climate change thing. Farmers have to be more flexible with variability, they have to be a bit more reactive to when it does get dry to for stock sales.<br>-Farmer need worm control programs. I don't think it is happening right now but we need to be aware that those things might happen. | -Lambing time is an important driver of profitability<br>-You can run more sheep if you have the lambing time later in the year, there is less feeding of the sheep from August, September is ideal<br>-Changes in lambing time due to higher commodity prices for lamb than for wool<br>- Climate change with warmer conditions could enable to shift lambing times earlier in the year in future<br>- The biggest impact on staple strength is spring lambing is better than autumn lambing because of the nutrition stress.<br>- Worm control programs important also to address changing risks of flystrikes earlier in the season |
| IP19 | Well it is a serious issue because they certainly need more shade if they can get it and access to cool water that is about all they can do, they go off their food, they won't breed if you want them to mate, and they just sit around and do nothing, same as humans would do at 44 degree. In the long term, there are breeds of cows such as the Boss indicus cattle from the north of Australia and African countries which are more able to cope with warmer temperatures. There are certainly breeds of animals that can cope with higher temperature but they are generally not as productive and they have not got as good meat quality. But in the long term there is not a major issue there but more in the short to medium term. | -Provide shade and access to (cool) and reticulated water supply that goes around with pipes rather than relying on dams that are fed by rain<br>-In the longer term, animals that are able to cope with warmer temperatures getting more |

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| | - I think it is just the access to reticulated water supply that goes around with pipes and troughs rather than relying on dams that are fed by rain, to transport water around your farm wherever it is needed. Cows drink a lot of water so you can't car the water to the cows. The other things in terms of feed supply, I think perennial pastures are very important<br>- Those people who have Lucerne over summer and have perennial pastures and finish off lamb when other people have to feed have been a major advantage. | important<br>-Perennial pastures provide a good feed supply |
| IP20 | There is a farmer in Queensland who had to go through a 3 years drought without any rain and when he had a look at his records, he decided to destocked 10% and as a result he could cope with 3 years of drought and still have his core breeding program while his neighbours went out of business.<br>- I have a master student and if you summarize it says, if you are in a reliable high rainfall area, produce prime lamb, don't produce wool. Because prime lamb in those high rainfall areas in a good year makes a huge amount of money, in a bad year it will do badly but on a 100 year basis you make more money out of prime lamb in this region, which refers to the southern coastal areas of Victoria, Warrnambool, through to Colac in that area. Furthermore the study concludes, that for drier areas in north Victoria and western New South Wales, that areas that are more drought prone, you definitely go for wool because in a good year you make probably more money out of prime lamb than you would make out of wool but in a bad year you would crash so badly with prime lamb but at least wool will still give you a return. So on a longer term basis, wool actually performs better than lamb in these high variable areas. There is quite a lot adoption of this idea, I think intuitively they know that, so if they had some bad years it is all they need, trying to go into dry lamb in this dry area and the whole district knows that was actually a big failure. And they know they get a better price for wool. We actually already see this separation. If you go to the coastal areas, there is more prime lamb, if you go more in the drier margin areas, there is more wool production. This is the impact of the rainfall on pasture growth. That is one of the point where you do not need to talk about climate change, and this example is one of them and when you tell them, on average your income will be slightly lower than prime lamb per year, but in the long term you will make more money out of wool. The one separation between those 2 is a new thing that started emerging about feed locking sheep. What we found with a sheep lock, and that is a strategy to manage variability, if you have prime lamb you still want to finish them off, is becoming increasingly popular. Most of the sheep feed locks are not quite as formalized as cattle feed locks. We are currently doing research bout structures business plans for sheep locks.<br>- Dairy cattle farmers should have shade cloth, some also use sprinklers, with sheep and cattle we talk about planting native generation, planting corridors and we reckon that planting wildlife corridors with land care biodiversity together with potential carbon plantations to generate some income out of it serves a wind breaker in winter for sheep that has been shorn to avoid the cold and provides some shade in summer. So the only thing you can do with the extensive grazing industry is in summer is provide them with access to drinking water is vital to survive the heat and shade, that is all you can do.<br>- There is an interested for what we call slag gene, which is a gene that you find in the Black Angus breed of cattle which makes that the hair fibers have a silver coating which reflects infrared radiation. And these cows are doing better in Queensland than tropical cows because it has this ability of reflection. And I think as there is more evidenced of extremes, there might be more effort in breeding this type of cows.<br>- They just get 10th for of what you could get for lamb production on that land. So it is not a very viable option for farmers. But if we build in a small chance in lamb survival in winter in our models, because the sheltering effect of the tree and a small survival in weather survival during shearing from heat stress in summer or cold in winter, it paid hands down to put trees in.<br>- But the scenario of finishing an animal earlier is more interesting for farmers, as they can get in another crop earlier and the money they are going to make is far greater than the carbon farming income.<br>- So we talk to farmers about how can you couple land care with biodiversity, with wind breaks, with shade and shelter and be compliant with carbon farming and get extra income that way.<br>- There is now is recognition that we mare over cleared, farmers recognize that and plant corridors through their land. Another issue is the resell value of your farm. If your farm is completely free of any trees and you bring a family there and ask if they want to buy the farm, they would go for another farm with a pleasant landscape, so they always go for the more aesthetic one.<br>- One issue is the salinity. A mature eucalypt will take about 300 litres per day that they take out of the soil and transpire to the atmosphere. So that water cycle is far more active. There is evidence that taking out trees is affecting the amount of water in the atmosphere which causes reduced rainfall in tree cleared areas and secondly, by taking out the water out of the soil, they drop the water table. Now, without the trees, the water table is coming up to the surface and brings the salt with it. So dryland salinity is a result of land clearing. So if you have a salt problem, you have to put trees in to drop the water table or drainage, especially in the flat area around Colac and in general western Australia as there is not a fall in the landscape. | -Adapt your stocking rate to seasonal weather conditions<br>- In a longer term basis, producing prime lamb in a reliable high rainfall area (south Victoria) and wool in more drought prone areas gives you're the most income<br>-Sheep locks as good strategy to manage variability to finish them off<br>- planting wildlife corridors with potential carbon plantations to generate some income also serves a wind breaker in winter for<br>-Combine land cape and biodiversity by planting trees<br>-Increase resell value of farm<br>- Dryland salinity is a result of land clearing, putting in trees keep salinity under control |
| IP21 | - Heat stress on animals is another big issue coming up, they start to recognize the value of shade, which means planting more trees which also acts as a shelter belt against wind which is important at lambing time at winter when they might higher rates of mortality, so it has | -Planting enough trees that serve as shelter against winds (important at lambing time) |

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| | multiple benefits on the farms.<br>- In south west Victoria they have a shorter growing season as it is a bit drier than in Gippsland for example. So they would calve earlier in the year in early winter, May, June trying to maximize the pasture they can use. When your winter growing rates are higher, you should make better use of the pasture. | -Make the best use out of winter growth production |
| IP22 | In spring we grow 2/3 of the forage for pastures and if spring is a bit shorter, then you have to manage livestock differently to get them through, that is a challenge for south west Victoria. Some springs are really good, so you have to see how you make most out of the springs.<br>- Lots of farmers have invested in storage for fodder in silos, storing more grain. Rather than just having 2 month for stock feed they want to store more. That gives me more flexibility.<br>- Better storage, shift or sell livestock earlier. With the increase of the lamb and red meat industry, there are more farmers with bigger permanent breeding flock, which means the production is more constant throughout the year. But when they are getting variable seasons, they can just shift livestock off and sell. But if you try to maintain core breeding flocks, you need to have enough buffer in the system to cope with that. If you have short springs more often, there is a higher risk of having to feed sheep. South west has been a fairly reliable grazing land and some farmers do a good job and improve their production and get higher stocking levels. When the production does not match the higher stocking rate can be challenging and farmers need to take decision.<br>- Dairy farmers are generally really productive. But if they get bigger summers and a bigger feed gap in the summer, they have a bigger shock to their system, it is a change in the system that makes people vulnerable.<br>- Using feedlots as adaptation to increasing variable seasons is also good. | -Manage livestock accordingly to changing seasons (e.g. shorter springs) regarding pasture growth<br>-Better fodder storages give flexibility, e.g. through investments for fodder in silos<br>- Shift off or sell livestock earlier<br>-Plan for shorter springs and higher risk to feed sheep<br>-Match pasture production to stocking rate<br>- It is a change in the system that makes people vulnerable, e.g. bigger summer and bigger feed gap<br>- Using feedlots as adaptation to increasing variable seasons is also good. |
| IP26 | Adjust stocking rate, stocking off pastures earlier is important, sell stock earlier or put them in stock containment and feed them, for example. | Adjust stocking rate, stock off pastures earlier is important, sell stock earlier, use feed lots |
| IP27 | It is important to provide enough shade, there are farms that don't provide enough shade to their livestock. And to ensure that watering points have sufficient flow rate to meet the needs of stock on the hottest days. Another approach might be using pregnancy scanning to check on ewe conception with a view to re-joining or disposing of dry ewes. Due to the heater extremes, the rams fertility might be affected which means that they are only half of the time fertile they are joined with the ewes. So it is important to have this in mind for the case the ram is just fertile for half of the time they are joined with the ewes. So give them enough time for reproduction and instead of leaving them together only for the time of 2 ovulations, 3 might increase the chance of gestation. Also adjusting nutrition to feed requirements is important if they have twins or singles, to provide enough feed, especially with twins.<br>- Today's best practice management strategies are the best response for current period and the short term, but longer term climate change may require adjustments to management systems, e.g. have in mind fertility of rams during heat events, sell ewes that are that are not in lamb, adjust lambing time to allow lambs to finish on green feed according to market specifications or use alternative strategies for finishing lambs such as feedlot or paddock supplementation. Another approach might be to change business enterprise, e.g. to sell store (unfinished) lambs instead of prime (finished) lambs or go from cropping to grazing)<br>- The optimum lambing dates according to models of climate in 2030 are around 4 weeks before normal lambing time in Victoria, so in June/July instead of August/September to finish them off by the end of spring, which are getting more unreliable. However, earlier lambing requires earlier joining, which reduces potential reproductive rate at around 5% per year, so instead of 100 lambs there are maybe only 95 lambs. This is a balance act and depends on the season.<br>- Quicker fattening of sheep with shorter growing season might get more important in future as lambs need to be finished off earlier. | -Provide shade, ensure watering points with sufficient flow rate<br>- Use pregnancy scanning to check on ewe conception<br>- Have in mind ram fertility during heat events and joining time with ewes<br>- Adjust nutrition to feed requirements of ewe<br>- Sell ewes that are that are not in lamb, adjust lambing time to allow lambs to finish on green feed according to market specifications or use feedlots<br>-Another approach: change business enterprise, e.g. sell store (unfinished) lambs instead of prime (finished) lambs or go from cropping to grazing<br>- Optimum lambing dates in 2030 around 4 weeks before normal lambing time in Victoria<br>-Quicker fattening of sheep with shorter growing season might get more important in future |
| IP30 | - Meat sheep breeds for example want to increase growth rates and also increase the amount of muscle but decreasing the amount of fat as consumers don't like too much fat. One of the trade-offs is if you reduce the amount of fat in your livestock too much, the breeding stock that you retain in your fertile flock, find it harder to store enough energy, maintain conditions for variable seasons. Over the last few years we have seen more and more people swinging back away from breeding animals with leaner meant and start to think about maintaining or increasing fat levels particular in the females to retain the breeding flock. They have a better resilience and ability to cope with variable seasons. We see that in all districts but particularly in the more Mediterranean climate in the southern district with very short growing seasons, hot and dry summers, being able to have a ewe flock that is able to maintain body conditions easier in those seasons and making sure you have enough body conditions such as fat on slaughter or lambs to get them off the property before the season runs out. Recently we have really seen a change in the commercial level what sorts of fat they are looking for. Fat is positively related to reproductive trades and muscles and fat are highly correlated with body conditions. And by improving that again we make sure that animals can store more energy reserves.<br>-We rely on people measuring the muscle and fat depth with scan probes along the back bone and then we look at the genetic differences between the animals.<br>- I think there is an increasing amount of awareness of what they can do and what sort of impacts is having on people operations and how much feed animals need to maintain | -Breeding: reducing the amount of fat in livestock is a trade-off, it is harder for them to store enough energy, maintain conditions for variable seasons<br>- Animals, particular the females with fat levels retain better the breeding flock, have a better resilience and ability to cope with variable seasons<br>- Fat is positively related to reproductive trades and muscles and fat are highly correlated with body conditions.<br>- Make sure stocking rate and food demand matches, make sure sheep and cattle are able to cope with new conditions<br>- Breeding programs help to make sure having the right |

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| | conditions. One thing we are not sure about yet is, if these fat animals are efficient or do they just have an increased appetite? Some work that has been done in New Zealand shows that the fatter animals are, the more efficient at converting feed into live weight, which is a bit of a surprise. People are more and more aware of that in terms of reproductive rates.<br>-Yes you can breed animals that are more resilient and handle more variability. Also simple things for wool breeds such as Merinos, selecting animals for higher fleece weights is unfavourable related to? If you are only measuring fleece weight, at the same time it is going to trending in the wrong direction for fat. This has an impact on how resilient those animals are, how much feed they maintain conditions.<br>- *What would you recommend farmers in terms of climate change?*<br>It will need a range of different approaches. Farmers are going have to be more diligent on e.g. pasture assessment, looking at rainfall for the last month and forecast, sort of pasture production, making sure they are matching stocking rate and likely changes in feed demand for their livestock, making sure that sheep and cattle are able to cope with new conditions. Breeding programs are definitely good but making sure you have the rights animals in that sort of environment with the right management practices, you are able to keep viable production levels.<br>- We are certainly increasing awareness but there is still a lot that needs to be done in terms of breeding value and how to use them to start off. But there is evidence that this is happening because I have breeders that come to me and say: our clients won't buy rams that are so lean because they have trouble finishing lambs, they have trouble maintaining conditions on ewes and so on. There are certainly commercial producers out there who have made the link but there is still a lot of education needed. If they breed rams for their own use at home they can still get animals into genetic evaluation and have breeding values calculated on them. You don't have to be a registrated start breeder to participate in those programs, you should understand what for breeding values you are looking for and how you can use them.<br>- We don't know how it is going to influence the variability from one year to the next which makes it hard to manage maybe. In the one year you are overstocked while in the next year you don't use the whole feed efficiently because your stock number are low and you had more rain than expected, how do you manage that, which is really challenging. I think it needs people who think about how to rethink business models, rather than traditional way with running a breeding operation and lambs and carves though this way, we need more flexibility, to match annual production to rainfall that we had and pasture grow than we see. This could mean higher proportion of a stocking rate is a trading enterprise. The more variable your environment and grazing is, the lower the proportion of your stocking rate that should be made up off breeders that are on the property permanently, because it gives you more flexibility. If I have my entirely property stocked with ewes that are lambing down and I sell prime lamb and if I get a bad season, I don't have a class of stock that I can offload easily to reduce my stocking rate. If I have 50% of my stocking rates in ewes and the other 50% in growing out young cattle and taking them from 250 to 450 kg, I can get rid of this class of stock fairly easily during a dry season and then I am back to my half stocking rate. So being flexible funding system, in terms of getting off of enterprise that I can cash in, maintain ground cover to avoid wind erosion and degradation and take the right pasture species. As it is getting more variable, people have to think about how to manage this variability and to make sure, how to match feed requirements of the livestock to the feed that is available. And being more proactive, there is a whole range of opportunities and it that not mean to have a whole change of what they are doing, maybe still keeping the core enterprise but maybe at a lower proportion to previously. The more variable the climate gets, the sooner you have to make decisions along the way. | animals in that sort of environment<br>-More education needed in breeding values<br>- Rethink business models and more flexibility to match annual animal production to rainfall and pasture growth or get off animals earlier<br>- Being flexible in terms of getting off enterprises, maintain ground cover to avoid wind erosion and degradation and take the right pasture species.<br>-Be more proactive, use range of opportunities |
| IP33 | Sheep are less heat affected if they have been selected for having large floppy ears which is a sign of heat resistance. We deal with very extreme climate here in Australia. Some characteristics such as wool over the eyes, lots of wrinkles that attract to flystrikes, things that limit their movement such as short legs, those things we are looking at in terms of sheep breeding programs. We look at increasing rain events and humidity in hot weather, we look at animals that have wool types that are less susceptible to fleece rot. In terms of wool breaks, we are also looking for animals that are able to sustain wool growth during periods of low nutrition, so that there is a lower impact on staple strength from those animals, so they have genetic fat to protect them from changes during the growing season.<br>-But in the wool industry in Australia, there are 2 quite distinct groups: we have our traditional wool growers who have a traditional type of sheep that they have for a long time and then we have this progressive type of wool growers who are looking for animals that maybe not fit the normal picture but have these different trades. What is also interesting there are growers who have changed to a 6 month shearing. Traditionally, sheep are shorn every 12 month. The length of wool is what is required by the wool processing trade about 80 to 100mm of wool. When we select animals for high fleece growth with long staples it gives you the opportunity to have a 6 month shearing cycle. You are still able to harvest about 70mm of wool at 6 month. But it means you have the opportunity to reduce increased dust penetration possibly from periods of low rainfall. You also have the opportunity to influence high vegetable matter content like grass seeds in the wool because you can shear to avoid times what that is high. Furthermore you also avoid those changes in nutrition that decreases stable strength. So, by selecting animals that has high wool growth you can modify you shearing times to work around dramatic changes in vegetable matter in the paddock, dust penetration and staple | -Characteristics such as large floppy ears help with heat resistance, less wrinkles with flystrikes<br>-2 types of farmers: traditional wool growers and progressive type of wool growers who are looking for animals that maybe not fit the normal picture but have these different trades |

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| | strength<br>- There is a farmer who is very progressive in that area, he has sheep that have a 6 monthly shearing and have this big floppy ear and other heat resistance characteristics. We see a decrease in the amount of wool production in Australia over the last 20 years which is more an effect of price marketing rather than a climate issue. | |
| IP36 | - Plain body sheep instead of wrinkly skin, with natural selection pressures on it from its environment. Why would people want wrinkly sheep? It has simply been that it increases the surface area of the skin of animals growing more wool and they kept on doing that over time.<br>-75% of the sheep in Australia are joined out of season, at the wrong time of the year, November, December, January. Under those circumstances, the consequence is than when the ram ejaculates, the DNA might be damaged. We can't get the right type of sheep if we are joining in spring or summer, we should join in autumn or winter. Whatever is fertilized by damaged sperm, it also affects the female. In terms of climate change, there are some rules. You have to consider day length and how it affects the reproductive cycle of the ram and ewe. This is called epigenetics. If you follow the rules of natural selection or climate, it is better, as they must be during the breeding season not out of season which is spring and summer. In season is February, March and April. Next to the right joining time, you have to keep the animals free of wrinkles with a plain body. Sheep with many wrinkles can't regulate the body heat well enough and they suffer. And third, they need good body reserves such as muscles and fat. So when pasture conditions faded into drought or due to poor quality pasture, they need that muscle and fat reserves to be able to milk well. Merino sheep with woolly faces and wrinkly skin struggle to the watering points which might be 5km away, they can't regulate their body heat though moisture loss. This is observations my colleague and I made. They also have fewer lambs and loose more lambs and die first in the drought. The ones that do well are open face sheep, and the testicular are closer to the body, as they don't get too much heat which might cause heat induced infertility. It does not get that challenging in southern Victoria though but most of South Australia it does apply.<br>- They just cut as much or even more with better quality wool that processes a lot better though spinning and weaving. Most of them what father and grandfathers told them is wrong. They stuck with what they are doing forever. Summarizing I can say, farmers would make more money, they need less management and have less requirements with the plain body and they are certainly more adapted to climate change. Our sheep are naturally resistant against flystrikes does not matter how wet it get, because without the wrinkles they don't keep the moisture on their skin. Also in terms of soil health and land cover, they think normally about getting away from chemical stuff and improving soil structure that supplied the plants with nutrients, but organic matter can also improve soil health. | - Plain body sheep instead of wrinkly skin to regulate better body heat, better wool quality, more income, less management, better adapted to climate change<br>-Joining time should be autumn or winter, not spring or summer to avoid damages in the DNA<br>-Have in mind reproductive cycle of the ram and ewe<br>- Good body reserves such as muscles and fat to be able to milk well during drier times |
| IP37 | There is a range of things farmers can do. They can put in enough trees, making sure you have shelter belts or infrastructure such as shade shelters. Or also shade cloths can cool animals which are quite cost effective and pragmatic way. Some studies looked at sprinkling animals as a way cooling them down. But of course you need to have water available and it has to be cheap. I think that would not really work in the wetter environment such as the Corangamite area, it works better in drier environments. You can also manage the feed, by cut down the feed intake and make the feed more digestible to cut down the metabolic load and you can also choose different animals so you can breed more heat tolerant sheep.<br>- *Is it already common that farmers would use new type of animals?*<br>Probably more in the drier areas of Australia. The Merino sheep was originally a Spanish sheep has historically been used widely across Australia and there are different breeds within the Merino. Some of them are more heat tolerant than others. Recently there have been brought in several other varieties such as fat tale sheep and dopha sheep. By bringing those sheep in you can actually have animals that are more climate resistant but I think they are used in those environments such as Corangamite.<br>-There is a trend of seasonality of grass production which can flow on to changes in the amount of supplementary feed needed and choices of things like joining time, so when you have your reproductive cycle, when you mate the animals and when you have the babies. Depending on individual views on risk and return, farmers will sometimes makes changes from a spring to an autumn lambing system. | -Have enough trees or infrastructure such as shade shelters to provide shelter belts and access to water<br>-Manage feed, cut down feed intake, make feed more digestible to cut down the metabolic load, choose different animals so you can breed more heat tolerant sheep<br>-Adapt joining and lambing time to seasonality of grass production /supplementary feed needed |

Summary of comments on pasture management

| IP | Quote | Generalisation |
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| | **Pasture Management** | |
| IP17 | We want to run a profitable farm. Making sure, fertilizer input are adequate, pasture species are the right ones, I have always been for drought tolerant perennial pastures and I think the climate change scenarios just enforces that plant species that will tolerate periods of droughts, so we use Phalaris which is one of the most productive species and it is drought tolerant. The other major opportunity is perennial ryegrasses; they don't like heat as much and are fewer droughts tolerant. In a cc scenario with not enough rainfall to go with Phalaris, so down at Mt Hesse they have done a great job with establishing a lot of Phalaris. At the end of the day it is all about how much stock you can run, pasture utilization and having pasture species that mostly uses the water available. If you can grow Lucerne and if you get out of season rainfall, it is the best thing to utilize summer rainfall or also chicories that take advantage of summer | - Making sure, fertilizer input are adequate, pasture species are the right ones, go for drought tolerant perennial pastures such as Phalaris which is one of the most productive species and it is drought tolerant or perennial ryegrasses, they don't like heat as much and are fewer droughts tolerant. |

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| | rain, which is a way of extending your growing season. If you have pastures that are well enough drained, go for Lucerne type pastures as well. In western Australia where they have fairly reliable rainfall between May and September, 400 mil, the rest of the year is desert and it is too dry for the perennials to persist and what they have found is they have introduced some of the tropical pasture species. They have their annual pasture base in winter and then they have the tropical species and when a cyclone comes down the cost and they get 1 or 2 big rains in summer, the tropical grasses can take advantage of that rain. And they have actually extended their growing season by using this tropical pastures species. In Victoria we are not to this stage yet. We have Phalaris and Lucerne and that sort of stuff, but further north they also might use tropical pasture species which are not necessarily as good quality for stock but it is better than bare ground, this is one strategy to change pasture species. This example shows that using rather the traditional annual ryegrass pastures, putting in some of these tropical pasture species and then extending the growing season.<br>- There is a whole range. There are actually only a few who are doing pasture improvement and renovation, which our survey has shown. Reacting to climate change means that the principles of running your farming have not changed also if is tougher to do it is more important to run it profitably. There might be enterprise changes with a bit more cropping which has to come with appropriate drainage, introduction of appropriate pasture species to extend your growing season, pastures species which make use of out of season rainfall such as Lucerne. If our growing season does get shorter, ryegrass for instance might not persist. The logical thing might be to change to Phalaris anyway. There are winter active Phalaris species which are much more productive in winter that line can help to extend your growing season as well. This enables you to manage a tougher environment. You need drought tolerant species to persist.<br>- There will be opportunities with more winter growth. But with the drier climate in particular and shorter growing season, this will potentially have a greater impact. What are you doing, you are not getting rid of your perennial pastures if suddenly perennial pasture are not persistent. Changes don't happen overnight, there is enough time to adapt pasture management for example. If you change your enterprise, you always need to fit your enterprise system to your pasture growth cycle; you don't want to fight against them. People also look at opportunities out of season with feedlots, if we have a more variable climate we need to set up systems to handle those tough periods. Another reason why people put in feedlots are higher commodity, meat prices which goes hand in hand with drought management. I think climate change is difficult to understand for farmers. | - Having pasture species that mostly uses the water available such as Lucerne or Chicories to utilize summer rainfall and to extend growing season<br>- Pasture improvement and renovation important<br>- If growing season does get shorter, ryegrass might not persist, the logical thing might be to change to Phalaris anyway<br>- If farmers change enterprise, they need to fit the enterprise system to pasture growth cycle<br>- Look at opportunities out of season with feedlots with a more variable climate to handle tougher periods |
| IP19 | The other things in terms of feed supply, I think perennial pastures are very important and particularly having a proportion of the farm that can respond to rainfall in summer, productively and not just growing weeds such as Lucerne and phelpfer is potentially important north of the great divide in Victoria. Livestock producer that have a proportion of their farm in Lucerne might help, also if they are not a 100% drought proof but they do much better in most years than relying on annual pastures, which means having a pasture that also grows in summer. So if you get some rain and you have some productive green feed rather than just weed is a really good thing. | -Perennial pastures are very important<br>-Having a proportion of the farm that can respond to rainfall in summer such as Lucerne, they do much better in most years than relying on annual pastures |
| IP20 | If you think about adaptation to climate change, the genetic base of Themeda triandra, which is also called kangaroo grass and a native grass, can growth in different climate regions. If you have a grassland system for livestock production and you see climate change shifting, one species that will survive is Themeda. If I think about climate change adaptation, you think about perennial ryegrasses that comes from Europe that grows in a very narrow temperature range here in Australia because it has a very narrow genetic base because we bread it so intensely, same with tropical species that we have bread very intensively and we have narrowed the genetic base. If you shift the temperature range, they can't cope. But if you have something like Themeda which is native, they have a massive temperature range from 11 to 45 degree. The problem is that they are not as productive and there is a playoff you got. Having a good species composition of native pastures is of benefit in drier years as these pastures are still growing. In terms of production you get the best out of two worlds which means something that you can manage in a good years but stuff for the bad years as well. And part of adaptation in Australia to climate change is really coping with extremes.<br>- Better winter growth, less growth on the margins. The challenge for the farmers is how you change your system to cope with that. The good news is all you have to do is looking slightly west of you and you will see an agricultural system that is already coping with that. So from Colac you might look at what Albany and Esperance are doing and that is pretty much what you are going to get as it is on the same latitude. If you are a pastoral farmer, the opportunity might actually be to focus more on the winter period for you grazing than on the late spring, so just change the emphasis. So they might put some nitrogen fertilizer in winter and stimulate grass production earlier in the season. At Colac they probably get like 10ks of dry matter per day out of their grass, while with nitrogen fertilizer you can make that 20. And that will compensate for the 3 weeks that you lose at the end of the year. So you can also cut more hay or silage, so you have enough in storage to cope with that. That is what the western Australian do and that is an opportunity. But it is countered against mitigation because you put more fertilizer on and therefore more nitroixide emissions.<br>- you want to have more perennial rather than annual because every month there are no roots growing in the soil is a month where you don't get carbon laid down in the soil,<br>- On the Mt Hesse farm there is probably not a big replacing program going on. They might | - Native pastures such as Themeda triandra have a massive temperature range from 11 to 45 degree, more perennial rather than annual<br>- Having a good species composition of native pastures is of benefit in drier years to cope with extremes<br>-Focus more on the winter period for grazing than on the late spring, e.g. put some nitrogen fertilizer in winter and stimulate grass production earlier in the season to compensate for the 3 weeks that you lose at the end of the year |

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| | have more Phalaris than ryegrass in their pastures and they probably do better to keep that because Phalaris will still be there in 50 years' time. There are different vulnerabilities. | |
| IP21 | There is definitely an interest in new and different species. Species that tolerate warmer conditions and longer dry periods such as perennial ryegrass for western Victoria. The plant has a lot of great attributes but drought tolerance is probably not one of it. There are existing alternatives out there such as tall fescues and phalaris which has typically been used in the northern part of Victoria in the lower rainfall areas. They are not new plants but coming more down in that region and perhaps breeding new varieties which overcomes summer rainfall limitations. Perennial ryegrass is great because it establishes really quickly, it competes with the weed really well. Phalaris establishes quite slow, there is a lot of competition with weeds and your risk is higher but once you get it established it is more drought tolerant. There are always trade-offs. Phalaris and tall fescues are harder to manage.<br>- Lucerne is a summer active plant and has very specific soils type constraints. Any types of soils that get water logged, it won't persist. But what Lucerne does very well is responding to rain, so summer rainfall events is very beneficial and they jump out of the ground. As it is a perennial, you don't have to sow it, it will just persist there. Summer cropping is still a bit risky as it relies on having the rain and having stored some soil moisture. Typically they are used more in fairy which is more in the higher rainfall area. The more you go into the drier, it becomes more risky. Along with the extra summer rain, there is an increase in temperature. Summer crops then have a higher water requirement then. I think climate forecast has a lot to offer although they are not skill full enough yet. So if there is a good favour for summer rainfall, then make a good decision about a summer rainfall. But we still need to be very tactical as it is not reliable enough to do this every year. Andrew Moore published a lot about adaptation in this regard.<br>- Changes in seasonal distribution pastures is important.<br>- When you winter growing rates are higher, you should make better use of the pasture. | -New and different species that tolerate warmer conditions and longer dry periods such as perennial ryegrass<br>- Tall fescues and phalaris coming down from north Victoria, more drought tolerant, but establishes slower than ryegrass<br>- Lucerne good as summer active plant<br>- Changes in seasonal distribution pastures is important.<br>- When you winter growing rates are higher, you should make better use of the pasture. |
| IP24 | Yes there is quite a lot of research going on. There is a cooperative research centre on profitable perennials and the project I did, was associated with this research centre. So if you want to look at the research going done on perennial plants that could be an adaptation to climate change, because they have deeper roots and you can have a look at future farm industries at their website. | -Perennial plants have deeper roots and could be an adaptation to climate change |
| IP26 | So better adaptation requires deeper rooted perennial s pastures. Better grazing management techniques are required because they drier it becomes the better grazing management need to be. Probably climate change comes also along with changes in land values.<br>- Changes in pastures species and varieties that handle better drier conditions and different growing patterns such as deep rooted perennial.<br>- Diversify your pasture species on your farm to minimize risk: one paddock, ryegrass, another with Lucerne, Fescue, Cocksfoot, Phalaris, etc. Some farmers are already doing this. It is much more sustainable that just having one or 2 different species.<br>- If you have waterlogged soils, you don't want to out stock on it. Having the right species, so that you are only grazing in spring and summer and autumn. On waterlogged areas should be sown more summer active types of perennial.<br>- More perennial pastures such as Phalaris, Lucerne, Cocksfoot, Fescue. Ryegrass has better production rates but not as good in the long term persistence area. Go for pastures that are also able to handle waterlogging during winter times. | -Deeper rooted perennials pastures<br>-Better grazing management techniques<br>-Changes in pastures species and varieties that handle better drier conditions<br>-Diversify pasture species on farm to minimize risk<br>-Go for pastures that are also able to handle waterlogging during winter times |
| IP27 | It is important to balance pasture production and consumption, by planning the annual production cycle to have most consumptions during period of peak production (i.e. ensuring that lambs are sufficiently grown to be eating at their maximum potential for the spring peak). Deep rooted perennial pastures are also a potential adaptation strategy to allow pastures to tap further into soil moisture during dry periods. | -Balance pasture production and consumption<br>-Deep rooted perennial pastures as adaptation strategy to allow pastures to tap further into soil moisture during dry periods |

Summary of comments on cropping management

| IP | Quote | Generalisation |
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| | **Cropping Management** | |
| IP14 | -[…] possibly farmer may have to change the crop they are planting and adapt it to changing growing seasons but it is definitely possible | -Change crop and adapt it to changing seasons |
| IP16 | So there is a stronger need on short term adaptation in terms of choosing varieties that are more heat tolerant and in the long term frame, the is a good example with the wine industry. As the seasons are coming forward by nearly a day per year and therefore also the harvest is coming forward, basically the crops are being harvested a month earlier than 30 years ago. | - Choose varieties that are more heat tolerant<br>- Plan for seasons and harvest coming forward |
| IP17 | If you expand your cropping area let's say at Mt Hesse you often going to soils types which are most risk in waterlogging. You still need proper drainage such as raised beds. If you get a wet year on heavier soils types you might not get any crops at all. That why it is so important to management, to adopt e.g. drainage to mitigate risk if it is wet. | -Use proper drainage at soils types which are most risk in waterlogging |
| IP19 | More and more farmers are having bigger farms and the research and the practical experience shows that the crops is sown on time or earlier than on time, always yields better that the crops that are sown late as they don't get frost. Generally frost is an uncommon thing but you are better of sowing on time or earlier and trying to maximize the yield and to do that if it has | - Crops sown on time or earlier, always yields better that the crops that are sown late<br>- Good adaptation strategy: |

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| | not rain is quite difficult. People who are sowing earlier and perhaps sowing dry when there is actually no moisture in the soil which is a good adaptation strategy to have a proportion of your crops in the ground before it rains. I think it is very risky to have your entire crop in the ground if it has not rained but it would not be stupid to have a third or 50% of your crop in the ground if it has not rained by let's say the first week of May. If it has not been rained by then the crop has to be in the ground. A lot of people just start to sow based on their calendar once it get to Anzac day by the 25th of April they start sowing and I think that is a good strategy. The other thing is, using varieties that are not as long maturity and down in the south west you have the ability to sow crops with longer maturity but if you get rainfall in March or early April you can sow varieties there. Up here, in the northern part we are a bit limited. We have winter habit varieties that we can sow in March and April and harvest them in November, but they still come in in December when it is too hot. There is much more flexibility in sowing dates in south west than in northern Victoria. There is a much more favourable climate for cropping than up here in the north.<br>- The current farming systems are very cereal and canola cantered there is a lack of rotation in the crop. Which is a problem for weed and diseases and they can be overcome by using chemicals and more fertilizer but that comes at greater expenses. Anytime you spend more on your farming systems to keep going is arguably not financially sustainable in the long term. You have to grow crops the very best crops for the least money you can, particularly if the finish of the season is unreliable. You can't be spending money on growing 6 tones crops if every second year you only get 2 tons of crops. It is about making our crops flexible, starting them out at the start of the season that they can be yield anything and as the seasons goes along putting the inputs with the expected yields and if the season shows that it might be a good season, we can put more nutrients and more inputs into the crop, but if the season is going on quite poorly, hold back on that expenditure and don't waste your money.<br>That is an interesting one, because in a drier environment there is no doubt that the retention of stubbles has been a really great idea and is very helpful and allows timely sowing and retention of soil moisture but it helps provide soil moisture, which is especially important at the end of the season. In the higher rainfall areas we still have problems with having cereal stubbles that are very thick and machinery have difficulty to get though them, so farmers are still burning lot of their stubbles. And it is hard not to recommend that except moving a proportion of the stubble for the paddock for straw. There is no reason why people would burn canola or legume stubbles because they are generally not much but the cereal stubbles are still quite problematic because they are very dense. The other problem that we have at the moment is, we still can get quite wet in south west Victoria particularly in winter and having large amount of stubbles is not good and crops still die or get very badly diseases and yield very poorly because they can't evaporate extra water off due to the abundance of the stubble and the soil can become very anaerobic with the stubbles cover over it. At the moment while it can get still wet in winter, it is hard to recommend at least doing that at the whole farm. In northern part of Victoria where it is dry every year it is an advantage but in south west Victoria it may be beneficial in the future but I think we are not there yet, we are not in the need of that yet.<br>- Raised bed has helped to get rid of that water logging issues and it has worked well during the dry seasons as well. Subsoil manuring is something that worked quite well as well, it is quite expensive to do but it helps to remarkably increase the yields of crops in drier springs. To improve these terrible subsoils down there, there are soil limitations but with raised bed and subsoil manuring we have managed to overcome them, also in economic terms because down there it is a high yielding area. | Having a proportion of crops in the ground if it has not rained by the first week of May<br>- Much more flexibility in sowing dates in south west than in northern Victoria<br>-Rotation important to minimize weed and diseases problems, chemicals and fertilizer comes at greater expenses<br>- Making crops flexible, see how season unfolds, put more nutrients and more inputs into the crop in a good season, but if the season is going on quite poorly, hold back on that expenditure and don't waste your money<br>-In drier environments, stubble retention allows timely sowing and retention of soil moisture<br>- Raised bed has helped to get rid of that water logging issues and it has worked well during the dry seasons as well.<br>-Subsoil manuring is quite expensive to do but it helps to remarkably increase the yields of crops in drier springs. |
| IP20 | While let's say 40 years ago, you might get 3 failed crops out of 10, while now you get at least 6 failed. For a wheat farmer you might say from an adaptation point of view, they should be crop and sheep farmer as the failed crop is the food for wool production, as there are still 2 tons of dry matter in a paddock which is just not a viable wheat crop but then at least it will allow them to get some income from wool production. That is where we have to start rethinking our single activity we do. 100 years ago there were not dedicated crop farmers, they were all mixed farms. But as the fertilizer came more in we saw more going to dedicated wheat but now with increasing climate variability the flow in the systems doesn't come out anymore, as wheat on wheat on wheat, the soil carbon is slowly going down and the resilience of the soil has actually disappeared, even with minimum tillage and conservation agriculture. The only way to rebuild soil carbon is to rotate this wheat fields with permanent pasture and build up soil carbon again.<br>- Less reliable autumn breaks, instead of coming though by the mid of May, you start getting reliable rainfall from mid-June. A lot of farmers have changed to dry sowing, waiting for rain. Which is expensive but it works.<br>- Most inland areas they have to do fairly serious adaptation because we have already seen more failed wheat crops and worse heat conditions.<br>- The number of heat days will increase and you have to think about what agricultural systems can survive every day in summer over 30 degrees. […] You start thinking about something that is shorter season, that gives you the maximum out of this short period of time rather than we just flood the world market with wheat. We should think about how we produce something we valuate locally before we sent it out of Australia, so that the local economy benefits more. But as the fertilizer came more in we saw more going to dedicated wheat but now with increasing climate variability the flow in the systems doesn't come out anymore, as wheat on | -Mixed farm-cropping as good method to buffer failed crops, dry matter as food for sheep<br>-Rotate wheat fields with longer perennial systems help to keep soil carbon stable and to keep resilience of the soil<br>-Plan for more heat days |

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| | wheat on wheat, the soil carbon is slowly going down and the resilience of the soil has actually disappeared, even with minimum tillage and conservation agriculture.<br>-Better organic carbon in the soil, you want to have more perennial rather than annual because every month there are no roots growing in the soil is a month where you don't get carbon laid down in the soil, so an annual system such as wheat, you are disturbing the soil and you will slowly break down the organic carbon, so the best thing you can do for the system is longer perennial systems | |
| IP21 | Also maintaining ground cover, having a base of pasture to prevent water or wind erosion. | -Maintain ground cover to prevent water or wind erosion. |
| IP22 | Part of the adaptation challenge is to adapt to these new conditions, there are limits of plants that are drought tolerant that can handle the frost and the heat. The adaptation the farmers have made has been amazing, lots have better weed control and moisture conservation of summer rainfall that it is available for crops during the winter. | -I prove weed control and moisture conservation of summer rainfall to be available for crops during the winter |
| IP23 | There are other things, that farmers are thinking about in terms of changes in varieties, changes in the sowing practices, one of the thing that farmers seem to do is that they are moving from a situation where they would have sown a crop and then put a significant amount of fertilizer at the time of sowing to one where they are sowing the crop and then with far less fertilizer and then seeing how the season unfolds and applying fertilizer once they are more confident of the seasonal conditions. And in this way, they are saving money on one of the major inputs which is fertilizer and other things as well.<br>-Land that has more sandier soil has actually increased because there is a smaller bucket size, less rainfall required to be made available to crops, farmer finding it much easier and fewer failure growing crops on this sandier soils. Bucket size means, if you think about clay soils is able to hold a lot of water, a sandy soil does not hold much water so the bucket size is much smaller and it takes less water to actually fill that bucket. When crops growth, they need to access water at the top of the bucket and if you only have a little bit of rain in a heavy clay soil, all that water will be out of reach from the root, while in a sandier soil the water will be available. Some of the adaptation strategies to think about would be to reassess the farm operation, so have a look at and become familiar with the soil variability across the farm and have a check whether or not the farm practice matches the soil types under the changing conditions. | -Changes in varieties, changes in sowing practices<br>-Not putting a significant amount of fertilizer at the time of sowing but see how season unfolds and apply fertilizer once there is more confidence of the seasonal conditions<br>- Reassess farm operation, so have a look at and become familiar with the soil variability across the farm and have a check whether or not the farm practice matches the soil types under the changing conditions |
| IP24 | But if we then introduce new plant and the Mallee farming system, those things seems to be able to adapt to climate change and so the income, if you adapt, was higher than the income if you did not adapt. The message is, if you are interested in profit up to 2030, which is a relatively short timeframe, your profits are likely to be reduced if climate change without adaptation, but they won't be reduced as much if you adapt.<br>- New perennial plants for instance. There are of course also new machinery technology for automatic steering, tram lining and those sort of things which make a better use of soil efficiency and also conservation farming techniques where we don't plow but just direct drill the cropping to stubble and we let the stubble stay there have soil organic matter improvements, but a lot of Australian farmers are already doing that anyway.<br>-If they only have cropping on the farm and all the crops are getting lower yields, then it is a problem. But if they put some Mallees in, that might be a way of adapting and reducing the negative impact of climate change.<br>- Without adaptation, using our current varieties in crops and pasture, we think that there is likely to be a decline in yields. | - If you adapt, was higher than the income if you did not adapt<br>-Adapt crops and pasture varieties to conditions |
| IP25 | Ultimately major forms of adaptation which is viable to what they are producing, such as changing crops or varieties, shift planting times. But it is always a balancing act. Farms in Vitoria have to plant at times, when they on the one hand side don't get hit by late season frost but on the other hand they have to harvest before heat. | -Changing crops or varieties, shift planting times is always a balance act |
| IP26 | Keep ground cover at least 70%, destock early enough before an upcoming drought or dry time, and do not graze too much down into crown of plants. Keep monitoring soil moisture and base some decision around that. Put animals into stock containments, even if the feed expenses are higher in short term, the damage to the paddocks is less expensive in the long term as farmers do not have to re-sowing frequently<br>-Keep enough ground cover to avoid soil erosion 70% flat and 90% hills. Better pastures and less bare ground means less weed. less weed control needed | -Keep ground cover at least 70% flat or 90% at hills, destock early enough before an upcoming drought<br>-Keep monitoring soil moisture and base some decision around that<br>-Use stock containments |
| IP32 | - Farmers can enhance carbon in their soils which has benefits for fertilization but the other thing is really having large scale biomass production that you can then burn in power plants to generate electricity. | -Have soil carbon in mind which has benefits for fertilization |
| IP34 | All of the current RDN is very important so that we have tools available for farmers as over time we need to improve varieties to ensure that there are the best varieties for changing climatic conditions that the farmers experience.<br>- I think so, the tribes that are intolerant varieties are still the most widely grown varieties in Australia canola, and they are growing in every canola growing state.<br>-They are around for about 20 years. The roundup ready canola has only been available since about 2007 or 2008 in Australia. Overseas has been grown for a lot longer but not here.<br>- With the no tillage it is better for carbon sequestration. Research over the last 18 years show that no till farming gives you 23 to 25 billion kilogram of Co2 not being released into the atmosphere and fuel saving maybe contributes for another 2 or 3 billion kg not being released. No tilling also helped keeping nutrients in the soils, keeping soil moisture, as it gives you | -Over time, need to improve varieties to ensure that there are the best varieties for changing climatic conditions<br>- No tilling helps with carbon sequestration, keeping nutrients in the soils, keeping soil moisture |

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| | ground water it provided competition for weed germination as well. There are many benefits. | |
| IP37 | You may look at changes of crop types and changing your crop calendar so types that use less water during the crop cycle. | - Choose crop types and change crop calendar that use less water during the crop cycle |

Summary of comments on water management

| IP | Quote | Generalisation |
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| | **Water and Drought Management** | |
| IP21 | Water security on farms is becoming an important issue, particularly as they get these sequences of dry years without any runoff and then floods, so more water as you can store. Farmers have to think about a reliable water supply, having greater storing capacity and a buffer for that 2 or 3 years rather than just for one year. | -Have reliable water supply, having greater storing capacity and a buffer for that 2 or 3 years rather than just for one year |
| IP17 | The heat does not really impact the livestock, although last 2 years ago there was a heatwave for a week that killed quite a lot beef cattle. Drought is a major risk to a farm business. If I talk to farmers who want to increase profitability they might run more stock but they also need to be able to manage drought seasons. And farmers are much better managing droughts than 30 or 40 years ago. It is important that farmers are able to manage droughts, also from a financial point of view because this is putting their business at risk. We work out how much stock they can keep, how many they should sell and we work out the probability for the expectation costs for feeding. El Niño explains the droughts but unfortunately it is still not a good predictor for a drought, because once it gets to spring the management decision are already taken, the price of stock has dropped, the price of fodder has increased. So you really need to know like 3 or 4 month before if there is going to be a drought, so El Niño indicators might be there which does not necessarily means there will be a drought, it is a bit tricky. If you make a call that is going to be a drought back in July and it ends up in a good year that can cost you equally as much. The accuracy of forecast is bad; it is not good enough to take long term decisions. In NSW they had a fantastic year during El Niño that would have cost them a lot of money if they have sold their stock early. If you get low rainfall in August plus the SOI is negative, there is a 40% change of bottom 10% rainfall. You have to know how much it is to feed the sheep and what the cost of buying later on it. You need to have the funds for the worst case of a drought. The most likely scenario is you feed 10Dollar per sheep. It is really important to deal with uncertainty that is the nature of farming, in terms of the autumn break, forecast and so on. The most important I ask the farmer is: Can you fund the worst case scenario? Most say yes. It is mainly the uncertainty not knowing what is going to happen. But you need a plan. You also have to protect your resources. So the other thing to do is set up feedlots, so to not chew out any bare paddocks that don't have grass anyway. It is also called a drought lot, so put a 1000 sheep/ha and feed them there, rather than running around damaging the bare ground. So what we say is, once the pasture is down to 80% ground cover or 20% bare ground, in really light soils it is 90%. So the risk of wind and water on soil erosion is greater. So that is how we deal with drought. We go through these budgets, work out how to much to feed and protect the resources. Usually in most droughts, people will still sell extra sheep to make it a bit easier so you don't have to feed them all, so that's what Mt Hesse does, offloading some sheep earlier. If you don't, you are going to buy sheep that are not as good as your own sheep for a greater cost and potentially getting in some sort of diseases. | - Drought is a major risk to a farm business<br>-Farmers need to be able to manage drought seasons also from a financial point of view<br>- Have a plan and funds for the worst case of a drought, feeding costs etc.<br>-Protect resources: Use feedlots to not chew out any bare paddocks, leave 80% ground cover<br>-Offload sheep in time to save costs |
| IP22 | In terms of water, SW Victoria was a fairly wet environment, lots of shallow dams that farmers have would fill up regularly and would not fill up once in 25 years during a drought, while now even the smaller dams sometimes don't fill up properly. Water storage is a key issue. Deep dams are much more effective than shallow dams and better infrastructure with reticulation shows less evaporation and leakage. Town water is expensive but great as a backup. Having water can be the difference between selling the stock or keeping them. They are increasingly running out of water. That is a key challenge for some farmers. Some people start look at desalination, as there is enough groundwater available which is sometimes too salty. New technology like desalination plant can be good. Solar power pumps, in Western Australia they are cart water sometimes to keep livestock which is very expensive. I know from some farmers that have bought some extra blocks of lands to give them access to town water supply and they share privately with neighbours for emergency backup.<br>- Yes. Since 1998 groundwater is dropping. They went up in 2010 when we had a very wet year but the trend is dropping. Some of our local creeks and spring depend on groundwater, the catchment flow might also drop for south west Victoria. So they have to make most out of the time with pasture and water and make profit. So they really have to manage their systems.<br>- A lot of farmers have invested in improved infrastructure and to get water from one part of the farm all around.<br>- One option is also to get your pipes connected though all paddocks.<br>- But climate is a bigger driver of drooping groundwater than from trees. In south west Victoria there will be more water regulation coming as we used to be a quite wet landscape in the past. As the resource becomes more constraint there will be more authorities. The issue of equitable share of water will increase especially if we talk about a declining resource. This can be solved by good integrative discussion as there are different pressures and interests about water. Decisions | - Water storage is a key issue<br>- Deep dams are much more effective than shallow dams<br>-Investments in improved infrastructure with reticulation shows less evaporation and leakage and to deal with water shortages<br>-Town water is expensive but great as a backup. Having water can be the difference between selling the stock or keeping them<br>Manage system according to water availability and pasture growth<br>-New technology like desalination plant can be good.<br>- Integrative discussion helps to solve different pressures and interests about water<br>-Part of the challenge of south west is that the water cycle is |

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| | made on one levels can have impacts on other levels, farmers further down the river might run out of water. Part of the challenge of south west is that the water cycle is not well understood yet.<br>- Some investments makes even more sense and it can help them e.g. in better water structure for the next 30 years. We tend to see it as little decisions that farmers can take on the run every year. But the bigger decisions are that one that costs more and for doing that, it will have effects on other things on the farm, so you have to be careful of that as well.<br>- Big dams and so are good but big investments in terms of produce production. Some farmers can invest e.g. in water infrastructure but others prefer to take the risk as they think water shortage is just a short terms thing.<br>- But we have to think about how to sustain it with extra stress such as water shortages, infrastructure and good infrastructure facility to make farms viable.<br>- Yes they are getting better, especially each time we have a drought, and people are getting better. So this is human nature.<br>- Although is a farmer is good in handling droughts, there should more still effort in adapting for higher frequency in droughts. | not well understood yet<br>-Improvement around drought management can already be seen<br>-Adapt to higher frequencies of droughts |
| IP23 | The drought and exceptional circumstances support is not rewarding the most adaptive farmers even there are funds required that support those who are suffering during a drought. We need to set up structures that sort of reward these earlier adopters and the innovative and we don't have this legislative support to do that, this is actually a barrier to adaptation. | -Less governmental support during droughts |
| IP27 | Less surface and groundwater means less runoff. It is important to avoid high evaporation rates. Investments in bigger and deeper dams, depending on the region might help in future to deal with water shortages. It is more sustainable to have deeper dams have lower evaporation rates than several shallow dams on different paddocks. Farmers are already experiencing impacts of water shortages during summer and autumn. Some farmers already had to carter water for livestock where there is no available water to allow stock to graze standing feed in their paddocks. Also more efforts in regional schemes to guarantee water security may be necessary such as pipelines to supply water from major water storages to farms. | -Avoid high evaporation rates<br>- Investments in bigger and deeper dams might help in future to deal with water shortages<br>-Better deeper dams with lower evaporation rates than several shallow dams on different paddocks<br>-Efforts in regional schemes to guarantee water security |
| IP37 | First thing to look at is the efficiency; try to get more effective usage which depends on what you are doing. Maybe providing more efficient watering systems so that they don't waste so much water.<br>-If you have water rights, you can actually sell your water and buy in feed with the water that you sell. Other strategies would include increasing the amount of water you have available, you can put in farm dams or try to access ground water and buy licenses. There was a study called can a farm in Victoria increase it water efficiency by 4. It is important to look at the whole farm system rather than specific components to maximize your profitability | -Efficient use of water<br>- Increase the amount of water available, e.g. put in farm dams or try to access ground water and buy licenses<br>-Look at whole farm system rather than specific components to maximize profitability |

Summary of comments on constraints for adaptation

| IP | Quote | Generalisation |
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| | **Constraints Adaptation** | |
| Ip14 | -And because the variability is so strong anyway, most farmers don't care so much about what is going on in 20 or 30 years but more in this or next year.<br>-In Australia a lot of wealth depends on coal mining and people just don't want to see facts or it doesn't fit into their picture plus especially big companies have a strong interest in people not being worried about a man made climate change. Also the media in Australia are mostly controlled by the government so there is a clear bias in what kind of information do we want to get out to the public which are not based on facts. So there are clear agendas of not wanting public to accept the fact of global warming. And as global warming happens on a long time scale and it is quite complex because of the natural climate variability, it is hard for an individual to be really convinced of any changes. | -Due to strong variability, farmers more interested in short-term adaptation<br>-A lot of wealth depends on coal mining and big companies have a strong interest in people not being worried about man made climate change<br>-Influence of media |
| IP16 | Uncertainties to probabilities are really hard to understand and everybody likes to see black and white. | Lack of understanding probabilistic forecast |
| IP17 | I mainly deal with farmers who are really interested in sowing the right pasture species, that are productive and drought tolerant. I would not call it market failure but ignorance, as some farmers use species that don't persist. Market failure means when the seed companies are not prepared to invest in developing product which are going to be more suitable for the future. You also have to think about the timeline as developing a product and bring it it into the market might be 10 years, which is a long time frame. Most of the pasture development in the hand of private companies, there has been a bit of research done of the livestock cooperation but not a lot. There are so many different opportunities out there and people have to distinguish between good and bad information what I show farmers in my presentation and they like it and some just try to sell a product.<br>- Droughts in northern Victoria are much more common than in southern Victoria. I notice up there, they know what to do. In western Victoria, which has traditionally a bit more reliable climate, they are more stressed out when a drought comes than people up north; they are just | -Lack of knowledge or willingness to sow right pastures<br>-Market failure of (private) seed companies<br>- Lack of preparedness for external shocks in region that are impacted less by shocks |

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| | not familiar with this. There are differences between smaller and bigger farms, but some of the bigger farmers are hopeless. Most of them have drought management plans and they think about which are the most profitable enterprises or production system and how to manage that and this without climate or not, that things don't change. | |
| IP18 | Research suggests that the main one is institutional but I am not sure if that is really satisfactory. My work would suggest that it is a combination of lack of capacity and resources in financial terms and lack of time and understanding. Allocating resources when things feel risky for stuff that is uncertain in the long term is really difficult. I think doing something like changing lambing times or so is not a big movement to adapt. There is a cultural kind of resistance to being told what to do, how to think about climate. There is not a big step to adaption so far it is more incremental so far. One more is how you actually roll up professional development in ways that is accessible; there is a lot of sectoral expertise. In terms of family structures, usually a farm needs to be in a very strong financial position to have a succession between generations. If you can't get your farm under a position where your debt is under control and if your child has gone to Uni and started a job and they are waiting for their parents to hand over the farm, parents might say they can't pass on you let's say 8 million dollar. The window of opportunity of succession closes. In general there is a massive social change going on, younger people want to start a career and not come back to farms. There are big efforts in Australia to turn that around but the general trend is that young people don't want to go on farms. For those who want to sometimes have to start with big depts. So the business continuity is a strong issue in the succession questions. Another issue is that farmers mostly dependent of self-funded retiaries and if they don't have enough money to retire, they basically have to work until they dropped it. And the question of retirements is therefore also a big issue. That is a very miserable situation. A lot of old farmers are exhausted. Farmers in Australia have been detarget of so many information campaigns and the problem is changing between one message to another. So it is totally understandable that they are cynical. So in the past government encouraged to clear trees for modern efficient farming and they gave them subsidies. While now they pay them money to plant trees. If you lived though that, people are more relaxed about carbon markets messages for instance. So due to the history of past mistakes in the messages that farmers have received, partly in a very incentive way really teach you that you should switch off and there is a lot of anti-government. So there is a long history of bad government farming relationship. Historically, government supported farmers during droughts with subsidies, water and so on. There is a kind of re-education process that need to go on if the government is not continue to support farmers during droughts. We do have a massive policy shift away from drought support. Over the last 3 to 4 years there have been a massive effort to withdraw drought support; droughts are effectively not on a disaster list anymore, while fire and floods are. From a policy perspective they say they can't distinguish anymore whether it is a drought or normal, so they don't help anymore at all. That is a difficult process. As long as we have a federal liberal government there is likelihood that they will still get emergency responses. So there is a lot of policy going on. | - Combination of lack of capacity, financial resources, time and understanding<br>- Cultural kind of resistance to being told what to do, how to think about climate<br>- Family structures, usually a farm needs to be in a very strong financial position to have a succession between generation: sometimes window of opportunity of succession closes, also due to a massive social change<br>-Farmers in Australia have been detarget to different information campaigns and incentives<br>-Massive policy shift away from drought support |
| IP20 | I separate to 2 out and say, there are issues with climate change which are more on a long term horizon which is beyond the planning horizon of most farmers and from a scientific point of view we have to figure out what systems, what pasture species we need, what animal production systems, how do we prepare those farmers for that future that they going to have to adopt.<br>- A constraint might come from the fact that a lot of farmers sit on committee that approve funding for research and if they don't believe in the subject matter they never going to be approve funding for research in climate change. That might be a constraint in their long term future.<br>- But you don't sell seed this way, when the government went out the breeding industry. They outsourced that to private seed companies. That model works fine until climate change comes into signal because you don't sell more seed by producing a more perennial pasture. No private company is making money out of no selling seed again. So they have changed emphasis, they are selling seed that growth better in the winter, such as 15 years ago but ryegrass came on the market that promised to have more production than all other ryegrasses, but they did not tell the farmer it would just last for 2 or 3 years and then it dies and has to be replaced. They are interested in a system where people get into a cycle where they have to buy regularly new seeds. There is a market failure with adaptation, where you are reliant on a business sector that might not be motivated by selling a deeper rooted pasture species that can service that extra 3 weeks in November, selling a pasture species that handles the heat better that survive the summer and does not need to be replaced. There is no incentive for the companies to sell that. About 10% of all higher production dairy farmers are replacing about 10% every year just because they are locking into this cycle.<br>- Another problem is, the seed companies strongly respond to the demands of the farmers but there is not a lot of attention in breeding pasture species or a wheat variety that we need that mature by November right now because you won't sell it, because nobody want to buy it but they sell their wheat that can be harvest in December or January and that is where you can make your 4 or 5 tons of wheat. Inherently something that matures by November, would just give you 3 tones because it is early season. Seed companies are not getting a signal to breed new varieties but the problem is, you need to be breeding now for 2030, you have to start the breeding program now but no seed company are not seeing that as companies and farmers are not believing in climate change. In long terms that mean higher turnover of renovation processes for pasture for example which might man running into feed gaps and a lot of problems | -Climate change is more on a long term horizon and therefore beyond the planning horizon of most farmers<br>- Lack of funding and research, especially where farmers join committees<br>- Market failure of private seed companies, fail of governance<br>-Government gave different incentives over time |

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| | accociated? I think there is a market failure because there is a role for government to breed this deeper rooted and heat tolerant wheat that matures earlier. But government stays only in the GM area.<br>- They won't adapt to changes they are not facing today, if you tell them this area will look with western Victoria our South Australia for example. If there is not a reason to adopt systems or to new technologies they won't, but 2 years later they will if they face restrictions in water allocations during a big drought for example. There is then 100% adoption because something has changed.<br>- Well it is an issue for about 20 years and it is quite popular. While after the war were actually paid by the government one generation ago to get rid of trees. That memory has not been lost. And now, the same government want to pay me money to get trees back in. But if there are incentives, farmers will do it. | |
| IP21 | I think it is the responsibility of the big industry bodies to looking forward to the 20 years horizon to set us up better. Of course, they just want to sell and make money. | Big industry bodies are responsible to look forward to longer-term horizon |
| IP22 | Farmers often say, better forecast, better understanding of the literacy of the forecast and of climate and better tool tactic strategies to deal with climate variability. If you understand the literacy of climate forecast it is a bit of a head up. Some might sell stock earlier then for example. So understanding the variability from one year to the next but also the longer term climate. | -Still lack of good weather forecast & lack of understanding probabilistic forecast |
| IP23 | There are research constraints; we have a small research capacity to work with farmers. For farmers, to take up adaptation options they need to be convinced of their profitability. The way we can do that is by physical modelling but that is a very intensive activity to do that for individual farms. We are capacity constraint. We are not able to go out to all farmer groups and do this sort of modelling exercises to give farmers a sense of what the cost benefits are for adaptation options are. From a producer point of view, the constraint is the equity on farm. Unless you have a reasonable amount of equity in your property you are not able to be responsive and you are not able to adapt. Working on equity level on a farm or restructuring the farm to improve equity is probably a sort of a good adaption option. The other obvious ones are the state and governmental legislations provided. The drought and exceptional circumstances support is not rewarding the most adaptive farmers even there are funds required that support those who are suffering during a drought. We need to set up structures that sort of reward these earlier adopters and the innovative and we don't have this legislative support to do that, this is actually a barrier to adaptation. | -Research constraints: small research capacity to work with (single) farmers<br>-Farmers need to be convinced to take up adaptation options they need for their profitability<br>-Lack of equity to adapt<br>- Lack of legislative governmental support to reward earlier adopters and the innovative farmers |
| IP25 | One of the main restrictions of climate model is a lack of computer power. In the past you were unable to model on a 250 or 500 km2 model grids, so Victoria was maybe represented by 3 grid points but with more powerful computer you can run models on a much finer scale and separate with differences much better between northern or southern Victoria. The BOM is getting a new server computer which is much better than the previous one but with the cuts at Csiro it takes a lot of scientist away that can use that computer capacity. | - Lack of computer power<br>- Cuts of scientists and therefore less research |
| IP26 | Landholders making change as they don't believe in climate change. Another one is a market failure, because the seed selling companies are not interested in selling long lasting perennial pastures. More education needed to train farmer how to manage pastures and soils sustainably. The role of government becomes even more important, as private companies just enforce their own economic interests. There is also a lack of research in long lasting pasture species. | -Non-believe in climate change<br>-Market failure<br>-More education needed to train farmer how to manage pastures and soils sustainably |
| IP27 | Farmers attitudes, if they don't believe in climate change they won't take any actions. Most of the farmers are quite conservative which is different to Europe. Second, there are policy constraints and lack of current water infrastructure in south west Victoria. Preparing for climate change may require money to be spent on infrastructure or changing the farm enterprise mix. These are risky activities so there is a disincentive to invest. | - Farmers attitudes<br>- Policy constraints and lack of current water infrastructure in south-west Victoria |
| IP28 | One issue is communicating probabilities, to make the users understanding what probability means. Some people don't interpret our maps and results not in the right way which is also a challenge. It is important to make our research usable and understandable for the users. And of course you also need enough historical data for El Niño and La Niña for example events to run models properly. - The BOM is getting a new super computer, as a major constraint for us is the lack of computer power. So we can increase our modelling and it is much more complicated. | -Lack of understanding probabilistic forecast and lack in computer power |
| IP29 | We are pretty aware of that, also that farmer bases their decision on out weather forecast. In our market research study about our services and products came out that in some of the comprehensive question up to 50% out of 900 answered those questions incorrectly. That was really concerning for us that many people misunderstand our forecast.<br>- Previously we had a very different set up of our homepage, we just showed a map with lots of text. Our audience is also not the same. Some people don't understand a lot but we also have a lot of capable users that want to have very detailed information. That is a balance act as we also don't want to insult anybody. We needed a solution to deliver our forecast to people with simple and advanced needs. We redesigned our website which allows people to get forecast at a glance. One of the big things is how climatologists explain weather because that was rated really highly amongst that did not understand the wording. As we know people want to know about the weather at their farm, we unfortunately still have resolution issues but there are improvements and for those who want deeper information, they can click down these. We really listen to our users and try to improve. We know that there is a lot of misconception out there. People ability of complex analysis is sometimes poor which makes it poor to makes probability forecast. We also change the language that we use, we don't use words such as favour and bias | -Lack of understanding weather forecast<br>- Challenge to address different user groups with different previous knowledge<br>- Resolution issues with weather forecast<br>-Misconception in the system<br>- Sometimes poor ability of complex analysis |

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| | anymore but likely or unlikely instead or chances.<br>-The media is sometimes damaging for us. Big organizations have these issues all the time. In some location people have a bad internet access and they can't load all the maps that is why we also have text versions. But making people aware that this is also an option is also a challenge. Climate change is also a big issue for us as we have to be completely politically neutral, but it is quite a hot topic. We spent a lot of time about being very careful what information we can give about climate change. We want to be honest and transparent but it is very hard in some situations and some people are frustrated as they can't openly say their opinion and talk open about climate change. | |
| IP30 | We deal with very independent people; they don't like it when you tell them what to do. Just give them ideas and then come back later on. If you try pushing them, they will find reasons why it is not like this. It is also a topic of cultural change. | -Farmers don't like to be told what to do, it is also a topic of cultural change |
| IP31 | The government basically told us not to use the word climate change but you can't really ignore it. | -The government denies climate change which makes it harder to talk about it |
| IP32 | The Government agreed to keep global temperature below 2 degree increase by the end of the century and agreed to reduce greenhouse gas emissions. But there are no policies in place to do so. | -Lack of policies to keep global temperature below 2 degree by the end of the century |
| IP33 | Well for starters you need farmers that actually acknowledge that climate change is happening. They all vote right wing. For the political party. They stick to what our government is telling us and the government tells is that climate change does not exist. And all farmers are ultra conservative in their voting. Josh Gilbert, one politician was physically threatened because he stands on climate change and he resigned from his position, he was the leader from a conservative party. He tried to be progressive and useful and have new ideas but he was threatened that should stop talking about this. | -Farmers are very conservative: They stick to what our government is telling us and the government tells is that climate change does not exist |
| IP36 | If farmers don't believe in climate change, why would they change their type of sheep? Perception is not reality. They need to be educated and shown how to do this. A lot of understanding is based on historical learning, subjective evidence, but this is often wrong but they firmly believe it. They are unlikely to change the sheep type unless they are forced to, such as mulesing was band in Australia would either force them to move out of Merino sheep altogether and look towards plain body sheep that are naturally resistant. Few of them believe that climate change is happening anyway. I don't know how quite the realization begins and the necessary actions. | -Non believe in climate change and lack of actions<br>-Gap between perception and reality, lack of education |
| IP37 | The barriers may include a lack of information about climate change, also if scientists present a lot of maps to the farmers it may not be the information they need, Miriam Dumm did this survey. Managing an environment that at the same times gets drier but maybe also more flooded is difficult, so managing the widening of a risk profile. There are often barriers in terms of social acceptance, people who step out and do new things can often be seen as a bit weird by fellow farmers, so there are social norms that limit people. I think we don't have a very supportive policy environment for adaptation to support them through risky changes. | -Lack of information about climate change<br>-Managing the widening of a risk profile increasingly challenging<br>-Barriers in terms of social acceptance and lack of supportive policy environment |

Summary of comments on farmers perception and awareness of climate change

| IP | Quote | Generalisation |
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| | Perception & Awareness of Cc | |
| IP14 | I think it is in general a difficult thing for humans to experience and understand climate change as it happens on a timescale of 50 years and more. Memories are very subjective and how much do they really remember of what happened in 1960 and one important part is also that Australia is really strongly affected by the Pacific ocean water variability much stronger than Europe in terms of driving years that are hotter or colder or drier and they are strong enough that they even make a lot of variability even in the timescale we are analysing even if we have the exact data. As the variability for precipitation is so high here in Australia, the perception is very subjective but in terms of long-term changes, people just don't have such a good memory to exactly memorize, they would rather remember certain events in their life, maybe they even have a lock books.<br>-When people say climate has always changed it is a signature of the pacific variability which creates dry and wet years and it would have happened without human influence. But in top of this natural variability, humans are warming the planet makes that the temperature variability happens on a slightly higher level, also the rainfall variability happens on a slightly higher temperature level which means that you get more evaporation. It is hard in one person's memory life to actually make a clear statement that it is actually getting warmer. Droughts however are so complex, that even in the scientific community we are really sure about it. What in a warmer climate, you have higher evaporation even if you have the same amount of rainfall that might intensify droughts. But on the other side, a warmer atmosphere can hold more water which means that the potential for heavy rainfall is also increasing, so rain events might become more extreme. | -Difficulty for humans to experience and understand climate change as it happens on a timescale of 50 years and more<br>-Memories are very subjective in terms of long-term changes |

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| IP15 | Most Australians believe in climate change, about 60 % accept the basic science and also most farmers accept that climate is changing. Farmers are extremely vocal people and certain newspapers that remain being sceptical. Yes farmers maybe believe in climate change but not that is human induced more in natural climate change. There are certainly farmers who believe that but adding the word "most" is certainly not right and they would recognize a human influence on the climate that they are exposed to. You need to be careful with your sample size of interviews, because interviewing just 12 farmers in one region may not be very representative for the broader view of the farming community in Australia. There is a group called the farming champions and they are a group of farmers who are particularly strong in advocating and communicating with the farming community also in terms of climate change. If you interviewed them, you would get a 100% agreement rate.<br>-I am surprised you find a lot of sceptical farmers in the Corangamite area because some of the changes that has been experienced there are shockingly big.<br>- There are two groups. There is a group of sceptics who don't really know anything about climate at all and they are just confused. But you can talk to them and normally explain the science behind it. There is another group of sceptics that are paid to confuse the public and there is no point talking to them. In terms of farmers, the main argument I use is the term of risk.<br>- I don't try to convince farmers of anything. If they are already observing changes and they are already adapting, it doesn't matter whether or not they accept climate change. They adapt to reduce vulnerability and increase resilience. The problem comes with those farmers who are on land where they have no ability to adapt. | -Most Australians believe in climate change, about 60 % accept the basic science and also most farmers accept that climate is changing<br>-Certain newspapers remain being sceptical<br>-Farmers maybe believe in climate change but not that is human induced more in natural climate change<br>-Two wo groups: a group of sceptics who don't really know anything about climate at all and they are just confused and a second group of sceptics that are paid to confuse the public<br>- Most farmers are already adapting subconscious |
| IP16 | I am very comfortable using the term managing climate variability. In Australia there is quite a big debate around climate change and so nobody would deny if we talk about climate variability, I prefer it to use the term climate change. There is no doubt that climate is changing. There are a lot of data around that demonstrate that trend. | -Preferably using the term managing climate variability than climate change, due to Australia's big debate around climate change |
| IP17 | There is a very high awareness. But I would say very few farmers have really thought about it seriously. The principles of how you manage your farm with climate change or not are pretty similar. You want to have a resilient with seasonal influences and drought management and profitable farm anyway.<br>-The main barrier is that it is too complicated to understand climate change and with all the argument out there, the scepticism rises maybe. They struggle to understand it.<br>- Carbon tax would be an extra cost on their business but at the end of the day were farmers were against it due to that reason, but measuring would be quite difficult anyway and it is kind of a grey area because it never came in.<br>- The main barrier is that it is too complicated to understand climate change and with all the argument out there, the scepticism rises maybe. They struggle to understand it. | -High awareness<br>-Too complicated to understand climate change and with all the argument out there, the scepticism rises, they struggle to understand it<br>-Carbon tax as business threat<br>-Lack of understanding the science of climate change |
| IP18 | In terms of climate change attitudes, I think what you find is very common. You have strong arguments in the fact that climate is changing and farmers are more aware of small climatic shifts than people in urban areas.<br>- It is probably not as important as people might think a lot of adaptation is going to be responsive and it is also driven by what those around you are doing. So arguably you could have a farmer who is not aware of climate change but he is adapting in a functional sense because they are copying practices that other do around them. I mean where climate change really makes a difference is mitigation and stuff where you really need to plan in long term and one problem is individualism is responses; everybody seems to do its own thing.<br>- There is a whole host of historical and cultural reasons why these messages are going to be resisted. And one of the most obvious one is that poses a huge risk to farmers and individually, especially in terms of mitigation policies and also general social disapproval of agriculture.<br>-For most farmers their enterprise is very much mediated by the wealth bank of their families. You need to look at the whole farm family. There is also a difficulty in rural environments and can you actually living and working there in the long term. There is a degree of cognitive protection going on. If you are under incredible stress, dealing with short term pressures then it is very difficult to take on the broader kind of issues facing rural communities. And there is also a cultural history of resisting pessimistic messages, there is kind of a natural resistance of anything that is dark. So if you come with dark messages they would just deny it. That also has to do with gender norm what it is to be a strong rural man and also business norms that you have to be tough. | -Farmers are more aware of small climatic shifts than people in urban areas<br>-Historical and cultural reasons to be resisted<br>-Degree of cognitive protection: stress, dealing with short term pressures hard enough<br>-A cultural history of resisting pessimistic messages<br>-Gender norm: what it is to be a strong rural man and also business norms that you have to be tough |
| IP19 | Most farmers I speak to would not believe that is a humans fault but they certainly all observe higher pressure systems affecting them and rain barring frontal systems shifting south as well. But is a bit harder to make that connection that climate change is causing that to happen as well which we believe it is.<br>- In comparison to Europa we are not lacking temperatures; no one is notifying changes in plants in such an obvious way than in Europe. If they had we would not have this unbelieving people in Australia and because the rainfall changes are difficult to trace back to climate change, when it is really no big change to droughts than we experienced in our history, it is just harder to convince people what is going on if they don't really see major differences. We don't have snow kept mountain that are melting earlier and the obvious things that you see in the environment. But in the more Mediterranean climate, temperature is not such a big thing it is more an issue of rainfall and therefore, climate change is a harder sell. It is also a natural reaction, because if you believe in climate change you have to admit that you can't maybe do what you are doing right | -Most farmers would not believe that is a humans fault but they certainly all observe changes in climate<br>- It is just harder to convince people what is going on if they don't really see major differences<br>-Natural reaction and barrier |

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| | now in the future. It is just a natural barrier that people put up to make their life easier in the short term; otherwise they would have to make some really big decisions such as selling the farm now maybe. | |
| IP20 | When we talk to farmers, we tend to talk about climate variability. I separate to 2 out and say, there are issues with climate change which are more on a long term horizon which is beyond the planning horizon of most farmers and from a scientific point of view we have to figure out what systems, what pasture species we need, what animal production systems, how do we prepare those farmers for that future that they going to have to adopt. And our view is that climate change is expressed at a farm level on a day to day basis as climate variability so when the farmers walk out every morning is what they see is climate variability and not climate change and that is what they have to manage. So we prepare them to manage climate variability which can be though about as Mark Howdens first diagram the incremental, that is what we are helping them with. When they need to adapt to those systems they will.<br>-If a farmers doesn't believe in climate change, that doesn't bother us anymore. Although there no climate sceptics amongst viticultural farmers in Australia, they all believe in climate change because they have sitting the evidence right in front of them.<br>- It is not a serious constraint that farmers don't believe in climate change, it is a constraint that they might not be thinking about adapting their systems to an increasingly variable climate.<br>- There is then 100% adoption because something has changed. If a farmers doesn't believe in climate change, that doesn't bother us anymore.<br>-Woman and urban people tend to be more open for discussions about climate change<br>- Looking at the sugar content over time of a farmer that always took record shows that the ideal maturation date has moved to the left about 8 days per decade, there you can see a warming trend, bring maturity earlier in the season. This trend has been seen in all grapes. The evidence is there and it is not genetics that has shifted and cultural practices stayed the same, so it must be temperature or rainfall and that must be climate change. I think in the other industries there is not such evidence. If you talk to dairy farmers, they don't believe in climate change. If you asked them when they cut silage, there are shifts in the dates by about one month earlier. There is a disconnect. | -Climate change is more on a long term horizon which is beyond the planning horizon of most farmers<br>-No climate sceptics amongst viticultural farmers in Australia, they all believe in climate change because they have sitting the evidence right in front of them.<br>- It is not a serious constraint that farmers don't believe in climate change, it is a constraint that they might not be thinking about adapting their systems to an increasingly variable climate<br>-No climate sceptics amongst viticultural farmers in Australia, because they have sitting the evidence right in front of them |
| IP21 | Most farmers find it is getting more variable and more difficult to manage.<br>- For most it is enough to talk about climate variability. The industry has a responsibility to look further forward. I don't every individual farmers has to think in that long term if they not choose not to. They are already making decisions.<br>- There could be a shift of weeds or seasons but they are always under consideration when decisions are taken. It is hard to trace back certain decision just back on climate, there are also other considerations such as premiums for milk during drier times and so on. | Most farmers find it is getting more variable and more difficult to manage.<br>- For most it is enough to talk about climate variability |
| IP22 | Farmers notices stronger pressure systems over Victoria and if you show them actual measurements on that, that is always good. You can explain 10% less rainfall due to higher pressure systems and higher temperatures and it is always good to link explanations to what farmers perceive anyway.<br>- What is interesting, most farmers have good rainfall records but only 1 out of 4 farmers think that it is getting warmer. They remember hot days but our memory for temperature is bad. But when we were younger, we did not have air-conditioned houses or trucks. So even if we have hotter summer, we spend a lot time inside while 30 years ago where we base our memories on, we spend more time in the heat. But they do notice changes in flowering times; particular dates when the oats is ready to harvest or when they cut hay or silage. The environment has several shifting dates. If you talk about temperature in terms of natural stuff, most farmers say, we used oats starting on Christmas day but now we are doing those 2 weeks beforehand. That is more effective to talk about it.<br>- One of the challenges of climate change is, we don't believe it until we see it. If you tell farmers there will be more droughts, the actual responses will just happen if we go though one. Then they will spend more on another bore, putting more storage.<br>- Farmers are adapting to what the markets are up to.<br>-We did a big survey about the awareness of climate change. Most of them feel changes but a lot of them deny climate change. Farmers were quite sceptical. It is interesting, they are already adapting. Farmers noticed changes in climate. But hey keep sceptic as there is a desired optimism for farming. Models say there will be more droughts and it will generally get hotter and drier, which is not a very attractive forecast, so they prefer not to believe that because it scares the people, we depend ourselves emotionally from accepting as it is threatening. They don't want to hear it is too dry for a certain tree in probably 50 years' time. A lot of farmers would vote for the right site of the politics, they tend to want smaller governments, they fear big governments, and the left side is more social. And climate change means for them bigger governments maybe and more threats to their business.<br>- It is very hard to tell what climate change is and what is natural climate variability? But when I got more exposed to the scientists it surprised me how strong the science was on climate change and I felt quite a gap of how farmers are talking about it, what the science is actually measuring. They can't adapt if they are not sure what these changes are.<br>- Farmers are more solution oriented instead problem oriented | -Farmers notice stronger pressure systems over Victoria<br>-Most farmers have good rainfall records but only 1 out of 4 farmers think that it is getting warmer.<br>-Different perception: nowadays air-conditioning<br>-They do notice changes in flowering times, particular dates when the oats is ready to harvest or when they cut hay or silage<br>- One of the challenges of climate change is, we don't believe it until we see it<br>-Most farmers feel changes but a lot of them deny climate change<br>- They keep sceptic as there is a desired optimism for farming<br>- Models suggests more droughts and it will generally get hotter and drier, which is not a very attractive forecast, so they prefer not to believe that because it scares the people<br>-Climate change means more threats to their business<br>-Farmers are more solution - instead problem oriented |
| IP23 | We have done a national survey. Interestingly, farmers are still very aware of the issue the climate variability and there is more a dismissive of the issue and importance of climate change. There is this believe if they can adapt to climate variability, they can also adapt to climate change. So the way that I try to use these terms in a dialog with farmers is initially I talk about | -Fairly low believe of human made climate change<br>-Most farmers are already adapting without attributing it |

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| | climate variability and changes in the variability and try to get some sense of how effectively those farmers have been able to adapt to those changing conditions and then I start to bring in the issue of climate change and more strategic planning and then seems to be a successful way to engage farmers on this topic. You tend to find in the discussion of climate variability that they start talking about reductions in profitability and that would suggest that they are not effectively adapting to the changes in variability. If we can bring the conversation to improving their responsiveness to the variability, inherently we start the conversation about the climate change as well. There is a fairly low believe of farmers that climate change is anthropogenic in the study which also shows that overwhelmingly they had to change their management practices to manage their farm. Ironically you get a situation where farmers are already responding to climate change but they are not attributing it to climate change, they attribute it to variability. | to climate change |
| IP24 | When we spoke to the farmers beforehand, they were fairly confident that could adapt in the short term to some climate change because they are already used to deal with climate variability. Especially dryland farmers, not irrigation farmers, have to adapt to climate variability already. They thought if the research could deliver them better adapted varieties of pastures or crops to climate change, to a drier, hotter in increased CO2 level, they were confident they can adapt, if the research provides them with better adapted varieties to changing growing seasons and changes in temperature and moisture.<br>- I think there is a diversion of opinions, but lots of farmers are very observant of their own location and they often observe changes in climate. Some of them say, they feel a change in climate and ask what they can do about it while some farmers say, it is not changing and it is just normal variability. It is a matter of opinion whether you believe in science or not and I don't try to convince people what to believe. All I do is provide information to encourage them to take the right decision. If they don't believe in human induced climate change but they observe changes in the climate and they take some actions for their own farms to adapt to what they observe then are already adapting to climate change, also if they don't believe that it is human induced. I don't think that it is a major issue. Farmers are making their own management decisions, based on what they observe. | -Farmers are fairly confident that could adapt in the short term to some climate change because they are already used to deal with climate variability<br>- Farmers are very observant of their own location and they often observe changes in climate<br>-Many already adapt without attributing it to climate change |
| IP25 | - I find it quite interesting how the policy is involved here in Australia; it is very different to Europe. In some ways we are similar to the States but not so much to Europe. I think part of it is because mining is a big part of our economy which means that fossil fuel interests have more political influence than they have in most of Europe.<br>- I think part of the problem is that the issue becomes so political and believing in climate change or not mostly refers to a political identity as well. If your political believes are conservative you tend to reject the science climate change while people on the left side more accept it. Quite a lot of climate scepticism is because farmers always tend to be quite conservative politically | -Fossil fuel interests have more political influence than they have in most of Europe<br>- The issue becomes very political and believing in climate change or not mostly refers to a political identity as well |
| IP30 | We are certainly increasing awareness but there is still a lot that needs to be done in terms of breeding value and how to use them to start off.<br>-If you call it climate change, they will disagree. If you call is variable they will agree. It is a matter of how you package that. My father is the same. Most of them will argue it is a part of the normal cycle.<br>- We deal with very independent people, they don't like it when you tell them what to do. Just give them ideas and then come back later on. If you try pushing them, they will find reasons why it is not like this. It is also a topic of cultural change. | -General awareness is increasing<br>- Most farmers argue it is a part of the normal cycle<br>-Cultural change |
| IP32 | In Australia the debate is often lacking behind to other parts of the world, here it is still about if climate change is happening while in other parts of the world, they discuss about what to do about it, how to combine low carb and technology for example. | In Australia the debate is often lacking behind to other parts of the world |
| IP37 | Farmers will often say that they don't believe in climate change but their actions say that they do. There are probably good political reasons for this. There was this study done by Elgin Ztucenzka and he went out to farmers in the Corangamite and asked them about changes in practices that they have undertaken over the last decade. I think 87% of changes in management were in line with changes in adaptation to climate change. Farmers will get 2 to 3 time's higher numbers of negatron in climate change than the population average. As a group they say it is not happening. The representatives at the parliament say climate change is not happening and this impacts the policy such as the carbon markets. In the end the denier carry in to their farm and it does matter, as they won't be performing as they could. | -Non-believe in climate change high<br>-87% of changes in management in line with adaptation to climate change<br>-Government denies climate change |

Summary of comments on information gathering

| IP | Quote | Generalisation |
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| | **Gathering information about cc risk management** | |
| IP16 | This is a key issue and something we are really focusing on to explain what probabilistic forecast actually means and how to use it. The Australian Government has recently set up a program to actually trial a new ways of defining the value of the forecast, what the forecast actually means to a farmer in terms of value and then to how better to incorporate them, which includes a community practice using an online platform to engage climate scientists with farming sectoral experts and farmers itself to discuss different issues around climate, to inform them about research going on in that area and what a forecast actually means, how to use forecast in business decision making. We are also doing some work in education in how to use probabilistic | -Understand probabilistic forecast and how to incorporate them into business decisions making, several advisors teach farmers in that area<br>-BOM offers training practices |

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| | forecast.<br>-We develop products such as training practices and we have different sectoral experts for each sector, e.g. for the wine or cattle industry.<br>-We work with people who are professional in advising farmers and getting them to understand what probabilistic forecast means and how to use them, for the advisors and they teach the farmers. | |
| IP22 | Farmers who pick up some science are doing better I guess but there are others who just keep doing their things, doing their best but they are not getting necessary the right advices and can't sustain it at some point. | -Incorporate some science which might help to take longer-term decisions |
| IP26 | More education needed to train farmer how to manage pastures and soils sustainably. | -More education needed to train skills |
| IP28 | One issue is communicating probabilities, to make the users understanding what probability means. Some people don't interpret our maps and results not in the right way which is also a challenge. It is important to make our research usable and understandable for the users. And of course you also need enough historical data for El Niño and La Niña for example events to run models properly.<br>-There is an outlook video that we release every month that provides information for example to explain what probabilities mean. It is a good communication tool, as it explains things to people. One problem in communicating to users is their lack in confidence in the system, we have that accuracy graph that shows how good these probabilities are. | -Dealing with uncertainties means also to understand probabilistic forecast<br>-Make use of communication tools that explain how to interpret maps |
| IP35 | The first thing is to try to keep as well informed as possible and to try to separate and understand the temperature versus the rainfall or water impacts, they are not always the same. Most farmers say, rainfall is critically important but actually temperature can also be informant in terms of flowering, ripening, grass growth cycle. In terms of water, it depends if you focus on sheep and grazing or on crops. The other critical thing will be increasing bushfire events but also it is about coping with | - Keep informed<br>- Understand temperature versus rainfall or water impacts |
| IP36 | Perception is not reality. They need to be educated and shown how to do this. A lot of understanding is based on historical learning, subjective evidence, but this is often wrong but they firmly believe it. They are unlikely to change the sheep type unless they are forced to, such as mulesing was band in Australia would either force them to move out of Merino sheep altogether and look towards plain body sheep that are naturally resistant. Few of them believe that climate change is happening anyway. I don't know how quite the realization begins and the necessary actions. | - Perception of farmers is not always in line with reality<br>-Education needed in some parts |

Summary of comments on farmers skepticism

| IP | Quote | Generalisation |
|---|---|---|
| | **Scepticism** | |
| IP15 | When I talk to farmers I talk about risk and I don't need to talk about climate change particularly. | -Farming feel more addresses if presenters talk about risk than climate change |
| IP16 | I am very comfortable using the term managing climate variability. In Australia there is quite a big debate around climate change and so nobody would deny if we talk about climate variability, I prefer it to use the term climate change. There is no doubt that climate is changing. There are a lot of data around that demonstrate that trend. | -Using the term managing climate variability sometimes easier as there is a big debate around climate change |
| IP17 | Funnily enough I know, if I want to make a change on a farm, I talk to the wife. Sometimes they are not involved, so you can't do it. But if the woman is involved with the business, talk to her. I learned that very early. | -Women tend to be more open for changes on a farm, some advisors prefer talking to women |
| IP20 | We profile the audience before we give presentation. If you want some acceptance of the message you are talking about, you can't expect an older conservative farmer to accept the whole message of climate change. You have to avoid the word of climate change. If you speak to younger people of land care groups, half woman, half man, who are generally slightly left politically, climate change is on their agenda. If it is a city audience, usually they are very fine with it talking about climate change, if it is a country audience it is a bit harder, especially to older man, woman tend to believe more in climate change and in the end of the day you see it in voting preferences, if they vote for the national or liberals, they won't believe in climate change if they vote for labour or the greens they believe in climate change. This is very heavily published on profiling audiences in terms of believing in climate change or not. There is plenty of information on climate change denier. | -Avoid the word of climate change<br>-Younger people generally more open to climate change. country audience bit harder, especially to older man, woman tend to believe more in climate change |
| IP22 | If we talk to them about weather and variability, it attracts more people while when we talk about climate change it makes people jump into 2 different camps. We try not to use the word climate change but we openly talk about changing weather pattern and pressure systems are getting stronger, that is an example of how we word it. We gave for sure more than 100 talks to farmers and often got invited and they would not so that for someone who talks about climate change. Talking about weather and seasons is better than showing global climate models which are a bit negative, especially here it is more warmer and less rain. It is also important to talk about local weather such as Winchelsea and the development of rainfall in the las 100 years, what was behind the wet and dry years, they really like that. Afterwards you can talk about how it is changing recently and what might happen in future. | -Talking about weather and variability attracts more people while when talking about climate change makes people jump into 2 different camps<br>-Talk about local weather such as Winchelsea and the development of rainfall<br>-Trying to use the language of |

| | | |
|---|---|---|
| | - We try to get climate information out but in farmer's word, talking more about climate variability. Trying to use the language of the users and not of the science.<br>- it is always good to link explanations to what farmers perceive anyway | the users and not of the science<br>- Connect speech to what farmers perceive anyway |
| IP24 | I don't try to convince people what to believe. All I do is provide information to encourage them to take the right decision. | -Only providing information without convincing someone |
| IP28 | There is an outlook video that we release every month that provides information for example to explain what probabilities mean. It is a good communication tool, as it explains things to people. One problem in communicating to users is their lack in confidence in the system, we have that accuracy graph that shows how good these probabilities are. | -Use of communication tools |
| IP29 | We are basically the link between science and processing science into an understandable way to the public to make sure we get our messages across. We are very interested in what farmers think about the BOM and also their opinion about climate change. Just not using the word climate change can be helpful. Our monitoring team gets a lot of questions about climate change.<br>-We work a lot with key points and we have communication and media sectoral experts who help us. We put a lot of effort in making information accessible and summarize them in key points, which give us a framework for what we can say with confidence. Media is definitely one of our channels to spread information. We don't really talk to individual farmers we tend to get our information though media and websites and we also rely on the departments that get our messages out. We also have workshops to ask people what they think about our services, we have not pay much attention on that in the past how we communicate things but it turned to an really important issue for us.<br>-Previously we had a very different set up of our homepage, we just showed a map with lots of text. Our audience is also not the same. Some people don't understand a lot but we also have a lot of capable users that want to have very detailed information. That is a balance act as we also don't want to insult anybody. We needed a solution to deliver our forecast to people with simple and advanced needs. We redesigned our website which allows people to get forecast at a glance. One of the big things is how climatologists explain weather because that was rated really highly amongst that did not understand the wording.<br>-We really listen to our users and try to improve. We know that there is a lot of misconception out there. People ability of complex analysis is sometimes poor which makes it poor to makes probability forecast. We also change the language that we use, we don't use words such as favour and bias anymore but likely or unlikely instead or chances. So we knew that there were certain names that we can use that will help people to understand it better.<br>-We want to be honest and transparent but it is very hard in some situations and some people are frustrated as they can't openly say their opinion and talk open about climate change. | -Not using the word climate change can be helpful<br>- Making information accessible and summarize them in key points<br>-Use of media as channels to spread information<br>-Offer of workshops<br>-Different set up of homepage, change of wording |
| IP30 | If you call it climate change, they will disagree. If you call is variable they will agree. It is a matter of how you package that. My father is the same. Most of them will argue it is a part of the normal cycle. | -Package it the way farmers agree: call it variability and not climate change |
| IP35 | The most important thing is, talking to people in their own language. It is not so much a questions of believing or not but talking to them about what they have experienced. Many of them will remember heat waves, bushfires, frost but many of them also notice changes in heat waves for example and particularly changes in flowering of plants or growing seasons. | -Talk to people in their own language |

## Annex D – Summary of Online Survey

| Q1. Where is your farm located? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Colac Otway Shire | 5 | 12.50% | |
| Surf Coast shire | 17 | 42.50% | |
| Greater Geelong | 5 | 12.50% | |
| Corangamite Shire | 6 | 15.00% | |
| Golden Plains Shire | 6 | 15.00% | |
| Moorabool Shire | 0 | 0% | |
| Ballarat | 0 | 0% | |
| Wyndham | 0 | 0% | |
| Moyne | 1 | 2.50% | |
| Warnambool | 0 | 0% | |
| Other (Please specify) | 0 | 0% | |
| (Did not answer) | 0 | 0% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q2. Are you male or female? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Male | 32 | 80.00% | |
| Female | 7 | 17.50% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q3. What is your age? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| 18 to 24 | 0 | 0% | |
| 25 to 34 | 1 | 2.50% | |
| 35 to 44 | 4 | 10.00% | |
| 45 to 54 | 5 | 12.50% | |
| 55 to 64 | 12 | 30.00% | |
| 65 to 74 | 14 | 35.00% | |
| 75 or older | 3 | 7.50% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q4. How are you related to the farm where you work? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| I am the owner | 31 | 77.50% | |
| I partially own it | 4 | 10.00% | |
| I am an employee | 2 | 5.00% | |

| | | | |
|---|---|---|---|
| I am the tenant | 1 | 2.50% | |
| Other (Please specify) | 1 | 2.50% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| **Q5. How long have you been involved in agriculture?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| 1 to 10 years | 2 | 5.00% | |
| 11 to 20 years | 7 | 17.50% | |
| 21 to 30 years | 4 | 10.00% | |
| Longer than 30 years | 14 | 35.00% | |
| Lifetime | 12 | 30.00% | |
| The farm has been in family hands for generations | 6 | 15.00% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **46** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| **Q6. What is the approximate farm size (in ha)?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| 100-1000 | 29 | 72.50% | |
| 1001-2000 | 5 | 12.50% | |
| 2001-3000 | 1 | 2.50% | |
| 3001-4000 | 2 | 5.00% | |
| 4001-5000 | 0 | 0% | |
| 5000 and bigger | 0 | 0% | |
| (Did not answer) | 3 | 7.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| **Q7. How do your asses your climate change risk for your farm?** | | | | |
|---|---|---|---|---|
| **Answer** | **Responses** | **Value** | **%** | **Percentage of total respondents** |
| 0 - Not concerned | 0 | 0 | 0% | |
| 1 | 0 | 1 | 0% | |
| 2 | 0 | 2 | 0% | |
| 3 | 0 | 3 | 0% | |
| 4 - Neutral | 8 | 4 | 20.00% | |
| 5 | 3 | 5 | 7.50% | |
| 6 | 4 | 6 | 10.00% | |
| 7 | 9 | 7 | 22.50% | |
| 8 | 7 | 8 | 17.50% | |
| 9 - Maximum concerned | 4 | 9 | 10.00% | |

| | | | | |
|---|---|---|---|---|
| (Did not answer) | 5 | NULL | 12.50% | |
| Weighted Score : 6.46 | | | | |
| **Total Responses** | **40** | | | 20% 40% 60% 80% 100% |

| **Q8. Has your land been affected from the occurrence of extreme rainfall events in the last 15 years?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 19 | 47.50% | |
| No | 16 | 40.00% | |
| The timing of heavy rainfall event has changed | 11 | 27.50% | |
| Heavy rainfall events have increased | 1 | 2.50% | |
| Heavy rainfall events have decreased | 16 | 40.00% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **64** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| **Q9. Has your land been affected from the occurrence of an extreme drought in the last 15 years?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 30 | 75.00% | |
| No | 6 | 15.00% | |
| The frequency of droughts have increased | 22 | 55.00% | |
| The frequency of droughts have decreased | 0 | 0% | |
| No change in drought frequency | 6 | 15.00% | |
| The duration of droughts have increased | 15 | 37.50% | |
| The duration of droughts have decreased | 0 | 0% | |
| No change in the duration of droughts | 1 | 2.50% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **81** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| **Q10. Do you notice unusual strong winds in your area in the last 15 years?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 17 | 42.50% | |
| No | 19 | 47.50% | |
| Strong winds have increased | 17 | 42.50% | |
| Strong winds have decreased | 1 | 2.50% | |
| Seasonal changes in wind pattern | 6 | 15.00% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **61** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q11. Has your land been affected from the occurrence of floods in the last 15 years? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 9 | 22.50% | |
| No | 30 | 75.00% | |
| Flooding events have increased | 1 | 2.50% | |
| Flooding events have decreased | 5 | 12.50% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **46** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q12. Do you notice changes in the frequency of frost events? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 13 | 32.50% | |
| No | 25 | 62.50% | |
| The frequency of frost events have increased | 3 | 7.50% | |
| The frequency of frost events have decreased | 10 | 25.00% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **52** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q13. Do you notice new cropping diseases or new weeds in the last decade? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 11 | 27.50% | |
| No | 27 | 67.50% | |
| If yes, which? | 12 | 30.00% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **51** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q14. Have you noticed new animal diseases in the last decade? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 4 | 10.00% | |
| No | 33 | 82.50% | |
| If yes, which? | 5 | 12.50% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **44** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q15. Have you noticed changes in soil erosion in the last decade? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Less soil erosion | 9 | 22.50% | |
| No change | 22 | 55.00% | |
| More soil erosion | 7 | 17.50% | |
| Comments? (Please specify) | 10 | 25.00% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **49** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q16. Thinking back on the past 15 years, have you noticed any changes in the winter season rainfall? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 34 | 85.00% | |
| No | 5 | 12.50% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q17. If the winter season rainfall changed, it... | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| slightly decreased | 18 | 45.00% | |
| significantly decreased | 14 | 35.00% | |
| slightly increased | 2 | 5.00% | |
| significantly increased | 0 | 0% | |
| (Did not answer) | 6 | 15.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q18. Thinking back on the past 15 years, have you noticed any changes in the spring season rainfall? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 36 | 90.00% | |
| No | 3 | 7.50% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q19. If the spring season rainfall changed, it... | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| slightly decreased | 13 | 32.50% | |
| significantly decreased | 21 | 52.50% | |
| slightly increased | 2 | 5.00% | |
| significantly increased | 0 | 0% | |
| (Did not answer) | 4 | 10.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q20. Thinking back on the past 15 years, have you noticed any changes in the autumn break? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 20 | 50.00% | |
| No | 19 | 47.50% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q21. If the autumn break changed, it.. | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| tends to start earlier | 1 | 2.50% | |
| tends to start later | 10 | 25.00% | |
| comes along with less rainfall | 9 | 22.50% | |
| comes along with more rainfall | 0 | 0% | |
| False breaks have increased | 9 | 22.50% | |
| (Did not answer) | 20 | 50.00% | |
| **Total Responses** | **49** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q22. Do you think precipitation patterns will change in the future? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| No change | 3 | 7.50% | |
| More rain | 0 | 0% | |
| Less rain | 10 | 25.00% | |
| Higher variability | 26 | 65.00% | |
| More insecurity for planning | 9 | 22.50% | |
| Seasonal shifts | 12 | 30.00% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **62** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q23. Thinking back on the past 15 years, have you noticed any changes in summer temperature? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 17 | 42.50% | |
| No | 21 | 52.50% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q24. If the summer temperature has changed, it … | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |

| | | | |
|---|---|---|---|
| slightly decreased | 0 | 0% | |
| significantly decreased | 1 | 2.50% | |
| slightly increased | 12 | 30.00% | |
| significantly increased | 5 | 12.50% | |
| (Did not answer) | 22 | 55.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q25. Thinking back on the past 15 years, have you noticed any changes in winter temperature? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 24 | 60.00% | |
| No | 14 | 35.00% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q26. If the winter temperature has changed, it … | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| slightly decreased | 8 | 20.00% | |
| significantly decreased | 0 | 0% | |
| slightly increased | 16 | 40.00% | |
| significantly increased | 1 | 2.50% | |
| (Did not answer) | 15 | 37.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| Q27. Do you think that temperatures will change in future? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| No change | 2 | 5.00% | |
| Increase of temperature | 19 | 47.50% | |
| Decrease of temperature | 0 | 0% | |
| More insecurity for planning | 14 | 35.00% | |
| Seasonal shifts | 18 | 45.00% | |
| More heat waves | 15 | 37.50% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **70** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Q28. Have you observed any changes in the winter growing season in your area over the past 15 years? | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| No change in the length of the winter growing season | 11 | 27.50% | |
| The length slightly decreased | 7 | 17.50% | |
| The length significantly decreased | 0 | 0% | |

| | | | |
|---|---|---|---|
| The length slightly increased | 6 | 15.00% | |
| The length significantly increased | 0 | 0% | |
| It starts earlier in the season | 9 | 22.50% | |
| It starts later in the season | 3 | 7.50% | |
| It ends earlier in the season | 7 | 17.50% | |
| It ends later in the season | 3 | 7.50% | |
| No change in the beginning and end of the winter growing season | 1 | 2.50% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **49** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| **Q29. Do you notice any changes in the water quantity in the last decade? (River flow, groundwater table)** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Less water available in the last decade | 30 | 75.00% | |
| No Change | 5 | 12.50% | |
| More water available in the last decade | 1 | 2.50% | |
| Changes in seasonal availability | 4 | 10.00% | |
| (Did not answer) | 1 | 2.50% | |
| **Total Responses** | **41** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| **Q30. Do you notice any changes in the water quality in the last decade? (from rivers & groundwater)?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| No Change | 22 | 55.00% | |
| Water quality improved | 2 | 5.00% | |
| Water quality decreased (e.g. higher salinization) | 13 | 32.50% | |
| (Did not answer) | 3 | 7.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| **Q31.Please rate** | | | | |
|---|---|---|---|---|
| 31(a) : Please rate: Adaptation to climate change is important, as risks are increasing | | | | |
| **Answer** | **Responses** | **Value** | **%** | **Percentage of total respondents** |
| Fully agree | 18 | NULL | 45.00% | |
| Agree | 13 | NULL | 32.50% | |
| Neutral | 5 | NULL | 12.50% | |
| Partially agree | 1 | NULL | 2.50% | |
| Disagree | 1 | NULL | 2.50% | |
| (Did not answer) | 2 | NULL | 5.00% | |

| | | | | |
|---|---|---|---|---|
| Weighted Score : 0 | | | | |
| **Total Responses** | **40** | | | 20% 40% 60% 80% 100% |

| **Q31.Please rate** | | | | |
|---|---|---|---|---|
| 31(b) : Please rate: Adaptation strategies to changing weather conditions are planned for the future | | | | |
| **Answer** | **Responses** | **Value** | **%** | **Percentage of total respondents** |
| Fully agree | 7 | NULL | 17.50% | |
| Agree | 12 | NULL | 30.00% | |
| Neutral | 11 | NULL | 27.50% | |
| Partially agree | 6 | NULL | 15.00% | |
| Disagree | 1 | NULL | 2.50% | |
| (Did not answer) | 3 | NULL | 7.50% | |
| **Weighted Score : 0** | | | | |
| **Total Responses** | **40** | | | 20% 40% 60% 80% 100% |

| **Q31.Please rate** | | | | |
|---|---|---|---|---|
| 31(c) : Please rate: Adaptation to climate change is too costly | | | | |
| **Answer** | **Responses** | **Value** | **%** | **Percentage of total respondents** |
| Fully agree | 2 | NULL | 5.00% | |
| Agree | 4 | NULL | 10.00% | |
| Neutral | 16 | NULL | 40.00% | |
| Partially agree | 3 | NULL | 7.50% | |
| Disagree | 12 | NULL | 30.00% | |
| (Did not answer) | 3 | NULL | 7.50% | |
| **Weighted Score : 0** | | | | |
| **Total Responses** | **40** | | | 20% 40% 60% 80% 100% |

| **Q31.Please rate** | | | | |
|---|---|---|---|---|
| 31(d) : Please rate: Insurance is important for me to shift weather risks | | | | |
| **Answer** | **Responses** | **Value** | **%** | **Percentage of total respondents** |
| Fully agree | 6 | NULL | 15.00% | |
| Agree | 12 | NULL | 30.00% | |
| Neutral | 10 | NULL | 25.00% | |
| Partially agree | 2 | NULL | 5.00% | |
| Disagree | 7 | NULL | 17.50% | |
| (Did not answer) | 3 | NULL | 7.50% | |
| **Weighted Score : 0** | | | | |
| **Total Responses** | **40** | | | 20% 40% 60% 80% 100% |

| **Q31.Please rate** | | | | |
|---|---|---|---|---|
| 31(e) : Please rate: I seriously fear a lack of water availability for my business in | | | | |

| future | | | | |
|---|---|---|---|---|
| **Answer** | **Responses** | **Value** | **%** | **Percentage of total respondents** |
| Fully agree | 12 | NULL | 30.00% | |
| Agree | 10 | NULL | 25.00% | |
| Neutral | 5 | NULL | 12.50% | |
| Partially agree | 8 | NULL | 20.00% | |
| Disagree | 4 | NULL | 10.00% | |
| (Did not answer) | 1 | NULL | 2.50% | |
| | **Weighted Score : 0** | | | |
| **Total Responses** | **40** | | | 20% 40% 60% 80% 100% |

| **Q32. Are you informed about upcoming weather events in the short to mid-term period (for the next 3 month)?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 28 | 70.00% | |
| No | 9 | 22.50% | |
| (Did not answer) | 3 | 7.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| **Q33. How do you manage droughts?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| We have a drought management plan | 9 | 22.50% | |
| The decisions are taken in response to the situation | 30 | 75.00% | |
| Other (Please specify) | 2 | 5.00% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **43** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| **Q34. Have you been realizing any adaptation strategies to changing weather conditions in the last decade?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 26 | 65.00% | |
| No | 12 | 30.00% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| **Q35. Why did you not adapt to changing weather conditions?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| No need to adapt | 6 | 15.00% | |
| Lack of money | 0 | 0% | |
| Lack of information | 0 | 0% | |
| Shortage of labor | 0 | 0% | |

| | | | |
|---|---|---|---|
| Shortage of resources | 1 | 2.50% | |
| Other (Please specify) | 5 | 12.50% | |
| (Did not answer) | 28 | 70.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

**Q36. Which statements fit to your farm regarding adaptation strategies?**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| I gather information to improve my knowledge about climate change | 23 | 57.50% | |
| We make use of improved soil and water conservation methods | 21 | 52.50% | |
| Monitoring is used to control the spread of pests, weeds, and diseases under a warming climate | 11 | 27.50% | |
| We make successful break-of-season decisions around planting dates | 12 | 30.00% | |
| We make use of satellite information to take pasture and crop management decision | 3 | 7.50% | |
| We use crop varieties with higher tolerance to weather extremes (droughts, heat shocks etc.) | 16 | 40.00% | |
| We make use of erosion control infrastructure | 5 | 12.50% | |
| Management decisions (e.g. stocking and de-stocking, time of sowing) are based on climate prediction systems | 14 | 35.00% | |
| We make use of agricultural decision-support tools that help us to make climate-related decisions (e.g. APSIM. GrassGro etc.) | 7 | 17.50% | |
| We assess the genetic variation of livestock breeds regarding their production response to extreme heat to improve productive animal systems | 6 | 15.00% | |
| Other (Please specify) | 3 | 7.50% | |
| (Did not answer) | 3 | 7.50% | |
| **Total Responses** | **124** | | 20% 40% 60% 80% 100% |

Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

**Q37. Have you changed the type of your crops in the last 15 years?**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| Yes | 17 | 42.50% | |
| No | 20 | 50.00% | |
| (Did not answer) | 3 | 7.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

**Q38. Why have you changed your type of crops in the last 15 years?**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| Previous yields were reduced due to weather | 3 | 7.50% | |

| | | | |
|---|---|---|---|
| induced factors | | | |
| New crops are more drought tolerant and generally better adapted to environmental conditions | 10 | 25.00% | |
| Previous crops was subjected to pest attack | 2 | 5.00% | |
| Insufficient water for previous crops | 2 | 5.00% | |
| Expected more returns from new crop | 11 | 27.50% | |
| New ideas from neighboring farms | 4 | 10.00% | |
| Takes less financial resources than before | 1 | 2.50% | |
| To rotate crops | 8 | 20.00% | |
| Crop diversification to minimize weather risks | 6 | 15.00% | |
| Crop diversification to maximize long-term income | 7 | 17.50% | |
| Other (Please specify) | 3 | 7.50% | |
| (Did not answer) | 22 | 55.00% | |
| **Total Responses** | **79** | | 20% 40% 60% 80% 100% |

Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

**Q39. Have you changed your crop sowing dates in the last 15 years?**

| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
|---|---|---|---|
| Yes | 13 | 32.50% | |
| No | 23 | 57.50% | |
| (Did not answer) | 4 | 10.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

**Q40. Why did you change the sowing date?**

| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
|---|---|---|---|
| Sowing time varies annually according to weather forecast | 8 | 20.00% | |
| Due to earlier autumn break | 2 | 5.00% | |
| Due to later autumn break | 6 | 15.00% | |
| Avoid frost risk | 1 | 2.50% | |
| Avoid grain filling during hot conditions | 0 | 0% | |
| Due to changed requirements of crops | 1 | 2.50% | |
| Due to nutrition requirements of animals | 7 | 17.50% | |
| Due to earlier grain filling | 0 | 0% | |
| Due to later grain filling | 0 | 0% | |
| Other (Please specify) | 3 | 7.50% | |
| (Did not answer) | 26 | 65.00% | |
| **Total Responses** | **54** | | 20% 40% 60% 80% 100% |

Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

| Please indicate the months of sowing at your farm | | | |
|---|---|---|---|
| **Q41. Please choose month of sowing** | | | |
| **41 (a) : Please choose month of sowing: Month of sowing BEFORE last change** | | | |
| **Answer** | **Responses** | **%** | **Percentage of total respondents** |
| Jan | 0 | 0% | |
| Feb | 0 | 0% | |
| Mar | 2 | 5.00% | |
| Apr | 6 | 15.00% | |
| May | 4 | 10.00% | |
| Jun | 3 | 7.50% | |
| Jul | 0 | 0% | |
| Aug | 2 | 5.00% | |
| Sep | 2 | 5.00% | |
| Oct | 2 | 5.00% | |
| Nov / Dec | 3 | 7.50% | |
| (Did not answer) | 26 | 65.00% | |
| **Total Responses** | **50** | | 20% 40% 60% 80% 100% |

**Note:** Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

| Please indicate the months of sowing at your farm | | | |
|---|---|---|---|
| **Q41. Please choose month of sowing** | | | |
| **41 (b) : Please choose month of sowing: Month of sowing NOWADAYS** | | | |
| **Answer** | **Responses** | **%** | **Percentage of total respondents** |
| Jan | 3 | 7.50% | |
| Feb | 0 | 0% | |
| Mar | 2 | 5.00% | |
| Apr | 6 | 15.00% | |
| May | 6 | 15.00% | |
| Jun | 1 | 2.50% | |
| Jul | 0 | 0% | |
| Aug | 1 | 2.50% | |
| Sep | 2 | 5.00% | |

| | | | |
|---|---|---|---|
| Oct | 1 | 2.50% | |
| Nov / Dec | 1 | 2.50% | |
| (Did not answer) | 27 | 67.50% | |
| **Total Responses** | **50** | | 20% 40% 60% 80% 100% |

**Note:** Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

**Q42. Do you operate sheep production?**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| Yes | 27 | 67.50% | |
| No | 11 | 27.50% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

**Q43. What is your production objective?**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| Prime lamb | 12 | 30.00% | |
| Wool | 4 | 10.00% | |
| Both | 11 | 27.50% | |
| (Did not answer) | 13 | 32.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

**Q44. Have you changed your lambing time in the last 30 years?**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| Yes | 20 | 50.00% | |
| No | 6 | 15.00% | |
| (Did not answer) | 14 | 35.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

**Q45. Why have you changed the time of lambing? (Please choose the most important ones)**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| Market situation: Adapted to best time for selling | 3 | 7.50% | |
| More meat production | 0 | 0% | |
| Maximize lamb survival | 14 | 35.00% | |
| Changing seasonal conditions | 5 | 12.50% | |
| Ewe nutrition | 14 | 35.00% | |
| Higher wool quality | 1 | 2.50% | |
| Pasture availability | 15 | 37.50% | |
| Other (Please specify) | 4 | 10.00% | |

| | | | |
|---|---|---|---|
| (Did not answer) | 19 | 47.50% | |
| **Total Responses** | **75** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| **Please indicate the months of lambing** | | | |
|---|---|---|---|
| **Q46. Please choose month of lambing** | | | |
| **46 (a) : Please choose month of lambing: Month of lambing BEFORE last change** | | | |
| **Answer** | **Responses** | **%** | **Percentage of total respondents** |
| Jan | 0 | 0% | |
| Feb | 0 | 0% | |
| Mar | 0 | 0% | |
| Apr | 7 | 17.50% | |
| May | 6 | 15.00% | |
| Jun | 3 | 7.50% | |
| Jul | 3 | 7.50% | |
| Aug | 3 | 7.50% | |
| Sep | 3 | 7.50% | |
| Oct | 0 | 0% | |
| Nov / Dec | 0 | 0% | |
| (Did not answer) | 21 | 52.50% | |
| **Total Responses** | **46** | | 20% 40% 60% 80% 100% |

| **Please indicate the months of lambing** | | | |
|---|---|---|---|
| **Q46. Please choose month of lambing** | | | |
| **46 (b) : Please choose month of lambing: Month of lambing NOWADAYS** | | | |
| **Answer** | **Responses** | **%** | **Percentage of total respondents** |
| Jan | 0 | 0% | |
| Feb | 0 | 0% | |
| Mar | 0 | 0% | |
| Apr | 1 | 2.50% | |

| | | | |
|---|---|---|---|
| May | 3 | 7.50% | |
| Jun | 5 | 12.50% | |
| Jul | 5 | 12.50% | |
| Aug | 6 | 15.00% | |
| Sep | 5 | 12.50% | |
| Oct | 0 | 0% | |
| Nov / Dec | 0 | 0% | |
| (Did not answer) | 20 | 50.00% | |
| **Total Responses** | **45** | | 20% 40% 60% 80% 100% |
| **Note:** Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| **Q47. Have you changed your shearing time in the last 15 years?** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Yes | 10 | 25.00% | |
| No | 15 | 37.50% | |
| (Did not answer) | 15 | 37.50% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

| **Q48. If yes, what were your intentions to change the shearing date? (Please choose the 3 most important ones)** | | | |
|---|---|---|---|
| **Responses** | **Responses** | **%** | **Percentage of total respondents** |
| Pasture availability | 1 | 2.50% | |
| Time more suitable for farm staff | 2 | 5.00% | |
| Get closer to the autumn break | 1 | 2.50% | |
| Improve fiber diameter | 0 | 0% | |
| Improve staple strength | 2 | 5.00% | |
| Improve staple length | 1 | 2.50% | |
| To avoid a change of diet | 1 | 2.50% | |
| Availability of shearers | 3 | 7.50% | |
| To position the weakest point of the staple near the tip or the base | 2 | 5.00% | |
| To avoid too much vegetable matter contamination in the wool | 4 | 10.00% | |
| To avoid cold stress off-shears | 1 | 2.50% | |
| Other (Please specify) | 4 | 10.00% | |
| (Did not answer) | 28 | 70.00% | |
| **Total Responses** | **50** | | 20% 40% 60% 80% 100% |
| Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question. | | | |

| Please indicate the months of shearing | | | |
|---|---|---|---|
| **Q49. Please choose month of shearing** | | | |
| **49 (a) : Please choose month of shearing: Month of shearing BEFORE last change** | | | |
| **Answer** | **Responses** | **%** | **Percentage of total respondents** |
| Jan | 0 | 0% | |
| Feb | 2 | 5.00% | |
| Mar | 1 | 2.50% | |
| Apr | 0 | 0% | |
| May | 1 | 2.50% | |
| Jun | 0 | 0% | |
| Jul | 1 | 2.50% | |
| Aug | 3 | 7.50% | |
| Sep | 1 | 2.50% | |
| Oct | 0 | 0% | |
| Nov / Dec | 1 | 2.50% | |
| (Did not answer) | 31 | 77.50% | |
| **Total Responses** | **41** | | 20% 40% 60% 80% 100% |

**Note:** Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

| Please indicate the months of shearing | | | |
|---|---|---|---|
| **Q49. Please choose month of shearing** | | | |
| **49 (b) : Please choose month of shearing: Month of shearing NOWADAYS** | | | |
| **Answer** | **Responses** | **%** | **Percentage of total respondents** |
| Jan | 1 | 2.50% | |
| Feb | 0 | 0% | |
| Mar | 1 | 2.50% | |
| Apr | 0 | 0% | |
| May | 0 | 0% | |
| Jun | 0 | 0% | |

| | | | |
|---|---|---|---|
| Jul | 0 | 0% | |
| Aug | 0 | 0% | |
| Sep | 1 | 2.50% | |
| Oct | 5 | 12.50% | |
| Nov / Dec | 5 | 12.50% | |
| (Did not answer) | 30 | 75.00% | |
| **Total Responses** | **43** | | 20% 40% 60% 80% 100% |

**Note:** Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

**Q50. Which of the following statements fits best to your business regarding your pasture management?**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| Pasture management plays an important role on our farm | 28 | 70.00% | |
| We increase soil fertility through phosphorus application | 12 | 30.00% | |
| We changed to aluminum tolerant pasture species in the last years | 1 | 2.50% | |
| We changed pasture to more productive pasture species in the last years | 9 | 22.50% | |
| We changed pasture to more drought resistant pasture species in the last years | 9 | 22.50% | |
| We make use of rotational grazing to avoid diseases | 12 | 30.00% | |
| We make use of rotational grazing to meet animals requirements | 20 | 50.00% | |
| We fit stocking rates for improved pasture utilization | 16 | 40.00% | |
| We make use of pasture cropping or other innovative practices | 8 | 20.00% | |
| Other (Please specify) | 6 | 15.00% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **123** | | 20% 40% 60% 80% 100% |

Multiple answers per participant possible. Percentages added may exceed 100 since a participant may select more than one answer for this question.

**Q51. If the trend of increasing weather variability continues, do you think farming would become unsustainable in your region?**

| Responses | Responses | % | Percentage of total respondents |
|---|---|---|---|
| Yes | 3 | 7.50% | |
| Unsure | 18 | 45.00% | |
| No | 17 | 42.50% | |
| (Did not answer) | 2 | 5.00% | |
| **Total Responses** | **40** | | 20% 40% 60% 80% 100% |

## Annex E – Summary of PhD Thesis for Farmers in the Study Area

### 1. Introduction

Australia has one of the most variable climates in the world with a high seasonal, inter-annual and decadal variability (BOM 2017b; Climate Change Authority 2012). However, according to BOM/CSIRO (2016), observations and climate modelling paint a consistent picture of ongoing, long-term climate change interacting with underlying natural climate variability. Facing one of the most risky farming environments in the world agriculture in Australia has developed in a way that includes managing farm businesses to cope with a highly variable environment (RIRDC 2007). However, climate change is likely to add extra pressure on farm businesses as associated impacts pose *new* diverse risks for the agricultural sector coming along with financial, emotional and physical stress for farmers (RIRDC 2007; Nguyen et al. 2005). Especially a change in the frequency and magnitude of extremes and new or earlier emerging risks in the season might impact both economic (e.g. supply of and demand for farm input, changes in commodity prices and financial outcomes) and social (e.g. living standards) farm dimensions (RIRDC 2007). Hence, changing climate pattern in combination with increasingly degraded ecosystems through agricultural intensification strategies turn to the question to agricultural sustainability and how to better respond to changing conditions in increasing the resilience of social-ecological systems into the future (Morton and Abendroth 2017). As climate change is likely to increase Australia's already high natural, seasonal, yearly and decadal climate variability and trigger changes in the extremes of natural variations such as higher peak temperatures, managing climate variability and associated risks will be more important than it has been in the past (Harle et al. 2007; CSIRO 2001).

ARC Consulting Group (2017) therefore suggests that the key to moving forward in the agricultural sector to deal with climate related risks is a sound risk management approach. The process of risk management under climate change is a dynamic approach which can significantly lower potential risks from extreme events and longer term changes to the system of lower specific vulnerability. Since risk management is an effective way to mitigate the adverse consequences of climate change, it plays an important role in adaptation to increasing resilience to climate related impacts (Yuan et al. 2017).

Adaptation is an ongoing process and part of good farm risk management which includes identifying drivers of risks, assessing likely impacts under alternative management strategies on systems and to making use of potential opportunities (Howden et al. 2007). According to Schattman et al. (2016), how farmers conceptualize and take action to address risks is an important area of investigation. Farmers perceptions to risk and assessment in changing business threats is not only critical to appropriate management strategies but also influences their ability to make decisions that support positive future outcomes over immediate ones (Purdue University 2017; Schattman et al. 2016). Although perceptions are not necessarily consistent with reality, they must be identified, understood and considered in order to address socio-economic challenges, adaptation constraints and potential vulnerabilities (Kusakari et al. 2014).

## Objectives and Research Questions

This thesis aims to contribute to a better understanding of the impacts of climate change and possible adaptation strategies to associated adverse consequences on regional and local levels. To achieve the aim of this thesis, the following four **objectives** were pursued:

- to explore historical trends in climate for the study area and future climate scenarios to identify potential climate related risks and impacts
- to identify farmers climate related risk perception and potential factors influencing their perception and constraining adaptations
- to provide an application-oriented risk management framework for farmers in order to minimize potential vulnerability to climate change related impacts and to increase farm resilience from short to long-term

The primary key **research questions** that guided the study can be summarised as follows:

Which trends in climate can be identified, which risks do they pose to farmers and which risk management strategies help in reducing local vulnerability and increase resilience to climate related impacts in the study area?

**Sub-questions**

- How did the climate change in the last century and which developments in temperature and precipitation are expected in the future for the study area?
- Which impacts, risks and opportunities of climate change have been identified for agricultural production so far by the interviewed farmers and sectoral experts?
- Which factors influence farmers perception in terms of climate related risks including climate change and which factors determine potential constraints in adaptation?
- How can risk management help in managing changing risks under climate change in order to support environmental, economic and social farm resilience?

## 2. Study Area

The study area is the Corangamite catchment in south-west Victoria covers an area of approximately 1.3 million hectare (ha) of land of which 78 % are privately owned (CMA 2013). The Corangamite catchment stretches between the Otway Coast, Ballarat and Geelong in south-west central Victoria (figure 1). In the south-eastern part of the catchment, steeply dissected terrain of the Otway Ranges give way to low hills and volcanic plains to the middle area of Geelong before rising again to the moderate elevations of the northern uplands around Ballarat (DEDJTR 2017b). The Corangamite catchment offers diverse and productive landscapes, supporting cropping, grazing, livestock enterprises, production forests, horticulture and viticulture. The region offers a diverse range of rivers and waterways, underpinning water supplies to towns and cities. The major waterways in the region include the Barwon, Moorabool, Cumberland, Wye and Leigh rivers as well as Lake Corangamite (CMA 2013; DELWP 2008). The study area is characterized by expansive volcanic plains and rock formations. The soils in the catchment support a wide variety of natural resources for native vegetation and the agricultural sector (CMA 2013).

In terms of climate, Australia has one of the most variable climates in the world which can greatly vary from year to year coming along with different temporal and spatial levels of impact. Also Victoria and the surrounding catchment are influenced by several climatic features triggering high natural climate variability. Figure 2 shows the different drives influencing the country's climate of which several influence seasonal and decadal climates in the study area, including blocking highs, the Southern Annual Mode, East Coast Lows, El Niño/La Niña, Cut-off Lows or frontal systems. Additional factors such as the position of the subtropical ridge or the temperature of the Indian Ocean influences the climate in the study area (BOM 2017b).


**Figure 1: Map Corangamite catchment (Corangamite Catchment Management Authority 2017a).**

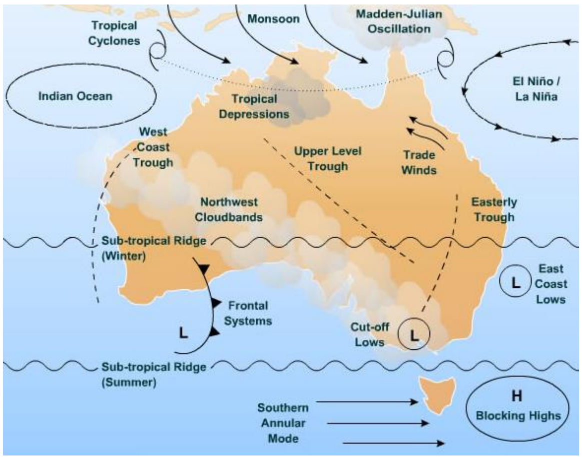


**Figure 2: Influences on Australia's and Victoria's climate (BOM 2017b)**

The Corangamite landscape is a cultural landscape, shaped and influenced by people. The catchment is home to about 370,000 people and includes all of the cities of Greater Geelong, Ballarat and Lismore and Peterborough. The population in the catchment is growing at one of the fastest rates in Victoria, 1.5 % expected growth per annum to approximately half a million by 2026 (CMA 2013).

The economy of the Corangamite catchment is diverse and reflects a mix of agricultural and other primary industries, tourism, manufacturing and service industries. Although regional employment in the agriculture and forestry sectors declined from 5 % to 3.4 % between 2001 and 2011, the sector remains an important employer for people from smaller regional communities and towns (CMA 2013). Agriculture is also the dominant land use in the region in which dairy and wool production play a major role. About 3,450 agricultural businesses are operating across 772,436 ha land within the catchment. Enterprises include sheep and cattle grazing, dairying, cropping, forestry, viticulture and horticulture. While over 75 % of private land is used for livestock grazing, only 20 % is used for crop production including timber (REMPLAN 2016; CMA 2013).

Looking back to Australia's agricultural history, the sector has experienced major changes in productivity over the last 100 years through the application of new technology and science. Through the use of advanced chemicals, farmers were able to make improvement in disease and weed control while the adoption of modern technology helped to improve and increase cropping/livestock production. The Australian cropping industry has always been dominated by wheat covering 14 million ha (55 %) of the Australian cropland in 2014. Australia has experienced substantial wheat yield progress over the last century up to about 2.0 t/ha with wheat areas increasingly expanding into drier areas (Fischer et al. 2014; Australian Bureau of Statistics 2000). Also the livestock industry plays a crucial role in Australia's agricultural sector. With a strong international and domestic demand for meat, beef cattle, mutton and lamb prices increased with an overall decline in real terms in the last two decades while the demand for wool declined over the same period of time (RIRCD 2007; Australian Bureau of Statistics 2000). Nowadays, Australia has over 30,000 woolgrowers (AWEX 2014). In end of the 1990s, Australian wool production fell by 35 % (Australian Bureau of Statistics 2000). The decline in wool production and returns also reflect changes in consumer tastes and preferences, thus heavily influencing the global demand for wool (Dickson et al. 2006). Also in Victoria, wool production and number of sheep declined since the early 1990s, falling from 190,600 tonnes of wool in 1990 to 70,500 tonnes in 2014 while sheep meat (lamb and mutton) production has increased by about 60 % over the same period of time. The decline in Victoria's wool production can be attributed to declines in wool prices and relatively better returns from meat production and/or cropping over the last two decades. However, despite the long-term decline in Victoria's wool production, exports from Victoria increased in value from $883 million in 2010 to $1,315 million in 2014 (DEDJTR 2014b).

## 3. Theoretical Background and defining Key Terminology

### Climate change at a glance

Human's activities, especially the emission of greenhouse gases into the atmosphere since the industrial revolution around 1850 has begun to influence the global climate in many significant ways. The amount of carbon dioxide in the atmosphere increased by 40 % since the beginning of the industrial revolution, trapping more heat within the upper and lower atmosphere of the Earths' surface and within the oceans (Climate Commission 2013, IPCC 2007). Along with the general increase in temperature, the duration and frequency of heatwaves have increased in the past decades as additional heat in the Earth surface increases the probability of hot weather (Climate Commission 2013; DELWP 2008).

The following two maps show global temperature anomalies and carbon dioxide concentrations from 1880-2012 and Australia´s annual mean temperature anomaly from 1910-2015 compared to 1961-1990 period. The global annual temperature has increased by about 0.8 °C on average since 1880. Blue and red pillars indicate the deviation from 1961 to 1990. Despite a high degree of climate variability from year to year and decade to decade, temperatures in Australia have increased since around 1950 with every decade being warmer than the decade before. This trend is consistent with the increased atmospheric carbon dioxide ($CO_2$) concentration which rose from 280 parts per million (ppm) in 1880 to almost 400 ppm in 2012. The average increase of air temperature in Australia of about 0.9°C since 1910 mirrors the global trend and is larger in the interior of the continent and lower along its coastlines (Climate Commission 2013).

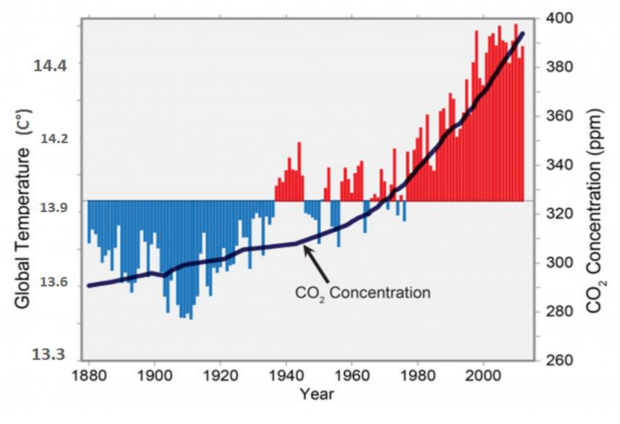


**Figure 3: Global Temperature anomaly and carbon Dioxide from 1880-2012 (compared to 1961-1990)** (Global Change Research Program 2016)

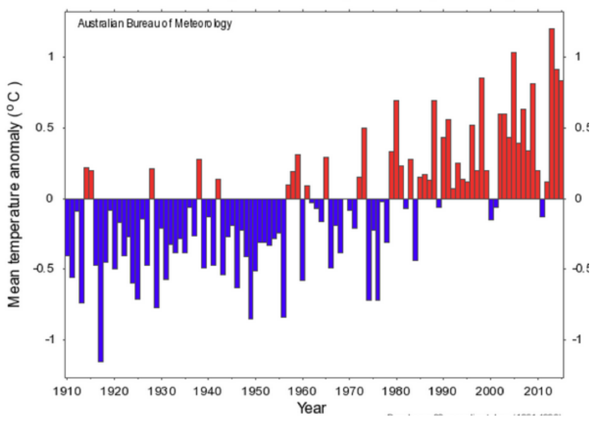


**Figure 4: Australian´s annual mean temperature anomaly from 1910-2015 (compared to 1961-1990)** (BOM 2016a)

Beside changes in temperature, precipitation patterns are changing globally with some areas facing significant rainfall surges while others face drying trends. However, as rainfall is highly variable in time and space it is more difficult to determine an overall trend (NOAA 2016b). In Australia, the overall annual rainfall trend shows a slight increase between 1900 and 2015. However, south-east Australia is becoming hotter and drier since the 1970s. Despite wet conditions associated with La Niña in 2011 across much of Australia, the long-term regional drying trends over the south-eastern part of Australia continued (Climate Commission 2013).

According to Murphy and Timbal (2008) the observed warming over the last century is improbable due to natural variability or natural external forcing, but rather to anthropogenic greenhouse warming. Models show that observed changes in temperature and precipitation differ from inter-decadal time scales in the absence of enhanced greenhouse gas forcing. The National Oceanic and Atmospheric Administration (NOAA) considers the increase in temperature over the past several decades as one of the most obvious signals of human-induced climate change (NOAA 2016a). Additionally, the decreasing trend in rainfall over the last two decades during the Millennium drought in south-east Australia is unlikely to be within the levels of natural variability. This is because it differs from earlier dry spells in the last century in terms of seasonal variations such as significant drier autumn months with less rainy days and lower rainfall intensities. Earlier dry periods were characterized by more homogenous below-than average precipitations during all seasons and showed a higher year to year variability (Murphy and Timbal 2008; Timbal and Drosdowsky 2012). Also if the attribution of single extreme events to anthropogenic climate change remains challenging, there is statistically significant evidence that some extremes have changed as a result of increased atmospheric greenhouse gases underlying with natural climate variability (IPCC 2007).

**Key Terminology**

The analytical framework of this thesis builds on the vulnerability, risk management and resilience context. Definitions and frameworks that systematize risk, vulnerability and resilience are multiple and overlapping and are briefly presented in the following (Oppenheimer et al. 2014).

<u>Risks</u>

Climate change it is not a risk per se for agriculture, but rather the combination of climate related risks that interact with the vulnerability and exposure of systems, which determines the changing level of risk (Oppenheimer et al. 2014). However, according to the Intergovernmental Panel on Climate Change (IPCC 2012), a changing climate leads to changes in the frequency, intensity, spatial and temporal extent and duration of weather or climate extremes posing a major risk for individuals, societies and ecosystems. Thus, extremes that would have happened due to natural climate variability become even more extreme due to the general shift in average temperature (IPCC 2012). If slower changes in climate seem less dramatic compared to the direct impacts of extreme events, risks and impacts are more complex. Thus increases in water temperatures in Oceans surrounding

Australia affect rainfall pattern and impact water supply and agricultural systems. While some regions may become climatically more suitable than previous ones, other regions may become too dry for agricultural production offering new opportunities as well (Oppenheimer et al. 2014; IPCC 2012). Risks can also evolve from risk perceptions and cognitive constructs, adaptation options and the cultural context that influence adaptive capacities and therefore people´s vulnerability. There are several factors shaping people´s risk perception and therefore influencing their responses to climate events; a) Their interpretations of the threat as well as their understanding of the root cause of the problem, b) their exposure and personal experience with events and especially recent consequences, c) their priorities and motivations d) environmental and general value systems (Oppenheimer et al. 2014). Thus, an improved understanding and knowledge of changing risks associated with climate change is considered to support effective and sustainable risk management both in the short and longer term future (Climate Commission 2013; IPCC 2012).

Vulnerability

According to the IPCC (2007), vulnerability is the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2007). According to IPCC (2012), climate change comes along with changes in vulnerability for socio-economic and ecological systems. There are several factors influencing individual's vulnerability. The exposure and the capacity to cope and adapt to climate related risks are typically influenced by the social status, wealth, education, health or gender. Especially people who are socially or economically disadvantaged are considered most sensitive to climate change, with sensitivity typically being the result of cross cutting social processes such as inequalities in the socio-economic status and exposure to risk (Keywood et al.2017; IPCC 2012). However, societies and their individuals are not only vulnerable to climate change, but also ecosystems on whose services and functions human societies depend on, including the agricultural sector. Previously degraded ecosystems due to human activities are especially considered highly vulnerable to climate change impacts. With increasing degradation of ecosystems and the lack of natural barriers against climate-related extremes, people's vulnerability increases. Hence, healthy and resilient ecosystems can facilitate adaptation to changing climate conditions through regulating services such as flood regulation or soil erosion avoidance which decreases vulnerabilities (Oppenheimer et al. 2014).

Resilience and Adaptation

According to the IPCC (2012), resilience is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change. Adaptive capacities refer to the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2014). Generally, the more adaptive a system, the less vulnerable it is to internal and external shocks. Adaptation to the dynamic and often uncertain consequences of climate change includes several concepts and approaches to manage associated risks. Effective adaptation includes learning, reassessing and reviewing past tactics to addresses current vulnerabilities and to prioritize system adjustments that increases resilience to present and potential future risks. Learning from prior experiences is considered as central capacity of adaptation and a major factor in terms of innovation, leadership and adaptive management strategies, which in combination with other strategies offer potential pathways into a more resilient and sustainable future. Learning as a part of the adaptation process furthermore reduces or avoids barriers for adaptation or maladaptive measures from the past. However, beside those skills and capacities, the improvement of basic structures and functions in societies may increase resilience (Lavell et at. 2012, IPCC 2012). Adaptation strategies to climate related risks might involve adjustment to current activities while others may require systems or transformational change (Lal et al. 2012). Incremental adaptation refers to maintaining existing activities with smaller adjustments to the system to be reactive and proactive, whiles systems and especially transformational change refer to more strategic strategies that deal with climate risks such as major changes in enterprises (Brundell et al. 2011).

Agricultural Risk Management

Risks and uncertainty are given in any business environment including the agricultural sector which makes its understanding and management critical to the long-term success of a farm business (Centrec Consulting Group 2010). Risks in agriculture arises from a variety of sources and while some risks can be managed with traditional or low regret measures, others can be reduced through the integration of a risk management framework (Gunjal 2016). A proper risk management approach can help in organizing the elements of a decision making process by identifying and analysing risks, developing appropriate strategies and applying tools to reduce addressed risks and thus help to deal with the consequences from climate risks. Additionally if applied tools will not guarantee success in risky decision-making, they do improve the change to capture all information available to make a solid decision (Bowyer et al. 2014; Centrec Consulting Group 2010).

## 4. Methodology

This study lasted three years, from September 2014 to September 2017 and included a) an extended literature review and Internet based research to obtain theoretical background information about the study area, climate change, associated risks for agriculture and potential risk management options in the agricultural sector, b) three field trips to Australia to conduct interviews with farmers and sectoral experts, to give presentation to farmers and at the University of Melbourne to discuss the methodology and interim results and c) several presentation at the  Institute of Climate Impact Research (PIK) and the graduate programme of the Humboldt University of Berlin *IRI THESYs*.

To answer the research questions and to achieve the aims of this dissertation, the study methodology consists of qualitative and quantitative methods. The main difference between quantitative and qualitative methods is their flexibility (Glaser 2004).

Qualitative research is a type of scientific research that seeks to understand a given research problem, mostly in the social contexts of particular populations and from the perspective of involved persons. As findings are not determined in advance, this approach is considered especially effective in obtaining culturally specific information about perceptions, opinions, values or behaviours. The explicit goal of qualitative data is description (Glaser 2004). Qualitative methods such as interviews are generally believed to provide a 'deeper' understanding of social phenomena than would be obtained from purely quantitative methods, such as pre-defined questionnaires. However, as the knowledge of interview partners is always limited to individual experiences, qualitative interviews as well as their interpretation are somewhat subjective. Thus views and opinions must be considered carefully and may not reflect the opinions of other people (Flick 2009; Glaser 2004).

Quantitative methods are generally more inflexible such as participants being identically asked the same questions in the same order in a questionnaire. Quantitative research is based on the assumption that there is an objective truth existing in the world that can be measured and explained scientifically. The advantage of inflexible closed-ended or fixed questions is that it allows for meaningful comparison of responses across all participants of a study which are generally less time consuming than qualitative approaches (Mack et al. 2005). Nonetheless, the main concerns of the quantitative approach include reliable measurements, lack of information and understanding of the studied phenomena from the researcher side, the inability to control the environment where the respondent provides the answers to the survey questions and limited outcomes due to closed-ended questions and pre-structured formats  (Matveev 2002).

All conducted interviews for this study during the field trips were conducted as *expert interviews*. According to Flick (2009), an expert is a person with specific capacities in a certain field of activity due to personal experiences and/or their own biography. Thus, as all interview partner of this study were experts, the terms ´farmers´ and ´sectoral experts´ were used to facilitate differentiation between the two interviewed groups.

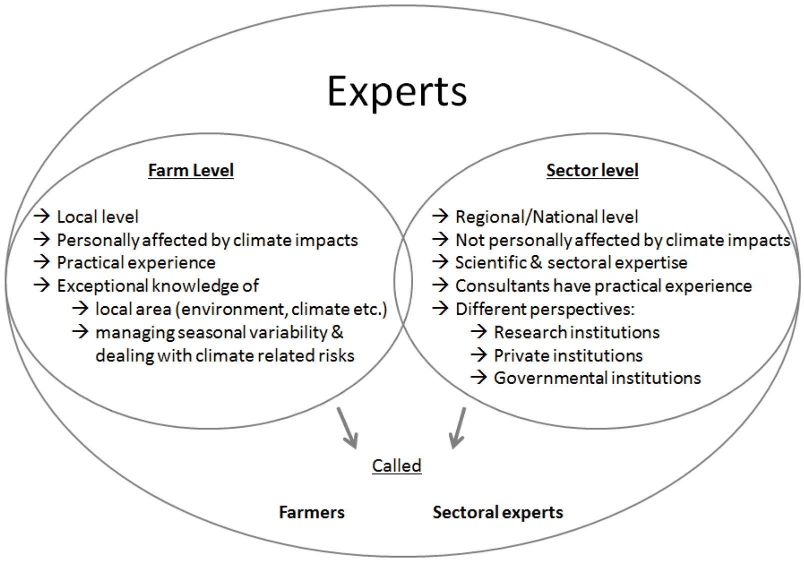


**Figure 5: Conceptualisation and differentiation between interview partners (Own illustration)**

In total, 13 semi-structured **qualitative interviews** with a common outline were carried out with farmers in the Corangamite catchment. Semi-structured interviews provide room for flexibility as well as open and follow-up questions to stimulate the participants' answers and uncover new information (Gill et al. 2008).

Beside the qualitative interviews with the farmers, a **quantitative online survey** was conducted to address more farmers in the Corangamite catchment. Structured interviews consist of a list of predetermined questions with little or no room for variation or follow-up questions, which supported quicker administrations and simplified comparison of given answers. About 300 farmers were requested to participate in the study of which 40 answered the questionnaire (13.3 %).

Additionally, **24 semi-structured qualitative interviews** with sectoral experts from research, private and governmental institutions were carried out. Interview partners were found through an extended Interned-based research and have been chosen according to their expertise and working fields in the areas of agriculture, climate science and their potential benefit in answering the research questions. The following table summarizes the list of interview partner with sectoral experts.

**Table 1: List of interviewed sectoral experts**

| IP Partner | Institute | Expertise in… |
|---|---|---|
| IP14 | Bureau of Meteorology | Development of long-term historical data sets for the assessment of climate change, analysis of extreme events |
| IP15 | Bureau of Meteorology | Climate predictions for Australia, global influences on Australia's climate variability, improvements and representation of climate models |
| IP16 | Bureau of Meteorology | Communication with the public and farmers |
| IP17 | University of Melbourne | Climate variability and change, stratospheric ozone depletion |
| IP18 | University of Melbourne | Agricultural technology adoption, water use and climate change |
| IP19 | University of Melbourne | Pasture production under climate change , cropping/livestock adaptation |
| IP20 | University of Melbourne | Agricultural and resource economics and farm management economics |
| IP21 | University of Melbourne | Atmospheric science and climate modelling |
| IP22 | University of Melbourne | Veterinary Services, Veterinary and Agricultural Sciences |
| IP23 | RMIT University | Sustainability and Urban Planning, Climate change and adaptation strategies |
| IP24 | Climate Change Research Center, University NSW | Terrestrial processes in global and regional climate models, global and regional impacts of land cover change |
| IP25 | Climate Change Research Center, University NSW | Climate extremes/parameter, changes on inter-annual to centennial time scales, quantifying uncertainties related to climate extremes in data sets |
| IP26 | DEDJTR | Seasonal climate variability and change, Farmers education |
| IP27 | DEDJTR | Seasonal risk agronomist |
| IP28 | DEDJTR | Crop and pasture agronomist |
| IP29 | DEDJTR | Sheep production and adaptation to climate change |
| IP30 | DEDJTR/University of Melbourne | Greenhouse gas emissions from agricultural/grazing systems, farm systems modelling of climate change impacts, adaptation and mitigation strategies |
| IP31 | CSIRO | Adaptation/Resilience of cropping systems to climate variability and change |
| IP32 | CSIRO | Climate variability and change, innovation and adaptation management |
| IP33 | Sheep Genetics | Biotechnology, Sheep genetics |
| IP34 | Crop Life | Biotechnology, Crop Genetics |
| IP35 | RIRDC | Sustainability across the rural sector, advisor for skills in climate forecast |
| IP36 | CMA | Sustainability in the Corangamite catchment, ecology and climate change |
| IP37 | SRS Company | Breeding advisor, climate change adaptation |

All interviews were transcribed to facilitate further data analysis with the computer program Maxqda, which is one of the most popular ´computer assisted qualitative data analysis´ tool for scientific qualitative research. The written transcripts were categorised during a coding process and analysed along a manifest content analysis to seek the meaning from the data. The online survey with farmers was conducted with *SoGo survey*, an online platform for quantitative research (SoGo Survey 2017). As all answers were categorised automatically by the program, results could be viewed online with different opportunities for data editing and visualisation. The study furthermore employed a historical climate analysis to show trends in climate over the last century for the catchment. Therefore, SILO climate data have been used with a spatial resolution of about 5km$^2$ which is a database of enhanced long-term Bureau of Meteorology data (DSITI 2017). For temperature and precipitation scenarios, ISIMIP data were used. The climate-input data are observational data sets covering the 20$^{th}$ century (PIK 2017). The framework provides a set of scenarios of climate projections from five Global Climate Models which are driven by the RCPs (Representative Concentration Pathways). The four RCPs (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) are the latest generation of scenarios and are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities (Bjørnæs 2016).

## 5. Results and Discussion

### Historical and projected climate for the study area

The study area is undergoing significant shifts to higher temperatures since the 1950s (figure 6) with increasing numbers of hot days per year within the last century (figure 8). Also the severity, duration and frequency of heatwaves have increased. The region has faced a drying trend in rainfall since the middle of the last century (figure 7) especially in autumn with slight declines in winter and spring rainfall, a small increase in summer rainfall over the last two decades and a reduction in the frequency of very wet years. The wet decades of the 1950 and 1970s were followed by the Millennium drought lasting from about 1995 to 2010/11 which has been the longest period of rainfall deficits on records (CMA 2017).

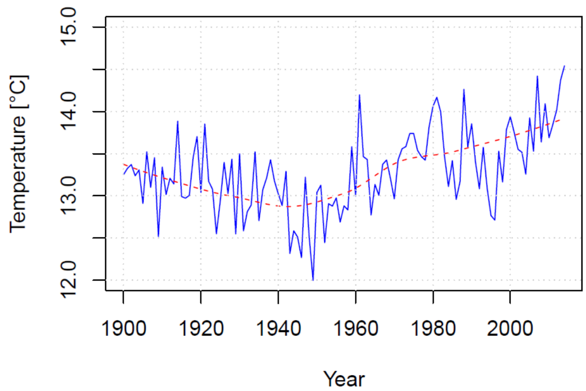


**Figure 6: Catchment mean temperature development from 1900 - 2014 (SILO data)**

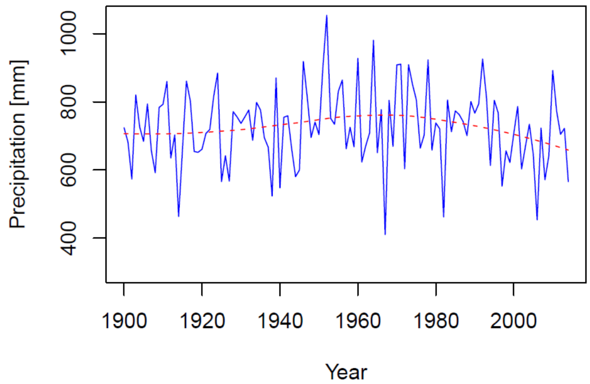


**Figure 7: Catchment rainfall development from 1900 - 2014 (SILO data)**

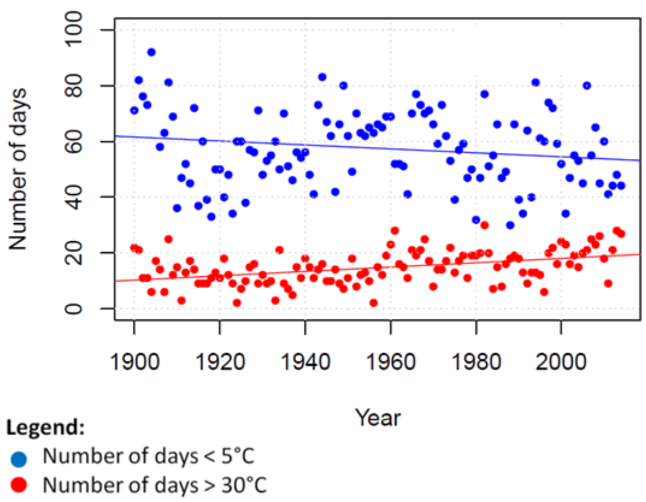


**Figure 8: Development of cold and hot days for the Corangamite catchment and Mt Hesse**
(SILO data)

The following two graphs present the average relative change in mean temperature from 2015 to 2099 compared to mean average temperature data of the reference period from 1961 to 1990 (figure 9) and the relative change in rainfall (in %) from 2015 to 2099 compared to mean average precipitation data of the reference period from 1961 to 1990 (figure 10). Thus, all models suggest a further increase in temperature until mid-century and a slight decrease in precipitation.

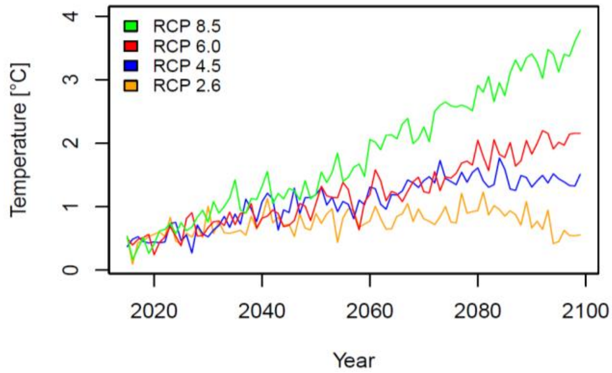


**Figure 9: Catchment relative average temperature change (in °C) compared to reference period 1961 to 1990**
(ISIMIP data)

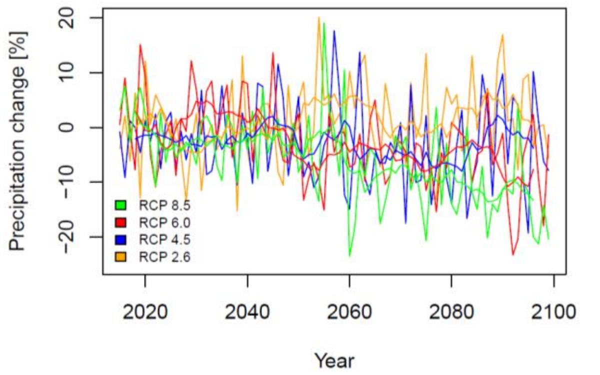


**Figure 10: Catchment relative average precipitation change (in %) compared to reference period 1961 to 1990**
(ISIMIP data)

Despite inherent uncertainties regarding climate change scenarios as pathways dependent on emissions, socio-economic developments and natural climate variability, the temperature in the study area is projected to further increase in all four seasons with more extreme hot days and warm spells, fewer extreme cool days and increasing risks of droughts. Additionally, decreases in winter and spring rainfall with unclear projected changes for summer and autumn rainfall are projected (CMA 2017; BOM/CSIRO 2016). As Australia is considered vulnerable to climate change the country including the study area will face increasingly severe impacts under higher levels of warming (Climate Change Authority 2012).

**Interviews with farmers and sectoral experts**

Interviewed farmers in the catchment perceived a general decrease in rainfall over the last two decades. The majority of farmers pointed particularly to a decrease in spring and winter season rainfall rather than to the observed decrease in autumn rainfall (BOM/CSIRO 2016). Perceived seasonal changes also included a slight increase in summer rainfall. Additionally many farmers were timid about trends in temperature compared to perceived changes in rainfall. However over 50 % of the farmers from the online survey perceived no change in summer temperatures, while 42.5 % did and a third felt a slight increase in summer temperatures. In terms of winter temperature, more than half of the farmers perceived a slight increase. Qualitative interviews revealed that farmers also perceived longer or earlier heat events, a general increase in hot days and milder winter in the study area. Associated with higher temperatures, farmers also noted changes in flowering times starting around 4-6 weeks earlier in the season compared to about 30 years ago and a general shortening of the growing season. Along with a decrease in rainfall and increasing temperatures over the last two decades, the majority of the interviewed farmers also perceived a decrease in surface water availability, while some farmers noted a decrease of groundwater availability in some areas of the catchment. However, with increasingly drier times presenting a major challenge for production, farmers nevertheless agreed that the general drying of the study area was beneficial for cropping production although wet years in between were mentioned as negative counterparts. The following table summarizes employed management strategies by interviewed farmers in the Corangamite catchment that deal with perceived climate related risks.

**Table 2: Examples of employed risk management strategies by farmers in the catchment**

| Management Strategies of Farmers |
|---|
| **Cropping & Soils** |
| • Earlier sowing to address more unreliable springs & to pick up more winter rainfall<br>• Changes of types and varieties with higher production rates and better handling of drier times<br>• Improved weed control or using mechanical rather than chemical weed control<br>• Stock off animals in time to keep at least 80 % ground cover to avoid wind erosion<br>• Soil conservation methods: no ploughing, minimal tillage or direct drilling to avoid wasting soil moisture and to encourage the roots to better access soil moisture, controlled traffic to avoid soils compaction<br>• Rotational farm systems<br>• Raised beds to better control water run off during wetter times |
| **Livestock & Pastures** |
| • Change from autumn to spring lambing to address more unreliable springs, a drier climate, for better feed usage and nutrition issues, to minimize the chance to feed them supplementary or to avoid worms during winter time<br>• Combine farming systems with Landcare which also provides shelter for animals<br>• Change in varieties of grazing species to increase production and use species that better handle heat & use of shorter season varieties<br>• Use of deep rooted perennials which are more drought tolerant such as phalaris or fescues<br>• Introduction of summer active crops to make use of more summer rainfall such as using Lucerne or native pastures with higher heat tolerance range<br>• Improved pasture management in terms of the feed growth cycle to work out carrying capacity along a feed budget plan<br>• Rotational grazing system |

According to interviewed sectoral experts, several **factors influence farmers risk perception** including personal experience with environmental conditions, socio-economic factors and political influence. The perception of risk greatly influences how farmer understand and assess risks, thus potentially determining their adaptive capacity to deal with changing risks under climate change and furthermore their vulnerability to climate related impacts. Hence, identifying factors influencing risk perception and constraining adaptation can help in addressing them within a broader risk management framework (Rickards 2012).

**Experiences with local environmental and climate conditions** are considered to be one of the most powerful influences on farmers risk perceptions. Farmers generally tend to use a longer historical reference range than members of the general public, not only because they take more notice of climate conditions and weather events, but also because farmers usually include experiences from earlier farming generations. This furthermore tends to broaden the degree of which variabilities that farmers perceive as *normal* (Rickards 2012). However several studies found that there is often a mismatch between perceived and actual risk (see e.g. Arbuckle et al. 2015; Botterill and Mazur 2004). In the Comparison between historical climate records with perceived changes in climate, farmers indicated that there are both differences and compliance. Certain changes such as failed springs are noticed by farmers than the general long-term decrease of autumn rainfall over the last decades as changes in spring rainfall were associated with stronger impacts for agricultural production systems than changes in autumn rainfall. Furthermore as geographic areas and agricultural production systems are affected differently to climate related risks and by climate related impacts, farmers in the catchment perceived changes in climate differently (Schattman et al. 2016).

In terms of **socio-economic factors**, interviewed sectoral experts identified differences in economic farm household conditions including incomes, social environments and willingness of farmers to gain climate change related information as major influences on farmers risks perception. Emtage et al. (2006) additionally suggests that farmers vary considerably in their socio-economic characteristics, values and capacities. Farmers also perceive and assess their situation and their risk associated with climate change according to the material and social circumstances in which they found themselves and the extension to which they saw themselves as being affected (Hogan et al. 2011; Latour 2004). Brumby et al. (2011) argues that the interplay of climate and socio-economic factors can exacerbate already existing vulnerabilities of farmers. Therefore, financial viability of farms in Australia are greatly affected by climate variability and associated impacts on production as well as changes of price markets or input costs (Berry et al. 2011a). Younger farmers often face other economic challenges compared with that of earlier generations as terms of trade continue to diminish while vulnerabilities to farm household risks derive from climate change and can increase if the financial viability of farms is already affected. Thus, if a farms household already faces economic instability, climate extremes can exacerbate financial stress which impact risk perceptions of younger farming generations as well (Schattman et al. 2016; Rickards 2012; Hogan et al. 2011). According to Cutter el al. (2012), social norms, social capital and networks shape people's perception of climate related risks and associated vulnerabilities to climate change as they influence behaviours and actions before, during, and after extreme events. Interview partners also suggested a social change within the Australian agricultural community including demographic variables, level of education, information and gender issues as factors influencing farmers risk perceptions.

Several interview partners raised concerns about the **political influence** on farmers risk perceptions. Interview partners pointed to the fact that Australia's energy sector and wealth is strongly based on coal mining which explains the low interest especially among the right wing on national level to discuss climate change issues and mitigation polices in reducing emissions. Thus, according to sectoral experts governmental media releases may not only influence farmers risk perceptions, but potentially hinder adaptation efforts. Beside political influences based on party affiliation, the long history of bad government-farming relationships in Australia was identified by the interviewed sectoral experts to influence farmers risk perceptions. Farmers have been subjected to many different changes in policy, information campaigns and incentives in the past which is why interviews partners assumed farmers are becoming more *relaxed* or even cynical about messages including issues of climate change and associated perceived risks of carbon taxes. The massive shift away from governmental drought support may have also influenced farmers risk perceptions.

**Potential constraints to adaptation** were seen around a **perceived psychological distance** to climate change. Especially uncertainties about future climate scenarios and developments make it harder for farmers to make decision nowadays to prepare for the future. Due to the strong natural seasonal, yearly and multi-decadal variability of Australis climate, the focus is more on short to mid-term response strategies while planning for the long-term future is behind the planning horizon of most farmers. However, interview partners suggested that including climate scenarios into the decision-making process would help farmers minimize potential risks and increase business resilience in the long-term, especially when larger investments are planned such as buying new farm land. Additionally, the time lines which are commonly used by climate scientists and other researchers to describe future changes in climate (2050 or 2100) are too far removed from personal experience of farmers and not conceptually accessible to most people (Pahl et al. 2014). Besides the limited utility in long-term climate projections for farmers, the high uncertainty of models at a finer spatial and temporal scale in terms of regional climate change projections bears many uncertainties which make decisions at present much harder for farmers (IPCC 2007; Giorgi 2005). However, according to Pitman and Perkins (2008) when reliable projections on the global, continental and regional scale remains a major scientific challenge, climate projections can help assess possible pathways and impacts on biophysical, human, or economic systems and therefore help make decisions in being better prepared for the future.

Also a **lack of information, capacities and equity** may potentially hinder adaptation to climate change and lower farm resilience according to several interview partners. Especially a lack of understanding the nature of climate change, including sources of certainty and uncertainty and mal-interpretation of probabilistic forecast were mentioned several times by sectoral experts, thus triggering decisions which may not suit later seasonal climate conditions. Furthermore, a lack of farm equity was considered to give less room for adaptation. According to interview partners, farm family equity also depends on family structures such as a lack of succession between generations, which might close the window of opportunities triggered by a massive social change shown by the Millennials. Also according to Klein et al. (2014) and Rickards (2012), the implementation of specific adaptation strategies can be constrained by access to financial capital and thus, a lack in farm equity and debts impede farmers' ability to take on some financial strains for adaptation strategies. The study of John et al. (2005) furthermore suggests that climate change is projected to reduce the financial capacity for adaptation responses due to reductions in financial liquidly. Therefore, making bigger capital investments (e.g. cropping gear or additional farmland) may be more difficult to undertake especially when increasingly unfavourable seasons inhibit capital replacements and affects farmers abilities in their decision-making processes (John et al. 2005).

Interviewed experts furthermore mentioned **internal and external dependencies** such as the reliance of farmers on certain business sectors such as private seed companies which were associated as market failure for farmers. This is, according to sectoral experts especially concerning when seed companies only focus on the promotion of higher production rates while at the same time hide information such as the life time and replacement cycles of pastures. This means higher frequencies in pasture renovation processes which avoid running into feed gaps and triggering locked-in systems where farmers regularly have to buy new seeds in the long-term. Beside the reliance on certain business sectors, the study from Rickards (2012) revealed that vulnerabilities perceived by farmers in Victoria also arise from the reliance on others' people skills, good will and integrity. The increased use of contract labour in Australia, allow farmers to rely heavily on labours availability, timely turn up and prices which can impede short-term responses especially during climatic extreme events (Rickards 2012). Another major vulnerability to many farm households is their exposure to volatile global price markets, both in selling their goods and purchasing inputs (Rickards 2012). Also dependencies on governmental regulation can lower adaptive capacities of farmers and increase vulnerabilities such as Australia's shift away from drought support (Oppenheimer et al. 2014; RIRDC 2007).

Some interviewed partners furthermore mentioned that **farmers attitude** can potentially hinder adaptation to climate change. A culturally kind of resistance and cognitive protection against pessimistic messages of farmers are considered as factors which may potentially hinder consideration and discussions about climate change which in the end might lower adaptive capacities to changing business risks under climate change.

**Risk management**

Interviews with sectoral experts revealed that the danger of climate change for farmers lies especially in the change of frequency and magnitude of extreme events, such as the increase of heatwaves. Climate change is likely to increase the already high natural seasonal variability which is considered to come along with a shift in risk profiles, triggering a higher vulnerability of agricultural systems (e.g. possible reduction of productivity, higher input costs and impacts on financial performance). Especially enterprises which already have trouble being profitable will be exposed more to climate change, depending on the risk management approach. Thus, interviewed experts assumed a trend of lower input systems in the long term which don't take as much advantage in good years, but are not as exposed in poorer seasons and therefore less risk prone by trading off some profitability. However, identified benefits of climate change included more viable cropping options, opportunities of higher pasture production rates with slightly warmer temperatures with enough rainfall, less issues with wet winters or waterlogging, improved access to farm land and easier use of tractors.

As many adaptation strategies closely follow general principles of good management strategies for farming, interview partners suggested that adaptation contributes to maintain a profitable farm and a healthy environment which reduces risks and makes use of opportunities. Therefore, sectoral experts suggested adding climate change as factors of the decision-making process by planning for a more variable climate in future, helping to minimize farm vulnerability and increase farm and business resilience. Interview partners suggested several strategies for farmers to manage the risks of changing climate conditions, which require a) farmers interest and motivation to deal with climate change related risks, such as acquiring relevant location-specific information to enable risk assessment and therefore to increase adaptive capacities and b) to develop and implement risk management strategies such as improving agronomic practices or the use of diversification strategies of on- and off farm activities to spread business risks under increasing climate variability. Also working on equity levels or restructuring the farm to improve equity was considered as good adaption technique since reasonable amounts of equity in a property are considered more responsive while less profitability gives less room for adaptation. Openness, flexibility and responsiveness to climate conditions and changes in the frequency of events while taking opportunities were considered to lower potential vulnerabilities and to maintain profitability. Also having a proper business model which takes into account changing risks associated with climate, planning for more heat days by setting up an agricultural farm system that can survive more extremes and making decisions in time helps in increasing resilience and provide certain forehead positions. Furthermore, making use of relevant information, which can be provided by other farmers, attending workshops or using decision support tools or online information portals helps in increasing adaptive capacities to better understand changing risks under climate change and take adequate actions. According to Barber (2009) and Howden et al. (2007), most adaptation efforts are extensions or intensifications of already existing climate risk management or production enhancement activities. The purpose of adaptation to effectively manage potential climate risks from climate variability and change, is to allow farmers to undertake adaptation efforts on different levels from incremental or system response strategies to more strategic transformational strategies (Howden et al. 2007). Incremental adaptation refers mostly to short to mid-term response efforts and includes extensions of actions and behaviours which reduce losses or enhance benefits of natural variations and extreme events. Since incremental adaptation may be accomplished by taking local seasonal climate forecasts from daily to inter-annual time scales into account it can refer to adjustments in planting times (Kates et al. 2012). Short-term planning typically faces less risk and uncertainty than long-term planning and thus may be easier to implement (McConnell and Dillon 1997). However there are limitations under increasing climate variability and more extreme events, thus requiring more systematic or even transformational changes to the farming system. System adaptation refers to major changes in the existing system such as diversification of production systems while transformational adaptation can be adopted on larger scales of intensity, transform places or shift locations. Proposed changes in the water rights system or scenarios for drying landscapes such as trigger decisions for transformational adaptation and promote decisions such as transforming cropping areas to grazing land, aims to reduce long-term vulnerability to climate change. As transformational adaptation is a radical spectrum of farm change, it requires explicit planning and implementation decision-making processes which may be driven by long-term climate trends and projections. However, given the high uncertainty of longer term climate projections and associated impacts at finer spatial and temporal scales, uncertainties of longer term adaptation benefits or high costs of transformational actions might complicate associated decisions (Kates et al. 2012). Nevertheless, Thamo et al. (2017) considered a delay in adaptive responses to climate change to cause losses in the farm business in the long-term.

However, differences between incremental, systems and transformational adaption may not always be clear-cut, thus making adaptation strategies often difficult to categorize (Kates et al. 2012). Therefore, short-term response actions need to be linked to long-term adaptation and thus be beneficial for coping with potentially larger impacts later in the future (Kates et al. 2012; Howden 2007; Giordi 2005).

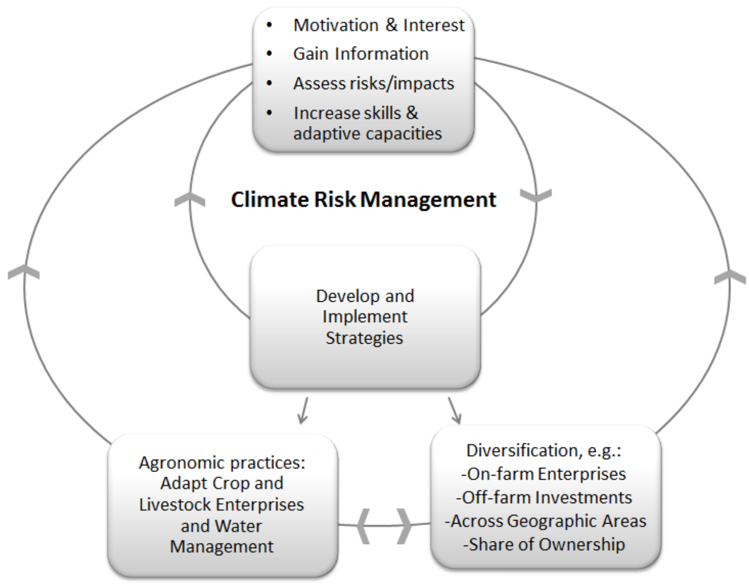


**Figure 11: Climate risk management to deal with climate change based upon interviewed with sectoral experts and literature**
(Own representation based on interviews with sectoral experts)

As shown in figure 11, climate risk management may include diversification actions in spreading risks such as diversification of on-farm enterprises, having additional off-farm investments, spatial diversification between different climatic zones to diversify rainfall mix or share of ownerships structures. According to the interviewed sectoral experts, diversification is a good adaption option to maintaining or improving farm equity which enables farmers to stay responsive to changing climate conditions. Other strategies suggested by interviewed experts referred to adjustments in agronomic practices itself in terms of crop and livestock enterprises and on-farm water management strategies. The following table summarizes both impacts of a changing climate and recommended climate risk management strategies by interviewed sectoral experts and literature.

**Table 3: Examples of direct and indirect impacts of changes in mean climate and impacts from extreme events**

| Impacts | Adaptation |
|---|---|
| **Cropping & Soils** | |
| Direct impacts:<br>• Temperature and water stress<br>→ Earlier threats in the season for the crops due to hot days hitting earlier in the season<br>→higher evaporation rates and quicker use of soil moisture<br>• Reductions in plant growth and yields → Increasing risks of failed crops<br>• Crop damage, e.g. grain number/size or mortality<br>• Reduction in soil moisture<br>Indirect Impacts: | • Choose better adapted varieties that to changing seasons, higher temperatures with lower water requirements<br>• Adjust sowing practices and the crop calendar to changing climate conditions<br>• Crops which are sown on time or earlier, always yield better than crops that are sown late<br>• Rotation of crops, e.g. wheat fields with longer perennial systems to minimize weed and diseases problems (chemicals and fertilizer come at greater expenses) and to keep soil carbon stable |

| | |
|---|---|
| • Variation of the quality and quantity of crops, e.g. protein content<br>• Shortening of the crop season: accelerated crop cycle & advancement in flowering dates and crop phenology<br>• Change in pests and disease distributions, e.g. more summer rain → more weeds, more room for insects and fungal diseases<br>• Soil erosion and lower water holding capacity<br>• Increased volatility of production and prices<br>• Increased costs through monitoring programs<br>• Harvest coming forward over time<br>• Southward shift of grazing and cropping areas | • Destock early enough/protect resources before an upcoming drought, e.g. use of stock containments<br>• Use proper drainage at soils types which are prone to waterlogging<br>• Reassess farm operation, match soil type to farm practices, e.g. by land class fencing<br>• Maintain ground cover at least 70 % flat or 90 % and have a base of pasture to avoid wind and water erosion<br>• Soil conservation methods, e.g. minimum or no tilling helps with carbon sequestration, to keep nutrients and soil moisture<br>• Subsoil manuring can help remarkably to increase yields of crops in drier springs |
| **Livestock & Pastures** | |
| Direct Impacts:<br>• Temperature and water stress<br>→ Impacts on animal health<br>→ Livestock mortality and distress sales<br>• Lowered productivity and reproduction of livestock<br>• Reduced feed intakes<br>Indirect impacts:<br>• More pressure on the pasture growing season (trend towards a later autumn break, springs being earlier and less productive)<br>• Opportunities with more winter growth rates but more variable growth in spring<br>• Pasture and fodder shortages<br>• Negative impacts on livestock numbers<br>• Variation of the quality, quantity, seasonality and distribution of pastures/fodder through changing seasons<br>• Increased volatility of feed supplies and their price<br>• Increased incidence of livestock pests and disease / Change in disease distributions, e.g.:<br>→ Tropical diseases might come further down in a warmer climate in future<br>→ Increase of risk for flystrikes, not only in late September but also later in autumn and a bit earlier in spring<br>• Decreased productivity of livestock<br>• Increased cost of feed and water<br>• Changing enterprise viability due to extra costs<br>• Increased cost of feed and water<br>• Increased variability in ground-cover<br>• Soil erosion and vegetation damage<br>• Destruction of infrastructure<br>• Increased costs through insurance<br>• Higher risk of having to feed livestock which comes along with more pressure on farming systems and their profitability due to shorter springs | • Provide enough shade (trees, wildlife corridors, shelter cloths) and access to (cool) reticulated water to avoid stress from wind and heat<br>• Plan for shorter springs, bigger summer and feed gaps & higher risk to feed sheep<br>• Manage variability: match and adjust stocking rates to pasture growth cycle, stock off pastures earlier, make use of feed lots & sell stock <u>in time</u> to deal with dry times<br>• Move to lower productivity but higher heat stress resistance breeds, prefer animal breeds that cope better with heat and diseases<br>• Investments in silos to increase storing capacity gives more flexibility<br>• Have in mind reproductive cycle of the animals: adjust joining time during or after heat events, provide enough time for reproduction or make use of pregnancy scanning to check on conception<br>• Good body reserves (amount of fat) help with better resilience and ability to cope with variable seasons<br>• Quicker fattening of lambs with shorter growing season becomes more important in future<br>• Warmer conditions could enable to shift lambing times earlier in the year in future<br>• Worm control programs help to address changing risks of e.g. flystrikes earlier in the season<br>• Go for deep rooted and more drought tolerant perennial pastures rather than annuals which also help with better organic carbon and fertilization<br>• Diversify pasture species composition and make sure fertilizer input are adequate<br>• Introduce summer active crops (e.g. Lucerne or Chicories) → way to extend growing season<br>• Focus more on winter period for grazing than on late spring, e.g. stimulate grass production earlier in the season by using nitrogen fertilizer<br>• Better grazing management techniques helps to keep pastures healthy, e.g. strip cell grazing |
| **Water and Droughts** | |
| • Climate change aggravates existing water stress | • Adapt to higher frequencies of droughts, e.g. have |

| | |
|---|---|
| and affects water security<br>• More water regulations in future assumed with water resources becoming more constraint<br>• Quicker use of soil moisture due to higher temperatures, slower fill up of dams<br>• Increasing risks of droughts as major risk to a farm business<br>• South-west Victoria is increasingly running out of water, key challenge for some farmers<br>• Wet year (with floods) in between remain<br>• Sequences of drier years without runoff might increase in future<br>• Trend in dropping groundwater in parts of Victoria affects catchment flow and some local creeks and springs, but also stable groundwater in some areas | funds for droughts (e.g. feeding costs) & protect resources and save costs (e.g. offloading sheep in time by using feedlots)<br>• Water security becoming more important: manage systems accordingly and make the most out of the time with pasture and water availability<br>• Increase the amount of water available, e.g. put in farm dams, try to access ground water or buy licenses<br>• Improve infrastructure to deal with water shortages; e.g. connected pipelines across paddocks with less leaking and evaporation<br>• Ensure reliable supply and efficient use of water, have greater storing capacity and a buffer for 2 or 3 years rather than just for one year → bigger and deeper dams to access ground water<br>• Town water is expensive but also help as backup<br>• Broader use of technologies to harvest, use and transport water where rainfall decreases |

By Comparing implemented risk management strategies by farmers with suggested adaptation strategies of interviewed sectoral experts and literature, the majority of interviewed farmers in the catchment are already adapting to climate change without classifying it as such, but rather as part of good risk management to climate variability. However, interviewed sectoral experts suggested that farmers who deny climate change and only attribute perceived changes in climate to natural variability will be more vulnerable to future climate change as the magnitude and frequency of extreme events is likely to increase. Additionally, the study of Howden et al. (2007) highlights the importance for farmers to accept that climate change is real and significantly impact production (Parson et al. 2003).

## 6. Conclusion

Farmers in Australia are exceptional in managing a highly variable environment. However, if many Australian producers are well adapted to natural climate variability, climate change triggers new risks such as changes in pattern of extreme events aided with reduced productivity and profitability in some locations. Nevertheless, there is an increasing urgency to focus on adapting agriculture to future climate change (Climate Commission 2013). Many adaptation options to climate change are on-going variations or extensions of existing climate risk management strategies on farm levels. However, integrating new emerging risks from climate change in the overall farm risk management framework might further increase farm resilience and help reduce potential vulnerabilities from climate related impacts (Howden et al. 2007).

## THESIS DECLARATION

I hereby declare, that I have completed this Doctoral Thesis, entitled „Climate Change Impacts and Risk Management: Improving farm resilience through adaptation in the crop-livestock zone of the Corangamite catchment in Victoria (Australia) with a Case Study of the ´Mount Hesse´ farm" independently, on my own, employing only the sources and aids specified and cited in this thesis. I have identified and acknowledged all words and ideas taken from other work. The submitted electronic copy is identical in form and content to the written version of the thesis.

I further declare that I have not previously submitted this work or any version of it for academic credit, nor has it been published.

I hereby declare that I do not consent to this thesis, or any part of it, being published, reproduced or distributed, in printed copy or electronic form by the University of Hamburg or any other entity without my explicit written consent.

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